Intelligent Speed Adaptation: Evaluating the possible effects of an innovative speed management system on driver behaviour and road safety

by

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

The University of Leeds

Institute for Transport Studies

November 2001

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

Acknowledgements

The research reported in the thesis could not have been completed without the support of friends and colleagues at the Institute for Transport Studies and the School of Psychology. Special thanks to my supervisors, Oliver Carsten and Nic Ward for their comments and suggestions and to all the members of the team at the driving simulator, in particular Hamish Jamson and Andrew Bailey. Other technical support was provided by the staff at the Motor Industry Research Association who provided the instrumented vehicle and supporting software.

In addition, I appreciate the input provided by my friend and colleague Fergus Tate, who motivated me when times got tough and helped with data collection in the on-road study. Your behavioural observations were always a source of amusement.

The research was supported financially by the Engineering and Physical Sciences Research Council, the Department of Transport, Local Government and the Regions, and the European Commission. The studies involved the participation of a large number of volunteer drivers, to all of whom I am grateful.

Finally, Hamish, you deserve a second mention. Not only did you create the simulator scenarios, but you also proved that team-building can be a lot of fun.

Abstract

The research reported in this thesis provides a comprehensive safety evaluation of Intelligent Speed Adaptation (ISA) using a range of experimental methodologies. An ISA system can have varying system characteristics but, in general, limits a vehicle to a particular speed (or provides advice about the appropriate speed). This evaluation offers an important contribution to the understanding of a range of issues pertinent to the implementation of such a technology.

This thesis reports a series of studies designed to evaluate the effect of ISA on driver behaviour and safety. Each of the studies addressed a separate issue and thus a number of research methodologies were used. The studies evaluated the effectiveness of ISA in comparison to other speed-reducing methods and investigated how drivers interacted with ISA across a variety of road types. In addition, a number of variants of ISA were developed and their comparative effectiveness was studied in a laboratory setting and in the real world.

In summary, the simulator studies reported decreases in mean and maximum speeds for areas of interest such as curves and village entry points. The field studies on the other hand only found decreases in maximum speeds, probably due to the small sample and high variability in traffic conditions. However these decreases in speed were located in road environments where excessive speed is a problem; thus safety benefits would undoubtedly accrue with ISA.

With regards to system design, drivers were more accepting of an ISA system that allowed an override particularly self-reported speeders. Increases in frustration and the perceived loss of time while driving with a mandatory ISA were also reported and may explain the negative shift in gap acceptance behaviour and car following observed in the simulator.

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Introduction

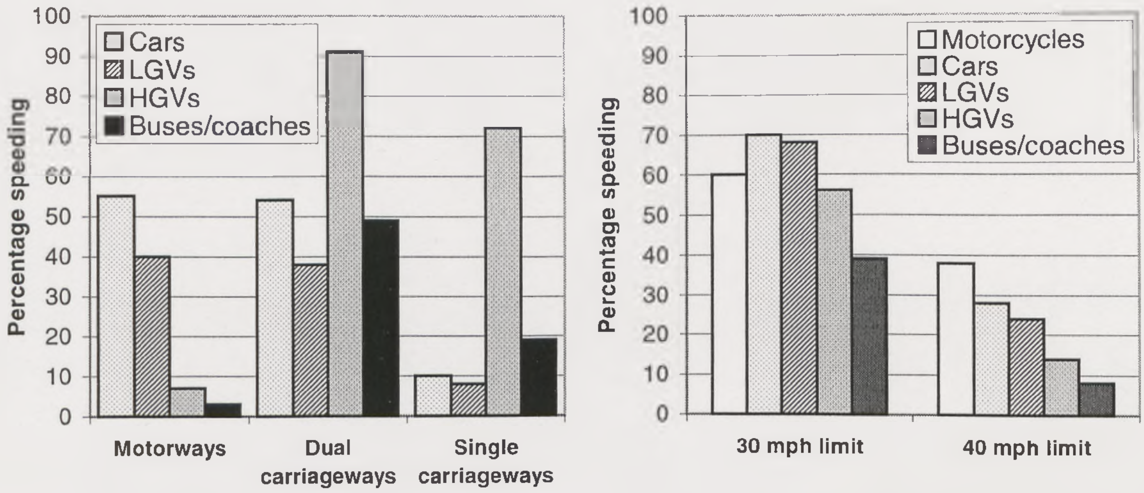
The research reported in this thesis attempts to evaluate an innovative solution to a long-standing problem in transport safety, namely that of excessive speed. Much theoretical and practical work has been carried out in this area in the past, but the issue is still to be resolved in any global sense. Traditionally, speed can be controlled using a range of methods based on enforcement, education and engineering. Technological advances have allowed the development of new methods for reducing driver speed. These new solutions require rigorous and extended evaluation in order to assess their true benefits and costs.

This thesis investigates how a technology-based system, Intelligent Speed Adaptation (ISA), might contribute to speed reduction. An ISA system can have varying system characteristics but, in general, limits a vehicle to a particular speed (or provides advice about the appropriate speed). First, the relevant literature on various speed countermeasures and recent work on ISA will be reviewed. A framework of behavioural studies is then proposed and these studies will be the focus of the thesis. The remainder of this chapter summarises the prevalence of speeding and the likely impacts of speed on road safety.

1.1 The prevalence of speeding

The Department for Transport, Local Government and the Regions (DTLR) carries out continuous surveys of traffic speed at around 130 sites in Britain. Although factors that could affect the data, such as traffic congestion, are not taken into account, the data collected provide a general overview of the prevalence of speeding.

Figure 1.1a and Figure 1.1b show the data collected from the 1998 speed survey (DETR, 1999a). Concentrating on the data collected for cars only, it can be seen that whilst speeding is not particularly common on single carriageways (perhaps due to poorer road design), more than half the cars surveyed were exceeding the speed limit on motorways and dual carriageways. The figures are similar for urban areas, with a prevalence of speeding between 40 and 60%.



(a) Non-urban areas **(b) Urban areas**

Figure 1.1: Prevalence of speeding

A number of studies have attempted to characterise a "typical speeder". Webster and Wells (2000) provide an overview of a number of these studies by examining the evidence for a relationship between personal characteristics and accidents. They summarise that although the majority of drivers admit to speeding at one time or the other, faster drivers tend to be male, in the younger age bracket and travelling alone. They also report that drivers justify their speed choice by characterising themselves as "ordinary, safe speeding drivers" while others are "dangerous speeding drivers".

The reasons drivers exceed the speed limit may be varied. Drivers may speed intentionally in order to decrease journey time or to increase their sense of enjoyment. However, drivers may also speed inadvertently whereby they fail to realise they are travelling too fast for the environment (e.g. junctions, curves, motorway exits, construction zones). Also, drivers who have been driving at a high speed for an extended period (e.g. on a motorway) may become habituated to this speed and overestimate the degree to which they are lowering their speed. After prolonged travel at higher speeds, low speeds seem even lower than they really are and the driver may believe they have decreased their speed more than they actually have (Schmidt and Tiffin, 1969; Denton, 1976; Matthews, 1978). According to Evans (1991), this kind of speed adaptation is a perceptual illusion and it is thus unlikely that experience or training can improve the phenomenon. Recarte and Nunes (1996) reported that this under-reporting of estimated speeds was greater after deceleration than acceleration.

A large body of research has shown that drivers tend to consider themselves to be safer and more skilled than the "average" driver. This self-enhancement bias was initially reported by Svenson (1981) and later by others (De Joy, 1989; Delhomme, 1991; McKenna, Stanier and Lewis, 1991; Groeger and Grande, 1996). Walton and Bathurst (1998) and Walton (1999) found that 85-90% of their driving sample reported driving slower than the average driver.

There is little doubt that exceeding the speed limit is a part of everyday driving for most drivers. Of more practical importance, however, is how speed choice affects accident risk. The next section discusses research that has attempted to formulate relationships between speed and the likelihood of accident involvement.

1.2 Speed and accident risk

Excessive speed is recognised by most European governments as being a contributory factor in a significant number of road accidents (European Road Safety News, 1997). There is much debate as to the exact proportion of accidents that can be directly attributed to excessive speed, particularly as accidents can be thought of as the result of a chain of events. Indeed, the very phrase "excessive speed" can provoke argument with regards to whether it applies to the posted speed limit or the specific road, traffic and weather conditions in which the driver is travelling. It is generally agreed that the term "inappropriate speed" is a more useful concept.

Travel speed can affect both the likelihood of an accident occurring and the severity of the accident, by reducing the amount of time drivers have to avoid the collision and by increasing stopping distances. As the impact speed increases, the amount of force a vehicle is subjected to increases (with the square of speed). The vehicle structure and safety features (such as airbags and seatbelts) can only protect the occupants from a certain amount of force. Lower impact speeds reduce the severity of injury: at 30 mph the risk of serious injury to a belted car occupant is three times greater than at 20 mph (Hobbs and Mills, 1984). Likewise, road design factors such as sight distance and curvature are compromised if drivers travel faster than circumstances warrant. Infrastructure design standards accommodate a range of vehicle impacts, but they are unable to provide sufficient protection for those in vehicles travelling at very high speeds.

Several studies have shown that there is a clear relationship between the speed level and the number of accidents and that small changes in mean traffic speed result in significant changes in the number of injury accidents (Salusjärvi, 1988; Nilsson, 1982; Kimber, 1990; O'Neill, 1990; Finch, Kompfner, Lockwood and Maycock, 1994). Finch et al.'s summary of the US and German interstate/autobahn evidence is that a 1 mph decrease in mean traffic speed leads to a reduction in fatalities in the order of 8-10%. This relationship, however, is assumed to be linear. Finch et al. (1994) suggest that the relationship is asymptotic rather than linear, such that the effect of speed on accidents may be prone to saturation – perhaps due to the fact that not all accidents are speed-related. He estimates the limits of the model in terms of maximum percentage change in accidents to be approximately 25% (in both directions).

An alternative model was developed by Nilsson (1982) that suggests that the *ratio* of the change in accident rate is proportional to the ratio of change in median traffic speed (Figure 1.2).

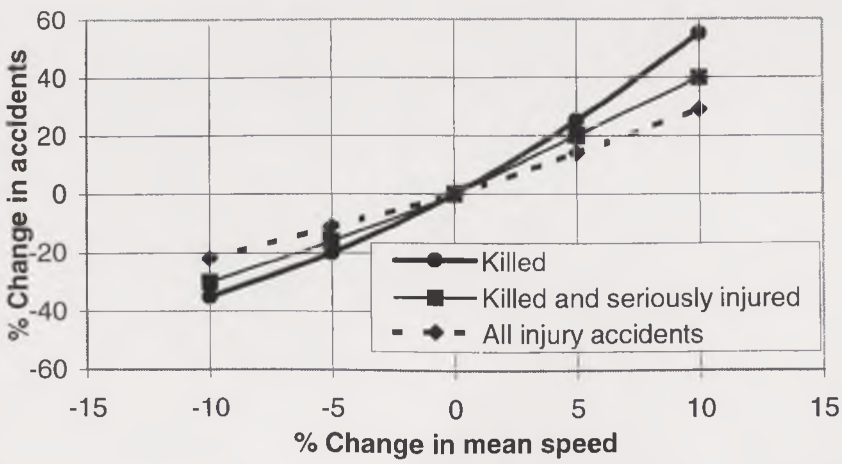


Figure 1.2: Relationship between changes in mean speed and accident rate (adapted from Nilsson, 1982).

This relationship is potentially attractive because due to the fact that the change in mean speed is treated as a ratio, the formula can be applied to a wider range of datasets.

However, the relationship between speed and accidents is likely to be dependent on variables other than just mean speed. Some evidence suggests that accident rate rises with increases in speed variance, rather than mean speed. Munden (1967) and Hauer (1971) cite a U-shaped relationship between the accident rate and speed for drivers, with the highest accident rates being associated with the fastest and slowest drivers.

A number of studies provide evidence for this relationship (at least in the U.K.), including Garber and Gadiraju (1989) and Aljanahi, Rhodes and Metcalfe (1999). These studies suggest that reducing speed variance and 85th percentile speed (the speed exceeded by the fastest 15% of drivers) are the most important aspects of speed to target for improved road safety. Figure 1.3 shows a theoretical relationship between changes in speed variance and accident risk (Salusjärvi, 1988).

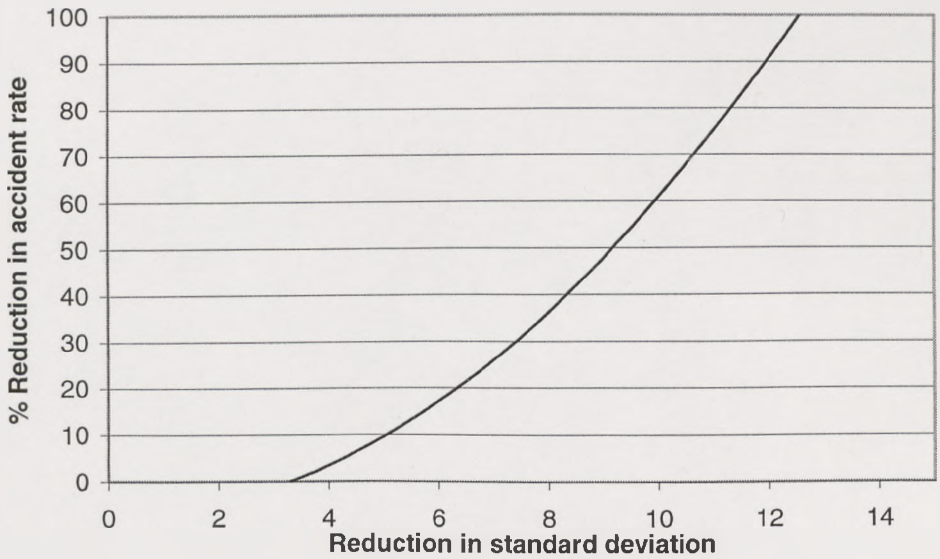


Figure 1.3: Theoretical relationship between speed variance and accident risk (adapted from Salusjärvi, 1988)

Recent accident modelling carried out at the Transport Research Laboratory (Taylor, Lynam and Baruya, 2000) found that an urban accident prediction model was most effective when *both* the average speed of the traffic and the coefficient of variation were included. The authors comment that speed-reducing measures should be designed such that they decrease both average speed and speed variation, otherwise no or only small advantages may result.

An additional variable to consider is the appropriate speed required for a specific situation. For example, drivers are required to adjust their speed in relation to road geometry, weather and traffic conditions. An in-depth study of the factors contributing to urban accidents (Carsten, Tight and Southwell, 1989) found that driving too fast for the situation was an underlying factor in approximately 10% of accidents. Drivers can, on the whole, correctly adapt their speed to given numeric speed levels when the speed limit changes but find it more difficult to adapt their speed to changing conditions (Denton, 1966). In addition, the speed limit on the current roads may be too rigid and inappropriate in many critical situations that demand speed adaptation below the speed limit (for example, school zones and sub-standard curves).

Thus the relationship between speed and accidents can be thought of as the interaction between the speed limit of the road, individual drivers' willingness to comply or adapt their speed appropriately (whether consciously or not) and the general behaviour of the surrounding traffic, in terms of density and flow.

In recent years, attempts to reduce speed have centred on engineering, enforcement and education. However, these techniques have met with limited success and no single intervention has proved effective for all driving contexts. Traditional countermeasures can be both costly to implement and context-specific with regards to the type and function of the road. This has led to the suggestion that speed needs to be controlled at the source, for example by using a technology-based solution in the form of a speed-limiting device within the vehicle itself.

Although such speed-limiting devices (governers) have been installed in Heavy Goods Vehicles for a number of years, implementing them into the private motor vehicle fleet fuels new debates including those concerned with personal freedom, system safety and system reliability. The latter of these is a relatively easy one to demonstrate or at least quantify. Personal freedom issues and the desire for drivers to "exercise their right" to exceed the speed limit are more difficult to tackle, but are the responsibility of government and legal agencies. The safety of the traffic system and the way in which drivers interact with such a system are areas to which more attention has been paid in recent years, especially as the technologies (e.g. Global Positioning Systems and digital road maps) are becoming increasingly available to support innovative approaches.

1.3 Overview of the thesis

The research reported in this thesis provides a comprehensive safety evaluation of Intelligent Speed Adaptation using a range of experimental methodologies. This evaluation will provide an important contribution to the understanding of a number of issues pertinent to the implementation of such a technology. An overview of the thesis format is shown in Figure 1.4.

Chapter Two reviews the research on the existing variety of speed-reducing methods, to include road treatments and technology-based solutions. A critical evaluation of their effectiveness is presented along with any associated benefits and costs. The chapter concludes by introducing the possibility of using ISA as a speed reducing measure. Chapter Three provides a summary of the research that has attempted to evaluate ISA. Such evaluations include microsimulation studies that investigate network effects and on-road trials that focus on behavioural and acceptability issues. Deficiencies in the research are highlighted and the framework of the proposed experiments in this thesis is detailed.

Chapter Four details an exploratory study carried out on a driving simulator. This required the development of an appropriate algorithm to implement the ISA system. In addition, this study was designed to allow the development of the appropriate evaluation techniques to be used in the main experimental studies. Chapter Five describes a driving simulator experiment that aimed to compare the effectiveness of ISA against a number of speed reducing measures. The study used a situation where excessive speed contributes to a high proportion of accidents (substandard rural curves). Chapter Six provides insight into how different variants of ISA might be effective. A driving simulator study was designed to test three types of system against a baseline condition. The road environment allowed the comparison of the systems across road types.

Chapter Seven and Chapter Eight describe two experiments with a common theme. These experiments were designed to investigate how drivers might react to using ISA over an extended period of time. Any changes in behaviour that arose as a result of using such a system were monitored over a number of sessions to discover if novelty effects occurred or indeed if changes only arose as a result of extended use. The first of these experiments was completed on a driving simulator using three variants of ISA and allowed the study of controlled and repeatable safety-critical events. The second was an on-road study using an instrumented vehicle equipped with two variants of the ISA system that had already been examined in the simulator. This experiment allowed drivers to be exposed to real traffic conditions and to facilitate the collection of naturalistic driving behaviour.

Chapter Nine summarises the findings of all the studies and provides an overview of the likely benefits and costs of ISA. A critical analysis of the techniques used in the research and recommendations for future work are provided.

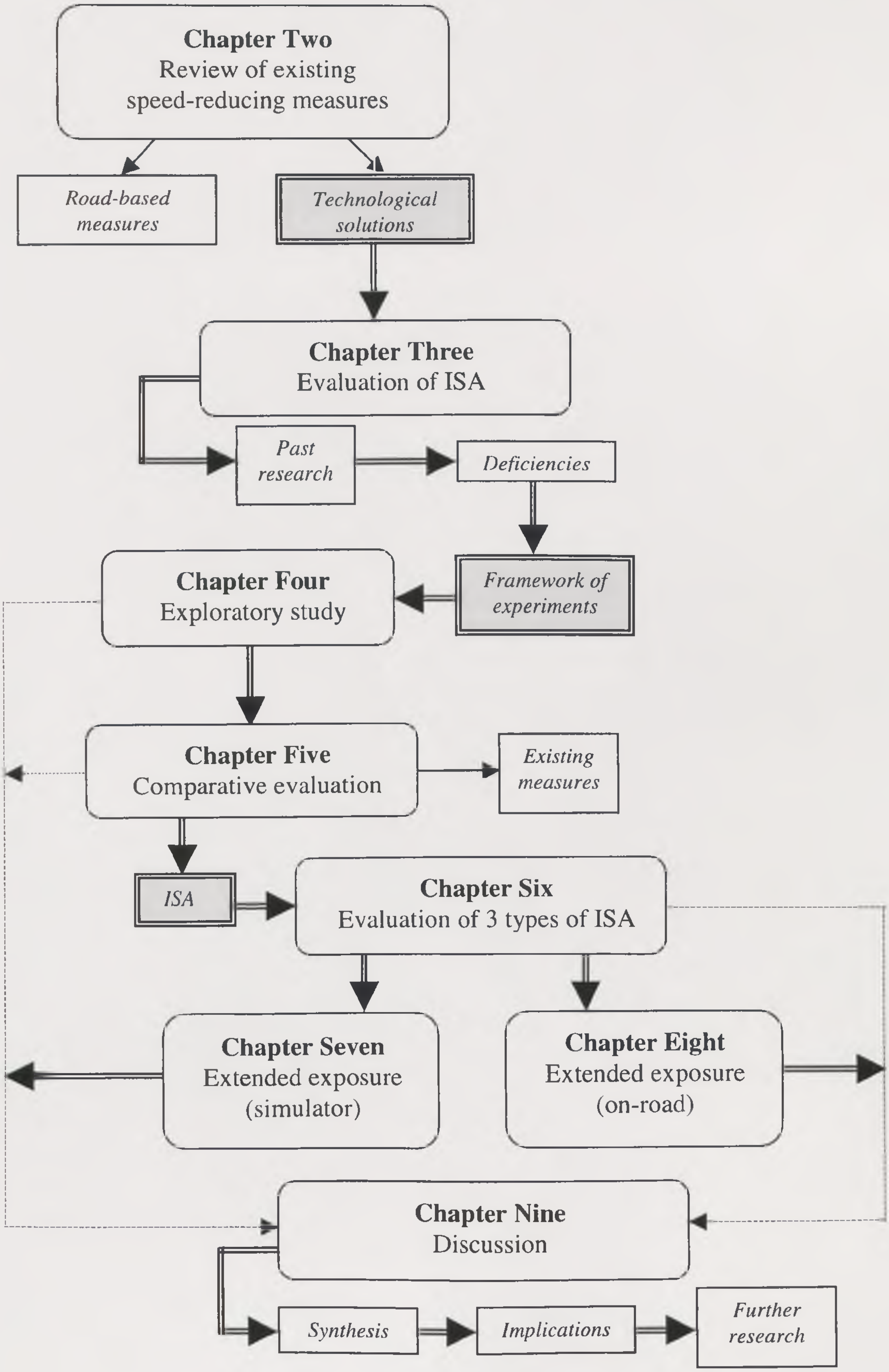


Figure 1.4: Overview of the thesis

Chapter Two

Review of existing speed reducing measures

This chapter provides a critical outline of the current solutions for reducing speed. The first section of this chapter covers solutions that relate to changes in the physical characteristics of the road, including traffic calming and signing schemes. The second section is devoted to technologically advanced solutions which can be implemented both in-vehicle and at the roadside, for example Variable Message Signs and enforcement techniques. A critical evaluation of their efficacy is presented and conclusions drawn as to their impact on road safety in general.

2.1 Road design treatments

Road design treatments include those that actually alter the alignment of the road (and are thus visible to the driver) and those that are referred to as perceptual countermeasures. Perceptual countermeasures attempt to induce, unobtrusively, a desired speed, i.e. without the driver being aware of any change in their behaviour. Road redesign applies the principles of traffic engineering to control speeds and encourage driving behaviour that is appropriate to the environment. The range of techniques used is diverse and they have been mainly applied to residential areas, although they can also be implemented on distributor roads and town centres.

2.1.1 Edge and centre-line treatments

Edge-lines are argued to be useful for controlling direction, vehicle speed and travel path (Gordon, 1966; Godthelp, Milgram and Blaauw, 1984; Riemersma, 1986 – cited in Várhelyi, 1996). By introducing edge-lines the effective road width is reduced, which in turn is known to reduce vehicle speeds (Armour and McLean, 1983). The literature surveyed, however, appears to be contradictory. Some studies (e.g. Van der Horst and Hoekstra, 1994) have found small speed reducing effects of continuous edge-lines. However, there are also studies that show no improvements after the implementation of edge-lines (Lum, 1984; Cottrell, Deacon and Pendleton, 1988). Hall (1987) and Cottrell et al. (1988) found that edge-line treatment sites did not provide benefits under conditions of darkness or curvature and that none of the accident types that this countermeasure would logically be expected to affect were reduced. In addition, an Australian field study (Johnston, 1983) and a U.S. driving simulator study (Ranney and Gawron, 1986) found that edge-lines were associated with *increased* speeds. The simulator study did, however, find that lane placement improved (i.e. there were fewer lane departures) when edge-lines were present. So perhaps the major benefit for edge-lining, particularly on straight sections of road, is the maintenance of a safe position within the lane itself (Triggs and Wisdom, 1979; Triggs, 1986). The actual speed-reducing effect of such edge-lining may in fact be neutralised by providing drivers with improved visual guidance (Van der Horst and Hoekstra, 1994).

Similar results concerning improved vehicle positioning have also been found for centre-lining schemes. Van der Horst and Hoekstra (1994), found that a continuous centre-line resulted in a shift away from the centre of wide roads, thereby reducing the number of centre-line encroachments.

The drawbacks of road markings are their sensitivity to wear and dirt. Their visibility at night is dependent on the retro-reflective properties of glass beads embedded in the paint. Consideration, when implementing such measures, should also be given to drivers' *expectations* with regards to road delineation. For example Kaptein and Theeuwes (1996) in a Dutch experiment, found that on the introduction of edge-lines, drivers no longer expected bicycles to be present, which may result in negative safety effects. Although this result may be limited in terms of generalisability to other European countries, it does demonstrate that changes in road design may have negative side effects if expectations are altered.

2.1.2 Transverse carriageway markings

In addition to centre and edge-line markings, transverse road markings are thought to be especially suitable at hazardous locations (e.g. at a roundabout or a bend). Structured patterns of transverse strips with decreased spacing painted on the road surface, are suggested as a solution for the speed adaptation phenomenon which can arise after having driven fast for some time e.g. on motorway exit ramps. This method of influencing speed is based on a deliberate distortion of the environment so that the driver has the illusion that their speed is increasing (Figure 2.1).

Reductions in mean driving speed have been reported in studies that implemented transverse markings on the approach to curves, (Denton, 1971; Denton, 1973; Hungerford and Rockwell, 1980; Agent, 1980). Besides reductions in mean driving speed, reductions in speed variance have also been reported (Denton, 1973).

Figure 2.1: Transverse carriage-way markings
(http://www.thermotor.co.uk)

These effects can be seen at other locations, where appropriate speed reductions are desirable. Burney (1977) implemented a pattern of transverse road markings on the approach to a roundabout. The pattern reduced approach speed and some drivers even started decelerating before they actually reached the markings. Helliar-Symons (1981) investigated the effects of similar markings on dual-carriageways at the approach to roundabouts. The analysis of accidents (two years before and two years after) showed an overall reduction in injury accidents of over 50% on these approaches (when corrected for the increase in accidents at control sites). The analysis also showed that the treatment continued to be effective in reducing speed-related accidents in their second year of use. Jarvis (1989) and Uber and Barton (1992) also found yellow road markings had a speed reducing effect; the former reported a speed reduction after more than 12 months.

There is, however, some uncertainty about the durability of the speed reductions. Havell (1984) suggests that the effectiveness of such measures can be maintained for months whilst others suggest the benefits fade in a matter of days or weeks (e.g. Maroney and Dewar, 1987).

Some research has indicated that particular measures may only be of use to particular driver types. For example, Shinar, Rockwell and Malecki (1980) found that transverse lines in a Wundt illusion (gives the allusion of road narrowing) on the approach to a bend only effectively decreased speed for freight vehicles. This was attributed to the fact that these drivers view the illusion from a higher perspective, which enlarges the effect.

2.1.3 Lane width reductions

Lane width reductions have been found to be generally effective in reducing vehicle speeds. A positive relationship was found between vehicle speed and road width in several studies (e.g. Oppenlander, 1966; Leong, 1966; Armour and McLean, 1983; Pau and Angius, 2001). Vey and Ferreri (1968) reported increased speed and shorter headways for 3.4 metre lanes as opposed to 3 metre lanes. Yagar and Van Aerde (1983) found a reduction in speed of 5.7 km/h for every metre of reduction beyond 4 metres. Von Morner (1984 – cited in Bowers, 1986) also demonstrated that in the relationship between carriageway width and speed it is the *perceived* width that is important. Smith and Appleyard (1981) were able to report a direct relationship between drivers' speed and 'apparent width' that encompasses the influence of the surrounding environment on the actual road surface (a perceptual interpretation of a geometric feature).

A number of studies have been conducted that compare the effect of specific lane widths on driver speed. Fildes, Fletcher and Corrigan (1989) obtained speed reductions of 3 km/h after implementing a white gravel perceptual separation strip that effectively reduced the travel lane width from 5.0 to 3.7 metres. Van der Horst and Hoekstra (1994), conducted a driving simulator experiment and showed that the narrowest lane width (2.25 metres with a 0.70 metre edge strip) reduced speed the most. Moreover, the narrow lane width particularly reduced the speeds of drivers under time pressure.

In summary, it appears that reducing the real or apparent width of the available road can be effective in reducing vehicle speed. It is important to note however, that reducing the lane width inevitably reduces the amount of space between opposing traffic (and in the case of motorways – adjacent traffic). Further research is required to establish the trade-off between lower speeds and the possibility of increases numbers of conflicts and, for motorways, a reduction in capacity.

2.1.4 Delineation measures

Delineation measures are roadway markers that provide the driver with information about the path of the road. For example, reflector posts are intended to provide improved optical guidance to help drivers perceive the road alignment ahead. Kallberg (1993) studied the effects of reflector posts on two-lane rural roads in Finland. The results showed that reflector posts on roads with an 80 km/h speed limit and relatively low geometric standard increased night-time driving speeds by up to 10 km/h. The number of night-time injury accidents increased by 60%. A similar finding was reported by Shepard (1990) in the United States. However, Krammes and Tyer (1991) found a positive effect in that the variability in lateral placement at the midpoint of the curve was less with delineators and fewer vehicles crossed the centre of the roadway. These results suggest that improving delineation provided better path indication, which may have given drivers the confidence to operate at higher speeds through the curves.

Mullowney (1982) studied the effect of reflective pavement markers on speeds on two-lane rural curves. He concluded that the markers caused a smoother speed profile through the curves, which resulted in less abrupt speed changes. This was attributed to earlier deceleration. However, speeds increased at the apex of the curve, which again may have been due to the increased driver confidence due to the improved view of the curve geometry.

In general, the research seems to suggest that although speeds may become less variable when delineation treatments are employed, they may encourage higher speeds due to increased confidence and improved visibility. This has the potential to offset any safety benefit or even lead to decreased safety.

2.1.5 Speed humps and tables

Speed humps provide drivers with clear physical feedback to encourage lower speeds (Figure 2.2). Speed humps can have a circular profile (round-top) or a flat-top with ramps up to the plateau. The most effective height of speed hump has been found to be between 75-100 mm (Webster and Layfield, 1993). Engel and Thomsen (1992) attributed speed humps with the speed reducing effect of 1 km/h reduction in speed for every 10 mm of height of the hump. Hence a hump of a height of 100 mm will produce a speed reduction of 10 km/h. However, due to passenger discomfort, 100 mm humps are not usually suitable for bus routes or where the emergency services may need access.

Figure 2.2: Speed hump
(http://www.trafficcalming.org)

With regards to accidents, Elvik and Muskaug (1994 – cited in Várhelyi, 1996) reported that speed humps reduced the number of injury accidents by between 25 and 55%. Elvik, Borger and Vaa (1996 – cited in Várhelyi, 1996) based on four different studies in England and Norway, concluded that humps reduced the number of injury accidents by between 51 and 68%.

One common concern with measures such as speed humps is that they cause accident migration whereby traffic is redistributed to alternative routes. No accident increase on such alternative streets were found in the studies cited above. In a study that also compared upstream and downstream speed at traffic-calmed areas, no evidence of downstream increases in speed was found (Barbosa, 1995).

Another concern is that the installation of speed humps encourages increased accelerations and brakings between the humps. This could cause problems for nearby residents in terms of both noise and pollution (Harris, Stait, Abbott and Watts, 1999). Measuring speed before and four weeks after the installation of humps in Gothenburg, Pettersson (1981 – cited in Várhelyi, 1996), showed that the mean speed at the humps was reduced from 45 km/h to 20 km/h but that the speed profile was very uneven. If the distance to the next hump was 100 m or more, drivers braked just before the humps and accelerated after them by 10-15 km/h. About 100 m after they passed the last hump, the mean speed was at the same level as before the introduction of the measures. Speed measurements two years later showed that the effects were stable. It was suggested that to achieve an average speed of about 30 km/h between humps, the distance between them should not exceed 85 m. Pau and Angius (2001) report that the effect of speed humps on driver behaviour is restricted to 20-30 metres before and after the hump. Even more worrying is that some research suggests that drivers have found that increasing their speed reduces the magnitude of the vertical acceleration thus producing a significant reduction of the effectiveness of such devices (Watts, 1973; Kassem and Al-Nassar, 1982).

Speed tables are often used as an alternative to speed humps. Speed tables are flat-topped humps extended at intervals across the width of the carriageway to provide a level path, at the same height as the pavement, for pedestrians to cross. Speed tables thus have the twin advantages of physically slowing down the traffic and also making it clear that pedestrians are present. European experience has shown that a 50 m interval is the optimal spacing to restrain speed (Bowers, 1986). It has been observed though that drivers sometimes 'gutter run' to minimise the effects of vertical alignment measures by aligning one side of the vehicle with a gap in the device (typically such devices terminate before the gutter to enable drainage).

It therefore seems that both humps and tables, although effective in their immediate location, may have undesirable side effects that could impact on both safety and emissions. There have also been reports of noise disturbance for local residents (Harris, Stait, Abbott and Watts, 1999).

2.1.6 Chicanes and narrowings

Chicanes, or lateral displacements, are designed to encourage drivers to slow down by forcing them to change their direction of travel (Figure 2.3). The research on chicanes is contradictory. A trial with chicanes in Malmö, Sweden, showed that the mean speed at the measures decreased from 50 km/h to 35 km/h, but conflict observations indicated a reduction in traffic safety (TSV, 1985 – cited in Várhelyi, 1996). Engel and Thomsen (1992) found that a double lateral dislocation on Danish residential streets reduced speeds on average by 4.7 km/h, and a single lateral dislocation by 2 km/h. Again some negative effects at the narrowings arose when vehicles attempted to arrive first (and thus pass first).

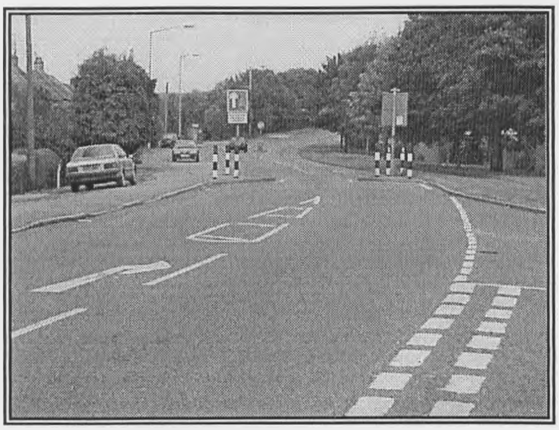


Figure 2.3: Chicane
(http://www.bobsarge.nildram.co.uk)

It is logical that narrowings will only slow drivers down when there is an oncoming car that is likely to arrive at the narrowing at the same time. On some roads this is not a common occurrence. Thus the effectiveness of road narrowings can be enhanced by the addition of vertical elements such as trees and lamp standards, the combination of which is often called a 'gateway treatment' (Bowers, 1986). He also suggests that the optimal configuration for the installation of "slow points" should create 45° changes in direction of the carriageway approximately every 50 m with an offset of the full width of the carriageway.

It appears that in order to induce speed changes, the lateral displacement has to be relatively severe. Barbosa, Tight and May (2000) compared the speed profiles for a number of traffic-calming measures, including chicanes and reported that the more aggressive and constraining measures were effective at reducing speeds. However this severity can lead to possible conflicts between vehicles as drivers attempt to negotiate them. As a result, conflicts may result when road users, in order to maintain the same level of driving performance, do not adapt their speed to the decreased road width (Jacobs, 1976; Lamm, Choueiri and Mailander, 1990).

2.1.7 Rumble strips

Rumble strips are widely used as a means of alerting drivers (by increasing arousal) to hazards such as junctions and bends in order to achieve reductions in speed. Many different devices and arrangements have been used, generally bands of coarse surface texture (rumble areas) or narrow strips of material (rumble strips) are laid across the carriageway. Rumble strips, besides the visual stimulation, also give auditory and tactile stimulation that are intended to alert the driver (Figure 2.4).

Figure 2.4: Rumble strips
(http://www.trafficcalming.org)

Some success has been reported using rumble strips. Webster and Layfield (1993) assessed rumble strips and rumble areas at 35 sites in the U.K. and found that at most of the sites a small reduction (approximately 6%) in 85th percentile speed was demonstrated after the rumble strips had been installed. However there was evidence to suggest that the initial speed reduction diminished with time. Reductions in mean speeds were slightly higher than reductions in 85th percentile speeds suggesting that faster drivers may maintain or increase their speed at some sites to lessen the "cattle-grid" effect. The authors concluded that rumble devices need to be sited as close to the possible hazard as practical since the speed reducing effect of the rumble device decreases as the distance from the last rumble area increases.

It may be that the main effect of rumble strips is an alerting one. They are traditionally used as a divider between the inside lane and the hard shoulder on motorways and have been found to be successful in reducing the number of run-off-the-road incidents (Griffith, 2000; McCartt, Rohrbaugh, Hammer and Fuller, 2000). In Portugal, Ribeiro and Seco (1997) experimented with various patterns and spacings of rumble strips at nineteen uncontrolled, marked pedestrian crossing points. They found no reductions in speed but pedestrian accidents decreased overall in the city during the period of the study. Elvik et al. (1996 – cited in Várhelyi, 1996), synthesised the findings from several studies in different countries on the effects of rumble strips on the approaches to junctions and concluded that they reduced the number of injury accidents at the junctions on average by 33%.

A common criticism of rumble areas is the noise they generate. Gupta (1992) carried out a study in the U.S. that aimed to establish policy standards on the design and placing of rumble strips and to study the noise levels associated with each type of rumble strip. Seven sites were identified and a combination of design parameters including spacing of pads, width of strips and groove pattern selected and measurements of speed and noise levels inside and outside vehicles were taken. The results showed that noise levels inside vehicles rose between 5 and 10 dB and had a positive effect on drivers such that a speed reduction of 16 mph within 600 ft of the first rumble strip was seen. The increased outside ambient noise however drew strong opposition from nearby residents.

Some form of behavioural adaptation has also been reported in areas where rumble strips are placed. If rumble strips on a two-lane road are used only on one side of the road an adverse effect, in the form of swerving into the oncoming lane, can occur. This kind of effect was found by Parsonson and Rinalducci (1982), who suggested that rumble strips should be reserved for non-residential areas where unfamiliar drivers are numerous. On the other hand, full-carriageway devices generate extra noise from traffic travelling in the opposite direction. Petterson (1976) also points out that the alertness-increasing/surprise effect can be lost if rumble strips are used in too many places, especially if the share of local traffic is high at these places.

2.1.8 Mini-roundabouts

Mini-roundabouts were originally introduced as replacements for priority junctions, often to improve operating efficiency by altering the balance of priority in favour of the dominating streams. Varhelyi (1993) describes a large-scale experiment with mini-roundabouts in a Swedish town. On average, the roundabouts reduced speed from 48 km/h to 35 km/h at junctions, with decreases in speed on the links between the roundabouts. In addition, injury accidents at the roundabouts decreased by 44%.

Summersgill (1989) reviewed the accident frequencies and rates of all roundabouts with a central island diameter less than 4 m and concluded that mini-roundabouts are a relatively safe form of junction. This may be because roundabouts are effective in breaking up long lengths of road that otherwise might encourage speeding. Lynam, Mackie and Davies (1988) also found that roundabouts were successful at reducing vehicle speeds and breaking up the perceived straightness of the road. Herrstedt (1992) suggests that roundabouts can be effective speed management tools but their effectiveness is mediated by the extent to which drivers are forced into a roundabout manoeuvre, i.e. deflection. A large roundabout used to mark the entrance to a small town was successful at reducing traffic speeds, whilst a mini-roundabout did not reduce speeds to an appropriate level.

In summary, although mini-roundabouts were originally designed to improve traffic flow through intersections, they have been seen to improve safety by decreasing speeds and associated conflicts. Again, as with the lateral displacements discussed above, the reductions in speeds are more noticeable with increases in the lateral movement the vehicle must undertake.

2.1.9 Village gateway schemes

Gateway schemes are mostly used at the transition between high speed and low speed areas such as at the entrance to rural villages. It is their purpose to make it clear to drivers that the speed limit has changed and they are often combined with additional traffic calming measures and signing (Figure 2.5).

Figure 2.5: Gateway treatments
(http://www.trafficcalming.org)

During 1992, gateways were installed on the approaches to 18 villages in the U.K. Many of the schemes were not particularly successful and it was recommended that speed reductions in villages can only be achieved if stringent physical measures are also used at regular intervals along the route (Wheeler, Taylor and Barker, 1994). The study highlighted that the design and siting of measures need careful consideration. In addition, it appears that the visual impact of the gateway is important; contrasting red/white road surfaces and a '30' roundel were particularly effective. It was also suggested that gateways should be sited away from features that already constrain speed, such as bends and summits. Gateways are probably more appropriate to relatively wide roads where there is more opportunity to provide horizontal deflection by, for example, narrowing and central islands. Advance warning signs of speed reducing measures may make the measures more effective by influencing drivers who are unfamiliar to the area.

Riemersma, Van der Horst, Hoekstra, Alink and Otten (1990), studied the speed reducing effect of gateways implemented on rural roads at entrances to villages in Germany. The gateway implementation used poles, speed limit signing and paint on the road. The results showed that the mean speed at the gateway decreased from 77 km/h to 66 km/h with the largest reductions for the fastest drivers. However, recorded speed still far exceeded the 50 km/h speed limit.

It is relatively difficult to assess the effects of gateway treatments as they are often a combination of a number of physical interventions. It thus becomes hard to partial out the separate effects, but the literature reviewed in the previous sections suggests that speed reductions are most likely to be obtained where drivers are required to manoeuvre around an object (e.g. chicane). Thus gateways that include elements such as these will probably be more effective.

2.1.10 Advisory speed signing

Advisory speed signs are often used at sharp curves. Hammer (1969 – cited in Zwahlen, 1987), found that curve warning signs on their own did not result in significant accident reductions, but the introduction of curve warning signs in conjunction with advisory speed signs did result in significant reductions in accidents, especially run-off-the-road accidents at night. However Zwahlen (1987), questions the validity of the results because of the small size of the sample and lack of control; his study found that advisory speed signs were not effective at reducing their speed through curves compared to curve warning signs alone.

Rutley (1972) studied the effects of the addition of advisory speed signs to existing curve warning signs at about 150 sites in the U.K. The signs displayed the maximum speed at which drivers could comfortably negotiate the curve. The results showed that the average speed of vehicles in the curves were affected by the sign when the signs showed a speed different from the mean speed at which vehicles had been travelling before the signs were installed. The mean speed moved towards the advice given by the sign: for some drivers this was a downwards and for others an upwards move.

Trials of speed limit countdown signs and roundel markings were carried out in several rural villages in the U.K. (Barker and Helliar-Symons, 1997). Countdown signs show a black speed limit symbol with three, two or one black diagonal bars on a white background. They are situated at 300, 200 and 100 m respectively from the start of a new speed limit. Roundels are elongated circles with the speed limit in the centre, painted on the road surface at one or more positions within a speed-limited area. The findings overall suggested that while the 40 mph roundel markings produced a statistically significant reduction in speed of about 3 mph, the 30 mph roundels and the countdown signs had no significant effect on mean speed.

2.2 Technological solutions

Technological advances in measurement and communication have created the opportunity for the development and testing of a number of innovative speed reducing solutions. There is a distinction between systems based at the roadside, those based in the vehicle itself and those which combine information from both roadside and in-vehicle sources. Roadside systems concentrate on feedback about traffic measured by equipment outside the vehicle, whereas in-vehicle technology relies on the modelling of vehicle parameters. Brookhuis and Egberink (1992) provide an overview of the various types of systems.

2.2.1 Variable Message Signs

Road-based measures often employ Variable Message Signs (VMS) to convey information to the driver. A wide range of messages can be displayed on VMS in the form of text or pictograms. VMS allows motorists to be kept up to date with current road conditions ahead and may be interfaced to traffic monitoring systems. Many of the studies reviewed focus on rates of compliance with the VMS, either in survey form or via observational studies. Bonsall and Palmer (1999) provide an overview.

Some studies have observed reductions in mean speeds when VMS provided the reason for the reduction. A study of VMS with radar at road works in South Dakota indicated that they were effective in reducing the speed of the traffic entering the road works (McCoy, Bonneson and Kollbaum, 1995). The mean speeds were 4 to 5 mph lower after the signs were installed. The speeds of vehicles exceeding the speed limit of the work zone were reduced significantly, and the number of vehicles exceeding the speed limit by 10 mph was reduced by 40%.

The study of the effectiveness of VMS at road works (Benekohal, 1992) and testing of VMS at seven sites on interstate highways (Garber and Patel, 1995) showed that a VMS was more effective than a static sign in altering driver behaviour at roadworks. The use of a personalized message to the high-speed drivers made the drivers more willing to reduce speeds in these areas. It was concluded that both mean speeds and speed variance could be reduced through the use of VMS thus improving safety at roadworks.

Van der Horst (1993) measured the effects of a VMS that displayed the speed limit on a motorway. The percentage of drivers exceeding the speed limit was more than 50% in good weather conditions and more than 80% in rainy weather. With the VMS system showing the “130 km/h” speed limit (in good weather), the speed in the slow lane decreased by about 5 km/h and the percentage of drivers exceeding the speed limit in that lane decreased from 42% to 32%. In the fast lane, the speed was reduced up to 7 km/h and the percentage of drivers exceeding the speed limit decreased from 66% to 50%. However, these effects occurred only at the beginning of the site and decreased after that. With the VMS showing the “110 km/h” speed limit (i.e. when raining) the impact of the message was more pronounced and long-lasting; speed reduction was 9 km/h in the fast lane and up to 6 km/h in the slow lane. The impact of VMS persisted at least 800 m after the sign.

Overall, VMS appear to relatively effective, especially if the reason for the speed reduction is clear to drivers.

2.2.2 Variable speed limits

Variable Speed Limits (VSL) are employed in an effort to improve traffic flow and thus hopefully reduce accidents. They were implemented on the M25 (London Orbital Motorway), by linking traffic volume detection with mandatory variable speed limits and an enforcement system (speed cameras). Thus the speed limits are triggered and displayed according to detected vehicle volumes. At 1650 vehicles per lane per hour (vph) the speed limit decreases to 60 mph and above 2050 vph a 50 mph speed limit is imposed. The project evaluation (Harbord, 1998) suggests that the majority of drivers obeyed the speed limits and that excessive speeding diminished significantly. It was also reported that lane utilisation improved due to a better spread of traffic over the different lanes. A 30% decrease in injury accidents and a 25% reduction in damage-only accidents were noted during the first year. Drivers' opinions were also sought, and proved to be positive: almost 60% thought that VSL improved traffic flow and would like to see similar systems used more widely.

A similar project was undertaken on a 13 km stretch of autobahn near Frankfurt. Before introduction of the system, the average traffic speed was 85 mph with significant stop-start fluctuations. After implementation, average speeds reduced to approximately 50 mph with improvements in the traffic flow. The associated 29% reduction in accidents implied that the installation would be cost efficient in less than 7 years. Dutch results from a stretch of motorway between Amsterdam and Utrecht were equally as encouraging (Nuttall, 1995).

This type of scheme appears to encourage both reductions in mean speeds and reductions in speed variance. Coupled with signs instructing drivers to remain in their lane, such schemes could also contribute to reduced accident rates whereby less lane changes occur. The scheme on the M25 also makes use of heavy enforcement and it is doubtful that the scheme would work without it.

2.2.3 Interactive feedback signs

It has been suggested that the provision of extrinsic feedback, i.e. feedback from an external source that makes reference to a normative or standard performance, is essential in reducing driving errors (Kuiken, 1996). Groeger (1990) suggests that the lack of feedback regarding errors (i.e. exceeding the speed limit) weakens the association between actions and consequences, leading to over-learning of inappropriate behaviours. Feedback information can either pertain directly to an individual driver or to the surrounding general driving population.

The provision of *individual* feedback is based on the assumption that personalised information is more relevant than information that is given about general driver behaviour. In addition, an underlying motivation to comply may also exist whereby motorists believe that detection of their speed and sometimes their numberplate too, implies enforcement.

Trials were undertaken using a mobile roadside speedometer to measure speeds and a display that indicated the speed of an approaching vehicle (Vaa, Ragnøy and Sætermo, 1995). The speed of individual vehicles was shown immediately to the appropriate driver and significant reductions in speed were found. The effects of mobile roadside speedometers were also evaluated as a means of controlling urban traffic speeds (Casey and Lund, 1993). The data indicate that generally the presence of the speedometers reduced average traffic speeds by about 10% where it was located and about 7% at short distances downstream. The proportion of drivers exceeding the speed limit by at least 10% fell from 15% to 2% on days the speedometer was deployed. However the effect was limited to the times when it was actually deployed. The associated police enforcement in this study was clearly important with regard to the long-term effectiveness of roadside speedometers as the effect appeared to last for about three weeks.

In the U.K. at roadworks on the M1, two cameras were mounted on overhead bridges, 225 m apart at the start of the works area (Symonds Travers Morgan, 1995) to test the effect of a Speed Violation Detection/Deterrent system (SVDD). A trailer-mounted sign was used to display vehicle number-plates and speeds. After implementation, average speeds were 10 mph lower and although the 85th percentile speed was approximately 5 mph above the speed limit (50 mph), this was nearly 12 mph lower than when the trial started. The reduction in high-speed violations (>70 mph) was maintained at levels which were a quarter of those which prevailed before the operation of SVDD. Consistent with the reductions in speed, there was also a reduction in the severity of accidents. Calculated benefits in respect of direct injury accident costs showed a saving in excess of £500 a day. It should be noted however that driver speeds may also have been modified by the media interest in the scheme and the high presence of police before the scheme was implemented.

Automatic speed warning signs were installed in Hampshire, U.K. in 30 mph zones of two villages (Helliar-Symons, Wheeler and Scott, 1984). Vehicles exceeding a pre-set trigger speed activated the signs that then displayed the message “SLOW DOWN 30”. Speed reductions in the centre of the villages were very small. The data indicated an overall reduction in injury accidents of 52%, although this was not statistically significant. It may be that such signs alert drivers to be more attentive to the road ahead even if they do not slow down, serving a similar function to rumble strips as discussed above.

The provision of *collective* feedback to drivers rests on the assumption that drivers wish to conform to the actions of others. The use of VMS to display alternative types of collective feedback to drivers has been evaluated (e.g. Van Houten and Nau, 1981, 1983; Van Houten, Rolider, Nau, Friedman, Becker, Chalodovsky and Scherer, 1985). Ragnarsson and Bjorgvinsson (1991), cite supportive evidence for the use of feedback signs that display the percentage of vehicles not speeding on the previous day or week. The first sign read “Yesterday XX% drove through here at the right speed”. In some locations there was an additional sign reading “Best record so far XX%”. The percentage numbers on each sign were chosen randomly from numbers between 85 and 95 and were not based on actual speed data. With the single sign there was a statistically significant speed reduction from an average of 69.0 km/h to 63.4 km/h and the additional sign further reduced this to 62.9 km/h. The effects were as long lasting as 6 months after exposure, a result also achieved by Philips and Maisey (1989). However these results were not replicated by Roqué and Roberts (1989) and it is doubtful that these effects are transferable to roads where no feedback is given.

Van Houten and Nau (1983) showed that the technique of posting the percentage of drivers not speeding, along with the best record to date, reduced excessive speeding (85^{th} percentile) by over 50%. It was claimed that the effects persisted to some degree for up to 6 km downstream. The use of a lenient criterion to define speeding (20 km/h over the speed limit), which allowed for the posting of high percentages of drivers not speeding (80%-90%) was more effective in reducing speeding than the use of a stringent criterion (10 km/h over the speed limit). The explanation of this stronger effect when high numbers are posted may be that drivers are more likely to adapt to the behaviour of the majority. Haglund and Åberg (2000) suggest that drivers' perceptions about the average speed on a road on which they regularly drive is biased in that they tend to overestimate. They argue that Van Houten and Nau's (1983) results are a result of reduced social pressure towards keeping pace with the traffic in general. Similar results were found by Maroney and Dewar (1987) with the latter reporting a mean speed decrease from 61.5 km/h to 58.7 km/h.

These feedback mechanisms have proved to be relatively successful, in the short term at least. They have often relied on enforcement or the threat of enforcement, and it could be this aspect that induces speed reductions. De Waard, Van der Hulst and Brookhuis (1999) for example, reported speed reductions of up to 10 km/h with a speed feedback system that implied enforcement, as opposed to a later experiment (Brookhuis and De Waard, 1999) that used only an advisory system.

2.2.4 Speed detection and enforcement

Local authorities have deployed speed cameras in areas where there is or where there is *perceived* to be a speeding problem. Only a small number of well controlled studies have been reported in the U.K., the largest of which is the West London trials. These trials were launched in 1992, with cameras placed at sites having a high incidence of speed-related accidents. Early results were promising in demonstrating success in deterring drivers from travelling at very high speeds. The number of drivers travelling at 60 mph or higher in a 40 mph zone reduced by 97% (Swali, 1993). It was also claimed that accidents were reduced by 22% overall and fatal and serious casualties by 38%. The author reported that mean speeds were reduced by 5 mph and 85^{th} percentile speeds reduced by 7 mph. These are broadly in line with the TRL estimate that a 1 mph reduction in mean speed is likely to result in a 5% saving in accidents and a 7% reduction in fatalities (Finch et al., 1994).

However a subsequent press report (Local Transport Today, 1996) suggested that speed cameras may bring about only a temporary reduction in accidents. The report concludes:

> *'New figures show that accidents are now rising steeply again on trunk roads in the West London area, reversing much of the improvement seen since cameras were first introduced. The Highways Agency admits "the effectiveness of the camera installations may decrease as drivers become familiar with the locations". It is also widely known among motorists that the installations are fitted with cameras for only part of the time. The new figures show that in the second year of the trial, casualties rose again by 16% and the upswing in numbers killed or seriously injured was even steeper. A similar pattern was shown in the number of personal injury accidents.'*

A New Zealand study compared the effectiveness of overt versus covert enforcement (Keall, Povey and Frith, 2000). Visible speed cameras were clearly signposted, whilst hidden ones introduced some uncertainty as to their location. The authors report statistically significant decreases in mean speed and accident rates. They state that hidden cameras had more of a general effect than the visible cameras which, unsurprisingly, were only effective in their vicinity.

Enforcement or the threat of enforcement appears to be one of the most effective speed reducing measures. However, the reductions in speed are usually short-lived and drivers are able to learn the position of the cameras. Such information about the locations of cameras is even available on the Internet, and discussion forums exist whereby information is exchanged concerning their locations. The obvious cost of enforcement, both in installing and maintaining the cameras and personnel costs, has an important part to play when calculating the cost/benefit ratios of such schemes.

Until recently in the U.K., the state-of-the-art for detecting speed used an autonomous photographic camera linked to a speed detection device. The process of retrieving and developing the film and subsequently tracing the offender via vehicle records can, however, be time consuming and inefficient. Although photographic evidence can be used as evidence for prosecution, the police must meet a legal requirement to serve a Notice of Prosecution within 14 days of the offence. More recently, systems have been developed to improve the speed and efficiency of detection systems by using digital photographic technology combined with automatic number-plate recognition software. Rather than using instantaneous speed, the average speed of every vehicle over a distance of about a mile is measured by reading the license plates and matching them up camera-to-camera. An average speed for the vehicle is calculated and if this is above the trigger speed, then the vehicle's identification is recorded along with its speed. It operates 24 hours a day, needs no film and uses no flash or radar. The system has been proven to be over 99% accurate in almost all weather conditions.

2.2.5 Incident warning systems

The purpose of an incident warning system (IWS) is to make road users aware of a hazard on the road ahead and thus be better prepared to reduce speed. Incidents can include adverse weather conditions, congestion, accidents or accident blackspots such as sharp bends. Alm and Nilsson (2000), demonstrated that an IWS encouraged drivers to reduce their speed earlier on approach to incidents such as congestion, road works and accidents.

An automatic fog warning system using advisory speeds was implemented on the M25 London orbital motorway. There was found to be an overall reduction in mean vehicle speeds of approximately 2 mph when the signals were switched on based on data from six test sites (Cooper and Sawyer, 1993). Greater speed reductions occurred in lanes two and three and increases in speed occurred when the signals were switched off. It was found that faster vehicles slowed down more and it was estimated that the 85th percentile speed fell by about 0.5 mph more than the reduction in the mean when the signals were switched on. These speed reductions indicate that drivers were alerted to the presence of fog ahead which coupled with the greater credibility associated with an automatic system, perhaps meant that drivers were more likely to respond quickly to the hazard itself. Another study tested a fog warning system consisting of a VMS and VSL in the U.S. by Janoff, David and Rosenbaum (1982). In the presence of fog, a warning sign and a sign with a lowered speed limit was shown. The results showed that the speed level decreased by about 10% and the number of accidents by about 20%.

Rämä and Kulmala (2000), investigated the effects of VMS in Finland. The sign consisted of a VMS with a pictogram of a snowflake and a recommended following-distance. The speed-reducing effect of the sign was about 2 km/h when the sign flashed, and about 1 km/h when the sign was on continuously. The duration of the speed effect of the sign warning about slippery road conditions was approximately 3 km. The flashing sign affected speeds up to a distance of 14 km. During the following winter, the effects were about one third smaller, perhaps due to the decrease of the novelty effect of the sign.

It is likely that in order to be effective, the message displayed on an IWS has to be perceived by the driver as being relevant and reliable. In this respect, IWS that warn of bad weather conditions are likely to work effectively as the reason for the speed reduction is obvious.

2.2.6 In-car information

Rutley (1975) claimed that if drivers could be made continually aware of their actual speed then they might drive at more appropriate speeds. A Head-Up Display (HUD) speedometer, which gives continual speed information to the driver in their normal field of view, might thus improve speed behaviour. Rutley's (1975) experiment with such speedometers in conjunction with advisory speed signs at sharp bends, showed improved compliance. Sojourner and Antin (1990) also found that a HUD speedometer generally improved performance in a simulated environment. However, care needs to be taken that in complex driving situations, the HUD does not create distraction or overload the driver (Ward and Parkes, 1994).

Other types of in-car information have also been evaluated. Nilsson and Berlin, (1992) carried out a field test in Sweden whereby the legal speed limit was displayed below the speedometer on the dashboard. The average speed with the system was 70 km/h and without the system was 72 km/h (not a statistically significant difference). Speed limit compliance in a 30 km/h school zone was slightly improved with the system. The number of glances at the dashboard was on average three times higher with the display compared to driving without the system. The authors conclude there may be some distraction effects of providing such information.

One way of reducing distraction may be to provide an auditory warning as opposed to a visual one. Brookhuis and De Waard (1996) developed a display that was located on the instrument panel and continuously displayed the speed limit. The colour of the display changed according to speeding behaviour (green for normal, amber for a warning and red for violation). When the display was red, an audible warning message was also issued. There were few effects of the display in terms of speeding, except in 50 km/h limit zones. In addition, the authors report that some subjects used the continuous feedback to keep their speed just within the amber region.

2.2.7 Adaptive cruise control

Adaptive Cruise Control (ACC) helps drivers to adapt their speed to the prevailing conditions. Using radar, ACC detects vehicles ahead and adapts speed automatically such that a safe distance is maintained to the vehicle ahead. ACC was developed primarily as a comfort system, but also as a way of increasing road capacity (Smulders, 1990; Rao and Varaiya, 1993; Ferrari, 1994).

In a micro-simulation study (O'Cinneide, Dryselius, Gutowski, Gynnerstedt, Risser, McCaul and Merza, 1995) three functions of an ACC were tested (speed control, overtaking assistance and headway control). The results showed an increase in average speed under all simulated traffic conditions, accompanied by a clear reduction of speed variance. The speed control function had a positive effect on the road capacity and on travel speeds, however, the safety outcome did not seem to be positive as the number of overtakings with low safety margins increased.

A common criticism of ACC, is the fact that drivers may rely on the system as a collision avoidance system. In a Swedish field study, information on the advisory speed in urban areas was transmitted to an instrumented vehicle (Almqvist and Towliat, 1993). Test drivers drove twice along a route. In the first drive, the "information" mode, the driver had to decide whether to comply with the displayed speed limit. On the second drive, the "control" mode, the speed was automatically set to the current speed limit or to the recommended speed depending on the situation (sharp curve, pedestrian crossing, etc.). When the situation demanded lower speed, the driver had to activate the brakes. The results showed that in the "information" mode, violations of the speed limit were frequent. The "control" mode did not allow, of course, any speed limit violations, and driver's adaptation at some critical locations deteriorated. Drivers may thus have become dependant on the system to control their speed appropriately at all locations.

This concept was further investigated by Nilsson (1995). She carried out a simulator study on the effects of ACC in critical situations (which the ACC was not designed to handle). The ACC adapted the speed to keep a safe distance to the vehicle ahead, but the ACC could not detect stationary objects ahead. In this critical situation several collisions occurred in the group of ACC users. The author suggests this was due to drivers misunderstanding the system and trusting it to respond in such situations. They then realised too late that the ACC would not act and therefore they had to intervene. An additional finding was that drivers using ACC travelled more in the outside lane of the motorway than drivers without ACC, a finding also reported by Hoedemaeker and Brookhuis (1998). This could be due to drivers trying to prevent the ACC system from slowing them down on approach to a vehicle ahead. Heino, Rothengatter and Van der Hulst (1995) report that drivers using ACC chose shorter time headways than those with unsupported driving. In addition, Hoedemaeker and Brookhuis (1998) and Ward (2000) found that ACC resulted in more lane keeping errors.

The largest field trial of ACC was recently completed in the U.S. Funded by the National Highway Traffic Safety Administration, 108 volunteer drivers were provided with an ACC equipped vehicle. Over 110,000 miles were driven in total, of which 35,000 were under ACC. The final report (Fancher, Ervin, Sayer, Hagan, Bogard, Bareket, Mefford and Haugen, 1998) concluded that overall, ACC increased average headway to lead vehicles from 0.8 seconds in manual driving to 1.1 seconds under ACC. However, this was due to the fact that the shortest headway setting on the ACC system was 1.1 seconds. Thus no downward shift in headway distribution was possible due to system constraints.

In summary, although ACC systems have now penetrated the market, few wide-scale studies have been undertaken. Behavioural adaptations to the systems have been noted and should be used as a starting point in future ISA evaluations.

2.3 Summary

Many of the countermeasures described above have been able to demonstrate their effectiveness at reducing speed to some extent. Elvik (2001) carried out a meta-analysis of 33 studies that evaluated the safety effects of area wide traffic calming measures in urban areas. He reports that, on average, area wide traffic calming reduces accidents by about 15% (main roads and local roads combined).

However, it can also be said that these measures are generally only effective locally (i.e. at their location of installation) and that some of the measures, in particular those which improve road design, may encourage drivers to driver faster than before. The costs of installing (and maintaining) some of the countermeasures mentioned above can be high in relation to the benefits they provide and of course these benefits are only applied locally.

The argument naturally leads to a solution that is global in its impact and that has flexibility in its implementation. One possible solution is known as Intelligent Speed Adaptation (ISA), a system that, using a variety of technical solutions, is able to restrict the maximum speed of a vehicle. Research focussing on various aspects of ISA is taking place in a number of European countries, but is still very much in its infancy. In addition, the research has focussed mainly on issues of driver acceptance, with little evaluation of possible safety benefits and costs (apart from system effects of reduced maximum speed).

How ISA might address the deficiencies in current speed reduction techniques is summarised in Table 2.1. This table shows clearly that ISA could be a global, flexible method of controlling driver speed. Such a system could be implemented using a variety of existing technology: there is nothing complicated in actually designing a reliable system that forces drivers to drive at or below the speed limit. What is more challenging is the assessment of the safety costs and benefits that are associated with such a system. The next chapter describes the research on ISA to date and critically evaluates the methodologies and measures used.

Table 2.1: Deficiencies in current speed reducing measures

Measure	Deficiency	Solution
Edge and centre line treatments	Sensitive to wear, dirt, snow and rain	ISA does not rely on physical measures. In conditions of poor visibility ISA still operates.
Transverse carriageway markings	Effect is short lived in terms of distance	ISA acts globally.
Lane narrowing and chicanes, mini roundabouts	Increase in conflicts. Unsightly and only effective if oncoming vehicles are present.	ISA does not require drivers to alter their lateral placement. ISA requires no changes to road infrastructure.
Delineation/road way markers	May increase speeds due to enhanced driver confidence	ISA dispenses the need for additional road delineation schemes. Although ISA is not a solution to lane departure, reduced speeds allow the driver to travel at more appropriate speeds.
Rumble strips, speed humps	Increase in noise or pollution Decrease of speed reducing effect over time	ISA dispenses with the need for physical measures. The system acts silently with no change to the vehicle emissions profile. The system is operational permanently.
Incident warning systems Curve warning or advisory signs	May only be effective when the reason is obvious	A dynamic system lowers driver speed at hazardous locations. ISA can be linked to a control centre that provides this information.
Village gateway schemes	Speed reductions small and may only be achieved with physical measures.	An ISA system can automatically reduce speeds in line with a lower speed limit.
Variable speed limits	Although generally successful, they rely on enforcement	With ISA these schemes could be more widespread and would not require enforcement.
Enforcement (implicit or explicit)	Enforcement is costly and locally based.	ISA is global and does not rely on the availability of manpower and other resources.
Incident warning systems	Drivers must perceive the warning to be relevant for there to be reductions in speed.	The appropriate speed can be maintained for the duration of the incident.
Speed limit display/warning system	Driver distraction may increase.	With ISA, drivers do not need to monitor their speed continuously.

Chapter Three

Evaluating Intelligent Speed Adaptation

This chapter firstly reviews the existing literature on the evaluation of various types of ISA systems. Such evaluations include microsimulation studies, theoretical accident-reduction relationships and on-road trials. Key deficiencies in the research will be outlined. A framework of proposed experiments is presented at the end of the chapter, based on the deficiencies identified.

3.1 Microsimulation studies

Microsimulations model road networks to allow the large-scale evaluation of a particular implementation under a variety of conditions. For example, the number of vehicles equipped with a system can be varied as can traffic density and flow. Global measures of journey time, travel speeds and, in some cases, emissions can be calculated to provide an overall picture of how ISA may affect the traffic environment.

A Finnish traffic simulation study on the effects of mandatory ISA on HGVs proposed that traffic safety would improve due to a decrease in the number of fatalities and injuries (Kulmala and Beilinson, 1993 – cited in Várhelyi, 1996). Decreases in travel speeds were suggested to be larger for HGVs (at the highest between 2.2 and 2.9 km/h at free flow) than for cars. There was little effect on speed variation. This result contrasts with Gynnerstedt, Risser and Gutowski (1996), who used a Swedish simulation model to study the effects of ISA on two-lane rural roads. All vehicles were assumed to be equipped with ISA (set at the current speed limit). Whilst mean speeds were unchanged, the standard deviation decreased, i.e. traffic speeds were more homogenous. In addition, the number of overtakings decreased, leading to an increase in the percentage of cars driving in platoons.

Davidsson (1995 – cited in Várhelyi, 1996) also noted this reduction in speed variation in a model simulating an urban area in Sweden. A maximum speed of 25 km/h (15 mph) was permitted at junctions. However, mean speeds, in spite of lower maximal speeds, increased slightly; this was attributed to the effect of platooning whereby vehicles passed the intersections more smoothly.

In the U.K., a microsimulation analysis of the effect of ISA on network congestion and pollution was carried out using the DRACULA (Dynamic Route Assignment Combining User Learning and microsimulAtion) model. Simulation runs were carried out using actual road networks including differing road types (Liu and Tate, 2000). Two time-periods (peak and off-peak) were modelled for an urban network to compare the impacts of ISA at different levels of congestion. As in previous work, it was found that ISA effectively reduced variation in travel speeds, but more importantly did not induce additional congestion in the network. ISA also reduced fuel consumption, particularly in the urban environment. A total reduction in fuel consumption of 8% was achieved when 100% of vehicles were equipped in the urban networks.

The results from these microsimulation studies suggest that ISA could lead to network benefits, particularly when system penetration rate is high. Secondary benefits as a result of improved traffic flow and reduced maximum speeds include savings in fuel and the safety benefit of reduced critical overtakings.

Although microsimulation models provide predictions about network effects, their fundamental flaw is that, at present, the behaviour of the simulated vehicles is homogenous and inflexible. The vehicles follow simple rules in a deterministic manner, such as adhering to a two-second headway. The introduction of an intervention such as ISA into the microsimulation model does not take account of any interaction between the original rule set and the functioning of that intervention. That is, microsimulation does not take account of how drivers may change their own driving behaviour in response to the system. Such changes in behaviour may have important consequences for network safety. For example, if ISA is perceived by drivers to increase travel time as a result of speed limitation, then drivers may modify their "rules" and adopt a shorter headway to reduce travel time. It is therefore vital that changes in behaviour with ISA are assessed in order to be able to provide these microsimulation models with realistic performance data. Such changes in behaviour can only be observed in on-road or simulator studies.

3.2 On-road trials

The first trial with a variant of ISA equipped in a passenger car was carried out in France (Saad and Malaterre, 1982). The test drivers manually set a speed limit, which could not be exceeded unless they disengaged the system. The authors reported that drivers adapted their set speed depending on the surrounding traffic speed. This resulted in small changes in speed around the speed limit. Drivers interacted with the system in this way in order to keep up with the surrounding traffic. Some drivers reported that this was physically tiring and found keeping to the speed limit on 40 and 50 mph roads difficult. On roads where drivers had to adapt their speed frequently, the system was used less frequently, compared to motorway driving. Most drivers set the top speed on the system significantly above the speed limit and it was found that as the speed limit on a road decreased, the difference between the speed set on the system and the road speed limit increased. In addition, on shorter stretches of road with a lower speed limit, e.g. through villages or curves, the drivers did not adjust the speed set on the limiter.

For a while, there was little subsequent research in the field, apart from an evaluation of speed limiters (governors) on Heavy Goods Vehicles (HGVs) in Australia. A number of Australian accident studies (Sweatman, 1990; Rankine and Hill, 1990, cited in Tan, 1992) suggested that excessive speed is a major contributing factor in accidents involving HGVs. Thus, speed limiters for new and existing HGVs were introduced in Australia in 1991 and the impact of this initiative was monitored by measuring truck speed and efficiency of service on major truck routes (Tan, 1992). In addition, the speed of speed-limited trucks through rural towns and curves was examined. The results were promising in terms of mean speed and speed variance (both generally decreased in the after period). On the other hand, the analysis suggested that queue lengths increased when the queue leader was a truck. The author assumed that this was due to the increasing number of trucks being speed-limited on the routes; however, the measurement technique was unable to discriminate between speed-limited and non-speed limited vehicles. No significant differences were found between speeds in the before and after periods through rural areas and curves.

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At approximately the same time as the study above, a programme of work on ISA was being undertaken in Sweden. After initial round table discussions, an ISA system was implemented in two Volvos using a German system called TempoMASTER. The maximum speeds permitted were 30 and 50 mph (these were set by the observer in the car as appropriate). This field study collected speed profile data along with fuel consumption and emissions, travel times and behavioural observations (Persson, Towliat, Almqvist, Risser and Magdeburg, 1993). The authors reported that ISA was most beneficial on links with mean speeds reduced by up to 8%. In-car observers noted that the test drivers committed fewer traffic light violations with ISA and maintained a more appropriate headway. The number of conflicts also decreased. On the negative side though, drivers with ISA engaged in a higher number of inappropriate behaviours with other road users. Of concern also, was the fact that drivers using ISA tended to drive faster on approach to junctions.

This Swedish research program then expanded with 25 members of the public having their own cars equipped with ISA. All entry and exit roads of the town of Eslöv were equipped with transponders (radio transmitters) mounted on the 50 km/h (30 mph) speed signs. When the equipped cars passed the transponders, the maximum speed allowed was automatically set at the 50 km/h speed limit and when the cars left Eslöv the speed limiter was disengaged. The study (Almqvist and Nygard, 1997) focussed mainly on speed profiles and acceptance of the system over a period of two months of use. As in previous work, mean speed and speed variance reduced when ISA was used, a finding that was verified in later field studies (Vårhelyi and Mäkinen, 2001). The acceptability data suggested that drivers were generally supportive of such a system, and did not find that it interfered with their (urban) driving. In contrast to the previous study, observation data showed an improvement in interactions with other road users.

Since then, the Swedish government has made available approximately £5.3 million for the national evaluation of ISA. This evaluation is co-ordinated by the Swedish National Road Administration (SNRA) and four trial areas have been identified (Borlänge, Lidköping, Lund and Umeå). Table 3.1 describes the activities in each of the cities.

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The Swedish trials will be completed at the end of 2001, and the data collected include trip diaries, interviews, behavioural observations and measurements of speed, acceleration, travel time and emissions.

Table 3.1: Swedish ISA evaluations

	Umeå	**Lidköping**	**Borlänge**	**Lund**
Type of system	Informative, using transmitters	Informative and/or active support using GPS and digital road map	Informative and quality assurance system using GPS and digital road map	Active support using GPS and digital road map
No. of vehicles	4500	280	400	290
Test drivers	Private motorists, professional drivers and public transport	Private motorists, companies and local authority vehicles	Private motorists and professional drivers	Private motorists, professional drivers and public transport

Informative system – when the driver exceeds the speed limit, a dashboard light illuminates and an auditory signal is presented. The intensity of the signal increases if speed increases further.

Active support – when the driver exceeds the speed limit, he/she feels resistance in the accelerator. A kick-down function is provided, whereby drivers can disengage the system by pressing hard on the accelerator.

Quality assurance – the informative system is installed on school buses and similar public services. The installed unit registers and stores any speed violations that occur despite being given a warning signal. The organisation then receives feedback on driver performance.

Another European country with an interest in the evaluation of ISA is the Netherlands. In July 1996, the Dutch Ministry of Transport, Public Works and Water Management presented a new multilayer programme for road safety including a pilot study to assess the feasibility of using ISA. Twenty vehicles in the city of Tilburg were equipped with a mandatory ISA system in 1999. Each of the 40 volunteers drove a car for eight weeks. The emphasis of this trial was on acceptability – overall most drivers expressed positive opinions of ISA (Besseling and van Boxtel, 2001). The researchers found differences in acceptance depending on the speed limit: drivers were more negative about ISA in the 18 km/h (a car-park) and 30 km/h areas. With regards to speed measurements, decreases in mean speed and speed variation were reported.

Although the Netherlands, Sweden and the U.K. have nationally funded ISA projects at present, other countries (e.g. France, Belgium, Denmark and Finland) are also looking to implement such projects. There is also some interest in the U.S. (McKeever, 1998; Jozwiak, 2000).

The evaluations reported here have provided a good starting point for ISA and have developed a range of working prototype systems; however there is a danger that as enthusiasm grows (both in the research and industrial fields), some fundamental research issues will be ignored. This thesis presents a number of studies, each of which attempts to address these research issues, detailed at the end of this chapter.

3.3 Accident reduction estimation

The central research question that an evaluation of ISA should attempt to answer is that of likely accident reduction. The complex nature of accidents and the lack of detailed reporting makes this question a difficult one to assess. Some researchers have attempted to calculate the likely safety benefits that ISA might provide by using known empirical relationships between speed and accidents. Using these relationships, they have attempted to predict the impact of a reduction in speed on accident rate and/or severity.

Várhelyi (1996) analysed the occurrence of accidents under differing road and lighting conditions and attempted to predict the reduction in accident rate as a result of implementing ISA. He used Nilsson's (1982) formula that calculates the ratio of speed and injury accidents before and after an implementation:

(Accident rate after) / (Accident rate before) = $(v_a/v_b)^2$

(Injury accident rate after) / (Injury accident rate before) = $(v_a/v_b)^3$

(Fatal accident rate after) / (Fatal accident rate before) = $(v_a/v_b)^4$

where v_a = mean speed in the after case

v_b = mean speed in the before case

He concluded that an ISA system would lower the number of injury-accidents, on all roads, by between 19% and 34%. He states that this is a conservative estimation, because it does not include accidents that occur under impaired visibility such as those in fog or on sharp curves. He suggested that a more optimistic estimate is a reduction in accidents between 24% and 42%. This study however did not take into account any changes in the speed distribution that ISA may produce.

In an analysis by Tate (1998), it was demonstrated how different types of ISA (e.g. advisory and mandatory) could affect the speed distribution in different ways. An advisory system, which provides a warning only, could *translate* the speed distribution whereby the shape of the speed distribution remains the same, but is shifted downwards in terms of speed (Figure 3.1).

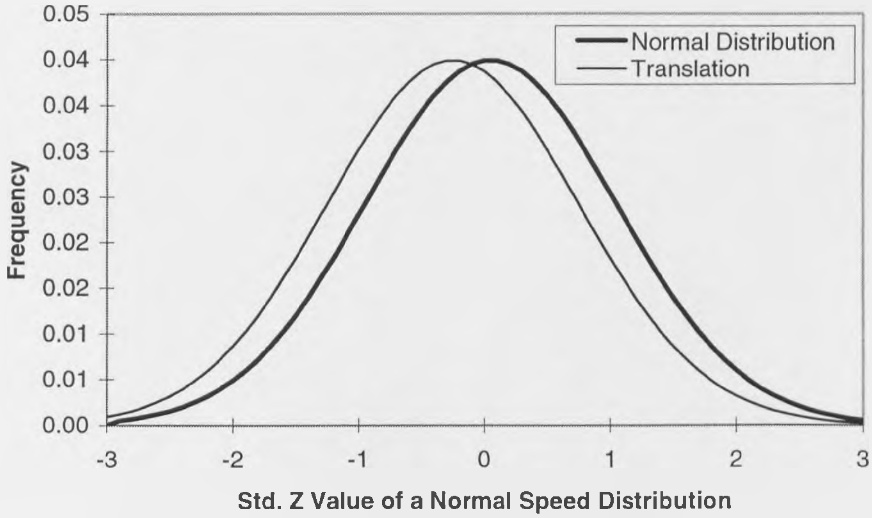


Figure 3.1: Translation of the speed distribution (taken from Tate, 1998)

On the other hand, a mandatory system that enforces maximum speed would *transform* the distribution whereby speed distribution is truncated, with no vehicles exceeding the speed limit (Figure 3.2).

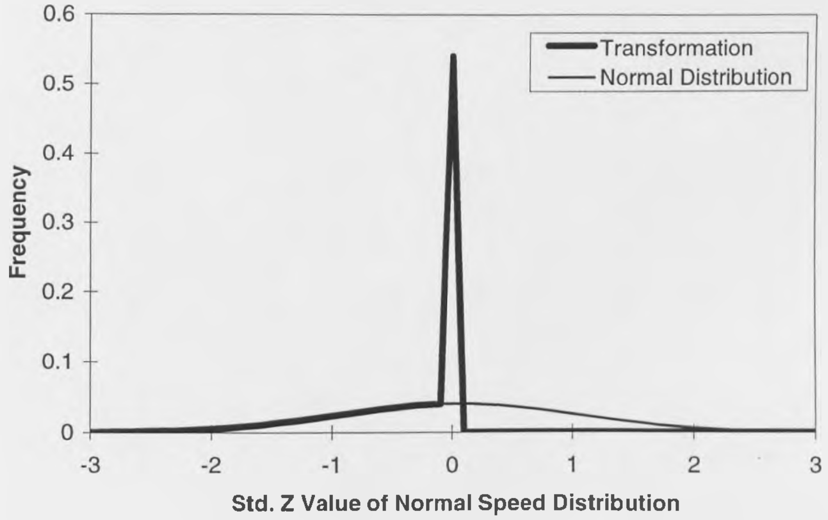


Figure 3.2: Transformation of the speed distribution (taken from Tate, 1998)

Using these assumptions, Tate (1998) then calculated the likely reductions in speed that could be obtained by an ISA system (based on real speed measurements) using known relationships between speed and accidents in the literature, see Table 3.2.

Table 3.2: Estimates of the possible accident reductions[1] with ISA (taken from Tate, 1998)

System Type	System status	Low Estimate (%)	Best Estimate (%)	High Estimate (%)
Advisory	Fixed	2.3	9.0	20.9
	Variable	2.3	10.0	21.5
	Dynamic	3.0	12.0	26.5
Mandatory	Fixed	11.0	20.0	31.0
	Variable	12.0	22.0	32.0
	Dynamic	19.3	35.0	49.0

It can be seen that the best estimate for a mandatory ISA system is a 20% reduction in accidents (similar to that predicted by Vårhelyi, 1996). This reduction rises to 35% if consideration is given to a fully dynamic ISA system that is able to reduce speed at hazardous locations such as curves and in poor weather conditions.

[1] Percentages based upon a total of 230,376 DETR reported injury accidents in 1995

Using these empirical relationships between speed and accidents provides some idea as to the likely benefits of an ISA system. However, it is more difficult to assess how these benefits might be enhanced or outweighed by how drivers actually interact with the system. For example direct system effects, such as reduced maximum speed, may be accompanied by indirect effects by way of a general “calming” effect and a reduction in speed variance. Such calming effects may be manifest in improvements in interactions with other road users, increased control of the vehicle in critical locations and opportunities for drivers to have more time for decision-making. On the other hand, ISA may increase driver frustration and result in increases in negative behaviour such as increased speed at previously low-speed locations, increases in the propensity to remain near the speed limit, or other perceived “time-saving” strategies such as inappropriate overtaking or merging behaviour. Such “unexpected” behaviour is often termed *behavioural adaptation* and is addressed in more detail in the following section.

3.4 Behavioural adaptation

> *‘Behavioural Adaptations are those behaviours which may occur following the introduction of changes to the road-vehicle-user system that satisfy needs of the driver other than for which the intervention was designed’*
> *(OECD, 1990)*

Road safety interventions are designed to reduce the number of accidents of a certain type that are known to occur with regularity at a particular location on the road network. For example, a curve on a rural road may be realigned in order to improve negotiation around it. However, as reported in Chapter Two, it would be simplistic to assume that driver behaviour would be the same after the realignment as it was before: at the very least drivers may increase their speed due to the increase in comfort on curve negotiation.

An OECD (1990) report reviews studies on the effects of various road improvement schemes for evidence of behavioural adaptation. The report concludes that a number of interventions have been shown to attract negative adaptation effects and that these often involve increases in speed (Table 3.3).

Table 3.3: Reported behavioural adaptations to road improvement schemes (adapted from OECD report, page 42)

Safety Measure	Safety effect	Presence of behavioural adaptation	Direction of Adaptation effect	Observed behavioural effect
Increase in lane width	Strong positive	Proven	Positive and negative	Speed increases Lane wobble decreased
Increase in shoulder width	Strong positive	Proven	Positive and negative	Speed increases Lane wobble decreased
Centre markings	Negative and positive	Not proven	-	-
Edge line markings	Positive	Proven	Positive and negative	Speed increases Vehicle positioning improves
Arterial lighting	Strong positive	Not proven		-
Freeway lighting	Positive	Suggested	Possible positive	-
Increased intersection sight distance	Strong positive	Suggested	Possibly negative	Approach speeds increase

Technological innovations for vehicle safety have, in recent years, become important in the marketing of vehicles. Along with high performance, it seems that the general public is eager to embrace safety features and consider them in their purchasing decision-making. In the 1997 Lex report, more than 80% of respondents stated they wanted their next car to have all the latest safety features (including power assisted steering, Antilock Braking System and driver airbag). Studies have found behavioural adaptations to such features. For example, Sagberg, Fosser and Sætermo (1997) reported that taxi drivers with ABS exhibited shorter headways than those without. The OECD report provides an overview of the literature on behavioural adaptations for such safety related vehicle features (Table 3.4). Again, increases in speed appear to be the most common form of behavioural adaptation.

Table 3.4: Reported behavioural adaptations to safety-related vehicle features (adapted from OECD report, page 64)

Safety measure	Safety effect	Presence of behavioural adaptation	Direction of Adaptation effect	Observed behavioural effect
Primary safety in conjunction with sporty vehicle design	Negative, if any	Proven	Negative	Increased speed, riskier overtaking, short headways
Daytime running lights	Positive	Not proven	-	-
High-mounted braking lights	Positive	Suggested	If present, negative	Shorter headways
Studded tyres	Positive	Proven	Positive and negative	Increased speed, decreased speed
Antilocking system	Not proven	Proven	Negative	Increased speed
Seat belts	Positive	Not proven	-	-

There have been many attempts to understand the mechanisms of behavioural adaptation and as a result a number of models have been developed. For a review, see Underwood, Jiang and Howarth (1993) who present their own model that suggests that motivational measures (e.g. education campaigns) are more effective than engineering measures with regards to improving traffic safety. They argue that this is due to the fact that motivational measures are designed to change underlying psychological mechanisms that direct automatic behaviour. Thus there is no room for risk compensation. There is, however, much literature that cites evidence that changes in attitude are difficult to produce, particularly in the area of road safety (e.g. Chesham, Rutter and Quine, 1993).

Behavioural adaptation with ACC was alluded to in Chapter Two. Drivers with ACC tended to travel more in the outside lane of the motorway than drivers without ACC (Nilsson, 1995; Hoedemaeker and Brookhuis, 1998). Headway distributions were also affected with drivers using ACC choosing shorter time-headways than those with unsupported driving (Heino, Rothengatter and Van der Hulst, 1995). A simulator study carried out by Stanton and Pinto (2000) used Wilde's (1988) Risk Homeostasis Theory (RHT) as a basis for explaining behavioural adaptation to a Vision Enhancement

System (VES illuminates the road ahead in poor visibility using infrared). The authors hypothesised that by reducing the risk of driving by installing a VES, drivers might compensate by increasing their speed and overtaking more. Increases in speed were found with the VES operational and the authors draw comparison between their results and those reported elsewhere (e.g. Ward and Wilde, 1996; Hoyes, Stanton and Taylor, 1996; Glendon, Hoyes, Haigney and Taylor, 1996).

These studies generally conclude that new technologies should be introduced with caution and certainly not before a thorough examination of likely compensatory behaviours.

3.5 Deficiencies in the research

This chapter has so far reviewed the ISA evaluations that have taken place in recent years. The methodologies used have been varied, but a number of deficiencies are noted:

1. The behavioural trials that have already taken place have been limited in terms of performance parameters. Behavioural adaptation may also arise in the form of a positive secondary effect of a system. For example Persson et al. (1993), reported that an additional benefit of ISA was safer car-following behaviour. Thus it is important when evaluating such systems, that a wide range of behavioural variables is studied. Whilst it is assumed that ISA will reduce mean speed and speed variance, the effects of the system on *other components* of the driving task have not been thoroughly investigated.
2. No attempt has been made to *compare* directly the effectiveness of ISA with more traditional speed reducing measures, such as road markings. It is vital that the benefits of ISA (taking into account its associated implementation costs) are considered in the light of benefits obtained by other means. This requires systematic and controlled assessment, using comparable scenarios and drivers.
3. Research to date has been unable to make comparisons of *different ISA systems*, mostly due to the fact that prototype systems for on-road experiments are expensive to build. For example, if an ISA system is to be considered as truly intelligent, then the requisite infrastructure and communication links need to be established. Using a driving simulator it is possible, by simply changing the characteristics of the vehicle

dynamics model and properties of a road section, to implement different types of ISA systems. Of particular interest is the evaluation of a hierarchy of systems which have increasing control over the driver.

4. Past research has tended to focus on evaluating ISA in urban areas. There has, to date, been no attempt to study how drivers interact with ISA across a *variety of road types*. ISA may be more beneficial on some roads compared to others and this is an important factor when considering implementation.
5. New systems can sometimes be associated with *novelty effects*, i.e. behaviour that is noted on first use can disappear as familiarity increases (e.g., Rämä and Kulmala, 2000). Alternatively, changes in behaviour may only become apparent after prolonged use of a system. Such issues have not, as yet, been addressed in the ISA evaluations.
6. The early Swedish trials were ground-breaking in that actual driver behaviour (as opposed to attitudinal) was studied using a real ISA system. However, on-road trials do not provide the experimenter with the opportunity of investigating how drivers behave in *critical* situations. Research in the ACC field suggests that automation may lead to decreased vigilance and thus poor performance in critical scenarios. Using a driving simulator to create such scenarios could provide some interesting data.
7. Recent research by the Swedes and the Dutch has provided strong evidence that mean speed and speed variation are reduced with ISA. It is clear from Tables 3.3 and 3.4, that the most common *behavioural adaptation* to an intervention is an increase in speed. This therefore makes ISA an interesting intervention to study. According to models of behavioural adaptation (e.g. Wilde, 1988; Näätänen and Summala, 1974), drivers must be able to detect the change in the environment brought about by the intervention (either consciously or sub-consciously). A driver has very clear feedback of the effects of ISA (perceived loss of time, inability to overtake etc.). On the other hand, drivers cannot engage in the most commonly expressed form of behavioural adaptation (speed increase). It will be interesting to discover if behavioural adaptations manifest themselves in other ways. For example, Persson et al. (1993), showed that although mean speed decreased on links, there was a slight tendency for drivers to compensate by travelling faster through junctions.

8. On-road trials, although they have the advantage of allowing the experimenter to observe driver behaviour close-hand, do not allow drivers to *interact* with other ISA equipped traffic. In a mixed fleet, drivers may exhibit behaviour that would not occur if the total vehicle fleet were equipped. For example, in a mixed fleet scenario, drivers may have feelings of anxiety provoked by the surrounding traffic travelling faster than they can.

There are thus currently many "unknowns" about the effect of ISA on driver behaviour and traffic safety. These "unknowns" are often difficult to assess, due to the difficulty in interpreting changes in behaviour into calculated safety benefits or costs. Therefore evaluating a relatively novel system, such as ISA, should employ a variety of techniques ranging from qualitative methods of questionnaires and behavioural studies in order to allow the measurement of both negative and positive effects of the system. The remainder of this chapter describes the techniques and measures that will be used in the planned evaluations in this thesis.

3.6 Planned evaluations

This thesis reports five studies that attempt to address the deficiencies outlined in Section 3.5. Due to the breadth of issues, the studies tend to evaluate more than one of the deficiencies at a time.

- Chapter Four allowed the development of the ISA algorithm and the examination of the appropriate behavioural parameters to be investigated. This simulator study was carried out in an urban environment and addressed *Deficiency 1.*

- Chapter Five details a comparative evaluation of ISA designed to assess the effectiveness of ISA against a number of speed reducing measures. This simulator study was carried out in a rural environment and addressed *Deficiency 2.*

- Chapter Six tested three ISA systems across a number of road types. This simulator study allowed the comparative effectiveness of different ISA systems ranging from one that provided advice, to one that exerted physical control. This study addressed *Deficiencies 3 and 4.*

- Chapter Seven developed a further ISA system, based on the results of the previous study. A simulator study evaluated how drivers interacted with the ISA systems over an extended period of time and addressed *Deficiency 5.*

- Chapter Eight details an on-road study designed not only to validate the results obtained in the simulator, but also to allow real-world observations of natural driving behaviour. As in Chapter Seven, this study evaluated driving behaviour over an extended period of time thus also addressing *Deficiency 5*, but in a real-world environment.

- A number of the studies allowed additional issues to be investigated. All the studies employed measures of workload, either by using subjective techniques or by exploring drivers' reactions in critical scenarios *(Deficiency 6).* Consideration to experimental design allowed the area of behavioural adaptation to be investigated whereby individual drivers drove with and without ISA *(Deficiency 7).* Finally, with the ease of being able to alter the characteristics of the traffic in the driving simulator it was possible to immerse drivers in a "fully-implemented ISA world". This addressed the issue that in the on-road trial drivers were equipped in isolation, which could affect their perception of ISA *(Deficiency 8).*

The next two sections outline the types of data that were collected in the studies and why they were deemed important for the evaluation of ISA.

3.7 Behavioural parameters

In selecting the appropriate performance indicators, there are a number of issues to bear in mind.

- How do the measures relate to traffic safety?
- What changes in the data should we look for?
- What constitutes a change in behaviour?
- When does a change in behaviour initiate a change in traffic safety?

Undoubtedly, the most complex issue to address is the last one, and it is no coincidence that this is an issue that has not been resolved. The issue becomes even more complex when one attempts to consider how changes in behaviour (if observed) might interact with one another.

The parameters selected for evaluation can be thought of as *accident surrogates.* With real life incidents being rare, researchers are forced to use behavioural measures that are thought to be precursors or be more likely to lead to a collision. A description of the parameters to be used in the evaluations are described below and where possible reference made to the issues raised above.

3.7.1 Speed

Chapter One of this thesis reported on the relationships between speed and accidents. To summarise, reduced speed is likely to lower the chances of an incident occurring (with there being more time for the driver to react to changes in the environment) and mitigate the outcome of any incident that does occur. Although a functioning, mandatory ISA system will reduce maximum speeds to the posted speed limit, the system cannot take into account small changes in the traffic environment. For example, the system will not reduce a driver's speed if the vehicle in front brakes sharply. Thus the issue of appropriate speed for the road/weather conditions will be taken into consideration. Not only will average, minimum and maximum speeds be measured, but also situations will be defined where the appropriate speed is considerably less than the speed limit. Such scenarios will include reduced visibility and substandard curvature.

Measurements of speed variance will also be taken; the research reported in Chapter One suggested that a reduction in speed variance is associated with a reduction in accident rates. It is important to note at this point that measures of speed variation in the overall vehicle fleet on a particular section of road will not be taken. This is due to the fact that this would require a large amount of resources to equip enough vehicles to ensure valid results (approximately 60% according to Liu and Tate, 2000). Instead, individual vehicle speed variation will be measured over sections of road, which not only provides an estimate of the calming effect of ISA (fewer accelerations and decelerations) but also an indication of the effect of ISA on emissions.

3.7.2 Car following

As discussed above, drivers using ISA may try to express their feelings of impatience (or maintain their subjective risk) by engaging in riskier car following behaviour. Being able to maintain and adapt one's headway to a lead vehicle is essential in maintaining traffic flow and safety. A breakdown in flow can lead to shockwaves in the traffic stream and increase the likelihood of incidents.

The Highway Code (DETR, 1999b) includes the following statement concerning car following:

"Drive at a speed that will allow you to stop well within the distance you can see to be clear. You should:

- *leave enough space between you and the vehicle in front so that you can pull up safely if it suddenly slows down or stops. The safe rule is never to get closer than the overall stopping distance (see Typical Stopping Distances diagram, pages 28 - 29)*
- *allow at least a two-second gap between you and the vehicle in front on roads carrying fast traffic. The gap should be at least doubled on wet roads and increased still further on icy roads*
- *remember, large vehicles and motorcycles need a greater distance to stop.*
- *use a fixed point to help measure a two second gap"*

The recommended gap of 2 seconds is largely ignored, at least on motorways. Postans and Wilson (1983) gathered observational data on a U.K. motorway. Using the definition of close following as being time-headway of one second or less, they estimated that 11% of the vehicle fleet were tail-gaiting. They also reported that of the close following incidents that occurred, 23% maintained a headway of less than 0.5 seconds.

Data gathered for modelling purposes in the U.S. (Farber, 1994) showed that approximately 25% of vehicles were travelling with time-headways of 1 second or less and approximately 6% at time-headways of 0.5 second or less (Figure 3.3).

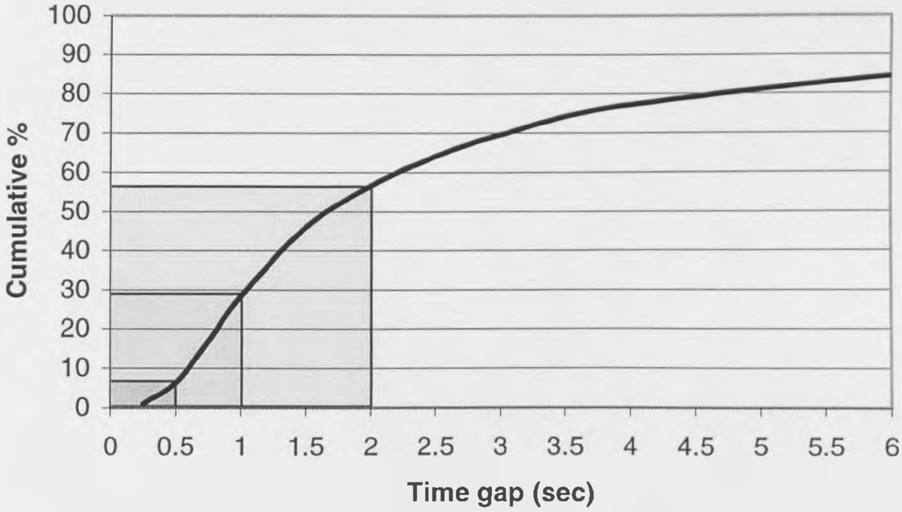


Figure 3.3: Cumulative distribution of time gaps (adapted from Farber, page 419)

Michael, Leeming and Dwyer (2000) report that close following is not only a problem on motorways, but on urban roads too. From observations of over 12,000 vehicles having a headway of four seconds or less, the authors state that 50% of drivers were not in compliance with the two-second rule. Approximately 7% were following at less than one second.

Changes in following behaviour have been noted in the ACC literature. A large dataset of headway distributions was collected as part of the ACC, Field Operational Tests in the US (Fancher et al., 1998). With 110,000 km of data on manual control and 56,000 km of data on ACC collected, the results are similar to those reported by Farber (1994). The manual control data acted as baseline data, whilst in ACC mode, drivers were able to set their headway to either 1.1, 1.5 or 2.1 seconds (Figure 3.4).

It can be seen here that without ACC (for speeds greater than 55 mph), drivers spent most of their time at a preferred headway of 1 second or less. The most likely value of time headway was 0.8 seconds. When ACC was operational, drivers tended to set the headway to a higher value, such that headways of between 1–2 seconds were more frequent, and a tendency to operate the system at the 1.1 second level. This type of data collection is an important demonstration of how a design of a system such as

ACC should be carefully considered. By giving drivers a minimum headway setting of 1.1 seconds, it has changed their driving style (albeit for the better in this case).

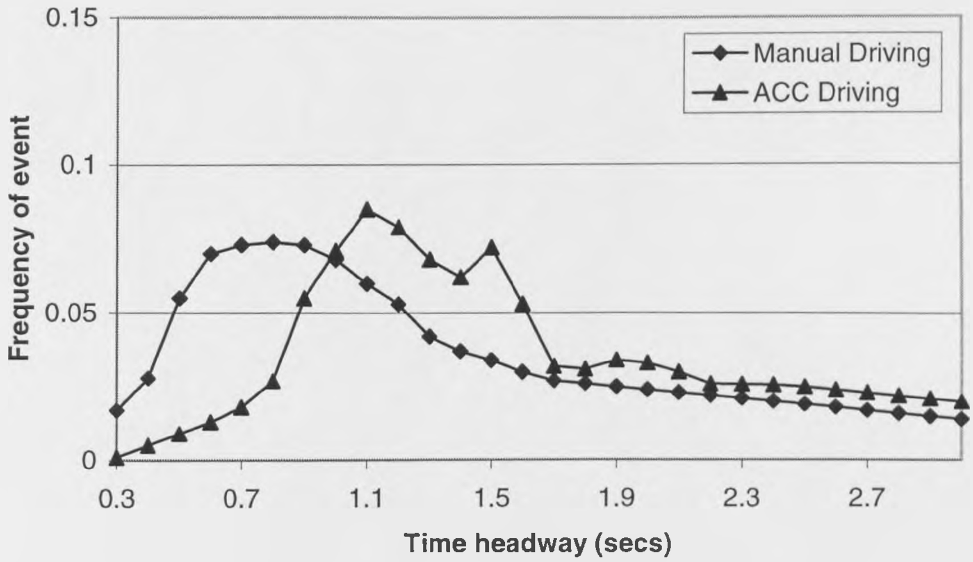


Figure 3.4: Time headway distributions with and without ACC

An important consideration is: what is the relationship between time headway and accident risk? The relationship is intuitively appealing and empirical evidence exists to support it (Evans and Wasielewski, 1982; Evans and Wasielewski, 1983). They demonstrated a statistically robust association between the headway a driver maintained in free-flow motorway traffic and their accident involvement.

In the planned evaluations, when drivers use ISA, it will be of interest to discover if their car-following behaviours adapts. By measuring the amount of time a driver spends at various time headways, a before/after comparison can be made. Any changes in shape of the distributions will be noted. Time-headway is defined as the amount of time it would take for the following car to collide with the lead car, if the lead car were to come to a complete halt. Time headway was chosen as an alternative to time-to-collision (TTC) due to the fact that TTC takes into account the relative speed of the two vehicles. Thus if drivers are travelling at the same speed a TTC value of infinity is obtained; if the lead car accelerates a negative value of TTC is obtained.

Critical headways will be treated as those less than one second. This is based on past research and seems sensible given the literature on Perception Time and Reaction Time. Perception Time (PT) is the time taken to detect a hazard, identify its significance and decide on a course of action. PT depends on the complexity of the problem and the solution and on the expectancy a driver has and can thus have a wide range of values. Reaction Time (RT) is the time taken to execute a response (e.g. move the foot from accelerator to brake). This is usually constant for a given driver in a given situation. Perception Reaction Time (PRT) is therefore the total time for driver to commence an appropriate response to a hazard.

There are two types of PRT:

- Design PRT is used by highway engineers and can range between 2.5-10 seconds. This is longer than average real life PRTs as the worst case has to be taken into account. Imagine the PRT of an alert driver in a school zone on a familiar road, when a child runs out in front of them. Expectancy may be raised anyway and the solution is relatively simple: brake hard. Compare that to the PRT of a fatigued driver, on an unfamiliar road, distracted by children in the back of the car, on a wet road, driving through a construction zone. This is a complex problem with a complex solution.
- Actual PRT. For a simple problem it may be as low as 0.75 seconds.

Olson and Sivak (1986), looked at differences in PRT when an event was expected or unexpected. They found that for an unexpected event the range of PRTs was 0.8 - 1.8 seconds, with an average of 1.1 seconds. On the other hand, for an expected event the range of PRTs was 0.35 - 1.0 seconds, with an average of 0.6 seconds. Therefore, assuming that the lead vehicle has the same PRT as that of the one following it, a time-headway of approximately less that 1 second is deemed to be critical. Thus this will be the critical value adopted.

3.7.3 Overtaking

With reduced maximum speed, there may be occasions where drivers with ISA are prevented from overtaking a slower moving vehicle in front. This may be due to the fact that the speed differential between the vehicles is small, either because system penetration in the fleet is high, or because the lead driver chooses to adopt a speed below the desired speed of the following car. If the speed differential is small, the amount of time the following car has to spend in the opposite lane is increased. On the other hand, in the instance where not all vehicles are equipped with ISA, the amount of times an ISA vehicle is overtaken may increase.

In the U.K. only a small percentage (approximately 3.5%) of accidents involve an overtaking manoeuvre (DETR, 2000). However it is likely, although no data have been able to confirm, that these overtaking incidents occur at high speed and thus could be over-represented in the fatal accident statistics. The important question is: how does speed choice affect overtaking involvement and ultimately accident risk?

There exists little literature in this field except an interesting paper by Hauer (1971). His paper attempted to find a relationship between overtaking manoeuvres and accident involvement (on rural roads only). He presents data to demonstrate that the variation with speed of the number of overtakings is very similar to that of the speed/accident involvement curve.

In the planned evaluations, scenarios will be designed whereby drivers with ISA will be required to follow a slow moving vehicle. Their propensity to overtake and the safety of the manoeuvre will be recorded.

3.7.4 Gap acceptance

When a driver is required to turn into or across a main road traffic stream, they have to make two decisions:

- How much time they have available – t_A – (depends on the speed and position of the oncoming vehicle), and
- How much time they require to complete the manoeuvre – t_R – (depends on driving style, junction characteristics, etc.).

Drivers who accept a gap with $t_A < t_R$, initiate a conflict, and thus force the approaching vehicle to decelerate. But how can we define a "risky" gap and does this actually relate to accident risk? Some modelling work carried out by Darzentas, McDowell and Cooper (1980) and McDowell, Darzentas and Wennell (1981), may throw some light on this. Using observed gap acceptance data they developed a traffic simulation model. This model was able to estimate the decelerations of vehicles on the main road to avoid a collision with joining minor road traffic. A number of non-urban T-junctions were modelled, and their accident histories for the previous five years were sought. The model was then used to identify the number of possible conflicts. A conflict was defined as $t_A - t_R < 1.5$ seconds. The results are shown in Table 3.5.

Table 3.5: Relationship between crossing conflicts and accidents (adapted from McDowell, Darzentas and Wennell, 1981)

Site no.	Conflicts		Accidents	
	Number	Rank	Number	Rank
1	1840	1	10	2
2	560	6	4	4.5
3	840	4	4	4.5
4	935	3	8	3
5	1390	2	11	1
6	760	5	3	7
7	215	10	3	7
8	450	7	3	7
9	375	8	1	10
10	300	9	2	9

The correlation between the rankings on the two variables was calculated at 0.9. The authors conclude that the model conflicts are a valid representation of real conflicts and hence of risk (except model conflicts are observed with much more frequency).

The planned evaluation of ISA will therefore measure drivers' gap acceptance behaviour as a surrogate measure of accident risk. Bearing in mind that the work reported above used a gap of 1.5 seconds or less as the conflict area, the experiments will gauge whether there are any shifts in gap acceptance patterns. Developing a hypothesis *a priori* is difficult as a number of scenarios could be envisaged. Firstly, ISA may have a general calming effect on drivers and thus make their gap acceptance behaviour safer. On the other hand, if drivers perceive that ISA is increasing their journey time, they may become frustrated waiting at a junction and accept a smaller than normal gap.

3.8 Additional issues

3.8.1 System use

The benefits of an ISA system can only be predicted if the propensity to use the system is known (in the case of a voluntary system). Simply asking drivers how inclined they would be to use ISA in any given situation is unlikely to provide an accurate answer. *Actual* interaction with the system is necessary, preferably over an extended period of time. A calculation of the amount of time a driver engages a voluntary system is a direct measure of acceptability and willingness to use the system. Therefore the evaluations, where appropriate will take note of the amount of time drivers use a voluntary system and in which situations they choose to disengage it.

3.8.2 Situation Awareness

Ultimately ISA automates some components of the driving task, i.e. it decreases the need for the driver to monitor their speedometer in order to keep to the speed limit and/or to avoid citations. It has been suggested (Parasuraman, Molloy and Singh, 1993) that automation of part of the driving task may lead to driver underload and hence loss of *Situation Awareness*. Situational Awareness (SA) can be regarded as consisting of three levels: perception of elements in the current situation, comprehension of the current situation and projection of future status (Endsley, 1995). A loss of SA may mean that drivers are less responsive to critical incidents. Such loss of SA has been reported to be the likely cause of a number of aviation disasters and as reported in Section 3.4.3, could have attributed to an increased number of incidents in an ACC trial (Nilsson, 1995). A similar result was found in a simulator study examining the effect of automation on the driving task in terms of reduced arousal (Richardson, Ward, Fairclough and Graham, 1996). In their study, drivers encountered a queue of stationary traffic at the end of a one-hour driving session. It was reported that the minimum time-to-collision in responding to this event was significantly shorter with ACC than for unassisted driving. The authors of these two studies suggest that drivers either may have become complacent and reliant on the system, or that the additional demands of the ACC interface distracted drivers from the primary driving task.

Some research has also suggested that problems may occur when drivers are required to *regain* control of a previously automated system. Stanton, Young and

McCaulder (1997) reported such effects for an ACC system and Desmond, Hancock and Monette (1998) for an automated lane guidance system. The authors comment that the results strongly support *human-centred* transportation strategies, whereby the driver is involved in the driving task. Whether ISA will suffer the same problems in not known, although ISA does differ from the above mentioned systems in that it does not fully automate a control level task (as defined by Michon, 1985). ISA simply limits the range of a control level task (speed choice).

3.8.3 Workload

The previous section referred to driver underload caused by automation. Conversely, if additional information is provided via an in-car display or other modality, required cognitive functioning, or *mental workload* may increase. Such increases may lead to driver overload that could be potentially hazardous in terms of the ability to carry out the driving task. Such increases in workload have been reported in mobile telephone studies (Brookhuis, De Vries and De Waard, 1991; McKNight and McKnight, 1993), in information feedback systems (De Waard et al., 1999) and for in-vehicle e-mail systems (Lee, Brown, Caven, Haake and Schmidt, 2000).

Mental workload can be measured in a variety of ways, ranging from self-report physiological and performance measures. For an overview of these techniques, see De Waard (1996). For the purposes of this evaluation of ISA, only performance and self report measures will be used. The performance measures to be used will be speed and lateral positioning: both of these measures have been found to be sensitive to increases in mental workload (Cnossen, Brookhuis and Meijman, 1997; Nakayama, Futami, Nakamura and Boer, 1999). In addition, the self report measure to be used is a simplified version of the NASA-TLX, developed by Hart and Staveland (1988). This requires drivers to rate task difficulty using the six sub-scales of mental demand, physical demand, time pressure, performance, effort and frustration level. A bipolar scale represents each of these items and participants place a line on the scale between the two extremes of the item to indicate the strength of the attribute (Appendix A).

3.8.4 Acceptability

As mentioned in Section 3.8.1, measures of system use will provide a good indicator of drivers' willingness to accept a voluntary system. In order to compare these results across different types of systems, an alternative tool has to be used (in the case of a mandatory system, drivers will have no choice but to use the system). Therefore a questionnaire, developed specifically by researchers in the transport telematics field, will be administered during the evaluations (Van de Laan, Heino and De Waard, 1997). This allows participants to express a preference between the different systems in terms of "usefulness" and "satisfaction" using nine items (Appendix B). The concept of *usefulness* refers to how effective or supportive a system is, whilst *satisfying* refers to how pleasant it is to use. The authors predict that acceptability lies along a continuum according to the complexity of the system and the amount of control it exerts over driver behaviour (Figure 3.5).

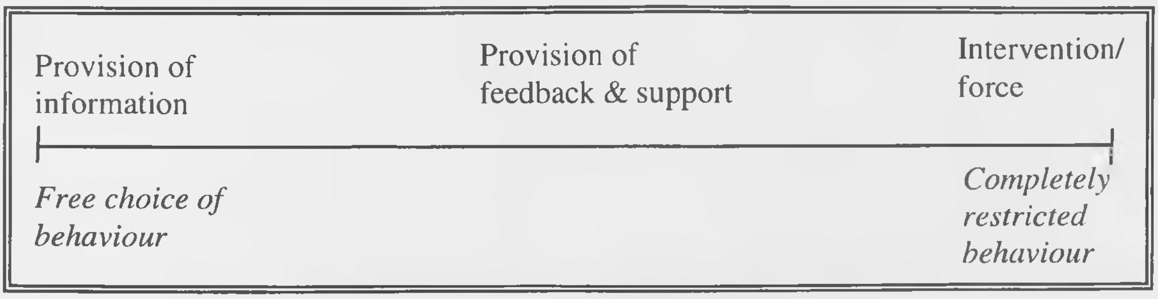


Figure 3.5: Acceptability and control

According to this model, one would expect the acceptability ratings for an informative system to be located at the left extreme of the scale, whilst an intervening system would be further to the right.

Several studies, using hypothetical situations, have shown that acceptance of ISA is fairly high. The SARTRE study (Dahlstedt, 1994) reported that a voluntary ISA system was favoured by about 46% of questionnaire respondents, while about 42% were against. Whilst these results are encouraging, it should be noted that the respondents had no practical experience of the system. An evaluation of a system such as ISA should involve actual users interacting with the actual system.

In the planned evaluation, drivers will be asked to complete acceptability questionnaires before and after experience with the system. In this way, it will be possible to gauge if and how acceptability changes on use of the system. In addition, acceptability scores can be directly compared across the different system implementations. These system implementations are outlined in the next section.

3.8.5 Driving style

A voluntary ISA system is of little use if only the "safe" drivers use it. Such "selective recruitment" was termed by Evans (1985) in his analysis of seat belt and non-seatbelt wearing fatalities. Using U.S. crash statistics he was able to demonstrate that the probability that a driver was wearing a seat belt at the time of the crash declined as crash severity increased. In other words, drivers who would benefit most are those least likely to wear a seat-belt (Evans, 1996).

In order to investigate individual differences, drivers completed the Driving Style Questionnaire (DSQ). This questionnaire, developed by West, Elander and French (1992), characterises drivers in terms of a number of safe and unsafe behaviours. The DSQ scores will be correlated with drivers' propensity to engage the Driver Select ISA system and their acceptability scores.

3.9 Systems to be studied

Speeding is prevalent on all road classes and thus an ISA system could have network-wide benefits. The magnitude of benefits may differ across road class, as might any secondary (positive or negative) effects. This may lead to the development of a system that is adaptive to the road environment. For example, a speed limit may be inappropriate to a particular piece of road geometry or to the weather conditions. The range of systems that will be studied are described below.

3.9.1 Advisory ISA

It has been suggested that drivers may speed because they are unaware of the speed limit (De Waard, Jessurun, Steyvers, Raggatt and Brookhuis, 1995). Cameron (1980) investigated the effect of knowledge of the speed limit on drivers travel speed. He found that in urban areas, 26% of drivers were unaware of the speed limit. In addition, those drivers who were unaware of the correct speed limit, exhibited a higher speed distribution than those who were. The study concluded that the use of repeater speed signs could increase awareness of the speed limit.

A system that provides drivers with a continuous reminder of the external speed limit, via a visual display, could therefore be an effective way of reducing inadvertent speeding. No external control of the car is implemented, thus the driver remains "in-the-loop", but could be considered as more informed of the external conditions. Such a system obviously relies on drivers' willingness to comply and the realism of the speed limit displayed. One of the studies reported in this thesis specifically evaluates the effectiveness of such an advisory system compared to a system that actually enforced the speed limit. It was hypothesised that although the advisory system would not be as effective, it would be considered as more acceptable by drivers than a system that controls speed automatically.

3.9.2 Driver Select ISA

This system allowed the driver to decide whether to engage the ISA system or not. By providing drivers with an on/off switch, drivers were able to engage and disengage the system as required. If the system was engaged, then the maximum speed of the vehicle was limited to the posted speed limit. If the driver chose to turn the system off, then the car operated in a normal fashion. The effectiveness of such a system also relies on acceptability and driver compliance.

3.9.3 Mandatory ISA

This system limited the maximum speed of the driver's car to the speed limit of the road along which the car was travelling. The driver was unable to disengage the system. It was hypothesised that, although the Mandatory system would be effective in lowering speeds, drivers may dislike the amount of control exerted over them and negative behavioural adaptation effects could occur.

3.9.4 Variable ISA

The Variable system operated in the same way as the Mandatory system, but additionally lowered speed further in poor road and weather conditions. The system was operational in foggy conditions, on sub-standard horizontal curves and in the vicinity of junctions and pedestrian crossings.

3.10 Evaluation tools

3.10.1 The Leeds Driving Simulator

The *Leeds Advanced Driving Simulator* was a suitable tool for the preliminary assessment of an ISA system (Figure 3.6). The simulator was fixed-base, presenting a 120° forward view and 50° rear view. The system featured a fully interactive Silicon

Graphics (Onyx RE²) driving simulator with a six degree of freedom vehicle model. A servo-motor linked to the steering mechanism provided control over handling torque and speed and digitised samples of engine, wind, road and other vehicles are provided. Photo-realistic scene texturing allowed presentation of various road types and features.

Figure 3.6: The Leeds Driving Simulator

A recent study (Carsten, Groeger, Blana and Jamson, 1997) evaluated the behavioural validity of the Leeds Driving Simulator. The results show that overall there was a broad correspondence between driving in the simulator and in the real world. There were very high correlations between speed along the real road and speeds in the simulator. However, with regard to lateral position, the correlations were less satisfactory, perhaps due to the absence of a motion base in the simulator. It should therefore be possible to draw conclusions based on speed behaviour in the simulator.

Simulator studies allow the capture of behaviour in a safe, controlled environment, in which traffic events (including critical ones) are pre-programmed and thus repeatable. Although simulator studies can never replicate exactly the real driving experience, they attempt to shed light on how drivers may adapt their behaviour and the effect that this adaptation may have on overall safety. Using a driving simulator allows critical incidents to be included in the evaluation, where in an on-road study they are neither predictable nor ethically sound.

The ISA systems were implemented by making alterations to the simulator's vehicle dynamics model. The vehicle dynamics model replicates that of a Rover 216GTi, the vehicle on which the simulator is based. Using a logical road network, each individual section of road can be given a speed limit that the car will, if required, adhere to. If the participant is driving the simulator at or below the speed limit the ISA system is inactive. If the participant attempts to accelerate above the speed limit, the vehicle dynamics model automatically prevents any further increase in speed by closing the throttle and applying a small brake pressure to the hydraulic system. Therefore even if the driver depresses the accelerator to its full extent there results no increase in speed.

If a change in maximum speed is required (for example travelling from a high to low speed limit) and the speed of the simulator car is in excess of the speed limit, deceleration is applied using the formula:

$$a = \frac{v_l - v}{T_c}$$

where a = acceleration (m/s/s)

v_l = the speed limit of a particular road section (m/s)

v = the current speed (m/s)

and T_c is the time constant of this first order system (1.5s)

..........until the new maximum speed is attained. If the simulator car was travelling at less than the speed limit then the ISA system was inactive.

3.10.2 Instrumented vehicle

In order for the ISA system to function in the real world for the on-road trials, an *instrumented vehicle* was designed to receive information pertaining to the posted speed limit of the road on which it was travelling and where the changes in the speed limit occurred. A differential Global Positioning System (dGPS) gave a reliable accuracy of around 1m, with virtually instant update of position.

The position and value of every speed limit along the test route was stored in the laptop computer as a "virtual beacon". This virtual beacon could be moved and its radius altered according to where the ISA system should operate. For example, if the speed limit changed from 60 mph to 30 mph, the beacon was positioned so that the ISA system would engage before the speed limit change. This ensured that the ISA system was able to decelerate the car sufficiently, such that the vehicle was travelling at the lower speed limit as it passed the speed limit sign. The software allowed great flexibility in moving the beacons so that overlapping was avoided.

The ISA software calculated the appropriate speed limit (as described above) and compared this with the car's actual speed, determined from the ABS wheel speed sensors. If the car was travelling below the speed limit, it behaved as a normal car. However, if the speed was above the limit, a signal was sent to a pair of auxiliary Engine Control Units. These first reduced engine power by retarding the ignition for up to 30 seconds. In order to provide a longer and/or greater reduction in power, the amount of fuel injected into the engine was progressively cut. If the retardation and the fuel cut-off were insufficient, because the car was going down hill for example, the brakes were gently applied to decelerate the car to the speed limit. A laptop PC, installed in the boot of the car, not only ran the ISA software but also recorded the required data.

The advantages of using both the driving simulator and an instrumented vehicle are that with a driving simulator, the experimenter can include critical incidents in a road network, without risk to the experimenter or participant. In addition, the events the participant encounters are choreographed and repeatable and thus control can be taken of the surrounding traffic behaviour (and weather conditions). On the other hand, the experience of driving in real traffic in the instrumented car provides a wide range of traffic scenarios and provides the experimenter with the opportunity of observing participants' interactions first-hand.

3.11 Summary

This chapter has outlined the past research designed to evaluate ISA. A number of deficiencies were noted and a framework of experiments was presented to address these. By using a range of methodologies a thorough investigation of how drivers interact with ISA will be undertaken. These investigations will then be used as a basis for an evaluation of ISA's likely contribution to traffic safety.

As well as using standard measures of driver performance and safety identified in Section 3.7, further issues were also investigated as noted in Section 3.8. It was not possible to study all the issues in each of the experiments, due to design constraints; the distribution of issues across the studies is shown in Table 3.6.

Table 3.6: Distribution of issues across the planned studies

	ISSUES				
	Acceptability	Workload	System type	Situation Awareness	Driving Style
Chapter 4		✔	✔		
Chapter 5	✔	✔			
Chapter 6	✔	✔	✔		
Chapter 7	✔	✔	✔	✔	✔
Chapter 8	✔	✔	✔		✔

The next Chapter describes an exploratory study undertaken to allow the development of the ISA algorithm and an initial investigation of driver behaviour.

Chapter Four

Exploratory study

4.1 Study aims

This chapter reports an exploratory study performed on a driving simulator. This study is the first of five reported in this thesis and was undertaken in order to develop and test the ISA algorithm required for the driving simulator experiments. The study also provided the opportunity for exploring the possible effects that an ISA system might have on driver behaviour by collecting a wide range of data. At the time the study was carried out, little was known about the possible adaptational effects that ISA could have on driver behaviour. This study therefore also allowed the refining of measures to be used in later experiments.

4.2 Method

4.2.1 Systems studied

This study enabled the design and investigation of two types of ISA systems:

1. *Mandatory ISA* system – this system limited the maximum speed of the (simulator) car to the posted speed limit of the road on which the driver was travelling. If the driver attempted to accelerate above the speed limit, the simulator's vehicle dynamics model automatically prevented any further increase in speed by closing the throttle and applying a small brake pressure. Thus even if the driver depressed the accelerator to its full extent, there resulted no increase in speed. The acceleration characteristics of the (simulator) car remained unchanged.
2. *Variable ISA* system – this system operated in the same way as the Mandatory system, but additionally restricted driver's maximum speed to 25 mph in the vicinity of junctions (Figure 4.1). The Variable ISA system was studied as almost two-thirds of fatal or serious accidents in built-up areas take place at junctions (DETR, 2000). Thus to reduce the speed of vehicles around junctions may be beneficial in terms of accident reduction.

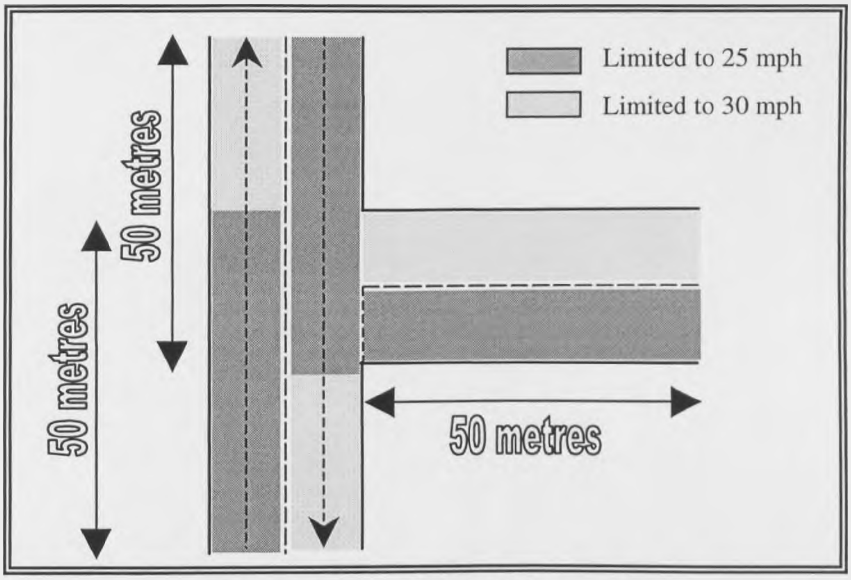


Figure 4.1: Variable ISA system

4.2.2 Experimental design

As well as the two types of ISA system, three levels of system penetration were implemented. These levels of system implementation allowed the investigation of how drivers might react at various stages of ISA market penetration. The three levels were defined as:

- the *baseline* condition where neither the participant nor any of the other vehicles on the road were equipped with ISA
- a *mixed fleet* scenario where 50% of the other cars on the road were equipped with ISA
- *full implementation* phase where all cars were equipped with ISA.

Thus, the study allowed the investigation of two types of system implementation (mandatory and variable) and three levels of system penetration (no vehicles equipped, 50% of vehicles equipped and all vehicles equipped). However, the combination of all these factors, including a baseline scenario, would result in a large number of permutations. To test the complete set of permutations using a within-subjects design would require participants to drive for approximately two or three hours on the simulator. This would likely result in a high incidence simulator sickness in the form of fatigue, discomfort and disorientation (Kennedy and Frank, 1986). Conversely, to conduct a between-subjects design also seemed inappropriate. According to the risk compensation literature (e.g. Streff & Geller, 1988), adjustments in risky behaviour are most often observed in a within-subjects design. The authors conclude that this is probably due to the fact that the occurrence of risk compensation is dependent on individuals being able to compare the sensations of the two conditions; in an identical risk compensation study using a between-subjects design, risk compensation did not occur. It was therefore felt that a within-subjects design would be more practical and powerful.

Selecting those that might logically be encountered in a real world implementation of ISA therefore reduced the high number of treatment conditions. Participants encountered the four conditions described in Table 4.1.

Table 4.1: Experimental conditions

Condition name[1]	Description
NoISA/NoISA	This is the baseline condition. Neither the simulator car nor any of the other cars on the road are equipped with ISA.
NoISA/50%ISA	This is the 'mixed-fleet' scenario. The simulator car is not equipped with ISA, but approximately 50% of the other cars on the road are.
ISA/ISA	This is the full implementation stage. Both the simulator car and all the other cars on the road have been equipped with a mandatory ISA system.
ISA+/ISA+	Both the simulator car and all the other cars on the road have been equipped with a variable ISA system.

Two further experimental conditions were considered, but rejected. First, the situation where the driver was equipped with ISA but none of the other traffic was (ISA/NoISA) could have been tested. However, although it was recognised that some interesting results might have occurred in terms of driver frustration and sense of "inequality" (being the only one equipped), it was rejected as being unrealistic. It would be unlikely that implementation of ISA would occur unless a significant proportion of vehicles were equipped. More realistic would be a scenario where an equipped driver was interacting with partially equipped traffic (ISA/50%ISA). This was considered for inclusion in the experimental design but was rejected in favour of the NoISA/50%ISA condition as being more psychologically interesting; drivers may

[1] The first half of the Condition name refers to the simulator car and the second refers to other cars in the scene.

perceive increases in opportunities for overtaking and engage in other behaviour characterised as being “competitive”.

Each participant drove the simulated road network four times, corresponding to the experimental conditions in Table 4.1. The order in which they drove the four routes was randomised to reduce practise effects. The same road network was used for all the experimental conditions to produce exactly the same traffic scenarios in terms of the nature and order of junction types and the environment to reduce the effect of extraneous confounding variables. It is noted, however that due to the identical nature of the routes themselves, event ordering and learning effects might occur. The total time for the experiment to take place was approximately 75 minutes including briefing, short breaks between experimental trials, debriefing and payment.

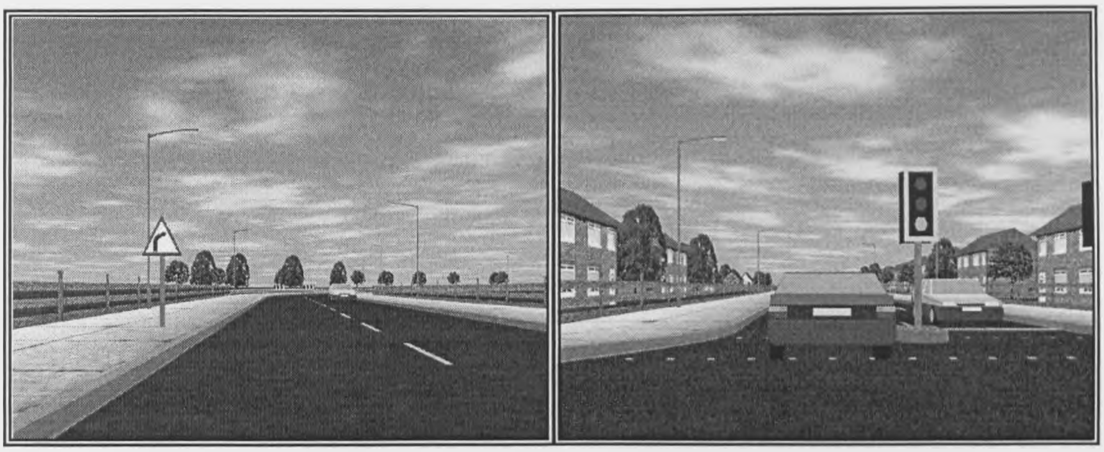
4.2.3 Participants

Thirty participants completed the experiment. All had a clean driving licence. The sample included 15 males between the ages of 23 and 54 [Mean= 37 years] with a reported annual mileage of between 7,000 and 40,000 miles [Mean= 17,600 miles]. In addition, 15 females took part between the ages of 24 and 49 [Mean= 37 years] with a reported annual mileage of between 6,000 and 25,000 miles [Mean 15,200 miles]. The participants who completed this study were all members of an existing participant database.

4.2.4 Simulated road network

As this was an exploratory study, the road environment was restricted to urban roads with a speed limit of 30 mph. The road network consisted of unsignalised t-junctions and crossroads, both approached from the major road only. All the minor junctions were at 90° to the major road and were separated by straight and curved lengths of road.

When driving each experimental road, participants encountered four right-hand turns and six left-hand turns. In addition, they had to negotiate four circular (constant radius) curves and five sets of traffic lights (Figure 4.2). Speed limit signs were posted at the beginning of each network. Participants found their way through the network by following directional signposts. Road markings and signs were modelled as described in the Traffic Signs Manual (Department of Transport, 1985). The road environment varied from being relatively built up with terraced houses, shops, fences, trees, pavements with kerbs and street lights, to a more open environment with detached houses and fields.



(a) Approach to curve **(b) Traffic lights**

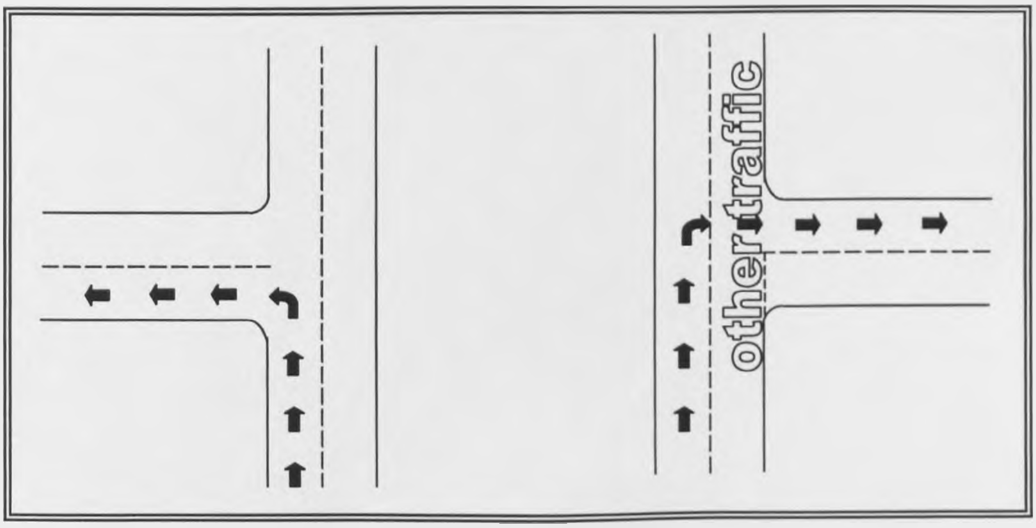
Figure 4.2: Simulator scenarios

4.2.5 Data collection

A wide range of data was collected from a variety of driving scenarios, each of which is described below.

4.2.5.1 Junctions

Data was collected at four left turns and four right turns in each experimental condition (Figure 4.3).



(a) Left hand turn **(b) Right hand turn**

Figure 4.3: Junction tasks

These junctions were included to assess any time-saving strategies that drivers might employ with ISA. Each left turn (Figure 4.3a) required the driver to turn 90° from the major road to minor road. The junctions were unsignalised and did not require the driver to give way to any other traffic. The junctions were designed so drivers had at least 300 metres of straight, unobstructed road before they had to turn. Two directional sign-posts were displayed at the roadside, the first approximately 150 metres before the left hand turn and another at 50 metres before the junction. These junctions were included in the road database to observe any changes in drivers' approach in terms of speed. It was hypothesised that ISA may encourage drivers to maintain a higher speed on approach to the junctions as a time-saving mechanism.

Participants were also required to make four right-hand crossing manoeuvres at unsignalised t-junctions (Figure 4.3b). Two directional sign-posts were displayed at the roadside, the first approximately 150 metres before the right hand turn and another at 50 metres before the junction. On approach to these junctions it was clearly visible to drivers that there was oncoming traffic and that they would be required to give way to it. There were 11 oncoming cars at each junction. These cars were programmed to maintain a constant speed and headway to the preceeding vehicle, but the gaps between the cars varied.

The oncoming traffic was deliberately choreographed to force the driver to come to a stop at the junction. This was achieved by the presence of four cars having gaps of three seconds between them. Behind these were seven cars that maintained gaps of between 5 and 11 seconds (in ascending size) by being assigned a "preferred headway" to the preceeding vehicle. This pattern was repeated for each right turn; the speed of the oncoming cars was 30 mph (except when the Variable ISA system was implemented, where their speed was decreased to 25 mph).

4.2.5.2 Curve negotiation

In each experimental run, drivers were required to negotiate two sharp curves (radius 63 metres, length 100 metres). A pilot study indicated that curves with a radius of less than 70 metres encouraged drivers to drive at a maximum speed of approximately 25 mph. These curves were included as, even with ISA fitted, driver could exceed 25 mph if they wished to. These curves were included in the road network to study whether adaptational effects occurred as a result of driving with ISA. For example, would drivers with ISA attempt to maintain a higher speed on the curves in order to gain time.

4.2.5.3 Car following

The road network was designed to allow the driver to engage in car-following behaviour. Headway was recorded at 2 metre intervals along a 600 metres stretch of straight road where drivers were required to follow a lead vehicle. The presence of traffic on the approaching carriageway made it difficult for the drivers to overtake. However when overtaking did occur, these data were excluded from the analysis as the close approach to the lead vehicle during overtaking would skew the headway values. The lead car was travelling at a speed of 25 mph and thus it was physically possible for drivers, even with ISA, to adopt very short headways if they wished to. It was hypothesised that the nature of car-following might change, although to what extent was unknown.

4.2.5.4 Traffic light violation

There were five sets of traffic lights in each network. In each experimental trial participants encountered one situation where they were required to make a rapid stop/go decision at a set of traffic lights. If drivers were travelling at or around the speed limit and reacted immediately to the amber phase, then they were able to stop in time. If the driver travelled through the red light a violation was recorded. The position of this set of traffic lights was varied across experimental runs to reduce the effect of learning. This scenario was included to investigate whether drivers with ISA were more reluctant to stop at the traffic lights, as this would additionally impede their progress.

4.2.5.5 Workload

Participants completed a mental workload questionnaire (NASA-RTLX) after each drive. It was hypothesised that reductions in workload might be seen with ISA due to increased automation of the driving task.

Table 4.2 describes the scenarios and the corresponding data collected.

Table 4.2: Pilot study data collection

Scenario	Variable	Unit	Location
Left turns	Braking point	metres	Distance from the junction at which the driver first started braking.
	Braking profile	bar	Subsequent braking profile.
	Speed	mph	For 80 metres before the junction.
	Acceleration	m/sec^2	For 80 metres before the junction.
	Turn speed	mph	Through the junction.
Right turns	Size of gap	metres	Between simulator and oncoming car.
Curves	Speed	mph	At entry, apex and exit to the curve.
	Lateral position	metres	Through the curve.
Car following	speed	mph	In following task.
	headway	metres	Front of simulator to rear of lead car.
Traffic lights	Violation	yes/no	One traffic light on each of the four routes.

4.2.6 Procedure

Participants were first asked to complete a practice route of approximately 15 minutes, in order to familiarise themselves with the controls of the car and to practise all the scenarios that were to follow in the experimental trials. A standard information sheet and consent form were provided.

The participants were then read the instructions referring to the particular trial they were about to undertake. They were then given the chance to ask questions and were told that if they wanted to stop at any point and for any reason, they should do so immediately. The simulation was started and participants were instructed to start driving when they were ready. At the end of each of the experimental trials, they were asked to complete the NASA-RTLX workload form and were allowed a short rest if required. When they were ready, the next trial began. Once the participant had completed the four experimental trials, they were debriefed, paid and thanked for their time.

4.3 Results

Data from each participant was contained in each of four files corresponding to the four experimental conditions. The data were checked for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene tests respectively and subjected to Analysis of Variance (ANOVA) to identify changes in behaviour across the System Implementations. Whilst a within-subjects design reduces unsystematic variability (e.g. individual differences), it also violates the ANOVA assumption of independence of scores. Therefore, tests of sphericity (similar to the assumption of homogeneity of variance in between-group ANOVA) were included in the analyses. This was achieved using Mauchly's test; if sphericity was violated the Greenhouse-Geisser correction was applied (Field, 2000).

There was found to be a main effect of Condition for the variables of interest. Post-hoc tests revealed there were neither statistically significant differences between the two "System on" conditions (ISA/ISA and ISA+/ISA+) nor between the two "System off" conditions (NoISA/NoISA and NoISA/50%ISA). Therefore the results reported here refer to differences between the combined conditions of ISA on and ISA off as a within-subjects factor. Age (above and below 35 years) and gender were included as between subjects factors.

4.3.1 Safety benefits

There were found to be several safety benefits when ISA was in operation. First, in the vicinity of left-turn junctions, a significant main effect of System was found [$F(1,87)= 50.87$; $p<0.001$]. With ISA, drivers approached the junctions more slowly [Mean= 22.42 mph] than when without ISA [Mean= 24.08 mph]. However, post-hoc analyses revealed that although speeds in general were lower on approach with ISA, they were very similar for the main deceleration profile on the immediate approach to the junction (Figure 4.4).

The reduction in speed was statistically reliable in the approach sections between 80-31 metres only. As drivers neared the left-hand turn, the difference in speed was no longer significant.

The point at which the drivers first began to brake was recorded (within 80 metres of the junction). An average braking point for all left turns was calculated for each participant. Without ISA, drivers began braking, on average, at 45 metres before the junction; with ISA they braked approximately 7 metres later. This reduction was statistically significant [$F(1,87)=9.89$; $p < 0.001$] and is likely to contribute to the observed speed difference reported above.

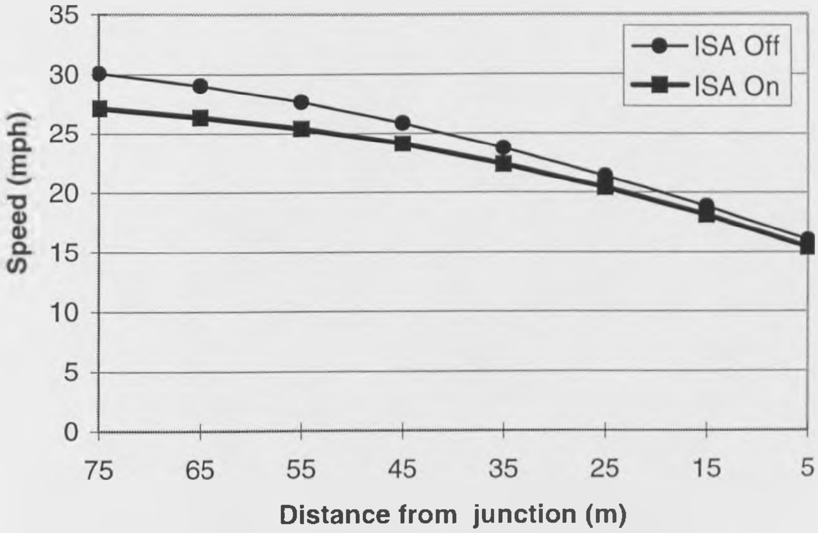


Figure 4.4: Approach speeds to junctions

A significant main effect of Age [$F(1,87)= 47.96$; $p < 0.001$] was found indicating that those participants under the age of 35 drove faster overall on approach to junctions than those over the age of 35 (Figure 4.5).

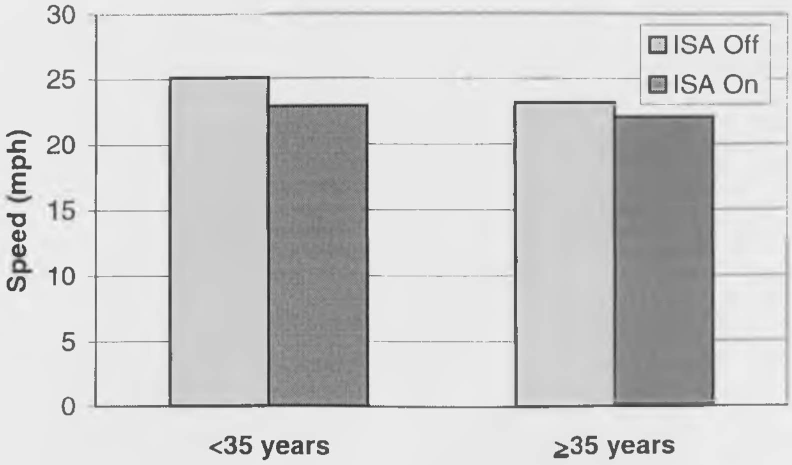


Figure 4.5: Approach speed to junctions by age group

This was accompanied by a significant interaction between System and Age [$F(1,87)=12.32$; $p < 0.01$]. Post-hoc tests (Tukey) revealed there to be a significant difference for the young Age group only [$F(1,87)=8.64$; $p < 0.01$]. Thus the reported higher speeds for younger drivers were not observable when the ISA system was active.

The number of red light violations that drivers committed in each experimental run was calculated (Table 4.3). A chi-square test for independence revealed a significant difference in the number of traffic light violations committed [$\chi^2 = 4.358$, df=1, $p<0.05$]. With ISA, drivers tended to commit fewer traffic light violations. There were no Age or Gender effects.

Table 4.3: Red light violations

	ISA Off	ISA On
Number of violations	16	7
Number of non-violations	44	53

An additional safety benefit was found in the car-following task. For each participant, the percentage of time occupied in each half-second headway unit between 0-6 seconds was calculated. A mean percentage in each unit was then derived across participants in each condition (Figure 4.6).

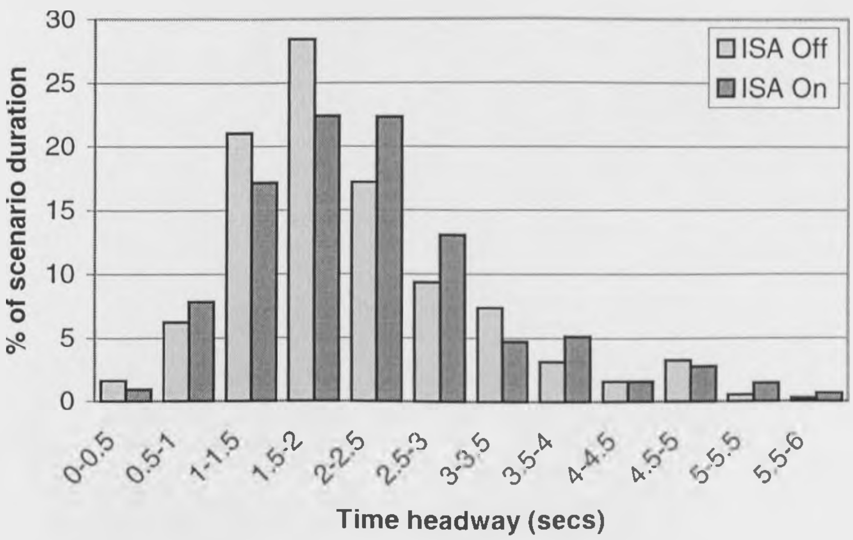


Figure 4.6: Mean headway exposure for each condition

The characteristics of the distributions were calculated in terms of skew and kurtosis. Kurtosis is based on the size of a distribution's tails whereas a distribution is skewed if one of its tails is longer than the other. When ISA was implemented, there was a trend towards reduced positive skew in the distribution, i.e. following behaviour became safer with less of a tendency to adopt short headways and an increased tendency for more frequent long headways (Table 4.4). In addition, the change in kurtosis denotes the distribution has less spread and values are concentrated around the mean.

Table 4.4: Headway distribution characteristics

	ISA Off	ISA On
Skew	1. 28	0. 88
Kurtosis	0. 68	-0. 81

Related t-tests were carried out to test differences in the amount of time drivers spent at critical headways. There were no differences with respect to very small headways (less than one second); however there was a significant difference in the amount of time drivers spent at less than the recommended headway (two seconds). Drivers with ISA spent less time following at less than two seconds headway than without ISA [$t(29)=6.97$; $p<0.05$].

With regards to curves, there were no effects of ISA on entry, apex or exit speeds. However a main effect of System did exist for speed variance over the whole curve: when ISA was active, speed variance decreased from 1.28 mph to 0.63 mph. This reduction was statistically significant [$F(1,87)=3.29$; $p<0.05$]. There were no effects of Age or Gender.

4.3.2 Safety costs

In contrast, some negative safety effects were also found. In the gap acceptance task, a value for the mean gap accepted was calculated. There was a main effect of System on size of gap accepted, [$F(1,87)= 6.23$; $p<0.01$]. Drivers accepted smaller gaps when using ISA [Mean= 46.69 metres] than when they were not [Mean= 54.15 metres]. There was also a significant main effect of Gender (Figure 4.7) such that males [Mean= 47.25 metres] accepted smaller gaps than females [Mean= 52.25 metres].

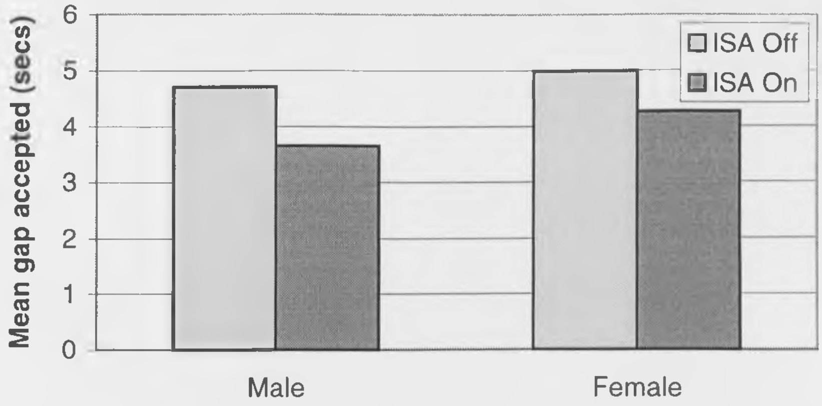


Figure 4.7: Mean gap accepted

Participants completed the NASA-RTLX, a standard measurement of subjective mental workload after each trial (Table 4.5). No differences were found in overall workload scores, but paired t-tests revealed differences in the individual components. When ISA was active, drivers reported less physical demand [$t(29)=4.27$; $p<0.05$] and improved driving performance [$t(29)=5.98$; $p<0.05$]. However, they also reported that their frustration levels increased [$t(29)=5.19$; $p<0.01$] as did time pressure when driving with ISA [$t(29)=6.97$; $p<0.05$].

Table 4.5: Mean mental workload scores

	ISA Off	ISA On
Mental Demand	38.32	36.22
Physical Demand	32.93	27.77
Performance	46.80	37.97
Time Pressure	27.60	35.97
Effort	36.83	33.46
Frustration Level	30.43	43.57

4.4 Conclusions

The results suggest that particular components of drivers' behaviour become safer when ISA is activated. In car-following scenarios there appeared to be a shift towards safer behaviour whereby less time was spent at short headways. This cannot be attributed to a system effect, as the lead car was only travelling at 25 mph and therefore drivers were themselves able to choose the appropriate headway (as they were limited to

30 mph). It is more likely that using ISA discouraged drivers from pulling up close to the car in front and then dropping back in an attempt to overtake. Where participants were not using ISA they could not overtake, due to oncoming traffic, but in the process of attempting to, drove close to the car in front and thus increased the incidence of short headways. The results indicate that perhaps some sort of "calming" effect occurred when drivers used ISA. They were maybe resigned to the fact they were unable to overtake quickly (due the small speed differential between them and the car in front) and thus did not attempt to do so.

The frequency of traffic light violations decreased when drivers were using ISA. Unlike the car-following results, this change in behaviour is directly attributable to a system effect. When using ISA, drivers were unable to exceed the speed limit. As they were travelling slower, once they had noticed the lights changing from green to amber, they had more time to brake and hence stop at the red light. This result is interesting if considered in the light of some of the research on red light cameras. Robertson (1997) found increases in daytime speeds where traffic signals were enforced using cameras. He reported increases in mean speed at approximately 2 seconds after the amber onset, suggesting that drivers were accelerating to avoid violating the red light (and thus avoid citation). With ISA, this ability to accelerate further was not available and drivers were more inclined to stop on seeing the (stop-phase) amber light.

Drivers reported that their driving performance improved with ISA, however the results of the mental workload questionnaire also indicated that feelings of frustration and time-pressure increased when using ISA. This increase in time-pressure may have been reflected in the riskier gap acceptance behaviour that was observed. Drivers with ISA may have been reducing their waiting time at junctions in order to make up for time lost elsewhere. This finding has important implications for safety at junctions. At present, approximately 70% of accidents in built-up areas occur at junctions, and to introduce a system that may encourage drivers to make riskier decisions would be counterproductive to safety. Further studies need to clarify whether this was a spurious finding and if not what are the underlying behavioural mechanisms.

Finally, drivers tended to brake later on approach to junctions. However, the onset of braking is a function of speed on approach to junctions. Therefore without ISA, drivers travelled faster on approach to junctions and thus were required to engage in earlier braking behaviour than when ISA was equipped.

4.5 Implications for remaining studies

The results from this exploratory study indicate that driver behaviour does change when using an ISA system. However it was noted that these changes were bi-directional; i.e., both safer driving and riskier driving were observed. This study highlighted the following issues:

- Additional research is also necessary to establish long-term adaptation effects of ISA. The results of the exploratory study are only applicable to short term effects and are not generalisable to a situation where an ISA system has been in operation for a longer period of time. It might be that maladaptive behaviour disappears as lower speeds become more acceptable; on the other hand as drivers are constrained to lower speeds for longer and longer periods of time, compensatory behaviour may become more evident. Only by conducting longitudinal studies can these effects be monitored.
- This exploratory study only implemented ISA in an urban area. Further work is needed to establish whether there are benefits of ISA for rural roads and the motorway network.
- Further work needs to examine the benefits of ISA in relation to more traditional measures such as traffic calming and enforcement.
- Finally additional research should be undertaken to determine public acceptability towards ISA. This acceptability should be monitored over time in order to evaluate if the system becomes more acceptable after use, and indeed how much people would be willing to pay for such a system.

The remaining studies will attempt to look at these issues more closely. The next chapter describes a study that addresses the first of these issues, whereby the effectiveness of an ISA system as a speed management tool is compared to that of more traditional interventions.

Chapter Five

A comparative evaluation of ISA

5.1 Study aims

This chapter details a study that tested the effectiveness of ISA against a variety of other speed reducing measures in a controlled environment on a driving simulator. In order to use realistic existing treatments, a specific real-world accident was identified. The accident that was addressed was the single vehicle "loss of control on a bend" accident in a rural environment.

In the experiment described in the following sections, drivers encountered curves in a simulated road network that were either treated with one of four speed-reducing measures or untreated. The four treatments included a perceptual countermeasure, an in-car advisory system, a roadside Variable Message System (VMS) and an ISA system. A control condition was also included to serve as a behavioural baseline.

The aim of the study was to discover whether ISA is any more effective than measures used currently. It was hypothesised that by providing information and speed advice to the driver, speed would be reduced on the treated curves. In addition it was thought that the different treatments would differ in their effectiveness. It was also anticipated there might be negative effects of the treatments e.g. behavioural adaptation, distraction and increased mental workload.

5.2 Speed and accidents on rural curves

In the U.K., different road classes have different accident rates associated with them. At present, rural A-roads (speed limit is typically 60 mph) have a higher accident involvement rate (per mile) than motorways and the highest accident involvement rate for fatal accidents, compared to all other road types (Pyne, Dougherty, Carsten and Tight, 1995). A U.K. study (Taylor and Barker, 1992) analysed the injury accident database (STATS 19) for accidents on rural single-carriageway roads for the years 1988 and 1989. The study found that of the 49,342 accidents on rural single-carriageway A roads:

- 15% involved two vehicles on a two-lane road, "going ahead".
- 11% involved one vehicle on a two-lane road, "going ahead".
- 11% involved one vehicle on a two-lane road, "going ahead on a bend".
- 7.5% involved two vehicles on a two-lane road, "going ahead on a bend".

There is thus a significant proportion of accidents involving one or two vehicles on two-lane A roads "going ahead on a bend", accounting for 18.5% of all accidents on these roads. Such accidents are most likely caused by driving too quickly through the curve and either losing control of the vehicle or being forced into a corner-cutting manoeuvre (to maintain control of the vehicle). In order to prevent such incidents, it is desirable for the driver to have completed the appropriate deceleration before curve entry.

The fact that horizontal curves on two-lane rural roads are a safety problem may be due to the fact that many rural roads are substantially older than many urban roads. New roads are designed for a particular design speed, the original definition of which is "the maximum approximately uniform speed which probably would be adopted by the faster group of drivers but not, necessarily, by the small group of reckless ones" (McLean, 1979). In the U.K., the design speed is considered to be "the highest continuous speed at which individual vehicles can travel with safety on the highway when weather conditions are favourable, traffic density is low and design features of the highway are the governing conditions for safety" (O'Flaherty, 1986). Many rural roads pre-date the design speed concept and tend to have a wide variation in the maximum speed at which different elements (e.g. curves) can be safely negotiated, despite the fact that the posted speed limit is constant.

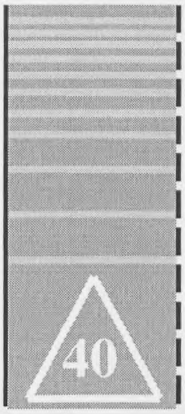
There have been various attempts to reduce speeds on curves, many of which are discussed in Chapter Two. In this study, three of the most commonly used interventions were selected and used as a comparison against ISA.

5.3 Method

In order to assess fairly the relative merits of ISA, a comparison was made with successful real world treatments. Each of these treatments was designed and implemented for use on the Leeds Driving Simulator and can be seen in Figure 5.1.

5.3.1 Treatments studied

1. *Transverse bars* are a type of perceptual countermeasure and can be particularly effective if the spacing between them decreases on the approach to the dangerous location, since this creates the illusion that one is accelerating. The use of transverse bars was thought to be particularly relevant in this study as the curves incorporated into the network were associated with considerably lower advisory speeds than the general speed limit around them. Studies have identified that the accident rate for curves on rural roads is strongly related to the difference between the speed environment approaching a curve and the design speed of the curve (e.g. Koorey and Tate, 1997). In addition, this type of implementation was chosen to be included in this study as it had already been identified as the most effective treatment for curves in an earlier simulator study (Pyne, et al. 1995).
2. Experiments with roadside signs giving *feedback* to individual drivers have demonstrated relatively successful results (Helliar-Symons et al. 1984; Casey and Lund, 1993; Garber and Patel, 1995). A similar VMS to that used in the Symonds Travers Morgan (1995) study was implemented on the simulated road network. The VMS displayed the licence plate of the driver, the advisory speed and the reason for the advisory speed (i.e. "curve ahead").
3. *Feedback* was also presented to the driver in the form of an in-car Liquid Crystal Display (LCD). This displayed exactly the same information as the VMS, omitting the licence plate. By providing information in this way it was possible to evaluate whether in-car information provided further benefits over information provided from the roadside.
4. The effectiveness of these three interventions was compared to that of the *ISA* system. The ISA system was only operational in the vicinity of the curves. It was automatically activated on approach to curves in order to decelerate drivers to the advisory speed. Drivers were warned of the impending speed reduction by means of a message displayed on the in-car LCD.



Transverse bars

Dimensions: 0.60 metres wide

Positioning: At right angles to the centre line of the carriageway. Placed at decreasing intervals from 150m before curve entry to curve apex, as laid out in Department of Transport Standard TD 6/79. Distance between bars ranged from 4.15m - 2.75m.

Activation: 150m before curve entry

Special features: Provided speed advice

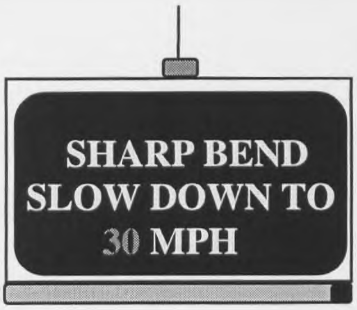
Variable message sign

Dimensions: 8.6m x 6m

Positioning: 100m before curve entry

Activation: 300m before curve entry

Special features: The sign was activated only when drivers exceeded the advisory speed. The advisory speed was displayed in red to improve legibility.



In-car LCD

Dimensions: 195mm x 150mm

Positioning: In the centre of the dash-board, level with the steering wheel.

Activation: 250m before curve entry.

Special features: The message was activated only when drivers were exceeding the advisory speed. The advisory speed was displayed in red to improve legibility. The message was deactivated at curve entry.

ISA Interface

Dimensions: 195mm x 150mm

Positioning: In the centre of the dash-board, level with the steering wheel.

Activation: The message "SPEED CONTROL AHEAD" was displayed 300m before curve entry and changed to "SPEED CONTROL ACTIVE" 200m before curve entry. ISA was deactivated on curve exit.

Figure 5.1: Design of the four systems

5.3.2 Experimental design

A repeated measures experimental design was chosen to reduce the chance of individual differences masking treatment effects. The route only required between 10-15 minutes driving time, making it possible for participants to experience all four experimental treatments described above (and one baseline condition) in a single experimental session. Thus each participant drove the route five times; on each of the routes only one of the four treatments was present. On the fifth route no treatments were present.

The analysis was undertaken using two (within-subject) comparisons. The first comparison identified whether *System State* (On or Off) impacted on driver performance. It was hypothesised that performance would improve (in terms of speed and lateral control) when the systems were activated, regardless of system type (Table 5.1, Comparisons 1a-1d). In contrast, it was hypothesised that there would be no differences in performance in the baseline conditions (Comparison 1e).

The second comparison identified the relative effectiveness of the four treatments (Table 5.1, Comparison 2). It was hypothesised that the different treatments would have different effects, with ISA demonstrating the most benefits.

Table 5.1: Statistical comparisons

System type	**VMS**		**LCD**		**ISA**		**Bars**		**Baseline**	
System status	On	Off	On	Off	On	Off	On	Off	Off	Off
Comparison 1	*a*		*b*		*c*		*d*		*e*	
Comparison 2										

The experiment used a two-factor (System x State) repeated measures design, whereby System consisted of five levels (VMS, LCD, ISA, Bars, Baseline) and State of two levels (On, Off). This experiment used an incomplete design whereby the Baseline condition could only have one level of system activity (Off). Sex and Age were incorporated as between-subjects factors. Where significant interactions were found, pairwise comparisons (using the Bonferroni correction to control the familywise error) were carried out.

Driving performance was measured in terms of curve approach and negotiation, using variables of speed and heading and their derivatives. Each participant completed five experimental routes, the ordering of which was balanced. The experiment lasted approximately 90 minutes.

5.3.3 Participants

Thirty participants took part in the experiment. All had clean driving licences. The sample included 15 males between the ages of 22 and 52 [Mean= 32 years] with a reported annual mileage of between 5,000 and 37,000 miles [Mean= 15,000]. In addition, 15 females took part between the ages of 23 and 48 [Mean= 30 years] with a reported annual mileage of between 8,000 and 22,000 [Mean= 13,000]. Approximately half the males were under 30 and half were over 30; the females were similarly distributed. All held current driving licences and had been driving for more than three years. Participants were paid for their time. Participants who suffered simulator sickness during the trial were excluded from the analyses.

5.3.4 Simulated road network

The road network was constructed from curves separated by straight sections of road. Within the road network, there were two types of left-hand and two types of right-hand curves. Of the left-hand curves, one type had a radius of 100 metres (75 metres length) and the other 200 metre radius (150 metres length) and similarly for the right-hand curves. In addition, for each type of curve there also existed an identical one on which the treatment was placed, totalling eight curves per road network, (Table 5.2). Each curved section was constructed of a 300 metres entry straight, the actual curve (75 m or 150 m in length) and an exit straight of 300 metres.

Table 5.2: Experimental curves

	100m radius		**200m radius**	
Left hand curve	Treated	Untreated	Treated	Untreated
Right hand curve	Treated	Untreated	Treated	Untreated

To minimise order effects, the ordering of the curves was randomised across the experimental conditions.

The curves were interspersed with a variety of pieces of road to alleviate boredom and create a more natural driving environment, including non-experimental curves and villages. All experimental curves were situated in a rural environment (60 mph speed limit) and an urban scene was also created where speed limit compliance was measured. The total length of the network was 7 miles. Opposing traffic was present on the straight sections and in the villages, but there was no other traffic in the driver's lane in order to create free-flowing conditions. The lane was a constant 4m width in both the curved and straight sections. Standard rural centre-lines (2m mark, 7m gap) and broken edge-lines with a 1m line and 3.5m gap were used on straight road sections. A bend warning sign was placed 150m before curve entry. At 95m before the bend, a double line, one continuous (on the driver's side) and one permissive broken (1m line, 5m gap, 150mm wide) was placed. At 35m before curve entry this changed to a double continuous centre line. Delineation is shown in Figure 5.2.

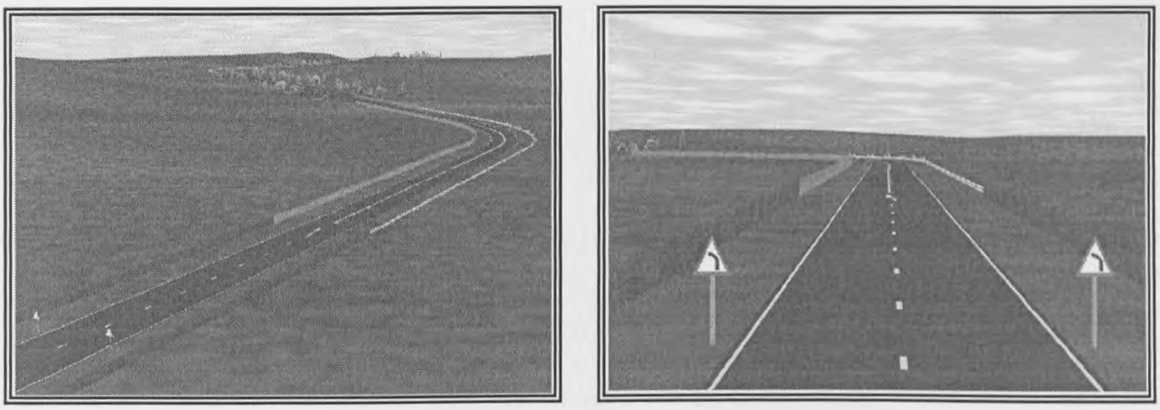


Figure 5.2: Road delineation

The roadside environment consisted of variously positioned trees and houses on the straight sections, with a consistent hedge and fences bordering the road. In order to maximise comparability, curved sections contained no additional features apart from a crash barrier in accordance with sub-standard curve design.

The advisory speeds for the particular curves used were calculated using a standard formula that calculates the maximum speed at which a vehicle can be kept on the road while negotiating a bend (Papacostas, 1987):

$$v = \sqrt{g * R * (e + f_s)}$$

where f_s = coefficient of side friction

R = curve radius (m)

e = superelevation

g = acceleration due to gravity (m/s^2)

Table 5.3 shows some examples of the appropriate highest speeds at which, theoretically, sharp curves with different radii can be negotiated.

Table 5.3: Appropriate highest speeds when negotiating curves with different radii and friction values (km/h) [superelevation e = 0.055]

Road condition		**Curve radius (m)**									
		100		**200**		**300**		**400**		**500**	
		f_s	mph	f_s	mph	f_s	mph	f_s	mph	f_s	mph
Dry	f=0.5	*0.20*	36	*0.18*	49	*0.17*	59	*0.16*	66	*0.15*	73
Wet	f=0.4	*0.17*	33	*0.16*	46	*0.14*	54	*0.14*	62	*0.13*	68
	f=0.3	*0.13*	30	*0.12*	42	*0.11*	50	*0.11*	56	*0.10*	63
Icy	f=0.2	*0.09*	27	*0.08*	37	*0.08*	44	*0.07*	51	*0.07*	56
	f=0.1	*0.05*	23	*0.04*	31	*0.04*	38	*0.04*	43	*0.04*	48

Drivers have been found to consider two efficiency measures when negotiating curves: speed and comfort (Andueza, 2000). Therefore, piloting of the experiment was essential to ensure that an advisory speed that was both attainable and realistic was chosen. A number of pilot participants were asked to drive through the curves. It was found that drivers chose to drive at speeds that were consistently below those shown in Table 5.3. These pilot data were used to calculate the advisory speeds for the curves. This required the use of an advisory speed relating to a decreased friction value, i.e. from Table 5.3, the 'wet road' values were used. The appropriate speeds for the curves used were approximated to 30mph and 40mph and used as the advisory speeds in this study.

5.3.5 Data collection

Driver performance was evaluated at both curve approach and negotiation using indicators of speed and lateral position.

5.3.5.1. Curve approach

The safe negotiation of a curve depends, in part, on driving behaviour on the road section immediately before it in terms of speed and road positioning. Measurements were therefore recorded on the 300m straight that preceded each curve (Koorey and Tate, 1997). This approach section was divided into 10 segments of 30m each. For each segment, average values of speed, acceleration and lateral position were taken.

In addition to absolute performance measures, several indicators of 'safe' behaviour were also derived. Firstly, as an indication of smooth approach and entry to the curve, maximum brake pressure (bar) was recorded; a high value indicated the driver performed an extreme braking manoeuvre that could be deemed as inappropriate to safe curve negotiation.

Secondly, the percentage of speed reduction completed before curve entry was calculated as a measure of anticipatory behaviour. This was calculated using the following formula:

$$\left(\frac{V^{300} - V^{entry}}{V^{300} - V^{min}}\right) \times 100$$

where

V^{300} = speed at 300m before curve entry

V^{entry} = speed at curve entry

V^{min} = observed minimum speed in curve

A high percentage indicated the driver anticipated the curve correctly and was able to complete the intended amount of deceleration before entering the curve.

Finally, as an indication of steering performance, total heading error on the 300m approach section was derived by calculating the total average difference between road heading and actual heading in each of the 10 segments. Road heading was defined as being a straight line. It was hypothesised that a low total heading error would be associated with a controlled approach to the curve. This measure was also used as an indicator of driver distraction, such that a high error score might reflect increased visual workload (e.g. due to the LCD or VMS).

5.3.5.2. Curve negotiation

Measurements within the curve were also collected including curve entry, apex and exit speeds. Mean, maximum, minimum and standard deviation of speed throughout the curve were derived. The number of lane departures and the minimum time-to-line crossing were also recorded in the curve, as an indication of controlled curve negotiation.

5.3.5.3. Workload

The evaluation of new technology should consider the effect of any additional demand it places on the driver. It is important that the primary task of driving is not disrupted in a way that could compromise safety. Of particular concern was the effect of additional information provided by the in-car LCD and the VMS on driver distraction. This study used the NASA-RTLX as a method of comparing workload between the different treatments. The NASA-RTLX, however, is a global measure of workload and was administered after a complete simulator run – workload at specific locations in the road network is not accessible. Therefore, an additional performance measure was included to address this issue. High visual workload has been shown to be associated with variations in driver performance measures such as reduced speed and increased lane deviation (Cnossen et al., 1997) and faster steering wheel reversals (Nakayama et al., 1999). Due to the fact that drivers were decelerating on the approach to curves anyway, speed was not considered to be a valid measure of workload. Instead, heading error was recorded as an indicator of the amount by which drivers deviated from the correct path on the road and thus an indicator of task difficulty.

5.3.5.4. Acceptability

Another important aspect of new technology is driver acceptability. In addition to measuring acceptability in the form of behavioural parameters such as speed behaviour, a questionnaire was also administered. An acceptability scale developed by Van der Laan et al., (1997) was used. As discussed in Chapter Three, one would expect the purely informative treatments such as the in-car LCD and the painted transverse bars to be more acceptable than the VMS (hinting at enforcement) and the ISA system.

5.3.6 Procedure

A description of the study was presented to the participants and their consent was obtained. They were asked to drive the simulator for 15 minutes in order to familiarise themselves with both the controls of the car and the speed management treatments under investigation. Participants were then asked to drive five successive trials, (one baseline and four experimental trials). Each of these trials took approximately 10 minutes to complete. Between each of the trials participants were allowed a short break in which they were asked to complete the NASA-RTLX and acceptability questionnaires. On completion of the five trials, the participants were asked to complete the acceptability questionnaire, debriefed and paid. In total the experiment lasted approximately 90 minutes. Participants who were unable to complete the five trials (due to simulator sickness or other reasons) were debriefed and paid in the same way, but their data was excluded from the analysis.

5.4 Results

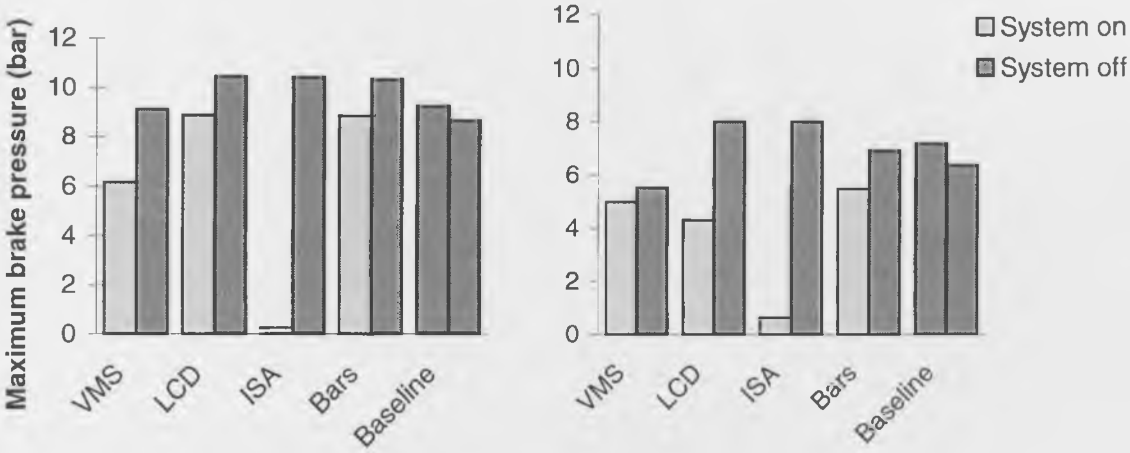
The data were checked for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene tests respectively. The data were analysed with a mixed factorial analysis of variance (ANOVA) to determine the effect of four within subjects factors (System Type, System State, Curve Radii and Curve Direction) and two between subjects factors (Sex and Age) on speed and lateral position. Main and interaction effects for System Type, System State and Curve Radii were found. However there were found to be no main or interaction effects of Curve Direction, Sex and Age. The results for the performance variables are presented in separate sections below.

5.4.1 Curve approach

5.4.1.1. Maximum brake pressure

As a measurement of safe and controlled approach to curves, a value of maximum brake pressure (range 0-80) was obtained for the 300m straight approach to curves. A high value indicated severe braking, perhaps arising from a lack of forward planning.

The results of the ANOVA showed significant main effects of System State ($F[1,104]=12.23$; $p<0.001$) indicating that drivers maximum braking was lower when systems were activated. A significant System State x System Type interaction was found (F[4,104]=6.94; p<0.001) indicating that the effect of System state was not consistent across System types. Post-hoc tests (Tukey) revealed that with ISA, on treated curves, maximum brake pressure was significantly lower than on untreated curves (F[4,104]=17.49; p<0.001). None of the other treatments were able to produce such results (Figure 5.3).



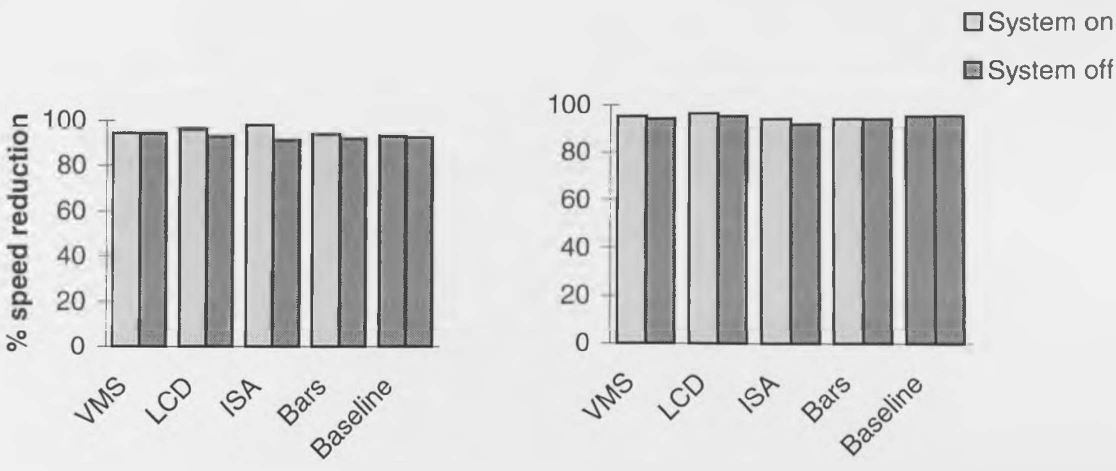
(a) 100m radius curves **(b) 200m radius curves**

Figure 5.3: Maximum brake pressure on approach to curves

A main effect of curve radii was found (F[1,104]=10.58; p<0.001). As would be expected, braking was more severe on the 100m radius curves.

5.4.1.2. Speed reduction

The percentage of speed reduction completed before curve entry was calculated as a measure of anticipatory behaviour. A main effect of System State was found (F[1,104]=5.26; p<0.001), such that drivers completed significantly more of their speed reduction before curve entry when the systems were activated (Figure 5.4). A significant System State x System Type interaction was found (F[4,104]=6.94; p<0.001) along with a significant System State x Curve Radius (F[4,104]=5.34; p<0.01) interaction indicating that the activation of the systems was not consistent across System Types or Curve Radius. Post-hoc tests (Tukey) revealed that, in the curves with smaller radii, all the treatments apart from the VMS had a significant effect on the percentage of speed reduction obtained when activated (p<0.01). This effect was still present, even when a Bonferroni correction was applied in each of the pairwise comparisons.



(a) 100m radius curves **(b) 200m radius curves**

Figure 5.4: Percentage speed reduction completed before curve entry

These differences were not observed in the 200m radius curves. Additional post-hoc testing revealed that when using ISA on the 100m radius curves, drivers were able to complete significantly more of their speed reduction before curve entry than with LCD or Bars ($F[4,104]=7.74$; $p<0.001$).

5.4.1.3. Speed profiles

Average speed measurements were recorded for each 300m section on approach to curves. Speed profiles for the different treatments on approach to curves are shown in Figure 5.5 and Figure 5.6. It can be seen that for both types of curve, a similar pattern of speed profile emerged. A clear reduction in speed in the Baseline condition was not observed until approximately 100m before curve entry; at this point deceleration was heavy into the curve. In contrast, the treated curves (VMS, LCD and Bars) exhibited similar speed profiles to one another. As would be expected with ISA, the deceleration curve was sharper but smooth and curve entry speed was reached before curve entry. Also noteworthy though, was that drivers appear to be reliant on ISA for deceleration, as indicated by the higher speeds observed in the first portion of the graph. This could be interpreted in two ways; either drivers were confident enough with ISA to depend on it for deceleration, or they were adapting their behaviour to maintain the maximum speed for as long as possible in preparation for lower than desired speeds, as imposed by ISA.

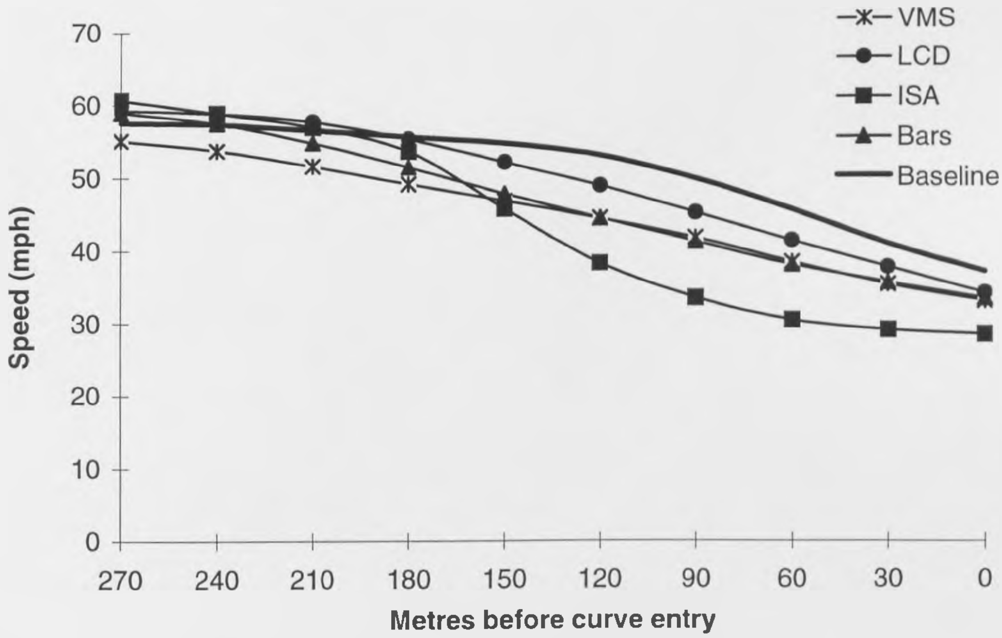


Figure 5.5: Speed on approach to 100m radius curves

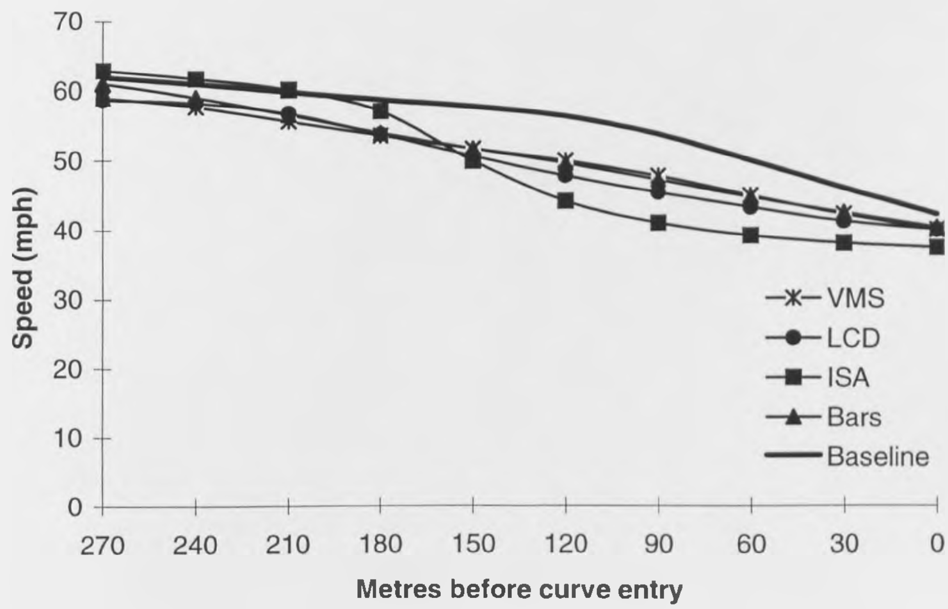


Figure 5.6: Speed on approach to 200m radius curves

Curvilinear regression lines were fitted to each of the curves in Figures 5.5 and 5.6. The regression equations are shown in Table 5.4. By fitting a regression line, it was possible to hypothesise about the characteristics of the curves. The regression equations indicated that the VMS encouraged drivers to reduce their speed earlier than the other treatments, probably due to early detection of the sign at the roadside. Alternatively, on detection of the VMS, drivers could have been adapting their behaviour by reducing their speed in order to read the sign.

The characteristics of the regression lines establish the pattern of speed reduction on the approach to curves. In the Baseline condition, a second-order model was the most appropriate (inclusion of the D^2 term). This can be seen quite clearly from Figures 5.5 and 5.6, in the form of the parabolic curve.

Table 5.4: Regression equations for curve approach

Curve radius	**System**	**R^2**	**Equation (y=)** *{Confidence Intervals}*
100 m	VMS	0.999*	90.18 *{88.64-91.71}* - 0.134D
	LCD	0.968*	99.87 *{96.11-103.63}* - 0.157D
	ISA	0.993*	98.01 *{95.22-100.8}* - 0.0026D^2 + 6.9E-06D^3
	Bars	0.995*	96.23 *{94.15-98.31}* - 0.165D
	Baseline	0.998*	93.14 *{91.72-94.55 }* - 4.5E-04D^2
200 m	VMS	0.994*	95.81 *{94.6-97.01}* - 0.116D
	LCD	0.909*	90.14 *{86.22-94.06}* - 4.3E-04D
	ISA	0.999*	101.51 *{98.86-104.16}*-2.2E-03 D^2 + 6.0E-06D^3
	Bars	0.999*	97.84 *{97.4-98.28}* - 0.126D
	Baseline	0.995*	98.24 *{97.37-99.12}* - 4.3E-04 D^2

*sig. p<0.001

Therefore speed reduction did not occur at a constant rate, and it can be noted that the deceleration rate increased in the second half of the curve, as the driver neared the approach to the curve.

In contrast, the curves for the VMS, Bars and LCD can all be described using a linear model. This indicates a smoother rate of deceleration towards curve approach. In the ISA condition a smooth reduction in speed can be noted until the advisory speed is reached. This curve required a higher order model, indicating that the curve changed direction more than once. The additional change in direction is shown by the inclusion of the D³ term that describes the tail of the curve where the advisory speed is attained and speed is constant.

5.4.1.4. Lane discipline

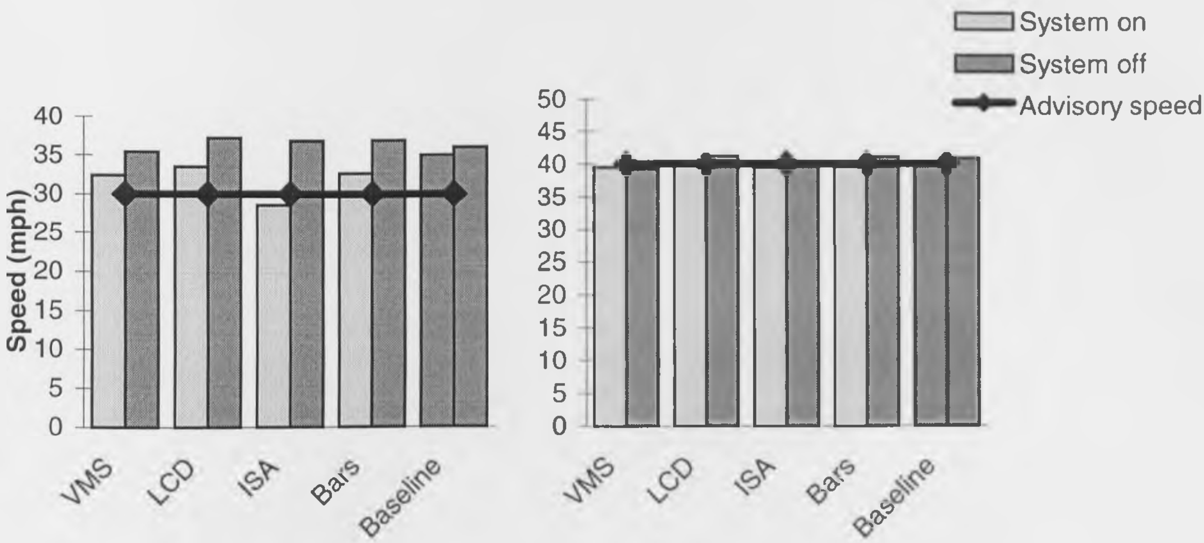
It was hypothesised that providing information in the form of visual messages (VMS and LCD) might disrupt steering performance on approach to curves. In order to test whether visual information distracted the driver, thus leading to increased lane position variability, an average total heading error score was obtained for each curve approach. There was found to be no significant differences between error scores on the treated and untreated curves in either the VMS or LCD conditions. This suggests that steering performance was not disrupted by the provision of visual information.

5.4.2 Curve negotiation

5.4.2.1. Spot speeds

Spot speeds were recorded at curve entry, apex and exit and additional measurements of mean, standard deviation, minimum and maximum speeds were also taken through the whole curve.

A main effect of System State was found for all the variables ($F[1,104]=8.29$; $p<0.001$) such that spot speeds were lower when the systems were activated. The example of curve entry speed is shown in Figure 5.7.



(a) 100m radius curves **(b) 200m radius curves**

Figure 5.7: Curve entry speed

As expected, there was also a System State x System Type interaction ($F[1,104]=7.43$; $p<0.001$) for all the speed measures. Post hoc tests (Tukey) revealed that, as anticipated, speeds with the ISA system were significantly lower than with all other treatments. Therefore, regardless of the type of treatment, driver speed choice on curves was affected by the provision of advice and as would be expected the greatest gains were achieved with ISA. The remaining measures follow a similar pattern and their means are shown in Tables 5.5 and 5.6.[1]

A main effect of Curve Radius ($F[1,104]=5.87$; $p<0.01$) was also found along with significant interaction effects with System Type ($F[1,104]=6.23$; $p<0.001$). For the 100m radius curves (with an advisory speed of 30 mph), within each experimental run each of the treatments significantly reduced speeds.

Table 5.5: Speed measurements for 100m radius curves (mph)

	System	**System on and [off]**	
		Mean	*SD*
Curve entry	*VMS*	32.41 [35.40]	3.58 [4.39]
	LCD	33.49 [37.21]	4.61 [4.89]
	ISA	28.53 [36.81]	2.24 [3.88]
	Bars	32.62 [36.86]	5.04 [4.36]
	Baseline	35.99	4.23
Curve apex	*VMS*	32.75 [36.11]	3.74 [4.04]
	LCD	34.34 [36.91]	3.94 [4.48]
	ISA	28.52 [36.53]	2.68 [3.68]
	Bars	32.78 [36.81]	4.68 [4.20]
	Baseline	36.16	3.87
Curve exit	*VMS*	36.27 [39.66]	3.68 [4.04]
	LCD	38.05 [39.93]	4.01 [4.31]
	ISA	28.53 [39.18]	3.07 [4.00]
	Bars	36.73 [40.06]	4.41 [3.40]
	Baseline	39.64	4.09

[1] The two baseline measurements have been averaged.

In contrast, the results from the analysis of the 200m radius curves (with an advisory speed of 40 mph), differed with regard to the effectiveness of the individual treatments. Although, as above, the System Type affected speeds through the curve such that lower speeds were obtained with ISA, the ability to induce lowered speeds was differential according to which system was implemented ($F[1,104]=16.98$; $p<0.001$). For all the measures of speeds at curve entry, apex and exit, and additional measurements of mean, minimum and maximum speeds, there were only significant differences between System On and System Off for the LCD, ISA and Bars. The impact of the VMS on driver speed through these curves was minimal.

Table 5.6: Speed measurements for 200m radius curves (mph)

	System	**System on and [off]**	
		Mean	*SD*
Curve entry	*VMS*	39.47 [39.31]	5.07 [5.18]
	LCD	39.66 [41.31]	4.31 [5.46]
	ISA	39.47 [39.77]	3.51 [5.02]
	Bars	39.49 [41.17]	4.59 [5.48]
	Baseline	40.86	4.84
Curve apex	*VMS*	42.68 [42.84]	4.66 [5.50]
	LCD	43.13 [44.65]	4.54 [5.41]
	ISA	36.80 [42.90]	4.52 [6.29]
	Bars	41.83 [44.41]	5.00 [5.77]
	Baseline	44.39	5.34
Curve exit	*VMS*	47.49 [48.28]	5.40 [6.38]
	LCD	47.23 [49.44]	5.29 [6.06]
	ISA	36.74 [47.72]	5.44 [7.19]
	Bars	46.79 [48.99]	5.63 [5.92]
	Baseline	49.49	5.70

As a general observation, it can be seen that the mean speeds with ISA are slightly lower than the advisory speed. A possible explanation for this is that drivers had to change down a gear in order to accommodate the slower speed. This would involve releasing the accelerator in order to operate the clutch, thus perhaps resulting in a loss of speed. Alternatively, drivers may have misunderstood the system and believed that it would maintain the speed automatically for them, even if they released the accelerator.

5.4.2.2. Lane discipline

Drivers' ability to control the vehicle in their lane was evaluated using measures of minimum time-to-line crossing. A significant interaction effect between System State and System Type (F[4,104]=3.22; p<0.01) revealed that minimum time-to-line crossing values were significantly higher than when the other treatments were present (Table 5.7). Due to the lower speeds enforced by ISA, it appears that an additional effect was improved lane-keeping ability. The speed reductions obtained with the other treatments were not sufficient enough to impact on lane-keeping performance.

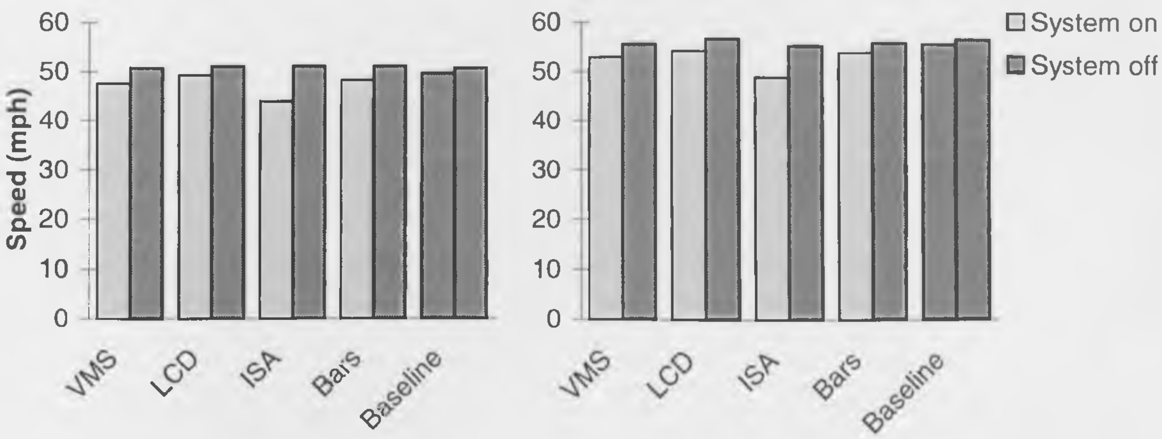
Table 5.7: Average minimum time-to-line crossing for 100m radius curves (secs)

System				
VMS	LCD	ISA	Bars	Baseline
1.05	1.10	1.49	1.21	1.07

A significant interaction effect between System State, System Type and Curve Radii, (F[4,104]=4.32; p<0.01) revealed this effect was present on 100m radius curves only.

5.4.3 Carry-over effects

As a measure of the effectiveness of maintaining reduced speeds, a spot speed was also recorded 100m past the end of the curve. All treatments were effective in maintaining the lowered speeds at this point (p< 0.001), as can be seen from Figure 5.8.



(a) 100m radius curves **(b) 200m radius curves**

Figure 5.8: Spot speed after curve

Although the road network was mainly rural, a section of urban road was included in order to relieve monotony and also to enable investigation of behavioural adaptation in terms of speeding in non-rural areas. It was thought that perhaps driving at slower than normal speeds on curves might have carry-over effects in other parts of the road network, for example exceeding the speed limit in urban areas. The percentage of time spent at 10, 20 and 30% above the speed limit was recorded. No significant differences were found between the experimental conditions either in terms of increased speeds in order to compensate for lost time on curves, or decreased speeds due to higher awareness of speed limits.

5.4.4 Workload

Subjective workload scores using the NASA-RTLX were obtained for each condition in terms of mental demand, physical demand, time pressure, performance, effort and frustration level. Each of these items was represented using a bipolar scale: participants placed a line on the scale between the two extremes of the item to indicate the strength of the attribute. A repeated measures one-way ANOVA (using the System comparison only) revealed no significant effects on either total workload scores or the individual components.

This contrasts with previous results, whereby increased time pressure and frustration were found with ISA. A possible explanation for this is the fact that each of the treatments was only present on the curves; the remainder of the drive was unsupported. Therefore, perhaps the presence of the treatments was not overly intrusive and thus did not affect drivers' perceptions of workload.

5.4.5 Acceptability

It was predicted that acceptability ratings would reflect the severity of the system under examination such that an advisory system would be more acceptable than one that controlled driver behaviour. The acceptability scores (ranging from –2 to +2) were coded and checked for reliability as in the methodology described by Van der Laan et al., (1997). Reliability was established (Cronbach's alpha = 0.9). Cronbach's alpha measures how well a set of items (or variables) measures a single unidimensional construct. Total scores for each participant on the two dimensions of "usefulness" and "satisfying" were calculated for each system. An overall system score was then obtained across participants (Figure 5.9).

The most acceptable treatments were those that were unobtrusive and did not control the driver. Statistical testing revealed that ISA received significantly lower acceptability ratings than the other implementations (Usefulness: $F(3,104)=8.21$; $p<0.001$; Satisfying: $F(3,104)=10.57$; $p<0.001$).

This result is in line with predictions made earlier, such that restrictive treatments produce lower acceptability scores.

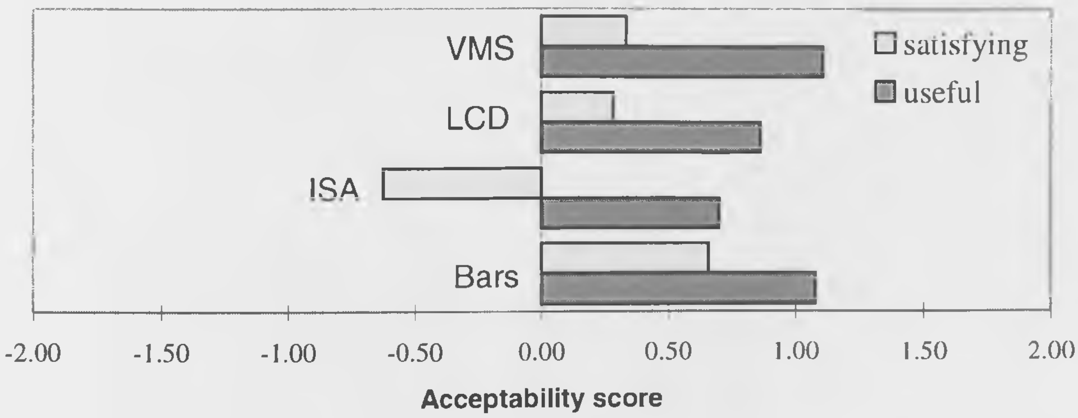


Figure 5.9: Average Acceptability scores

ISA probably required more frequent gear changes on approach to the curves, perhaps contributing to the lower acceptability scores. The other treatments received similar acceptability ratings to one another.

5.5 Discussion

A driving simulator was used to evaluate the effects of various speed management treatments on driver speed choice. Drivers encountered curves in a simulated road network that were either treated with one of four measures or untreated. The four treatments ranged from the purely advisory (transverse bars or an in-car LCD advice system), to one that conveyed the threat of punishment (VMS), to a fully automated ISA system. It was hypothesised that by providing information and speed advice to the driver, speed would be reduced on the treated curves. It was also hypothesised that the different treatments would differ in their effectiveness.

Driving performance measures were taken relating to both curve approach and negotiation. Optimal performance was defined as having the following characteristics:

- controlled and timely braking on approach to curves
- large percentage of speed reduction completed before curve entry
- minimal disruption to steering performance in the presence of a novel system
- curve negotiation speed reflecting advisory speed
- minimal behavioural adaptation on untreated sections of road.

As would be expected due to the design of the system, ISA surpassed all the other treatments in terms of effectively reducing speed on approach to curves and consequently having additional positive effects on lateral control in curve negotiation. In terms of user acceptability however, this system was least liked.

Encouragingly, all the "non-ISA" treatments significantly reduced speeds when activated (although not as effectively as the ISA system), by approximately 4 mph. However, there were found to be very few differences between them, perhaps suggesting that low-cost measures (e.g. transverse bars), in the short-term at least, are just as effective as technologically advanced ones.

Table 5.8 shows the comparative effectiveness of the different treatments in terms of the "take-up" of speed advice. For the 100m radius curves, the take-up is approximately 55%; the ISA system shows a much stronger effect as predicted. That is, drivers adjusted their speed by 55% of the amount that they had been advised to. This take-up of advice is similar to that reported in Rutley's (1972) study on advisory speed for curves – his reported take-up was 40%. The calculations for the 200m curves can be seen to be erratic. This is due to the fact that drivers were mostly travelling at the advisory speed in the baseline condition anyway.

Table 5.8: Comparison of speed advice take-up between systems

System	Advice take-up (%)[2]	
	100m radius	*200m radius*
VMS	55.42	23.42
LCD	51.59	125.83
ISA	121.46	-129.72[3]
Bars	61.77	143.31

The provision of information was thus particularly effective in smaller radius curves. This was a hypothesised result as the advisory speed for these curves was radically different to the speed environment immediately preceding them. The VMS was particularly effective in lowering speeds early in the approach to the curves, probably due in part to early detection of the sign by the road side, however this early advantage was not maintained, and eventually paralleled the speed reduction curves of the other treatments.

What is not clear from this experiment is how these speed management measures perform over time (and distance). There were no "hang-over" effects on untreated curves observed in this study. In some previous studies of this nature, only short-term speed reductions have been noted. These sorts of novelty effects are important to establish in terms of cost/benefits analysis, as any initial benefit may be lost over time.

In conclusion, it appears that the provision of speed advice to drivers does result in reduced speed on the approach and negotiation to curves. It seems to matter little exactly in what mode this advice is given to drivers; speed reductions with the "non-ISA" systems were in the order of 4 mph. Although these reductions did not reflect exact compliance with the advisory speed limit, they are substantial enough to represent a safety benefit (Finch et al. 1994). As would be expected, optimal performance was obtained with the ISA system: this simply reflects a system effect. Whilst acceptability

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[2] Calculated by finding the ratio between the change in mean speed (at curve entry) and the difference between the mean speed with the system off and the advisory speed.

[3] A negative value was obtained here due the fact that mean speed with ISA off was lower than the advisory speed (see Figure 5.7).

was low, no adverse effects in terms of higher speeds elsewhere on the road network, or increased distraction due to the in-car display. In fact, the improved lateral handling of the vehicle represents a secondary safety benefit. In terms of acceptability it is likely that this was low due to the variability in the implementation of the ISA system, i.e. some curves were untreated. This may have introduced some element of confusion for the driver.

This study has outlined the effectiveness of both traditional and innovative curve treatments. Whilst the treatments that provided advice to the driver seemed to impact on performance, the study has highlighted that drivers are more inclined to choose their preferred speed, over an advisory speed. In addition the effects of the advice were limited to treated curves and can thus be considered as a context-specific rather than a global speed-reducing measure.

The concept of ISA was further investigated in the remaining studies reported in this thesis. A combination of driving simulator studies and an on-road study was undertaken to allow a thorough examination of the possible safety benefits and costs associated with implementing ISA. The next chapter details a driving simulator experiment that implemented a variety of ISA systems across a complete road network to establish how drivers interacted with the system on a variety of road types.

Chapter Six
Evaluation of three variants of ISA

6.1 Study aims

The aim of the study was to evaluate three ISA systems across a variety of road types and traffic conditions. In the experiment described in this chapter, drivers used the ISA systems in a road environment incorporating urban, rural and motorway scenarios. A number of behavioural parameters were measured including speed and its derivatives, time headway, overtaking manoeuvres, traffic light violations and collision detection. Subjective measures of workload were taken to monitor any possible underload or overload effects and an acceptability questionnaire was administered to ascertain drivers' opinions about the ISA systems.

It was hypothesised that ISA would demonstrate safety benefits, including reductions in excessive speeds and speed variability. The safety benefits of these systems were hypothesised to be different, as were acceptability ratings. It was additionally hypothesised that safety costs might be found in the form of loss of situation awareness, complacency and behavioural adaptation (as discussed in Chapter Three).

6.2 Method

6.2.1 Systems studied

Three ISA systems were tested under identical traffic and road environment conditions. The ISA systems were conceptualised using a framework that varied both the presence of information and the presence of control (Table 6.1). This framework of ISA systems provided a range of driving experience: from that of normal driving, driving with advice only, driving with speed control only and driving with both advice and control. The three ISA systems represented a hierarchy of increasing control over the driver. Driver behaviour under these three systems was compared to that in a

Baseline Group where drivers did not have an ISA system. The rest of this section describes the ISA systems in more detail.

Table 6.1: Conceptual framework of ISA systems

Information = visual Control = physical		Information	
		Absent	*Present*
Control	*Absent*	**Baseline**	**Advisory**
	Present	**Mandatory**	**Variable**

1. *Advisory ISA system* – this system provided drivers with a continual reminder of the external speed limit. It has been suggested (e.g. De Waard et al., 1995) that speeding may be due to general unawareness of the speed limit. The Advisory system provided drivers with a continuous reminder of the posted speed limit, via a visual display, without exerting any control. Thus the driver remained in-the-loop, but could be considered as more informed of the external conditions. In addition, advisory speeds for any hazardous conditions ahead were also displayed. Drivers were warned when they were approaching a sub-standard horizontal curve or fog and the appropriate advisory speed was displayed on the LCD.

2. *Mandatory ISA system* – this system automatically limited the car to the posted speed limit. If the driver travelled from a higher speed limit to a lower one, the system automatically reduced the speed of the vehicle in readiness for the lower speed limit. Thus the driver was travelling at the speed limit as they passed the speed limit sign (as required by traffic law). When the driver travelled from a low speed limit zone to a higher one, the system allowed acceleration once the new speed limit was in operation.

3. *Variable ISA system* – in addition to automatically limiting the speed of the car to the posted speed limit, this system also further reduced the permitted top speed in hazardous situations. In this experiment, drivers were warned they were approaching a sub-standard horizontal curve or fog and the appropriate advisory

speed was displayed by the system. The system was activated and the car was decelerated, if necessary, to achieve this advisory speed.

6.2.2 Experimental design

A between-subjects design was employed for two reasons:

- Firstly, because the aim of the study was to allow participants to experience ISA on a number of road types, the length of time taken to complete the familiarisation and experimental road networks was approximately 45 minutes. If each participant were to experience each system, the total driving time would amount to more than three hours (including Baseline driving). This would undoubtedly cause fatigue and pollute the data.
- Secondly, a between-subjects design would provide the opportunity of presenting drivers with a critical incident at the end of the road network. A within-subjects design would have meant the drivers encountering critical incidents on more than one occasion and thus learning might have occurred.

Therefore, participants were allocated to one of four groups corresponding to the three systems and one Baseline Group and each participant drove the road network once.

6.2.3 Participants

A total of 60 participants took part in the experiment. All participants possessed a full, clean driving licence. Participants were matched for average annual mileage between the four Groups. The sample included 30 males between the ages of 21 and 55 [Mean= 31 years] with a reported annual mileage of between 4,500 and 32,000 miles [Mean= 12,500]. In addition, 30 females took part between the ages of 19 and 49 [Mean= 29 years] with a reported annual mileage of between 3,000 and 19,500 [Mean= 8,500]. Participants who suffered simulator sickness during the trial were excluded from the analyses.

6.2.4 Simulated road network

The simulated road network incorporated urban, rural and motorway environments to allow testing of the systems in a variety of posted speed limits and scenarios. Urban environments (30 mph speed limit) were created primarily to allow participants to interact with other traffic, whilst rural environments (60 mph speed limit) allowed the investigation of sub-standard curve negotiation and overtaking. The motorway scenario (70 mph speed limit) presented the opportunity to study possible driver underload effects in terms of reduced vigilance. Traffic violations and unsafe driver behaviour were recorded. This was achieved by providing car-following scenarios, critical decisions at traffic lights and overtaking opportunities. There was other traffic present on the road network, but apart from the following tasks, participants encountered free-flowing conditions. The other vehicles simulated on the route travelled at or below the speed limit in order to orchestrate certain scenarios such as car-following and overtaking opportunities.

A critical incident was placed at the end of the network, whereby participants encountered a stationary row of cars on the motorway. The stationary cars were partially obscured by dense fog and required rapid and harsh braking to avoid colliding with them. The road network was approximately 16 miles in length.

6.2.5 Data collection

Spot speed measurements were taken at 10 metre intervals throughout the whole journey. In addition, indices of safety critical behaviour such as minimum time-headway in following tasks and the incidence of overtaking manoeuvres were recorded. Traffic light violations, speed violations and curve negotiation behaviour were also noted.

Drivers' reactions to the critical event situated at the end of the road network were evaluated in two ways. Firstly, the *occurrence* of collisions with the lead vehicle was recorded. A collision was defined as the simulator car making contact with the rear of the lead vehicle. Secondly, if drivers did collide with the lead vehicle, speed on impact was also recorded as an indication of collision *severity*. Headway to the lead vehicle was measured both at the time of initial braking and at the instant the brake pedal was fully depressed to provide an account of drivers' braking behaviour.

Workload and acceptability were assessed used the NASA-RTLX and the Van der Laan et al. (1997) scales respectively.

6.2.6 Procedure

A description of the study was presented to the participants and their consent was obtained. They were asked to drive the simulator for 15 minutes in order to familiarise themselves with both the controls of the car and the ISA system under investigation. Following this, participants completed the appropriate experimental route and were then asked to complete the workload and the acceptability questionnaire. The total time to complete the experiment was approximately one hour.

6.3 Results

The data were checked for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene tests respectively. One-way ANOVAs were used where assumptions of analysis of variance were not violated and post-hoc multiple comparison tests (Tukey) were performed in order to determine differences between the Groups. Where the data violated the assumptions of ANOVA, nonparametric Kruskal-Wallis tests were used. The Kruskal-Wallis test transforms the values into ranks before determining the sum of the ranks for each Group and tests the hypothesis that the treatment medians do not differ significantly.

6.3.1 Speed measurements by section

Data from six sections of the road network were extracted for the analysis of driver speed. The sections covered all road types and speed was recorded every 10m where the driver was under free flowing traffic conditions, i.e. data from the car-following events were excluded.

6.3.1.1 Mean speed

Mean speed for these sections were calculated (Figure 6.1). A comparison of sample variances showed that some sections demonstrated unequal variances. Therefore, one-way analyses of variance (for those with equal variances) or Kruskal-Wallis tests (for those with unequal variances) were carried out appropriately on the separate sections. The analyses revealed significant differences between the Groups for the village sections [$F(3,56)=7.98$; $p<0.05$] and the motorway section [$F(3,56)=12.94$; $p<0.01$]. Non-parametric post-hoc analyses (Games-Howell) showed that mean speeds in the villages were higher in both the Baseline and Advisory Groups compared to the Mandatory and Variable Groups.

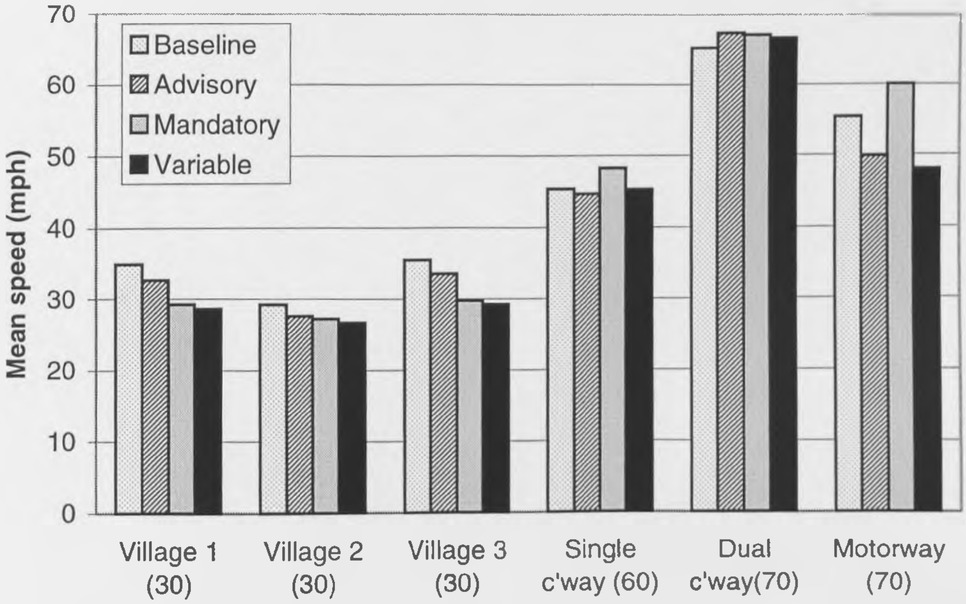

Figure 6.1: Mean speed through road sections

However in the motorway section, mean speed was higher in the Mandatory Group than in either the Advisory and Variable Groups [$F(3,56)=17.54$; $p<0.01$]. There were no significant differences in the rural sections.

6.3.1.2 Maximum speed

Driver maximum speed was also recorded through each of the sections (Figure 6.2).

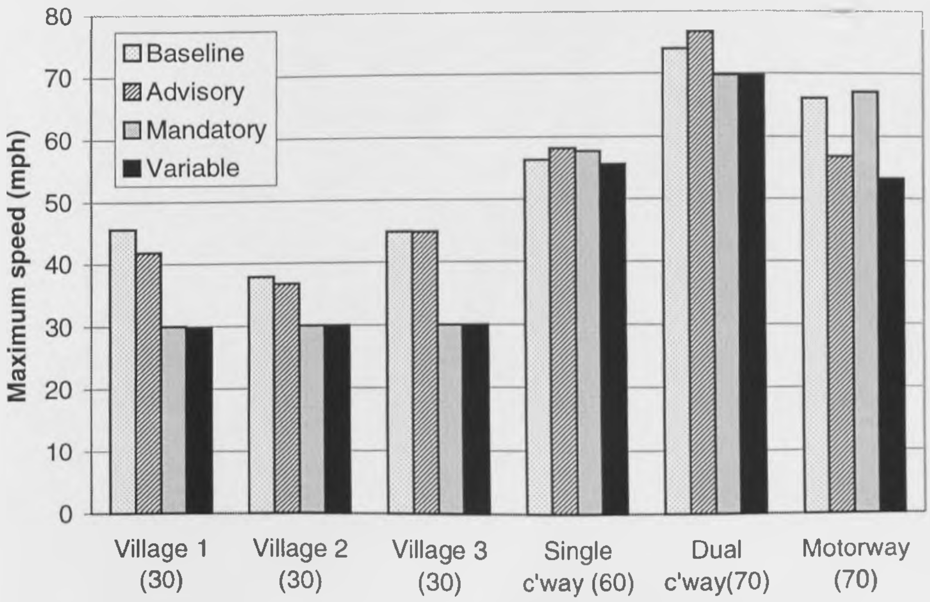

Figure 6.2: Maximum speed through road sections

ANOVA and Kruskal-Wallis tests revealed significant differences between the Groups on all of the sections apart from the rural single carriageway ($p<0.001$). Post-hoc analyses indicated that in urban areas drivers without ISA reach significantly higher maximum speeds than those with ISA.

6.3.1.3 Speed variance

Standard deviation of speed was calculated as a measure of speed variation (Figure 6.3). One-way ANOVA or Kruskal-Wallis tests were carried out appropriately on the separate section. There were found to be significant differences for all road types, [$F(3,56)=11.82$; $p<0.01$], apart from the rural single carriageway, where speed was expected to be variable in all Groups due to the curvature of the road (as natural accelerations and decelerations occur).

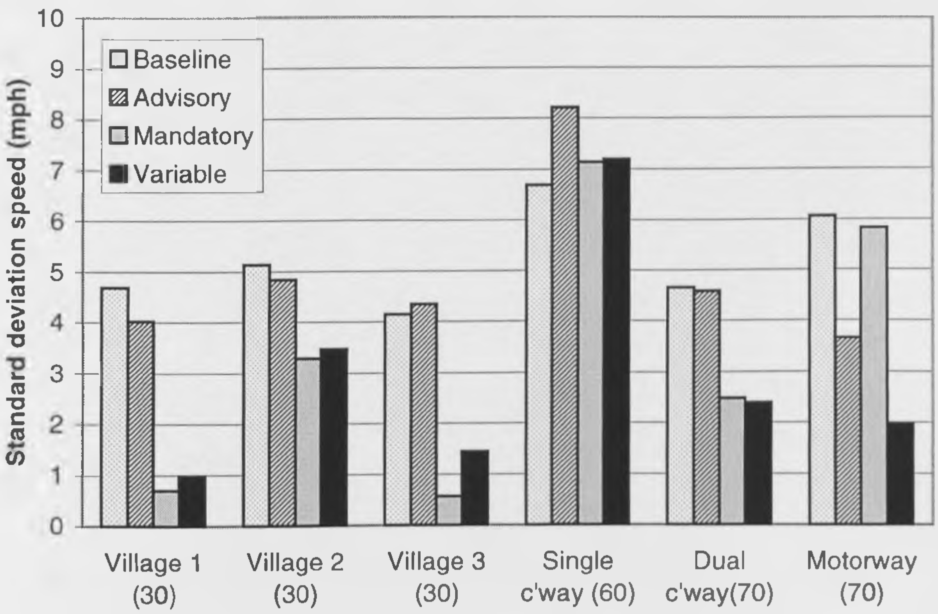

Figure 6.3: Standard deviation of speed through road sections

In the motorway section however, although speed variance was low with Variable ISA (due to the restriction to 50 mph), it can be seen that speed variance was virtually identical in the Mandatory and Baseline Groups. The Mandatory ISA performs significantly even more poorly in terms of speed variation than the Advisory system [$F(3,56)=12.76$; $p<0.01$]. This is likely due to driver's uncertainty of driving in the fog that was present on the motorway. Combined with average high speeds, it is possible that drivers were accelerating and decelerating more frequently.

6.3.2 Speed profiles

Whilst the results presented above provide a general overview of speed behaviour within the various road sections, data concerning behaviour in the vicinity of *changes* in the speed limit were also of interest. For example, how did drivers adapt their speed on encountering a lower speed limit? Such behaviour was studied by examining the data in the form of speed profiles, i.e. plotting mean speed (across participants) against distance for particular zones of interest. These profiles were evaluated by calculating the amount of time drivers spent above the speed limit (for the Baseline and Advisory Groups only). Where the pattern of deceleration was of interest (e.g. approaching a lower speed limit), calculations of the slope of the appropriate portion of the data were made.

6.3.2.1 Speed transitions

In Figure 6.4, the deceleration profiles on approach to the first village are shown for each of the Groups. At the change in speed limit, drivers who did not have ISA only reduced their speed by approximately 5 mph (as opposed to the appropriate reduction of approximately 20 mph).

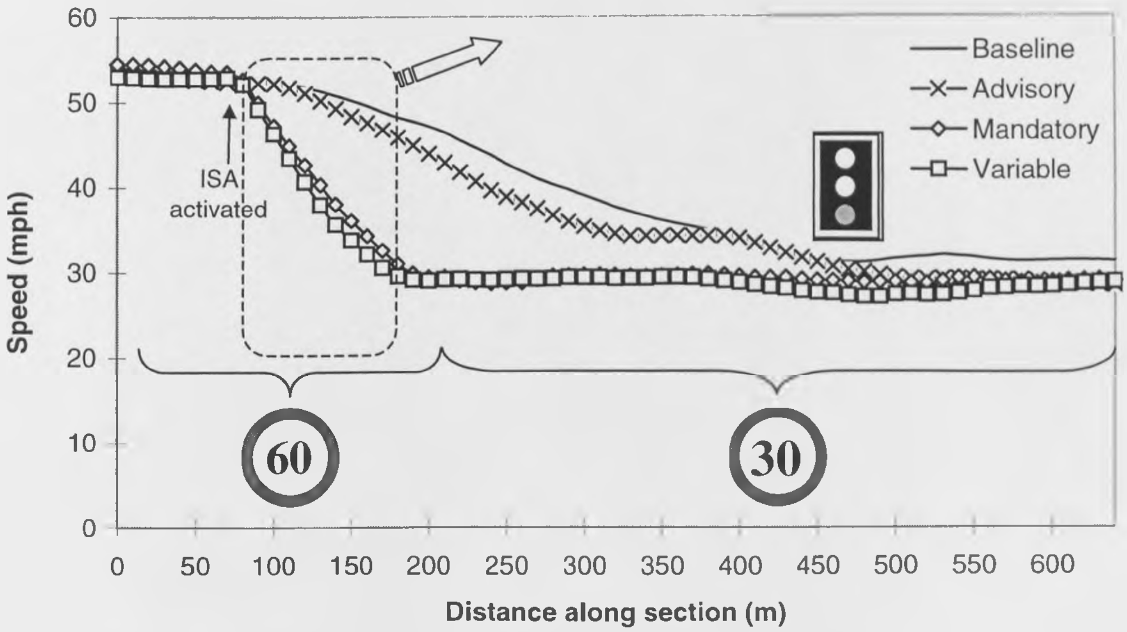

Figure 6.4: Speed profile through Village 1

Those with the Advisory ISA appear to have reduced their speed only slightly more than those in the Baseline Group, but this was probably due to the fact that changes in the Advisory speed were displayed at the point where drivers passed the speed limit sign on the road. This could be considered as a system design fault and, in future work, advance warning (e.g. using countdown signs) of the advisory speed should be provided.

The amount of time drivers spent above the speed limit (30mph) within the village boundaries was calculated (Table 6.2). Independent t-tests revealed that although the Advisory system did not reduce the amount of time drivers spent exceeding the speed limit, it did reduce excessive speeds [$t(28)=4.97$; $p<0.01$].

Table 6.2: Percentage of time drivers spent above the speed limit

	Baseline	Advisory	Reduction
Above speed limit	97	91	6 %
10% and over	92	37	60%
20% and over	54	16	70%
30% and over	22	8	64%

The deceleration slopes were calculated for the portion of the graph indicated by the dashed area (assuming a linear function). This data represents how well drivers performed at adjusting their speed in response to a lower speed limit (Table 6.3).

Table 6.3: Characteristics of deceleration slopes (entry to Village 1)

	Baseline	Advisory	Mandatory	Variable
Slope (*b*)	-0.04	-0.06	-0.22	-0.24
R^2	0.96	0.95	0.99	0.98

A one-way ANOVA performed on the slope data revealed differences between the Groups [$F(3,56)=12.50$; $p<0.01$]. Post-hoc comparisons (Tukey) revealed that the deceleration slopes for the Baseline and Advisory groups were similar. The Mandatory and Variable deceleration slopes were also similar to each other, but differed significantly from the other two Groups.

Table 6.3 shows that the deceleration profiles were smooth (i.e. described well using a linear function). System design produced smoother and sharper deceleration profiles for both the Mandatory and Variable ISA systems.

Figure 6.5 shows the speed profile for a village situated in the road network after a rural section (60 mph). It demonstrates the real-life speeding phenomena of 'speed adaptation' that can occur in rural villages. Drivers who have been driving at a high speed for an extended period may become habituated to this speed and overestimate the degree to which they are lowering their speed when they enter a lower speed limit area. At the 30 mph speed limit sign, drivers in the Baseline Group were still travelling approximately 10 mph above the speed limit. Interestingly, the Advisory system seems to have an effect on speed even though the change in speed limit is not displayed until they pass the speed limit sign. Speeds through the village in the Baseline Group never descend to the same level as in the other three Groups. Drivers in the Baseline and Advisory Groups also began anticipatory acceleration approximately 200m before village exit.

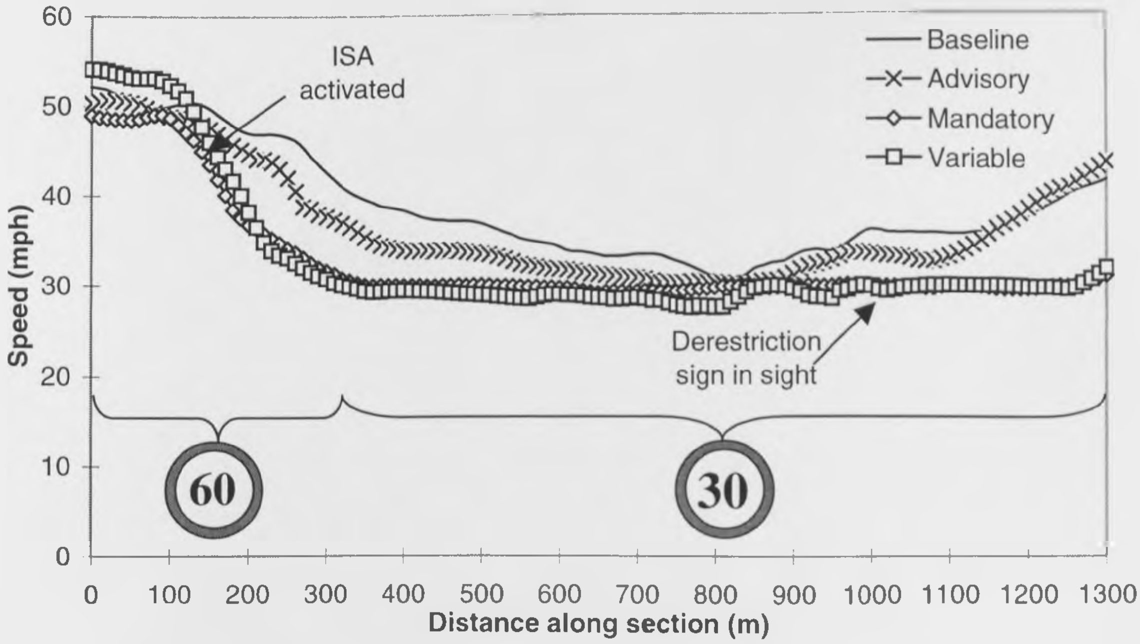

Figure 6.5: Speed profile through Village 3

A comparison was made of spot speeds at both ends of the village boundary. A one-way ANOVA revealed differences in spot speed at the village entry [$F(3,56)=7.89$; $p<0.01$]. As would be anticipated, post-hoc testing revealed that entry speeds were lower for the Mandatory and Variable groups compared the Baseline group. The spot speed for the Advisory group was found to be significantly different from all the other groups, suggesting that although drivers reduced their speed, it was still significantly higher than the posted speed limit.

A similar analysis was performed for village exit speeds. Again, a one-way ANOVA revealed differences in spot speed at the village exit [$F(3,56)=9.01$; $p<0.01$]. Post-hoc testing revealed that exit speeds were lower for the Mandatory and Variable groups compared the Baseline group. This time however, it appears the temptation to exceed the speed limit for drivers in the Advisory group was too strong. Their exit speeds were similar to those drivers in the Baseline Group.

The amount of time drivers spent above the speed limit (30mph) within the village boundaries was calculated (Table 6.4). Independent t-tests revealed that although the Advisory system did not reduce the amount of time drivers spent exceeding the speed limit, it did reduce excessive speeds [$t(28)=5.83$; $p<0.01$].

Table 6.4: Percentage of time drivers spent above the speed limit

	Baseline	Advisory	Reduction
Above speed limit	98	97	1 %
10% and over	89	73	18%
20% and over	79	32	61%
30% and over	23	12	48%

The deceleration slopes were calculated for the portion of the graph indicated by the dashed area (assuming a linear function). The results are shown in Table 6.5.

Table 6.5: Characteristics of deceleration slopes (entry to Village 3)

	Baseline	Advisory	Mandatory	Variable
Slope (*b*)	-0.29	-0.53	-0.95	-1.27
R^2	0.91	0.94	0.96	0.97

A one-way ANOVA performed on the slope data revealed differences between the Groups [F(3,56)=10.87; p<0.01]. Post-hoc comparisons (Tukey) revealed that the deceleration slopes for the Mandatory and Variable groups were similar. The slope for Advisory group was significantly different from all other groups. This confirms the results from the spot speeds in that drivers in the Advisory group reduced their speed to some extent, but not sufficiently to adhere to the posted speed limit.

6.3.2.2 Urban driving

Figure 6.6 shows the driver speed profiles through the second village in the road network. This was a relatively long village and only two sections of interest are shown. The first is a straight section of urban road that was located directly after drivers had been forced to follow a slow moving vehicle. The profile shows that drivers in the Baseline Group attained speeds of approximately 35mph, with those in the Advisory Group achieving slightly less.

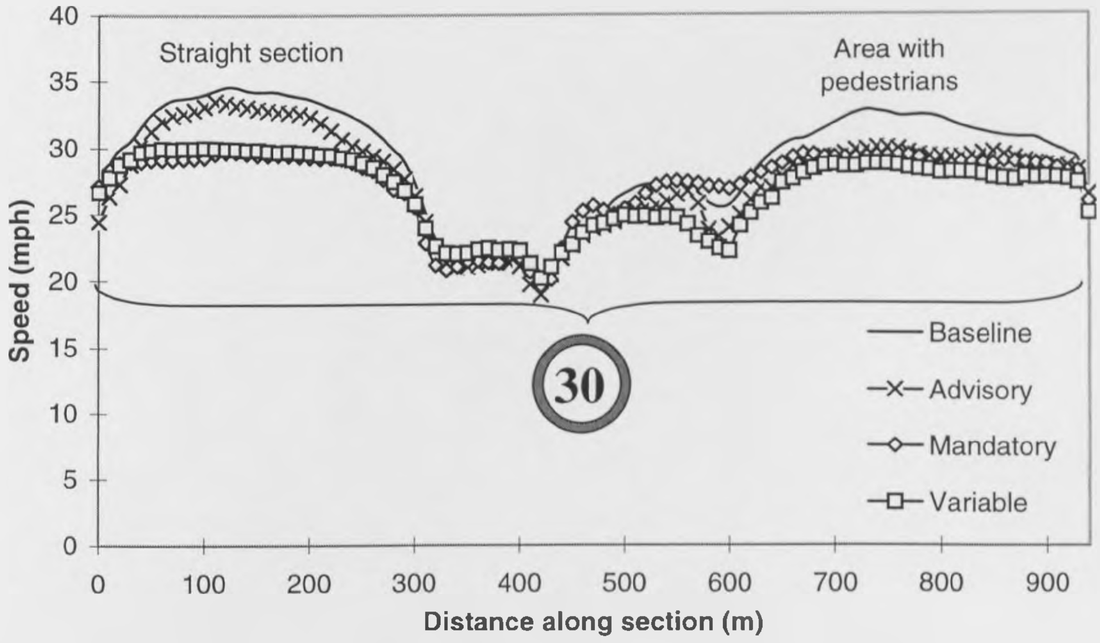

Figure 6.6: Speed profile through Village 2

The second section of the profile in Figure 6.6 depicts a location where pedestrians were present and parked cars effectively narrowed the available road width. It can be seen that drivers with ISA travelled at or slightly under the speed limit. Those in the Baseline Group travelled above the speed limit.

The percentage of time drivers spent travelling above the speed limit (30mph) was calculated in each of the Groups (Table 6.6). An independent t-test revealed that the Advisory system was successful in reducing speed violations [$t(28)=3.98$; $p<0.01$].

Table 6.6: Percentage of time drivers spent above the speed limit

	Baseline	Advisory	Reduction
Above speed limit	64	26	60%
10% and over	31	14	55%
20% and over	0	0	n/a
30% and over	0	0	n/a

Overall in urban areas, it seems that the ISA systems were effective in that they reduced driving speeds through built-up areas and it appears the Advisory system was sometimes effective in its role of reminding the driver of the appropriate speed at which to travel.

6.3.2.3 Motorway driving

Figure 6.7 shows the speed profile on the motorway section in foggy conditions.

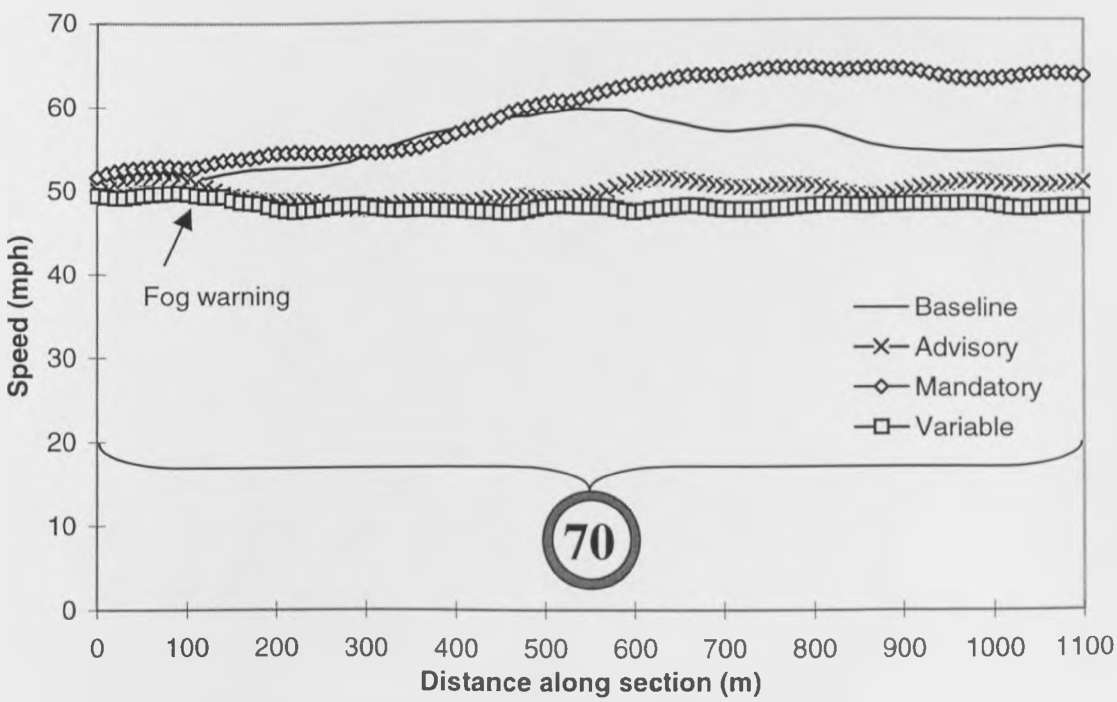

Figure 6.7: Speed profile on motorway section

This motorway section was placed at the end of the road network. The speed profiles show quite clearly that drivers with the Mandatory ISA exceeded speeds of even those in the Baseline Group.

The percentage of time drivers spent travelling above the advisory speed limit (50 mph) was calculated in each of the Groups (Table 6.7). A one-way ANOVA revealed some interesting results. There was a significant difference in the amount of time drivers spent above the advisory speed limit [$F(3,56)=6.92$; $p<0.01$]. Post-hoc tests revealed that the Advisory system was successful in reducing speed violations overall. For excessive speed violations (more than 10% or 20% above the speed limit), further one-way ANOVAS revealed that even drivers in the Baseline Group committed fewer violations than those in the Mandatory group [$F(3,56)=8.32$; $p<0.01$].

Table 6.7: Percentage of time drivers spent above the advisory speed limit

	Baseline	Advisory	Mandatory
Above speed limit	98	52	97
10% and over	32	9	72
20% and over	12	2	51
30% and over	0	0	6

There could be two possible explanations for such behaviour. Firstly, drivers with the Mandatory ISA system may have become reliant on the system to maintain a safe speed. Drivers appeared to be increasing speed towards the speed limit because the system allowed them to. Secondly, the difference in speed may be due to behavioural adaptational or habituation effects: drivers have been travelling at the speed limit for the last 25 minutes and see this location as an opportunity to make up for lost time or increase their sense of thrill.

6.3.3 Spot speeds

Spot speeds were taken at potentially hazardous locations on the road network. These locations were those where the Variable ISA system imposed a speed that was below the posted speed limit, or where the Advisory ISA displayed a reduced advisory speed. Of prime interest was whether the Advisory system would be as effective as the Variable system.

6.3.3.1 Traffic lights

Figure 6.4 shows there was a difference in speed passing the traffic lights. These traffic lights were included to evaluate driver behaviour on their approach to them. It was hypothesised that drivers using ISA would maintain their maximum speed at locations where drivers without ISA would naturally decelerate. Traffic lights are an example of a situation where some deceleration might occur in anticipation of them turning to red. Indeed it can be seen from Figure 6.4 that some deceleration does occur in the Advisory and Baseline Groups before the traffic lights. However, it also appears that drivers with ISA also engaged in a slight amount of deceleration. A spot speed was taken at the traffic lights to discover any differences in speeds between the Groups, (Table 6.8).

Table 6.8: Spot speed at traffic lights (mph)

Baseline	Advisory	Mandatory	Variable
31.75	29.32	29.09	27.55

Nonparametric Kruskal-Wallis tests revealed there to be a difference between the Groups [$\chi^2(df=3)=11.16$, $p<0.01$]. Post-hoc Games-Howell tests revealed the speed passing traffic lights was higher in the Baseline Group than in any of the other Groups. This is simply a reflection of the higher average speed in this section in the Baseline Group.

6.3.3.2 Curves

Entry speed to a sub-standard rural curve was recorded; here the Variable ISA system automatically reduced driver speed to the recommended curve negotiation speed of 25 mph. For drivers with the Advisory system, a message saying "Sharp bends, slow down to 25 mph" was shown on the in-car display. The mean curve entry speeds are shown in Table 6.9. A significant difference was found between the Groups [$F(3,56)=9.01$; $p<0.01$]. However post-hoc testing revealed that this difference existed only between the Baseline and Variable systems. Although the Advisory system appears to have reduced speeds to some extent, this difference did not reach statistical significance.

Table 6.9: Curve entry speeds (mph)

Baseline	Advisory	Mandatory	Variable
24.93	21.86	23.81	20.48

Figure 6.8 shows the speed profiles of drivers as they approach this rural curve. Drivers appear overall to be taking note of the advisory speed, although their deceleration profile is less steep than in the Variable Group. This seems to matter little however, as curve entry speed is similar in these two Groups. Drivers in the Mandatory ISA and Baseline Groups begin their deceleration towards the curve much later.

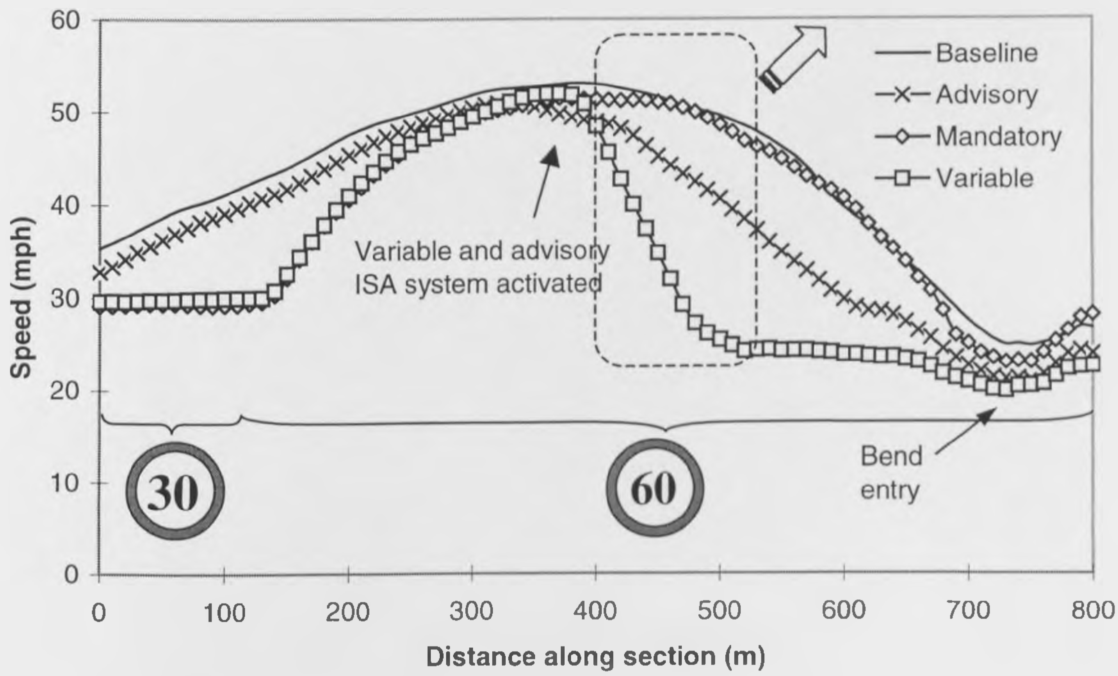

Figure 6.8: Speed profile on approach to rural curve

The deceleration slopes were calculated for the portion of the graph indicated by the dashed area (assuming a linear function). The results are shown in Table 6.10. A one-way ANOVA performed on the slope data revealed differences between the Groups [$F(3,56)=7.43$; $p<0.01$]. Post-hoc comparisons (Tukey) revealed that the deceleration slopes for the Baseline and Mandatory groups were similar. The Advisory Group's deceleration slope differed significantly from the other three Groups.

Table 6.10: Characteristics of deceleration slopes (entry to rural curve)

	Baseline	Advisory	Mandatory	Variable
Slope (*b*)	-0.57	-1.41	-0.50	-3.52
R^2	0.98	0.98	0.80	0.96

This suggests that the Advisory system worked to some extent by inducing lower speeds, but that drivers were still inclined to travel at a speed they thought was appropriate.

6.3.3.3 Reduced visibility

Mean speed along the stretch of motorway where conditions were foggy was calculated (Table 6.11).

Table 6.11: Mean speeds in fog (mph)

Baseline	Advisory	Mandatory	Variable
57.28	49.84	61.09	47.71

It was expected that the Variable Group would produce lower speeds, due to system activation. A one-way ANOVA revealed there to be a significant difference in mean driving speed between the Groups [$F(3,56)=12.87$; $p<0.01$]. Post-hoc tests showed that the Advisory system was as effective as the Variable Group in reducing speeds compared to the Mandatory ISA and Baseline Groups.

6.3.4 Traffic light violation

A situation was created whereby drivers were required to make a rapid stop/go decision at one set of traffic lights that turned from green to amber as they approached. The number of violations in each Group is shown in Table 6.12.

Table 6.12: Incidence of red light violations

	Baseline	Advisory	Mandatory	Variable
No. of violations	5	7	8	6
No. of non-violations	10	8	7	9

A chi-square test for independence revealed there was no statistically significant difference between the Groups.

6.3.5 Following behaviour

The road network allowed the inclusion of four car-following tasks, each approximately 1 mile in length. In two of these tasks, the driver was unable to overtake the car in front due to oncoming traffic. This created a "boxed-in" situation that allowed the measurement of drivers' following behaviour, which was translated into a time-headway distribution. The lead cars in these scenarios were travelling at a speed that was constant and below the speed limit. In the urban situation the lead car was travelling at 25 mph and in the rural area at 40 mph. Therefore, even with Mandatory ISA it was possible for drivers to adopt short headways if they wished to. The safety critical value of <1 second headway was calculated for the car following tasks. There was found to be an increase in the amount of time drivers adopted this headway in the ISA Groups, particularly in the urban scenario (Figure 6.9).

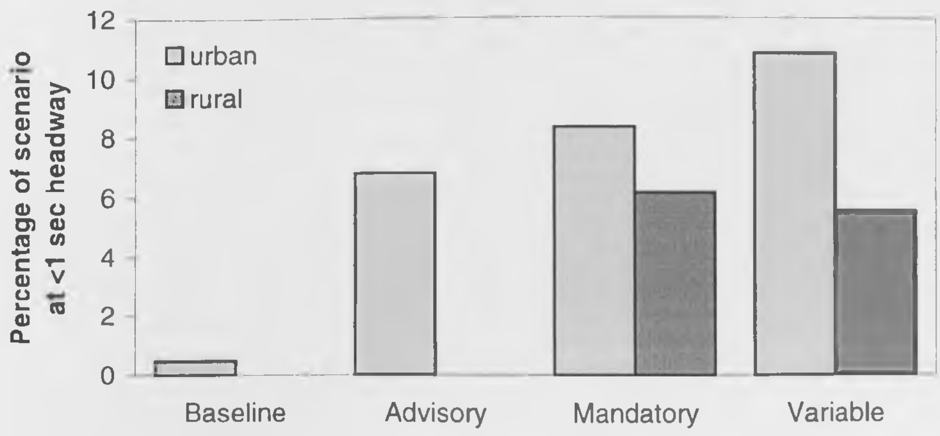

Figure 6.9: Percentage of scenario spent at <1 second headway

In order to test the differences, one-way ANOVA were carried out on both the rural and urban data. They revealed there to be a significant difference in the percentage of time spent at less than one second headway between Groups for both scenarios [$F(3,56)=7.89$; $p<0.05$]. Post-hoc (Tukey) tests showed that in the urban areas, drivers with all types of ISA drove closer than compared to the Baseline Group (but there were no differences between the ISA systems). In the rural areas, the advisory system had no impact, but both the Mandatory and Variable systems did.

These results suggest that drivers with ISA were more inclined to follow closer to the car in front. This could be either due to driver's misinterpretation of the system and believing that the system would maintain a safe distance for them (i.e. confusing ISA with ACC functionality), or due to drivers attempting to make up for perceived lost time.

The remaining two car-following events allowed drivers to overtake the lead car (which were travelling at the same speed as in the "boxed-in" events). The numbers of attempted and successful overtaking manoeuvres were recorded and are shown in Table 6.13.

Table 6.13: Total number of overtakings

	Baseline	Advisory	Mandatory	Variable
Attempted	2	1	1	0
Successful	2	1	1	0

Whilst the data is not sufficient for statistical testing, the table shows that few overtakings took place, regardless of Group.

6.3.6 Collision measures

In order to evaluate how drivers reacted in a critical situation, a potential collision scenario was created at the end of the road network. A line of stationary traffic, concealed in thick fog, was placed across all three lanes of the motorway. This scenario was placed at the end of the road network firstly for practical reasons, i.e. not wanting to affect subsequent behaviour, but more importantly to discover if driver vigilance, after approximately 25 minutes of driving under ISA, was reduced. A collision was defined as the simulator car making contact with the rear of the stationary cars (Table 6.14).

It can be seen that the incidence of collisions was generally low. This was probably due to the fact that, on detection of the thick fog, drivers naturally reduced their speed, thus permitting them to brake in good time and avoid the collision. However it can be seen from Table 6.14 that when collisions did occur, it was more often in the Mandatory ISA Group.

Table 6.14: Total number of collisions

Baseline	Advisory	Mandatory	Variable
1	0	3	0

A possible reason for the increased incidence of collisions with the Mandatory ISA was the high mean speeds in this Group on the motorway section (this can be seen quite clearly in Figure 6.7). Thus differences in driver speed in each Group may have led to the variation in the number of collisions between the Groups. To examine this possibility, spot speeds at 150 metres before the stationary cars (i.e. before any deceleration had occurred) were compared between the Groups (Table 6.15).

Table 6.15: Mean speed at 150m before critical event (mph)

Baseline	Advisory	Mandatory	Variable
56.69	51.06	61.05	47.42

A main effect of Group was found [$F(3,56)=3.29$; $p<0.01$]. Post-hoc tests (Tukey) revealed that there were significant differences in driving speed between the Baseline and Variable Groups (where drivers were limited to the advisory speed anyway) and between the Mandatory and Variable Groups ($p<0.01$). There was no difference observed between the Mandatory and Baseline Groups. Thus, even though speed is an important factor in the likelihood of collisions, the (small) increase in number of crashes in the Mandatory Group was possibly due to some other factor. For example, collisions may have been more likely to arise in the Mandatory Group due to the nature of drivers' braking patterns. A spot value of time-headway at maximum brake pressure was calculated and the values are shown in Table 6.16.

A main effect of Group was found [$F(3,56)=3.15$; $p<0.05$]. Post-hoc tests (Tukey) revealed that drivers with the Mandatory ISA applied their maximum braking later than in other Groups ($p<0.05$).

Table 6.16: Mean time headway at maximum brake pressure (seconds)

Baseline	Advisory	Mandatory	Variable
2.93	2.82	1.83	3.29

This might account for the increased number of collisions with this system and could be a result of automation-induced complacency.

6.3.7 Journey time

Drivers have been found to report that a negative benefit of ISA is that it would affect their travel times significantly (Comte, Wardman and Whelan, 2000). In order to test this, the time taken to complete the simulator trial was recorded (Table 6.17).

Table 6.17: Mean travel time (minutes)

Baseline	Advisory	Mandatory	Variable
24.17	24.44	23.64	25.01

A one-way ANOVA revealed there to be no difference in travel times between the Groups. Drivers therefore only *perceive* there to be a loss of time, where in fact due to lower speed variance journey times remain unaffected. This is the premise of the Variable Speed Limit trials on the M25 that rely on enforcement to maintain lower and less variable speeds. Travel time results will be an important area for further research if implementation of ISA goes ahead: the driving population will need to be provided with information on the effect of ISA on travel times if public acceptability is to be high.

6.3.8 Mental workload

Drivers' mental workload was assessed subjectively using the NASA-RTLX. Subjective workload scores were obtained for each Group in terms of mental demand, physical demand, time pressure, performance, effort and frustration level. One-way

ANOVAs performed on the individual factors revealed no significant differences in mental workload between the Groups.

6.3.9 Acceptability

Acceptability scores were taken before and after participants encountered the ISA systems (the appropriate ISA system was described to them in written instructions beforehand). This served to indicate any preconceptions drivers might have about the systems under investigation and more importantly demonstrate whether actual use of the system affected driver acceptability. The acceptability scores (ranging from –2 to +2) were coded and checked for reliability as in the methodology described by Van der Laan et al. (1997). Reliability was established (Cronbach's alpha = 0.9) and a total score for each participant on the two dimensions of "usefulness" and "satisfying" was calculated for each system. An overall system score was then obtained across participants (Figures 6.10 and 6.11).

Related t-tests were performed on the pre- and post-test usefulness and satisfying scores. The results indicate that, for the Advisory Group, drivers' scores decreased after use in terms of "usefulness" [$t(13)=2.87$; $p<0.05$]. Scores did not change after exposure for either the Mandatory or Variable groups. A one-way ANOVA revealed that overall, the Advisory system was thought of as more useful than the other two systems [$F(2,42)=5.46$; $p<0.05$].

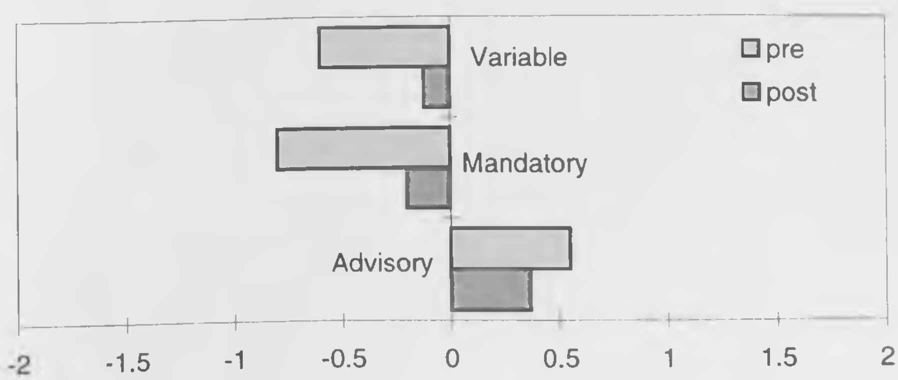

Figure 6.10: Acceptability ratings on the dimension of "useful"

Related t-tests performed on the "satisfying" scores, revealed that scores became more positive after exposure for both the Mandatory [$t(13)=3.17$; $p<0.05$] and the Variable groups [$t(13)=2.22$; $p<0.05$]. This suggests that drivers had pre-expectations about the ISA systems in terms of how satisfying they would be. Overall, a one-way ANOVA revealed that drivers found the Advisory system more pleasant to use than the other two systems [$F(2,42)=4.92$; $p<0.05$].

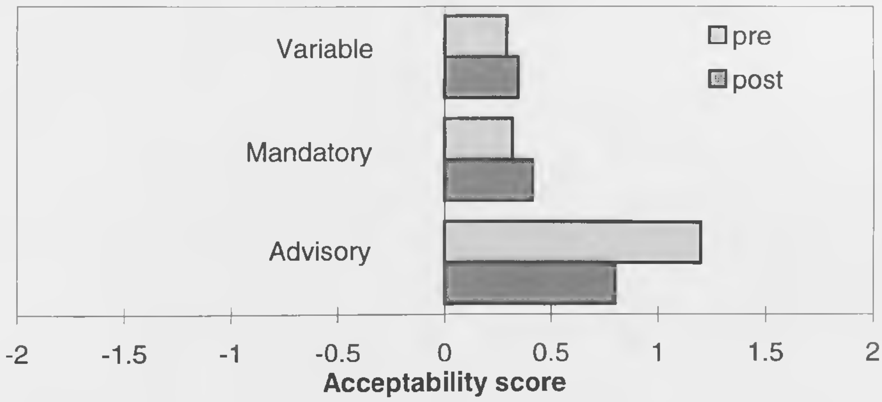

Figure 6.11: Acceptability ratings on the dimension of "satisfying"

As part of the acceptability exercise, several questions concerning overall safety and traffic violations were also posed to respondents (Figures 6.12-6.14). These questions reveal that drivers generally believe that ISA systems would encourage drivers to drive more safely and commit fewer offences, but they are adverse to actually owning one.

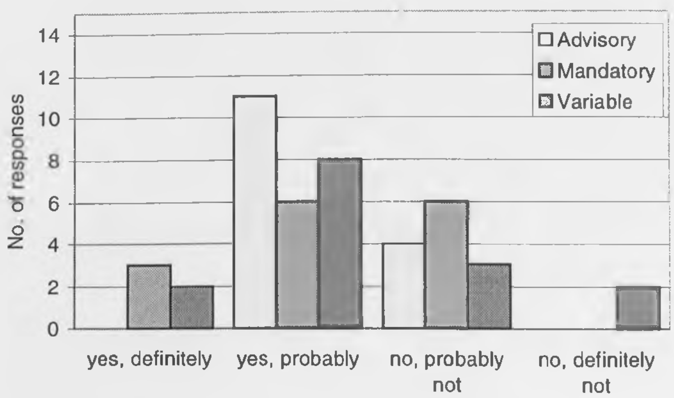

Figure 6.12: In your opinion, would this system make people drive more safely?

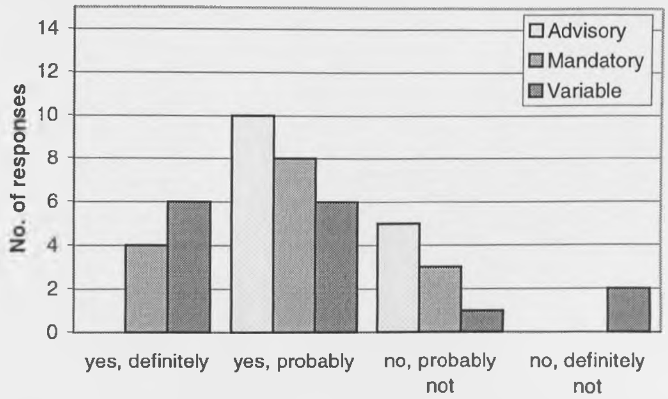

Figure 6.13: In your opinion, would this system make people commit fewer offences?

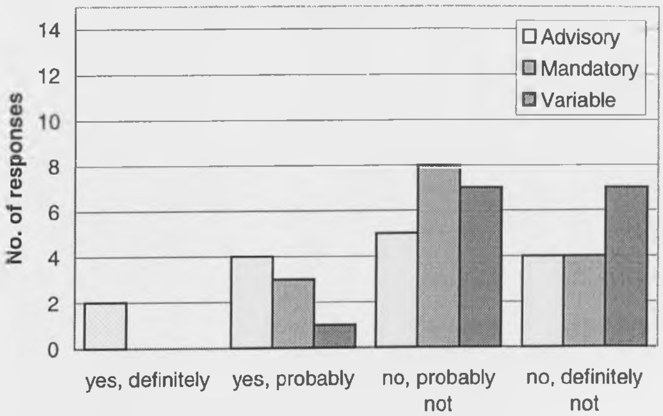

Figure 6.14: Would you have this system installed in your own car on a voluntary basis if it cost in the region of £50?

6.4 Discussion

This simulator study evaluated ISA in terms of driver behaviour parameters, workload and acceptability. Three types of ISA system were tested against a Baseline Group. The systems selected to study included one that only advised of the speed limit (Advisory), one that only controlled the maximum speed of the vehicle (Mandatory) and a final one which provided both information and control (Variable).

As hypothesised, the two ISA systems with an element of control successfully reduced excessive speed, particularly in urban areas. Speed profiles showed that without ISA, drivers were susceptible to poor speed adaptation when travelling from a high to low speed limit area. Drivers in both the Baseline and Advisory Groups did not decelerate to the speed limit of the villages (30 mph) as they approached the new speed limit, although the Advisory system did encourage drivers to reduce their speed further than in the Baseline Group. This speed adaptation phenomenon is known to be a particular problem in the real world where drivers are reluctant to reduce their speed in rural villages. In recent years this problem has been tackled using a variety of 'village gateway schemes'. Although these can be successful in the short run, the long-terms effects are less convincing. The Advisory system appears to be partly successful in reducing speed, although this effect could be enhanced by providing information about changes in speed limit earlier. This would provide drivers with the opportunity of decelerating before reaching the lower speed limit.

Mandatory ISA also demonstrated other benefits in urban areas such as maintaining lower speeds on curve negotiation and in areas where there were vulnerable road users. Speed variance was also reduced under Mandatory ISA, suggesting that widespread implementation could have the effect of smoothing traffic flow by reducing extreme speed values.

It was particularly encouraging to find that the Advisory system worked almost as effectively as the Variable ISA system in potentially hazardous situations such as sub-standard curvature and poor visibility conditions. Such benefits may be important considering the proportion of accidents that occur in such conditions.

However, there were also some negative effects of the ISA systems. Firstly, in the case of car following, it was found that those driving with Mandatory or Variable ISA spent more time at critically short headways. This may have been due to driver impatience manifested in drivers keeping their foot on the accelerator to maintain maximum speed. Such driving behaviour may result in a higher incidence of rear-end collisions, especially if drivers experience a degree of complacency whilst using ISA.

The incidence of collisions at the end of the road network was found to be higher in the Mandatory ISA Group, independent of speed. This may reflect some degree of loss of situational awareness, such that drivers using the Mandatory ISA were taken "out-of-loop" and faced with a critical situation found it consequently more difficult to react in time. This is supported by the relatively late braking that was observed in the Mandatory Group. However, the number of collisions that actually occurred was small, and these conclusions are therefore tentative. This effect could also be due to drivers' misinterpretation of the system, i.e. perhaps they relied on ISA to be "intelligent" in all situations.

The acceptability exercise demonstrated driver's dislike for a system that controls their speed. As predicted, drivers were more inclined to find a system that did not exert control more acceptable, i.e. the Advisory system. There was some effect of exposure on acceptability scores, indicating this is an interesting area for further research.

In summary, this study was designed to directly compare driver behaviour under a number of ISA implementations across a variety of road types. A number of points arose:

- ISA was an effective solution to the speed adaptation problem often encountered in rural villages,
- Urban areas may also benefit from the "calmed" behaviour demonstrated by drivers with ISA,
- Drivers may misinterpret the characteristics of an ISA system and relinquish some responsibility to it,
- An advisory system offers some benefits of speed reduction in hazardous areas,
- The benefits of ISA should be considered in the light of potential safety costs such as reduced following distances and possible complacency and loss of vigilance.

Overall, these results point to a dilemma. On the one hand ISA can obviously provide safety benefits with its ability to ensure drivers are limited to a maximum posted (or advisory) speed. On the other hand, these benefits will only ensue if the system is fully implemented (i.e. not just in parts of the network) and easily updated (in terms of dynamic weather and road conditions). Such a system implies a substantial initial cost outlay. Further work also needs to be carried out in the light of the findings on situation awareness. Whilst the findings from this study provide insight into behaviour over a variety of road types, they may constitute novelty effects.

The next two chapters detail two studies, one on the driving simulator and one on-road. These studies required drivers to use an ISA system over a number of sessions allowing the investigation of more long-term behavioural adaptation issues. Additionally, a new variant of ISA was studied; the studies reported so far have provided drivers with either an Advisory system or a Mandatory one. These represent the two extremes of control: how will drivers respond to a system that lies somewhere in between the extremes? The next two studies, therefore, incorporated into the experimental design an ISA system that was capable of providing control, but was voluntary in that drivers were able to engage and disengage it as they wished. It was of interest to discover if this voluntary system was more acceptable to drivers than a Mandatory one and examine the likelihood that drivers actually chose to use it in a variety of driving conditions.

Chapter Seven

Extended exposure to ISA – simulator study

7.1 Study aims

The aim of this study was to evaluate three ISA systems in a simulated environment. This study builds on the results presented in the previous chapter by allowing drivers to interact with the systems for a longer period of time. This was achieved by extended exposure to an ISA system over a number of experimental sessions. Similar behavioural parameters were recorded to achieve communality, but it was of interest as to whether any of the behavioural adaptation that was noted previously, was manifested any differently over a longer period of time. For example, it is possible that novelty effects might exist whereby some behaviours cease to occur after a period of time. On the other hand, it might be that only after increased exposure that other behaviours occur.

To expand on the studies already reported and to investigate further the likely impacts ISA could have on driver behaviour, a new ISA system was developed and included in the experimental design. In the previous studies, the Mandatory system allowed no exceedence of the posted speed limit and the Advisory system simply increased drivers' awareness of the posted speed limit. In this study, an ISA system was developed that integrated the Mandatory and Advisory systems by allowing drivers to choose when they engaged the ISA system. This system, referred to as the Driver Select ISA system, was thus a voluntary system that allowed the investigation of drivers' propensity to engage and disengage it.

It was hypothesised that different drivers would use the Driver Select system at varying rates. This study therefore aimed to study *individual differences* in terms of system use. As mentioned in Chapter Three, Evans (1986) demonstrated that the probability that a driver was wearing a seat belt at the time of the crash declined as crash severity increased. In other words, drivers who would benefit most are those least likely to wear a seat-belt.

In order to investigate individual differences, drivers completed the Driving Style Questionnaire (DSQ). This questionnaire, developed by West, et al. (1992), characterises drivers in terms of a number of safe and unsafe behaviours. The DSQ scores were correlated with drivers' propensity to engage the Driver Select ISA system and their acceptability scores.

This driving simulator experiment thus studied how drivers adapted to an ISA system in terms of safety-critical behaviour and investigated if and how behaviour changed over time. In addition, issues of workload and vigilance were examined as well as drivers' preferences in terms of system functionality.

7.2 Method

7.2.1 Systems studied

Three ISA systems were evaluated against a baseline condition. All the systems operated around the same mechanism, i.e. prevention of speed above the posted speed limit. However each of the systems varied slightly in its implementation, and represented an increasing level of physical control over the driver.

1. *Driver Select ISA system* – as the name suggests, drivers selected whether or not to use the ISA system. At each speed limit change, the driver was alerted by a visual display and an auditory prompt. The visual display relayed the posted speed limit to the driver and the auditory prompt indicated that a response was necessary. At this stage the driver had three choices:

a) Firstly, if the driver wished to engage the system and thereby be limited to the maximum speed as shown on the display, they could press a green button on the steering wheel. If, at the time, the driver was travelling from a higher speed limit to a lower one, the system automatically reduced the speed of the simulator in readiness for the lower speed limit. Thus the driver was travelling at the speed limit as they passed the speed limit sign (as is required by traffic law). When the driver travelled from a low speed limit to a higher one, then the system allowed acceleration after the new speed limit was in operation.

b) Secondly, if the driver chose not to engage the system and thus travel at their desired speed, they could press a red button on the steering wheel. If the driver pressed the red button, the system went into stand-by mode and no control was exerted over the vehicle. Information about the speed limit remained on the display.

c) Thirdly, the driver could choose to ignore the auditory prompt. If the driver ignored the prompt, they were alerted by a second auditory signal. If the driver ignored this, after 4 seconds, the system reverted to standby mode, whereby no control was exerted.

The Driver Select system could be engaged and disengaged at any point on the experimental drive (not just at the speed limit changes) by using the green and red buttons.

2. *Mandatory ISA system* – this system automatically limited the simulator to the posted speed limit. It operated in exactly the same way as in the previous study (Section 6.2.1).

3. *Variable ISA system* – this system operated in the same way as the Mandatory system but lowered the speed further on sharp curves and pedestrian crossings. Drivers were informed of the reason for this additional reduction of speed, in advance, via the in-car display.

7.2.2 System interface

An LCD was mounted on the dashboard to the left of the steering wheel (Figure 7.1). In Figure 7.1(a) the display is telling the driver that the speed limit of the road is 30 mph. In addition, the display shows the ISA system is engaged. In Figure 7.1(b) the ISA has been disengaged.

(a) ISA engaged

(b) ISA disengaged

Figure 7.1: ISA interface

7.2.3 Experimental Design

The experimental design allowed the evaluation of the effects of three types of ISA system on driver behaviour over a number of experimental sessions. Each participant completed four drives using the same route (Table 7.1). The system remained disengaged in the first drive for all participants, thus supplying baseline data on their normal driving behaviour[1]. Drivers in the *Driver Select, Mandatory* and *Variable* groups then drove with the appropriate system engaged on their second, third and fourth drive. The *Baseline* group continued to drive with the system off.

Table 7.1: Experimental design

Group	*Drive 1*	*Drive 2*	*Drive 3*	*Drive 4*	n
Baseline	Baseline	Baseline	Baseline	Baseline	10
Driver Select	Baseline	Driver Select	Driver Select	Driver Select	10
Mandatory	Baseline	Mandatory	Mandatory	Mandatory	10
Variable	Baseline	Variable	Variable	Variable	10

This design enabled drivers to be exposed to the system more than once, thus allowing the opportunity of insight into novelty or long-term effects of the system. This design also provided a group of drivers who never encountered an ISA system, yet also completed the drive four times. This provided a reference to examine possible learning effects.

7.2.4 Planned comparisons

A number of (within subjects) comparisons were undertaken for each of the four groups (Table 7.2).

Table 7.2: Statistical comparisons

Comparison	*Drive 1*	*Drive 2*	*Drive 3*	*Drive 4*
System				
Exposure				
– short term				
– medium term				
– long term				

These comparisons were carried out to discover firstly if there was an effect of ISA and secondly whether that effect was stable over time. These comparisons are described in more detail below.

7.2.4.1 System effect

The first comparison (System) used an orthogonal contrast (Helmert) to test the combined effect of Drives 2-4 against Drive 1. A significant difference would indicate that, overall, there was an effect of the ISA system. The analysis was carried out for the Driver Select, Mandatory and Variable Groups. The Baseline Group was excluded from this analysis due to the absence of system use.

7.2.4.2 Stability of behaviour

A second comparison (Exposure) was undertaken to test whether there was an effect of increased exposure to a system. A one-way was ANOVA performed on Drives 2-4. Pairwise comparisons (using the Bonferroni correction) were carried out to test where these differences lay.

The pairwise comparisons (Short-term, Medium-term and Long-term) tested for the presence of novelty effects, or whether changes in behaviour were only exhibited after repeated exposure. For example, if it was found that performance on Drive 2 differed to that on Drive 1, but that differences did not exist between Drive 3 and Drive

[1] Throughout the rest of this chapter, Baseline data will be shown as shaded in tables.

1, then it could be argued that a novelty effect occurred in Drive 2 (instability of behaviour). On the other hand if statistically significant differences (in the correct direction) were found in all three comparisons, then behaviour could be considered stable. Interaction effects between System and Exposure were also studied to discover possible differences in the effect of exposure, depending on the system in use.

This data analysis procedure was repeated for all four groups of participants (Baseline, Driver Select, Mandatory and Variable). These analyses were performed on the variables of mean, maximum and standard deviation speed in a variety of road environments.

7.2.5 Participants

A total of 40 participants took part in this study. The participants for the study were drawn from an existing database and the sample was balanced for age and gender. All participants possessed a full, clean driving licence. Participants were matched for average annual mileage between the four conditions. The sample included 20 males between the ages of 19 and 57 [Mean= 29 years] with a reported annual mileage of between 5,000 and 24,000 miles [Mean= 10,500]. In addition, 20 females took part between the ages of 19 and 52 [Mean= 31 years] with a reported annual mileage of between 4,000 and 20,500 [Mean= 7,000]. Participants who suffered simulator sickness during the trial were excluded from the analyses. Drivers were paid for their participation; this payment increased after each session to provide an incentive for their return.

7.2.6 Simulated road network

A new route was designed for this study to include additional scenarios of interest. The route was approximately 22 miles in length and comprised of urban, rural and motorway environments, providing a full range of speed limits between 30 and 70 mph. The presence of other cars in the scene provided the opportunity of simulating overtaking scenarios, gap acceptance tasks and car-following situations. The road environment also featured traffic lights and pedestrian crossings. Sub-standard curves were included in both the urban and rural sections.

The route was designed to include features that could not be studied in the on-road trials (detailed in Chapter Eight). For example, the rural section featured several sub-standard curves and some straight sections where overtaking was possible. This section was included to evaluate the possible negative effect of ISA on speed choice and overtaking. This adaptation could potentially be the result of increased driver frustration due to the speed-limiting effects of ISA. The other vehicles simulated on the route travelled at or below the speed limit in order to orchestrate certain scenarios such as car-following and overtaking opportunities. Table 7.3 shows the different road sections included in the simulated network.

Table 7.3: Description of road sections on the simulated route

Road type (speed limit)	Events/Features	Variables
Rural (60)	Free flowing situation with curvature	Speed
Urban (40)	One set of traffic lights (on green)	Speed at village entry
Urban (30)	Car following task, cannot overtake. Violation traffic lights #1 Curve, Variable ISA active/inactive	Minimum TH Violation Speed at curve entry
Urban (40)	Violation traffic lights #2	Violation
Urban (30)	Car following task, overtaking possible	Minimum TH,overtaking
Urban (40)	Left turn merge into traffic Violation traffic lights #3	Gap and min ttc Violation
Rural (50)	Sharp curve, Variable ISA active	Speed at curve entry
Dual-c'way (60)	Car following task, cannot overtake. Car following task, double white lines	Minimum TH Violation
Rural (50)	Sharp curve, Variable ISA disengaged	Speed at curve entry
Urban (40)	Violation traffic lights #4 Right turn merge across traffic Pedestrian crossing, Variable ISA active	Violation Gap and min ttc Spot speed
Rural (60)	Car following task, overtaking possible	Minimum TH,overtaking
Motorway (70)	Car following task, no overtaking	Minimum TH
Urban (40)	Pedestrian crossing, Variable ISA disengaged Pedestrian crossing – (final drive only)	Spot speed Collision

7.2.7 Data collection

Driver performance and safety were evaluated using a variety of parameters described below.

7.2.7.1 Speed

Spot speed was recorded every 10 metres throughout the whole journey. This provided a comparable number of data points for each participant.

7.2.7.2 Car-following

Three car-following situations were engineered requiring drivers to maintain their desired headway over a section of road. Drivers were unable to pass the slow-moving car in front due to oncoming traffic.

7.2.7.3 Gap acceptance

Two gap-acceptance tasks were incorporated into the road network, similar to those reported in Chapter Four. The first required the driver to merge from the minor road onto the major road, making a left turn. Traffic on the major road was approaching from the right with increasing gaps. The second gap-acceptance task required the driver to make a right turn across oncoming traffic from a major to a minor road. Again the cars were separated with increasing gaps.

7.2.7.4 Overtaking

Two overtaking scenarios were created; oncoming traffic was present, but it had sufficient gaps to allow the driver to pass. Propensity to overtake and proximity to the oncoming car were measured.

7.2.7.5 Traffic violations

Two types of possible violation scenarios were presented to the drivers. In the first, an overtaking scenario was created, again using a slow-moving vehicle in front. Here, drivers were constrained by double white lines; if they chose to overtake, a violation was recorded. In addition, four sets of traffic lights were placed in the road network. One was programmed to change from green to red as the driver approached. This required the driver to make a stop/go decision; a violation was recorded if they passed on the red light.

7.2.7.6 System use

For the Driver Select group, in order to examine system use, the proportion of time that drivers spent with the system on was calculated. In addition, drivers' propensity to turn the system off in order to overtake was observed. This was achieved by examining whether system state changed from on to off during the overtaking scenario.

7.2.7.7 Variable system

The Variable system was active in three specific locations: two sharp curves (one urban and the other rural) and at a pedestrian crossing. After each of these scenarios, an identical one was included where the Variable system was disengaged. This allowed for the testing of any adaptational or learning effects, i.e. did the additional slowing of the driver creating a tendency for them either to travel faster (to make up for lost time) or slower (as a result of a calming effect) at a subsequent similar location. These scenarios were also included to reflect the situation of a gradual roll-out of the system, where only some locations would be treated.

7.2.7.8 Vigilance

The study reported in the previous chapter indicated there might be some effects of ISA in terms of reduced vigilance. Such effects could arise as a result of decreases in vigilance associated with increased automation. This issue was investigated further in this study. Vigilance was measured in terms of performance on a choice reaction task incorporated into the road network. Drivers were required to respond to red and green squares that appeared within the visual scene. If the square was green, they were asked to ignore it and continue driving. If the square was red, they were asked to continue driving and to flash the headlights once. Throughout the whole drive there appeared three red and three green squares in a random sequence. In subsequent drives, the positioning of the squares was changed, in order to prevent associative learning effects. Drivers' responses to the stimuli were recorded in terms of reaction time, false/correct hits and missing responses.

7.2.7.9 Workload

As a measure of global subjective mental workload, the NASA TLX was administered. This required subjects to rate the completed task in terms of mental demand, physical demand, time pressure, performance, effort and frustration level. The individual scales were then averaged to give a total workload score.

7.2.7.10 Acceptability

Prior to drivers experiencing ISA, an acceptability questionnaire (Van der Laan et al., 1997) was administered. This was designed to measure drivers' general attitudes towards ISA. This questionnaire was also administered after subsequent drives, thus providing an indication of if and how acceptability changed after experience with ISA. There were indications in the previous reported study that exposure could affect acceptability. In addition, a more detailed system evaluation form was given to participants after the final drive, consisting of both open and closed questions. This allowed drivers to comment on various aspects of ISA, including their perception of its likely contribution to road safety and their personal likes and dislikes about the system.

7.2.7.11 Driving style

Participants completed the Driving Style Questionnaire before the experiment commenced. The DSQ contains 15 items based on behaviours that are associated with risky driving behaviour (Appendix C). The items relate to speed, traffic signal violation, headway, seatbelt use and gap acceptance. Self-reported speed as measured by the DSQ has been shown to correlate well with observed driving speed on a test route comprising motorway, rural and urban roads (West et al., 1992). The DSQ has been found to load onto six components namely: speed, calmness, social resistance, focus, planning and deviance. The scores relating to the three items concerning speed were totalled. These items were:

- Do you exceed the 70 mph limit during a motorway journey?
- Do you exceed the limit in built-up areas?
- Do you drive fast?

It was hypothesised that DSQ scores would correlate with system acceptability, such that those drivers who ordinarily choose to driver fast would exhibit lower scores on the acceptability questionnaire. In addition it was hypothesised that the fast drivers would be more inclined to disengage the Driver Select system.

7.3 Results

For the purpose of data analysis, the experimental road network was divided into six sections according to the speed limit. Of these sections, where the driver was in free flowing conditions (i.e. not engaged in a car-following task) mean and maximum speed across the section was derived. The six sections are described in Table 7.4.

Table 7.4: Description of road sections under analysis

Road Section	Speed limit
Rural #1	60
Village #1	40
Village #2	30
Rural #2	50
Dual-carriageway	60
Motorway	70

The data were analysed using the methods described in Section 7.2.2. The data were checked for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene tests respectively. Tests of sphericity were also included in the data-checking procedure.

7.3.1 Speed by section

The mean and maximum speeds in each condition along each of the road sections were calculated. Table 7.5 and Table 7.6 contain this speed data for the first rural section (speed limit 60 mph).

Table 7.5: Mean speed in rural section #1 (mph)

Group	**Mean speed [SD]**			
	Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
Baseline	46.81 [7.50]	48.36 [5.20]	50.33 [5.55]	50.58 [4.57]
Driver Select	48.29 [7.25]	50.23 [7.16]	50.28 [2.69]	50.22 [4.59]
Mandatory	48.90 [5.55]	48.76 [6.49]	49.97 [0.68]	50.40 [5.00]
Variable	48.07 [7.39]	50.39 [5.34]	50.02 [10.93]	50.39 [8.37]

There were found to be no overall System or Exposure effects on mean or maximum speeds for any of the groups (i.e. mean speed in Drives 2-4 was the same as in Drive 1). The data showed that drivers tended to remain below the posted speed limit in this rural section, probably due to the geometry of the road.

Table 7.6: Maximum speed in rural section #1 (mph)

Group	**Maximum speed [SD]**			
	Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
Baseline	60.63 [8.29]	61.20 [4.23]	64.64 [8.21]	61.97 [3.57]
Driver Select	55.44 [6.23]	61.14 [7.18]	50.28 [3.21]	50.22 [3.28]
Mandatory	57.67 [5.21]	58.34 [6.52]	56.73 [2.53]	57.39 [5.21]
Variable	56.51 [8.20]	58.10 [5.47]	56.72 [8.54]	57.98 [3.74]

Drivers then passed through two villages. The first had a 40 mph speed limit. Table 7.7 and Figure 7.2 show the mean and maximum speeds through this village. There were found to be no overall System or Exposure effects on mean speeds for any of the groups (i.e. mean speed in Drives 2-4 was the same as in Drive 1).

Table 7.7: Mean speed in village with a 40 mph speed limit (mph)

Group	**Mean speed [SD]**			
	Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
Baseline	34.86 [3.48]	35.26 [3.58]	33.03 [3.18]	37.22 [5.29]
Driver Select	34.87 [3.48]	36.05 [3.95]	31.99 [2.13]	34.22 [2.29]
Mandatory	34.94 [4.12]	34.64 [3.20]	32.05 [2.20]	34.51 [3.13]
Variable	36.47 [4.72]	35.46 [2.26]	32.06 [2.77]	34.78 [3.45]

However, for maximum speeds, there was found to be a System effect in the Mandatory group [$F(1,9)=9.34$; $p<0.05$] such that maximum speeds were lower in Drives 2-4 compared to Drive 1. There was found to be no effects of Exposure for the Mandatory group: maximum speeds were lower in each of Drives 2, 3 and 4 compared to the baseline drive, suggesting that behaviour was stable across time. There was no System effect for the Driver Select system, probably due to the fact that drivers' propensity to use the system in the low speed limit area was low (see Table 7.17). The lack of change in maximum speeds with the Variable system is a reflection of the low (perhaps spurious) speed in the initial baseline drive. As hypothesised, no Exposure effects were found in the Baseline group.

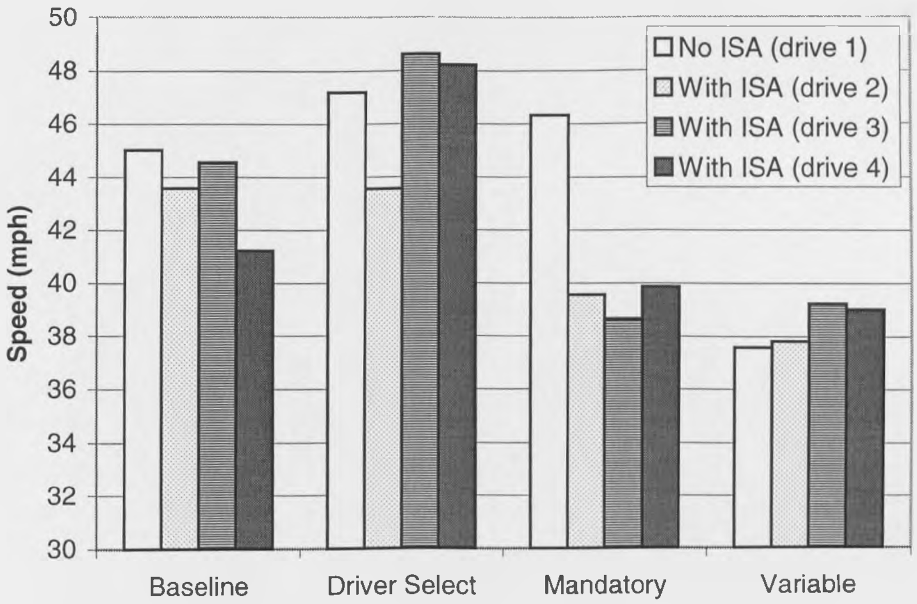

Figure 7.2: Maximum speed in village with a 40 mph speed limit (mph)

Whilst it appears that the effect of Exposure is different, depending on the System in use, no interaction effects were found. Figure 7.2 indicates that the baseline data was variable across driver groups that may have contributed to the lack of significant interactions found. However, additional analysis of the data confirmed this was still the case, even when the Drive 1 data was excluded (in order to remove the effects of unstable baseline data).

The second village had a 30 mph speed limit. Table 7.8 and Figure 7.3 show the mean and maximum speeds through this village.

Table 7.8: Mean speed in village with a 30 mph speed limit (mph)

Group	**Mean speed [SD]**			
	Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
Baseline	27.76 [1.78]	27.51 [1.88]	30.00 [2.65]	29.04 [2.89]
Driver Select	27.20 [2.37]	26.82 [1.20]	27.54 [0.98]	26.09 [1.29]
Mandatory	26.74 [2.03]	26.15 [1.23]	27.02 [1.13]	25.48 [1.22]
Variable	28.65 [2.08]	26.40 [0.42]	27.48 [0.34]	25.94 [0.78]

As in the previous village, there were found to be no overall System or Exposure effects on mean speeds for any of the groups (i.e. mean speed in Drives 2-4 was the same as in Drive 1). Again, there was found to be a System effect in the Mandatory group such that, compared to the baseline drive, maximum speeds were lower when the system was activated [$F(1,9)=8.31$; $p<0.05$]. This time, the System effect was also present for the Variable ISA group [$F(1,9)=9.11$; $p<0.05$].

A one-way ANOVA revealed no effect of Exposure such that when the Mandatory and Variable ISA systems were activated, maximum speeds were lower in each of Drives 2-4 than in the baseline drive suggesting that behaviour was stable across time. There were no effects of System for the Driver Select group.

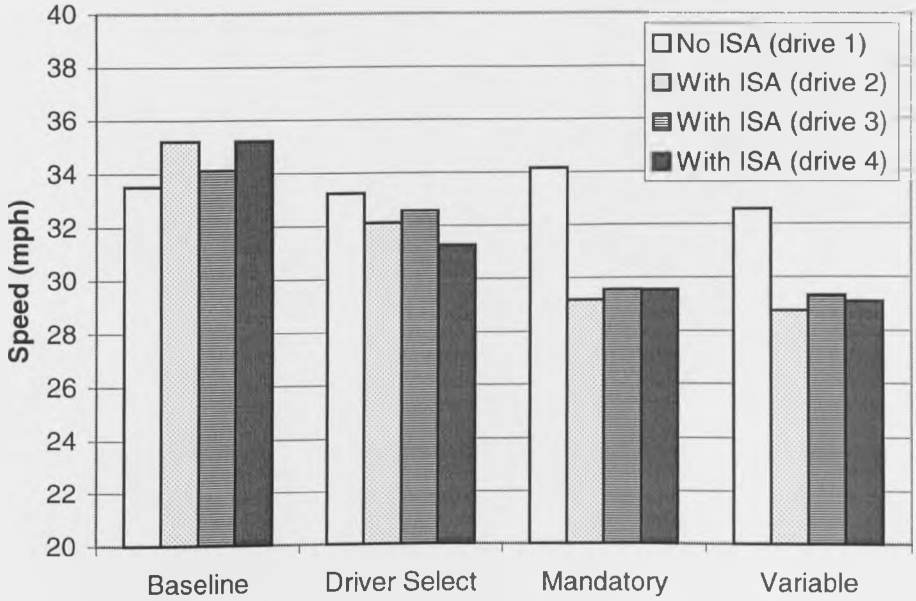

Figure 7.3: Maximum speed in village with a 30 mph speed limit (mph)

The fact that there were no changes in the mean speeds in either of the villages might be accounted by the presence of, in the first village, a set of traffic lights. This might have affected driver speeds by inducing caution (regardless of whether drivers were using ISA). In the second village, two sharp curves (on one of which the Variable system was activated) might have been more of an influence on driver speed than the ISA system, i.e. the mean speed was lower than the speed limit anyway.

Drivers then encountered a rural section of road (speed limit 50 mph). The road geometry consisted of substandard horizontal curves where the Variable system, if engaged, enforced a speed limit of 30 mph. Table 7.9 and Table 7.10 show the mean and maximum speeds in this road section. There were found to be no overall System or Exposure effects on mean or maximum speeds for any of the groups (i.e. speeds in Drives 2-4 were the same as in Drive 1). The data show that drivers tended to remain below the posted speed limit in this rural section, probably due to the geometry of the road. It is likely that this had a far greater effect on driver speeds than the ISA systems themselves.

Table 7.9: Mean speed in rural section #2 (mph)

Group	**Mean speed [SD]**			
	Drive 1	*Drive 2*	*Drive 3*	*Drive 4*
Baseline	41.38 [5.19]	43.99 [3.21]	44.02 [4.13]	44.82 [3.68]
Driver Select	42.58 [5.78]	43.56 [4.29]	44.41 [4.53]	43.99 [4.68]
Mandatory	40.19 [4.89]	42.54 [3.73]	42.52 [3.96]	43.18 [3.97]
Variable	41.91 [4.76]	43.22 [3.52]	43.09 [3.27]	43.66 [3.69]

Table 7.10: Maximum speed in rural section #2 (mph)

Group	**Maximum speed [SD]**			
	Drive 1	*Drive 2*	*Drive 3*	*Drive 4*
Baseline	46.48 [5.19]	45.25 [3.21]	45.98 [4.13]	46.27 [3.68]
Driver Select	46.32 [5.78]	45.68 [4.29]	44.44 [4.53]	48.22 [4.68]
Mandatory	45.32 [4.89]	44.85 [3.73]	45.74 [3.96]	47.56 [3.97]
Variable	48.21 [4.76]	45.23 [3.52]	47.23 [3.27]	45.89 [3.69]

Drivers then approached a four-lane dual-carriageway and eventually a motorway section. The mean speeds across these sections are shown in Table 7.11 and Table 7.12. Again, there were found to be no overall System or Exposure effects on mean or maximum speeds for any of the groups (i.e. speeds in Drives 2-4 were the same as in Drive 1).

The speed data presented suggests that the ISA systems had little impact on mean speeds. However, maximum speeds were reduced in urban areas with the Mandatory and Variable ISA systems. As in the study reported in Chapter Six, a number of speed profiles were then plotted to discover how drivers' deceleration patterns were affected by ISA.

Table 7.11: Mean speed on dual carriageway (mph)

Group	Mean speed [SD]			
	Drive 1	*Drive 2*	*Drive 3*	*Drive 4*
Baseline	61.79 [6.22]	65.17 [7.98]	66.27 [10.04]	66.12 [10.05]
Driver Select	64.67 [13.3]	66.03 [9.04]	65.74 [8.63]	64.94 [7.21]
Mandatory	61.51 [5.17]	59.07 [3.22]	59.41 [3.84]	60.31 [2.81]
Variable	65.46 [8.55]	60.27 [2.17]	60.10 [1.74]	60.65 [1.92]

Table 7.12: Mean speed on motorway (mph)

Group	Mean speed [SD]			
	Drive 1	*Drive 2*	*Drive 3*	*Drive 4*
Baseline	63.32 [6.45]	66.63 [5.83]	66.07 [5.90]	65.37 [5.93]
Driver Select	65.00 [9.71]	69.05 [9.94]	68.94 [6.65]	67.47 [5.48]
Mandatory	61.84 [8.31]	62.77 [5.07]	63.53 [4.96]	64.33 [3.06]
Variable	65.48 [10.3]	63.98 [3.24]	65.35 [1.79]	64.93 [2.29]

7.3.2 Speed profiles

In the transition from the higher speed limit to a lower speed limit, clear differences were seen in the way ISA impacted on driver behaviour. Figure 7.4 shows the mean speed profiles plotted against distance travelled for Drive 4 for each experimental condition. Those drivers in the Baseline group tended not to reduce their speed in readiness for the lower speed limit, nor did they adopt a lower speed until they were relatively far into the village. With the Mandatory and Variable systems, drivers were decelerated down to the lower speed limit before reaching the village entrance. The position of the Driver Select profile, between the Baseline and Mandatory system, is likely to be due to a combination of drivers disengaging the system, or reacting late to the auditory prompt.

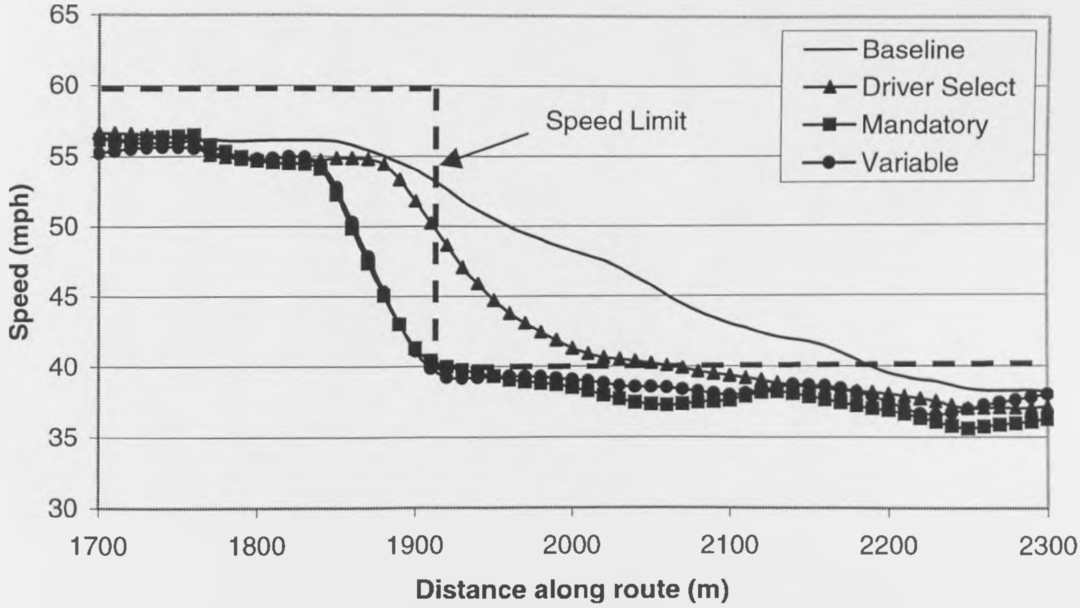

Figure 7.4: Speed profile on approach to village

Figure 7.5 shows a speed profile through a village with a 30 mph speed limit. It can be seen that the ISA systems had an impact on maximum speed in low speed limit areas. Drivers with no ISA tended to exceed the speed limit where possible.

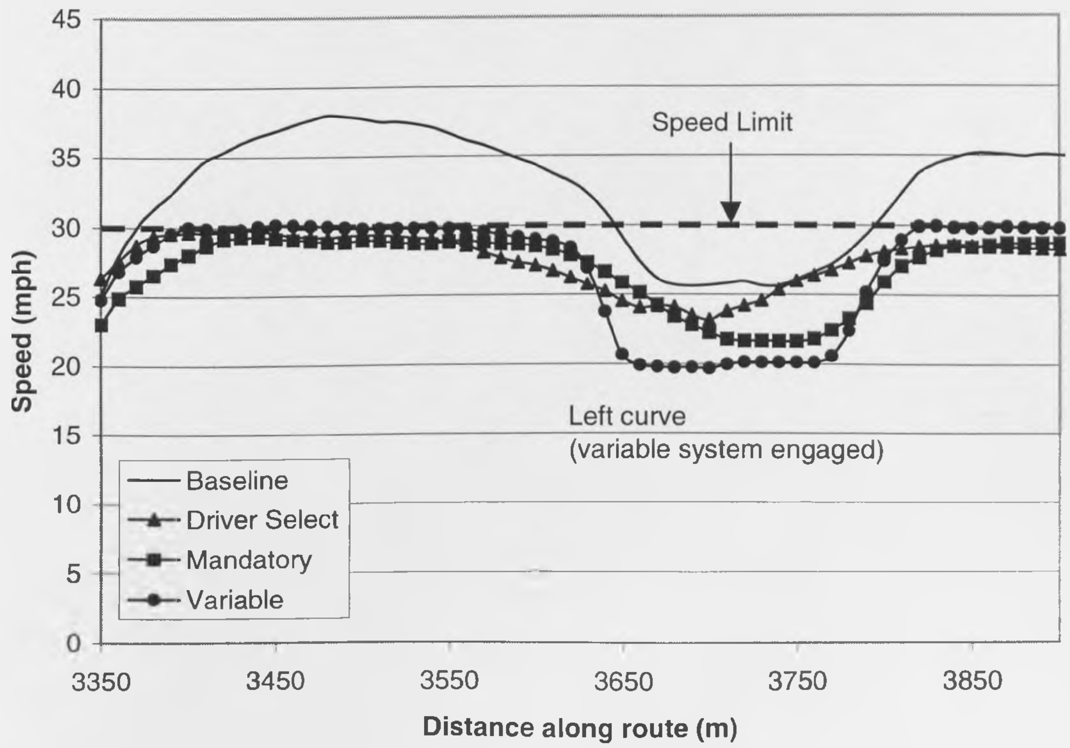

Figure 7.5: Speed profile through village

In summary, whilst mean speed across road sections showed little change with ISA, the effects were more prominent at specific locations, such as village entry, where drivers find it difficult to adapt their speed to the lower speed limit.

7.3.3 Car-following

The road network allowed the inclusion of several car-following tasks. In two of these tasks the driver was unable to overtake the car in front due to oncoming traffic. This created a "boxed-in" situation that allowed the measurement of the time-headway distribution. The lead cars in these scenarios were travelling at a speed that was constant and below the speed limit. In the urban situation the lead car was travelling at 25 mph and in the rural area at 40 mph. Therefore, even if speed-limited, it was possible for drivers to adopt short headways if they wished to. Figure 7.6 shows the time-headway distribution for drivers who were using the Driver Select system in an urban car-following situation. It can be seen that in Drive 1, where drivers did not have the system available, the amount of close following was minimal. However, in Drives 2-4, where the system was active, drivers appear to be spending more time at short headways.

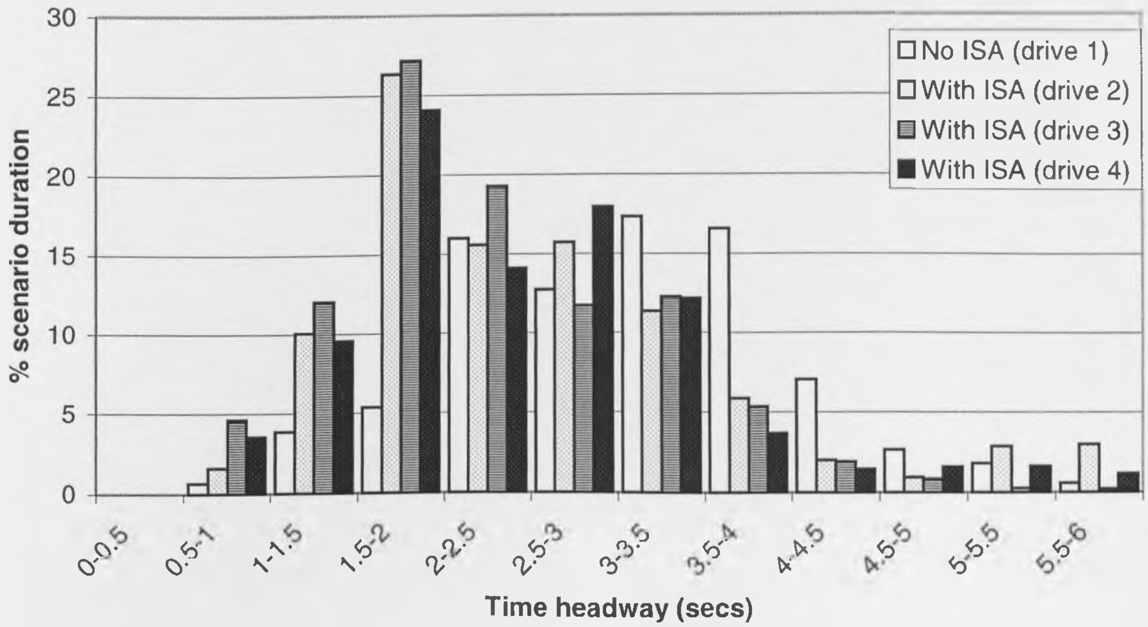

Figure 7.6: Time headway distribution in urban area (Driver Select ISA)

Analyses were performed on the amount of time drivers spent at less than one second headway. A System effect was found [$F(1,9)=7.91$; $p<0.05$] such that drivers spent more time at critical headways when the system was available. An Exposure effect [$F(3,27)=5.87$; $p<0.05$] revealed that this was only true for Drives 3 and 4. Behaviour in Drive 2 was similar to baseline behaviour.

This change in the distribution of headways is more striking for the Mandatory and Variable groups (Figure 7.7 and Figure 7.8). For the Mandatory group a System effect was found [$F(1,9)=5.77$; $p<0.05$] such that drivers spent more time at critical headways when the system was available. An effect of Exposure [$F(3,27)=4.27$; $p<0.05$] revealed that this was only true for Drives 2 and 3; on the last Drive, drivers were exhibiting their baseline car-following behaviour. This could tentatively be considered a learning effect, whereby drivers recognised that in this situation there was no use trying to overtake.

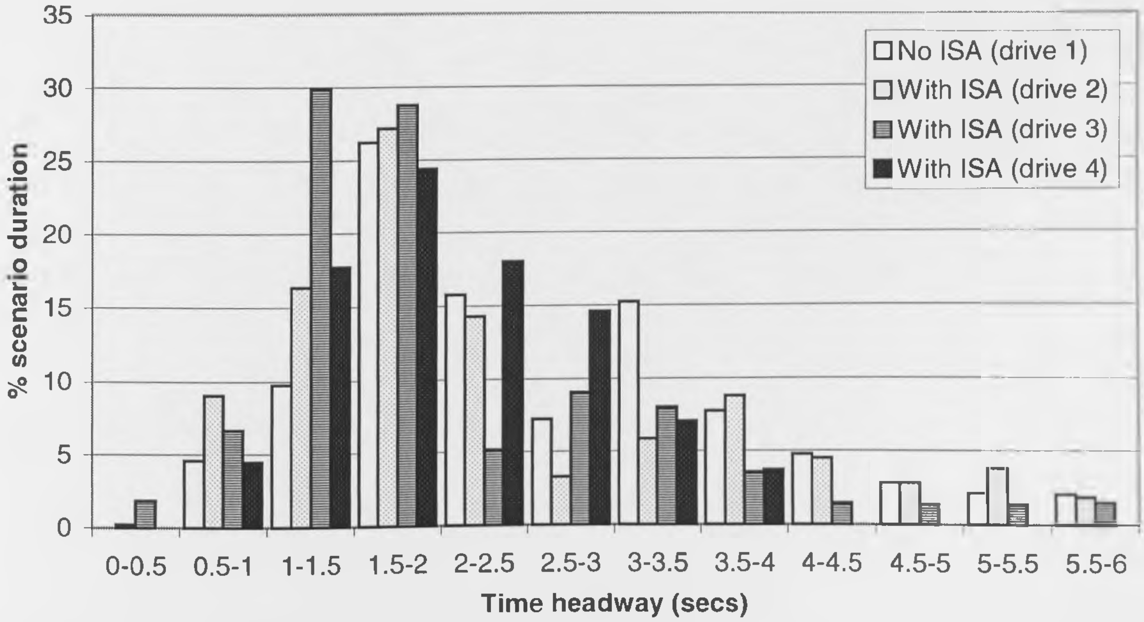

Figure 7.7: Time headway distribution in urban area (Mandatory ISA)

A similar pattern of results was found for the Variable ISA group. There was no change found in the Baseline condition.

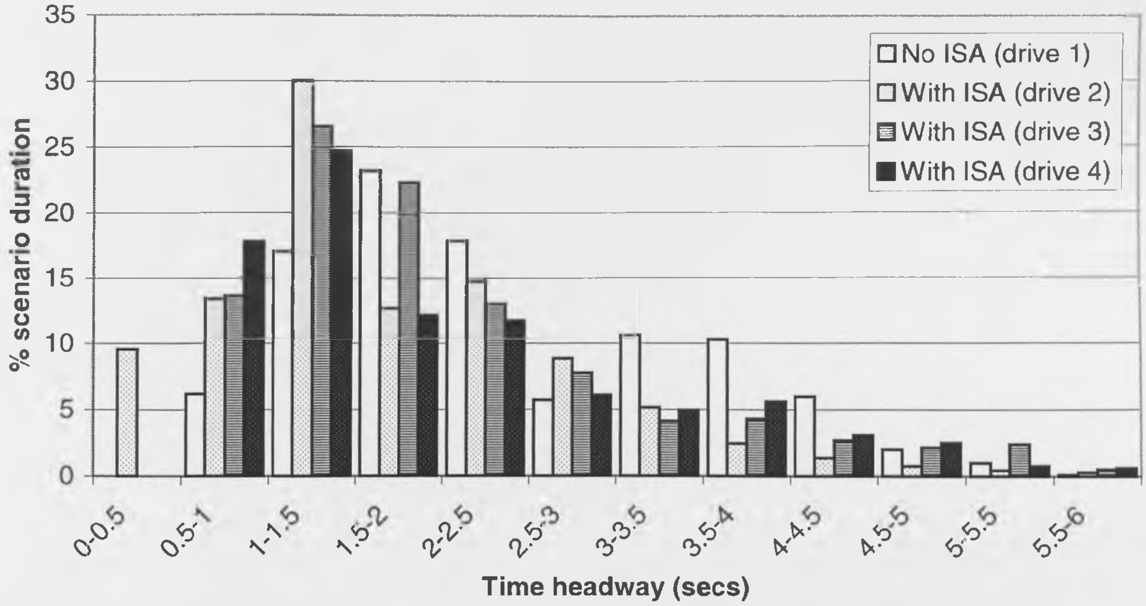

Figure 7.8: Time headway distribution in urban area (Variable ISA)

This pattern of results suggests that drivers, when using an ISA system, adapted their following behaviour and tended to spend more time following closer to the car in front. This supports the results from the previous study, adding weight to the conclusion that drivers feel under pressure to make up for perceived lost time. Not only is this manifested by accepting shorter gaps, but also by choosing to drive at a closer headway than previously. However, there is some indication that this might be a novelty effect that could subside after extended exposure.

7.3.4 Gap acceptance

Two gap acceptance tasks were included in the road network. The first required drivers to merge left into traffic approaching from the right, whilst the second required drivers to turn right across oncoming traffic. Gaps in the traffic increased by one second with each successive vehicle. The size of the gap that drivers accepted was calculated.

Analyses were performed on the data for each of the groups, separately for the left and right-hand turns. There found to be no effects of System or Exposure for the Driver Select group for either the left or right-hand turns.

The data shown in Figure 7.9 compares behaviour on Drive 1 and the combined data from Drives 2-4 for each of the groups for the left-hand merge.

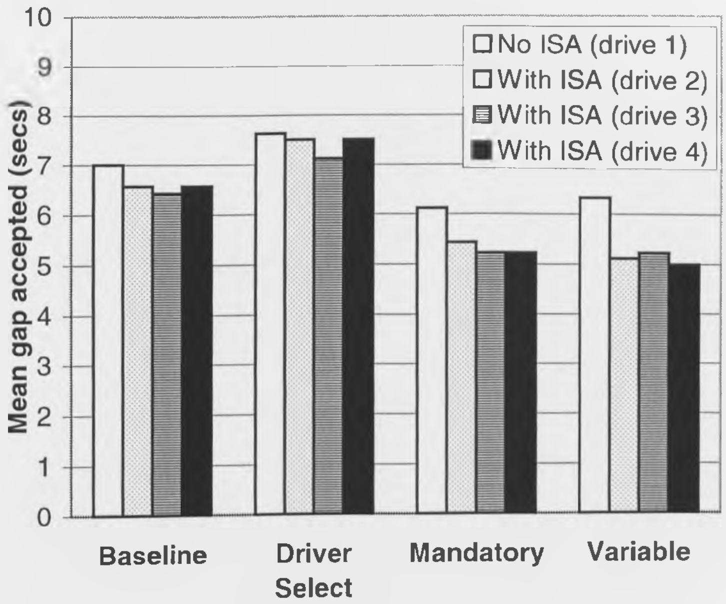

Figure 7.9: Mean gap accepted (left turn merge)

There were System effects for the Mandatory group (F[3,27]=6.92; p<0.01) and the Variable group [F(3,27)=7.91; p<0.01] for both the left and right-hand turns. The data show that the gaps accepted were shorter in Drives 2-4 compared to Drive 1. There was no effect of Exposure suggesting that this effect was stable.

In summary, the data suggest that drivers adapted their behaviour at junctions when using ISA and accepted significantly smaller gaps. This adaptation could be due to drivers believing they had lost time due to the ISA system. Such time pressure might have encouraged drivers to behave differently at these junctions. Similar findings were reported in Chapter Four.

7.3.5 Overtaking

In addition to the car-following tasks detailed in Section 7.3.3, two scenarios were created to examine how the use of ISA might affect overtaking behaviour. Whilst it was hypothesised that drivers might attempt to overtake more with ISA (thus mirroring the time-saving behaviour reported above) it was acknowledged that drivers might be hesitant in attempting to overtake due to their inability to exceed the speed limit. It was also hypothesised that drivers using the Driver Select system might be inclined to disengage the system in order to overtake.

Drivers encountered lead cars travelling below the posted speed limit on a straight stretch of road. There was little opposing traffic, providing the opportunity for drivers to overtake. Overtaking attempts and successful overtakings were recorded. It was found that these values were identical (thus once committed to an overtaking manoeuvre, drivers tended to complete it). The total number of overtaking manoeuvres is shown in Table 7.13.

Table 7.13: Total number of overtaking manoeuvres (urban)

Group	*Drive 1*	*Drive 2*	*Drive 3*	*Drive 4*
Baseline	1	3	3	5
Driver Select	2	3	3	4
Mandatory	1	1	4	4
Variable	2	1	2	1

The total number of overtaking manoeuvres was not sufficient to warrant a Chi-square test as expected frequencies have to exceed five. Therefore a Fisher's Exact test was performed. This test, however, can only be used for 2x2 contingency tables; therefore comparisons were made between the frequency of overtaking events using Drive 1 and Drive 4 only.

The tests performed on each of the groups revealed no differences in the numbers of overtaking manoeuvres between Drive 1 and Drive 4. A similar pattern of effects was found in an overtaking scenario in a rural setting (Table 7.14).

Table 7.14: Total number of overtaking manoeuvres (rural)

Group	*Drive 1*	*Drive 2*	*Drive 3*	*Drive 4*
Baseline	3	5	5	6
Driver Select	3	3	6	5
Mandatory	3	4	5	6
Variable	4	3	5	4

From these results, it is difficult to make conclusions about the likely effects of ISA on overtaking behaviour. It can be seen there was a general increase in the number of overtaking manoeuvres on successive drives for the Driver Select and Mandatory groups. This is likely to be a learning effect because the increase was also present in the Baseline group. There was no increase in overtaking with the Variable group, perhaps due to drivers' uncertainty as to whether the system was about to further decrease their allowable maximum speed and thus leave them "stranded" in the middle of an overtaking manoeuvre. The presence of a learning effect indicates that drivers required time to familiarise themselves either with the task, the simulator or with the road layout. This is an area that warrants further research.

7.3.6 Traffic violations

Both traffic light and overtaking violation scenarios were orchestrated within the road network. Drivers were given the opportunity to overtake a slow car where there were double white lines (i.e. no overtaking allowed). No differences were found in drivers' propensity to overtake illegally with regards to the type of system they were using. There was also no change in propensity to violate red lights.

7.3.7 Use of the Driver Select system

This study provided the opportunity to establish drivers' propensity to use the Driver Select system. It is difficult to calculate any predicted benefits from a Driver Select system without knowing the likely level of compliance. It was hypothesised that drivers would use the system differentially depending on the road environment. Therefore, a calculation of the propensity to use the system was made for the separate speed limit sections (Table 7.15). This calculation was made for Drives 2, 3 and 4 (i.e. the three drives on which the driver could use the system).

Table 7.15: Propensity to use the Driver Select system

Speed limit (mph)	% System use			
	Drive 2	*Drive 3*	*Drive 4*	*% Change (Drive2 to Drive4)*
30	82.95	82.46	89.23	+6.28
40	71.14	73.06	71.38	+0.24
50	67.52	49.84	56.94	-10.58
60	46.29	38.63	40.05	-6.24
70	37.14	50.87	39.73	+2.59

A two-way ANOVA was performed using Drive and Speed Limit as the two repeated measures. There was a main effect of Speed Limit [$F(4,36)=8.58$; $p<0.001$]. Pairwise comparisons revealed that system use in the 30 mph speed limit was significantly higher than system use in all other speed limit areas. There was no main effect of Drive, indicating that drivers used the system at the same rate across time.

Overall, in the lower speed limit areas (30 and 40 mph), the propensity to use the system was relatively high, probably due to the fact that driving speed in these areas was restricted anyway. For example, drivers were engaged in car-following tasks and junction interactions. There was thus perhaps little point in disengaging the system. Propensity to use the system in the higher speed limit areas was lower. Even though drivers tended not to exceed the speed limit in these areas, drivers might have been encouraged to disengage the system due to the lower traffic volume that meant that the *opportunity* to speed was greater. However as discussed earlier, drivers in the rural section were constrained by poor road geometry.

Of additional interest was drivers' use of the Driver Select system in overtaking scenarios. An analysis was carried out to determine whether drivers disengaged the system in order to overtake the lead car (Table 7.16).

Table 7.16: Propensity to disengage the system to overtake

Environment	*Drive 2*	*Drive 3*	*Drive 4*
Urban	2	3	3
Rural	1	0	1

Only a small number of drivers felt they needed to disengage the system in order to overtake. This reflects the small number of overtaking manoeuvres observed in the simulator trial.

7.3.8 Variable system

The Variable system was active in three specific locations: at two sharp curves (one urban and the other rural) and at a pedestrian crossing. After each of these scenarios an identical one was included where the Variable system was disengaged.

When drivers encountered a sharp curve in one of the urban areas, the Variable system slowed them down to 20 mph (Table 7.17). The reduction in speed when the system was active was significant [$F(3,36)=10.34$; $p<0.001$].

Table 7.17: Mean speed at urban curve entry (mph)

Speed with system off and [system on]			
Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
24.21	24.39 *[18.91]*	26.11 *[19.30]*	21.36 *[19.59]*

By comparing speeds at unsupported curves on the four drives, it is possible to study whether the ISA system was having any hang-over or learning effects (or indeed if drivers attempted to increase their speeds in order to male up for perceived lost time). There was no effect of Exposure for the unsupported curves, suggesting that neither effect occurred.

At the rural curve the Variable system automatically reduced maximum driver speed to 30 mph. As can be seen in Table 7.18, drivers were generally travelling at this speed anyway even without ISA. However the Variable system further reduced speeds when compared to both the Baseline condition and in locations where the system was disengaged [$F(3,36)=12.83$; $p<0.001$]. Again there were no hang-over or learning effects.

Table 7.18: Mean speed at rural curve entry (mph)

Speed with system off and [system on]			
Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
28.03	29.74 *[25.70]*	29.94 *[27.09]*	30.01 *[26.87]*

At the pedestrian crossing, the Variable system reduced maximum speed to 20 mph. Again the effect of the system was clear [$F(3,36)=11.27$; $p<0.001$] on speed reduction (Table 7.19). There were no hang-over or learning effects.

Table 7.19: Mean speed at pedestrian crossing (mph)

Speed with system off and [system on]			
Drive 1	***Drive 2***	***Drive 3***	***Drive 4***
43.56	39.06 *[20.11]*	39.86 *[20.12]*	39.06 *[20.14]*

7.3.9 Vigilance

A choice reaction task required drivers to differentially respond to randomly appearing targets in the visual scene. It was hypothesised that there might be differences in either response times or error rates depending on whether ISA was used or not (Table 7.20).

There was no effect of System or Exposure in any of the groups. This was probably due to the ease of the task: a floor effect was found with regards to the error rates in that drivers demonstrated a high degree of accuracy. A more complex task (or one using a sensory channel apart from a visual one) might give different results.

Table 7.20: Mean response times (secs)

Group	***Drive 1***	***Drive 2***	***Drive 3***	***Drive 4***
Baseline	1.16	1.05	1.11	1.09
Driver Select	1.14	1.12	1.27	1.16
Mandatory	1.09	1.01	1.14	1.07
Variable	1.23	1.11	1.26	1.12

A critical event at the end of the final session was added as an additional measure of vigilance. At the final pedestrian crossing, a pedestrian stepped into the road and crossed in front of the driver's path. This event was staged such that drivers were able, with heavy braking, to avoid collision with the pedestrian if braking was initiated immediately. Approximately 50% of drivers collided with the pedestrian, regardless of observation. Therefore, in this experiment, there was no confirmation that task automation led to reduced vigilance, at least in this type of task.

Table 7.21: Number of collisions

Group	**Total no. of collisions**
Baseline	6
Driver Select	4
Mandatory	5
Variable	5

Whilst it is recognised that further work needs to be considered, this result is encouraging given the research in the ACC field.

7.3.10 Workload

Subjective mental workload was measured using a standard workload questionnaire (NASA RTLX). The six dimensions of workload were analysed separately. In the Driver Select group (Figure 7.10) there were no effects of System for five of the dimensions; the only exception was mental demand [F(3,27)=6.52; p<0.01].

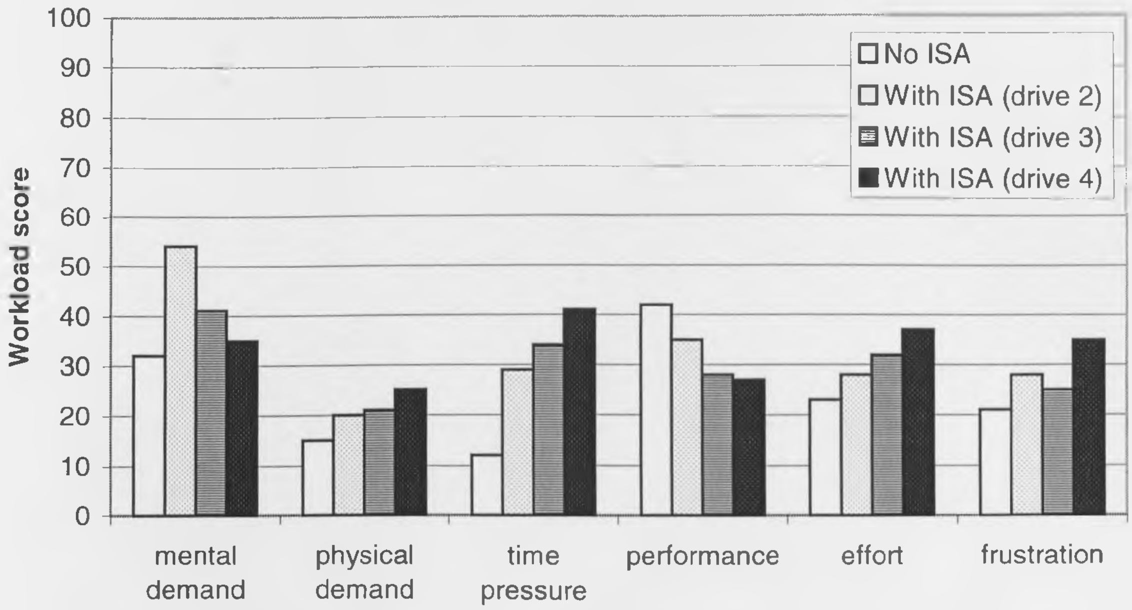

Figure 7.10: Mental workload scores (Driver Select ISA)

There was a significant effect of Exposure [F(3,27)=6.82; p<0.01]. Post-hoc analysis showed that mental demand was higher on Drive 2 compared to baseline workload. This increase was not present on Drives 3 and 4 suggesting drivers might have had a period of adjustment while learning to use the ISA interface.

Figure 7.11 shows the workload scores obtained on the six dimensions of the NASA RTLX questionnaire for the Mandatory group.

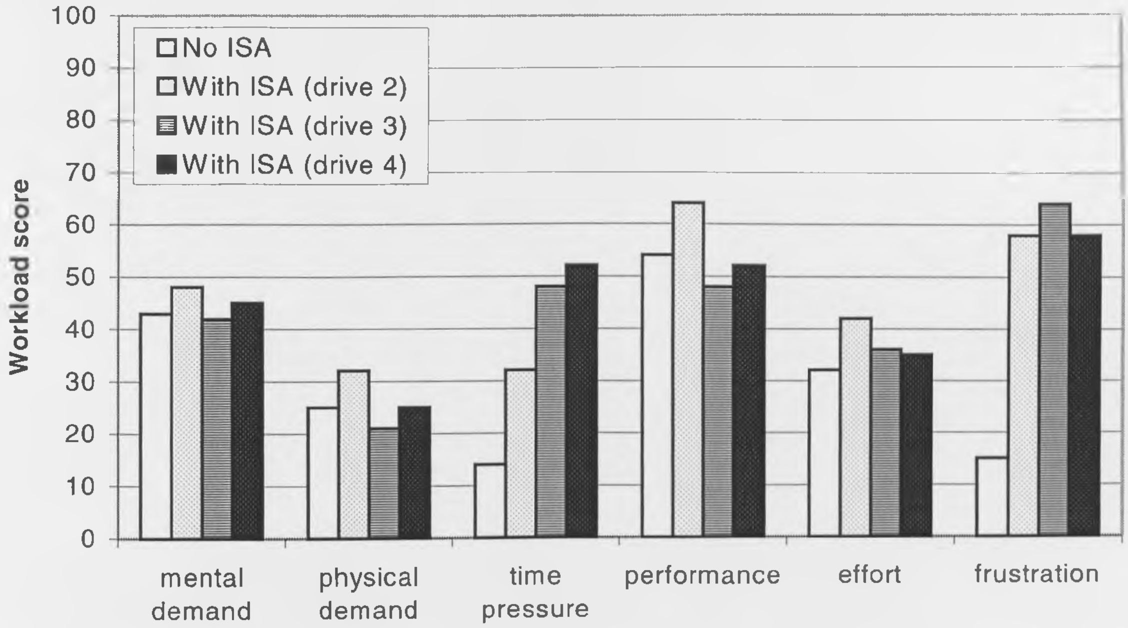

Figure 7.11: Mental workload scores (Mandatory ISA)

A significant effect of System was found such that time pressure [F(3,27)=8.91; p<0.01] and frustration [F(3,27)=10.76; p<0.01] were higher when the system was activated. There was no effect of exposure suggesting that this effect was stable across Drives 2-4.

Similar results were found for the Variable group (Figure 7.12). A significant effect of System was found such that time pressure [F(3,27)=5.71; p<0.01] and frustration [F(3,27)=12.56; p<0.01) were higher when the system was activated. There was no effect of exposure suggesting that this effect was stable across Drives 2-4.

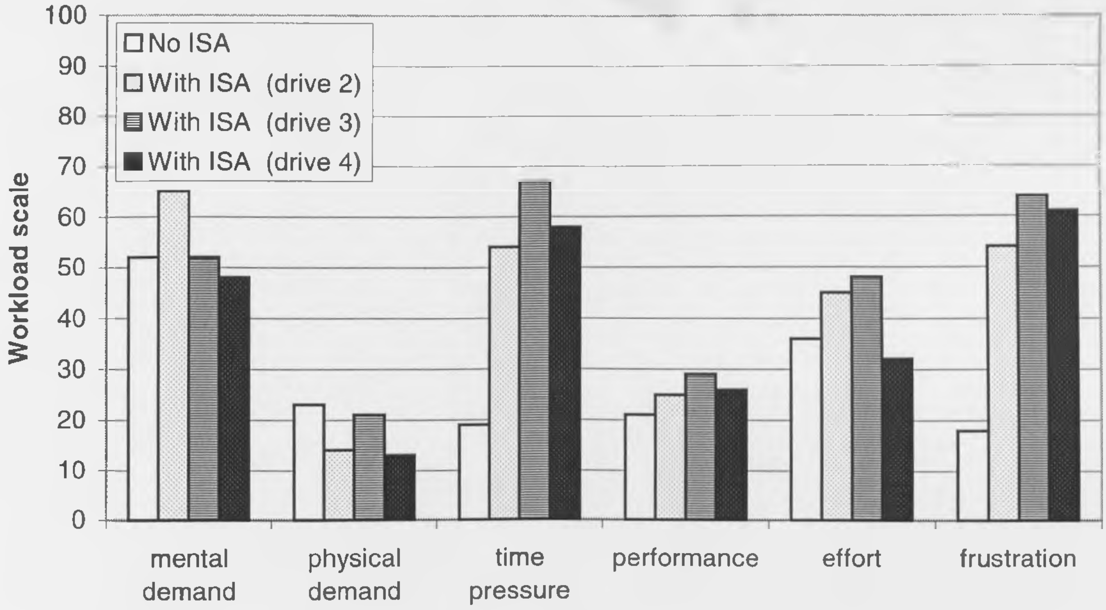

Figure 7.12: Mental workload scores (Variable ISA)

In summary, it appears that the Mandatory and Variable ISA systems induced increases in mental workload, specifically in terms of time pressure and frustration. This did not subside on repeated exposure. The Driver Select system initially caused some increases in mental demand, which decreased on prolonged exposure.

7.3.11 Acceptability

An acceptability questionnaire was administered before participants had experienced the system and after every subsequent drive with the system. The questionnaires were scored on the two dimensions of "useful" and "satisfying". There was no effect of System or Exposure on the scores for any of the groups. With regards to the post-trial scores only (as these related to actual interaction with ISA) drivers generally thought the Mandatory system was the most useful of the systems (Figure 7.13). Overall, it can be seen that the Variable system was thought to be of less use.

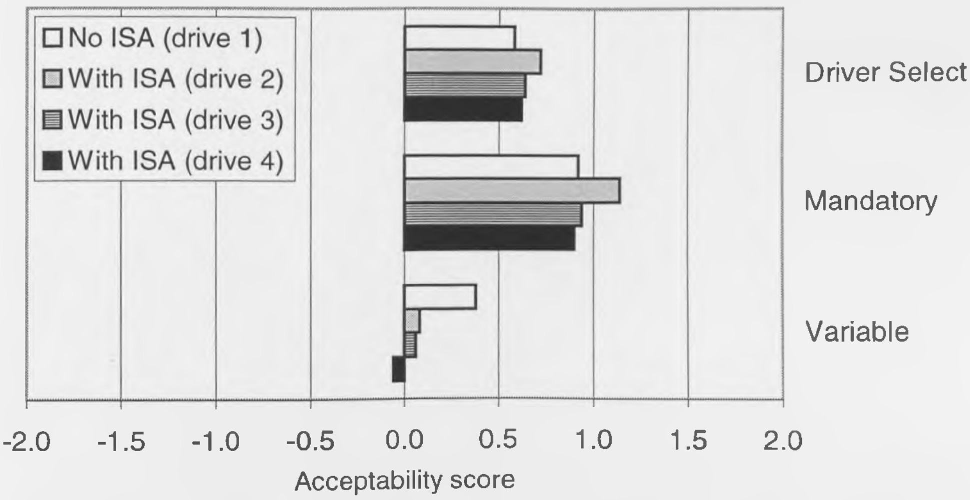

Figure 7.13: Post acceptability scores on the dimension of "useful"

Figure 7.14 shows the post-trial scores obtained on the dimension of "satisfaction". There was a significant effect of System for the Driver Select group whereby after use with the system, acceptability scores increased [$F(3,27)=6.91$; $p<0.01$]. There was no effect of Exposure, suggesting that scores were stable over time. There was also a System effect for those who used the Variable system; after use of the system acceptability scores increased [$F(3,27)=7.15$; $p<0.01$]. However, the Exposure analysis revealed that this increase was present only after the second drive [$F(3,27)=5.71$; $p<0.01$]. After prolonged exposure acceptability decreased to the original level. There were no effects of System or Exposure for the Mandatory group.

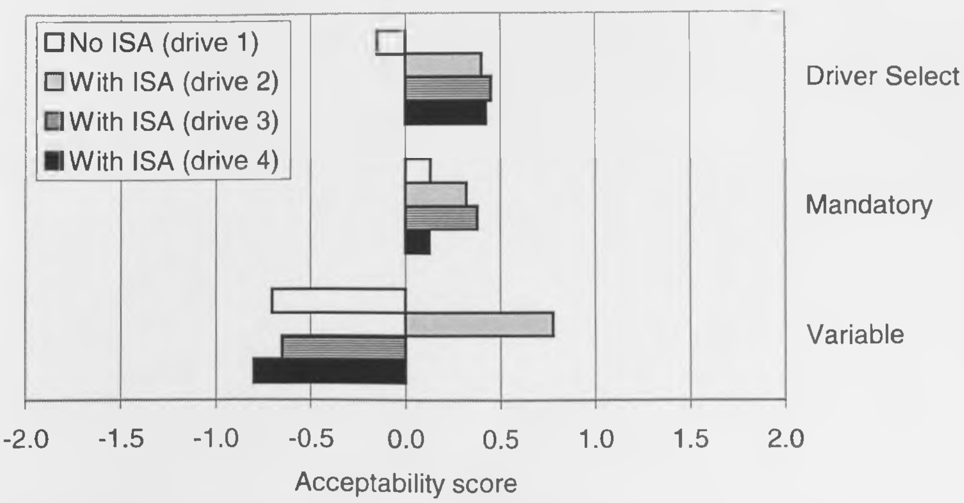

Figure 7.14: Post acceptability scores on the dimension of "satisfaction"

Overall, although drivers thought the Mandatory system would be the most useful, they preferred the idea of a Driver Select system. These findings are in agreement with the previously reported study.

7.3.12 Driving style

The scores for the three speed factors on the DSQ were combined for each driver. Correlation analysis was carried out on the variables of DSQ total score, age and mean acceptability scores. It was hypothesised that lower acceptability scores would be associated with lower age and higher DSQ scores. Table 7.22 shows the correlation matrix obtained.

Table 7.22: Correlation analyses for DSQ

	Age			**Acceptability**		
	D. Select	Mandatory	Variable	D. Select	Mandatory	Variable
DSQ Total						
Pearson's r	0.24	-0.14	0.31	0.04	0.37	-0.29
Sig. (1-tail)	0.37	0.51	0.14	0.81	0.14	0.25
Age						
Pearson's r				0.25	-0.45	0.38
Sig. (1-tail)				0.36	0.09	0.12

It can be seen that no associations were found between acceptability, age and DSQ scores, even when analysed by system type. This suggests that different driver types, as defined by their typical driving behaviour, did not hold different opinions about the utility or comfort of ISA. This result could be a reflection of the lack of motional cues in the simulator: drivers did not experience the feeling of deceleration with the ISA system that they would do in an actual vehicle. In addition, the acceptability scores may have been affected by the fact that other vehicles in the scene were travelling at or below the speed limit. Both of these issues will be addressed in Chapter Eight, where the field trials allowed interaction with other (non-ISA traffic) and drivers were able to experience the deceleration properties of ISA.

7.3.13 Journey time

The total time taken to travel along the road network was recorded for each of the driving sessions. This total travel time included events such as waiting at junctions and traffic lights. Table 7.23 reports these values, along with the corresponding decrease in time from Drive 1 to Drive 4. There were found to be no effects of System or Exposure for any of the groups, apart from the Baseline group [$F(3,27)=7.17$; $p<0.001$]. In this group, there was a decrease in journey time in Drives 2,3 and 4 compared to Drive 1.

Table 7.23: Total journey times (secs)

Group	*Drive 1*	*Drive 2*	*Drive 3*	*Drive 4*	*% Decrease*
Baseline	1971	1870	1845	1841	6.59
Driver Select	1929	1862	1848	1875	2.80
Mandatory	1943	1905	1900	1898	2.31
Variable	1875	1851	1763	1865	0.53

The statistically significant decrease in journey time in the Baseline condition might be due to a learning or boredom effect. Drivers might have familiarised themselves with the route and increased their speed as a result of this or they might have become bored with the experiment and increased their speed in order to finish the experiment sooner.

7.4 Conclusions

This simulator study allowed the investigation of how three types of ISA system might impact on driver behaviour over an extended period of time. Speed choice and traffic interactions were included in an experimental network that covered all road classes. Driver behaviour was monitored during a baseline situation (where no system was used) and on three subsequent drives that involved using one of the three systems. In addition, measures of driver attitudes were taken prior to and after using the system. Driver workload and vigilance were recorded to account for any secondary effects of using the system. By allowing drivers to attend the simulator on four occasions, it was hoped that insight into the effects of prolonged exposure could be gained.

As in previous studies reported in this thesis, both safety benefits and costs were associated with system use. The most predictable finding was the reduction in maximum speeds, although due to the nature of the simulated road network, this occurred relatively rarely. Traffic conditions and the road geometry contributed far more to driver speed choice than the ISA systems. The most dramatic effects were seen in the speed limit transition zones, where drivers were travelling from a high speed limit to a lower one. It is at these locations that drivers in real life have difficulty in adapting their speed to the recommended limit.

Drivers interacted with other traffic on the road at various locations. Previous work has indicated that the nature of these interactions changes when using an ISA system. This study can also report such changes, although whilst some of them complement earlier results, others are at odds with the previous studies.

As in previous work it was found that when using an ISA system, gap acceptance behaviour altered. For the Mandatory and Variable groups, the mean gaps accepted reduced in size suggesting that drivers were exhibiting riskier behaviour. However it is not clear whether this shift in behaviour would contribute to increased accident likelihood as the threshold for "safe" behaviour is unclear. Nevertheless, the fact that behaviour did alter in a negative direction should alert to the possibility that behavioural adaptation can occur when a new system is introduced to the driving context. The reason for this change in behaviour could be twofold. Firstly, as drivers returned on successive occasions, the gap acceptance task might have become progressively easier; as drivers built up more confidence on the driving simulator they might have been able to accept smaller gaps. However the analysis clearly showed that this was not the case as drivers in the Baseline condition (who never experienced an ISA system) did not exhibit this change in behaviour. Thus, a learning effect does not account for this adaptational behaviour. The second explanation is that drivers using either the Mandatory or Variable systems were becoming increasingly frustrated on increased exposure to the system. This frustration led to drivers becoming impatient and wanting to gain perceived lost time due to the ISA system. This impatience was exhibited in the smaller gaps taken. The mental workload results support this increase in frustration when using the ISA systems.

Also, as in previous work, there were observed changes in car following behaviour. Safety-critical close following (less than 1 second) increased in both urban and rural areas. When driving behind a slow moving vehicle (with no opportunity to overtake) it appears that drivers using an ISA system were more likely to want to maximise their speed and thus engage in close following. Further research should establish whether this has any implications for the mixed-fleet scenario where equipped and unequipped drivers interact. One such scenario might include unequipped vehicles following an ISA vehicle – could this lead to increased close following?

Overtaking behaviour was examined to investigate whether drivers were less likely to pass other drivers when using ISA. A common criticism of ISA is that flexibility in driving is restricted and this could make overtaking more dangerous, due to the fact that the speed limit cannot be exceeded and the overtaking manoeuvre would take more time. If the total fleet is equipped, traffic flow should be less variable, and thus fewer overtakings should occur. Overtaking opportunities were included to determine if any changes occurred as drivers became more used to the system and its limitations. The number of overtakings did generally increase over time, but this phenomenon also occurred in the Baseline group suggesting that drivers were becoming more competent in the driving simulator (regardless of system use). This effect was not observed for those using the Variable system, perhaps due to drivers' uncertainty as to whether the system would activate whilst they were mid-manoeuvre.

Previous work has shown that drivers using an ISA system were less likely to commit violations such as running red lights. This was thought to be due to the fact that drivers were unable to accelerate to "beat" the lights and thus were more likely to stop. However this was not found to be the case in this study; the number of violations remained constant regardless of whether drivers were using ISA or not.

Propensity to use the Driver Select system was monitored to provide an estimate of the likely benefits of such a system. Obviously a voluntary system relies on the driver choosing to use it. This experiment shows that, in general, drivers used the system for more than 50% of the time. However, for a variety of reasons, only tentative conclusions can be drawn from these results. Firstly, this was only a simulated drive. In the real world, where drivers might have a fixed time in which to reach their destination, there might be an increased tendency to disengage the system. Secondly, experimental pressure might increase drivers' propensity to use the system. Thirdly, for some of the experimental route, particularly in the urban scenarios, drivers were constrained anyway by other traffic ahead or road geometry. Under free-flow conditions, the results might differ.

Driver vigilance and workload were monitored in order to assess any secondary effects of the ISA system. Previous work has found some evidence for "automation induced complacency" with reference to loss of Situation Awareness leading to increased likelihood of collisions (Chapter Six). This was not demonstrated in this study, although the floor effect that was found on the vigilance task indicates that the task was probably too easy. Perhaps a more discreet secondary task was needed (e.g. one presented in the peripheral view). Subjective mental workload scores were obtained and, as in previous studies, both time pressure and frustration increased when drivers used the Mandatory and Variable systems. This perceived time pressure did not translate into actual loss of time, as there was no change in total journey time for each of the progressive drives. Thus this increased time pressure was only imagined, not actual.

Acceptability questionnaires reported that drivers found the Driver Select system more acceptable, but not as useful, in safety terms, as the Mandatory system. However, the Variable system was not well received. This could be attributed to the fact that the system was only active at certain locations and drivers might have found this confusing or irritating.

In summary, it can be seen that there are potential benefits of ISA systems, with reference to reduced maximum speeds and improved speed adaptation in speed limit transition zones. This experiment, however, has also highlighted the fact that only tentative conclusions can be drawn due to the secondary effects that occurred. Such secondary effects, including the propensity to adopt riskier driving behaviours, might not outweigh any benefits gained with ISA, but the possibility of their occurrence should be noted. No effects were found in terms of changes of behaviour over time (other than those that could be attributed to learning effects). The next chapter details the last experiment – the on-road trial. The on-road trial was undertaken to address some of the points raised above, namely those of lack of validity of the simulated environment. The on-road trial provided the opportunity of discovering how drivers interacted with a real ISA system in real traffic.

Chapter Eight

Extended exposure to ISA – On Road Study

8.1 Study aims

This chapter details the final study reported in this thesis. The study was carried out on-road using an instrumented car designed specifically to enact ISA. This vehicle was designed and built as part of the U.K. External Vehicle Speed Control project by the Motor Industry Research Association (MIRA). The study was designed to expand on the results obtained in the previous simulator studies by allowing drivers to use ISA under natural driving conditions over an extended period. An additional aim of this on-road study was to evaluate user opinion and acceptability. Whilst acceptability was evaluated in the driving simulator studies, the simulator has limitations in the fact that it is fixed-base. Therefore, participants were unable to experience the deceleration aspect of an ISA system, which may impact on the acceptability of such a system.

Due to technical and financial limitations, only two ISA systems were enacted (Mandatory and Driver Select). It was of particular interest to study how drivers chose to interact with the Driver Select System and indeed if their degree of interaction was different to the simulator trial results.

The evaluation of the ISA systems included measurements of speed along a predefined experimental route. In addition, behavioural observations were carried out using a technique designed to record drivers' interactions with other road users, propensity to commit traffic violations and safety-critical scenarios.

8.2 Method

8.2.1 Systems studied

Two ISA systems (Mandatory and Driver Select) were evaluated against a Baseline condition. As far as possible the systems were designed to work in the same way as in the simulator study reported in Chapter Seven. In addition, the same display used in the simulator trials was used in this on-road study (Figure 8.1). For a description of the ISA systems, see section 7.2.1.

Figure 8.1: ISA interface in the instrumented car

8.2.2 The vehicle

A number of vehicles were assessed for their suitability for use as the experimental car. It was thought necessary that the vehicle chosen should be relatively inconspicuous in normal traffic. This was preferred to a high performance car or one that was particularly unusual, so that volunteer drivers would adapt quickly to its characteristics and not be encouraged to drive differently than they would normally.

The vehicle also had to be relatively easy to modify and readily available second hand with the required specification. It was deemed necessary for the vehicle to have twin air bags on safety grounds and ABS and electronic fuel injection to facilitate the functionality of ISA. An additional requirement was that the vehicle had good visibility in order for the observers to note the surrounding traffic conditions and a spacious interior for the comfort of the observers and the housing of the hardware.

The vehicle chosen was a Ford Escort 1.8 Ghia X (Figure 8.2). Dual control brake and clutch pedals were installed to allow the front-seat observer to intervene if necessary.

To enact the characteristics of ISA, the vehicle had to register changes in the speed limit automatically and adjust the speed as appropriate. In order to control the speed both at a fixed value and at changes of speed limit, the vehicle had to be capable of reducing the power available to the driver and, if necessary, applying gentle braking. Full details of system functionality can be found in Appendix D.

Figure 8.2: ISA instrumented vehicle

The ISA system was installed in the Ford Escort and provided all the data collection for the duration of the field trials. The volunteer drivers tested the system in isolation, and the surrounding traffic was uncontrolled. It is important to consider that this may have an influence on the drivers' perceptions of the system.

It must be noted that, even with the ISA system activated, the drivers were able to exceed the speed limit. This occurred because the control algorithm allowed exceedence of the speed limit by up to 10%.

8.2.3 Experimental design

The experimental design was the same as used in the simulator study reported in Chapter Seven. It allowed the evaluation of the effects of two types of ISA system on driver behaviour. Each participant completed three drives using the same route (Table 8.1). The system remained disengaged in the first drive for all participants, thus supplying baseline data on their normal driving behaviour. Drivers in the *Driver Select* and *Mandatory* groups then drove with the appropriate system engaged on their second and third drives. The *Baseline* group continued to drive with the system off. This design enabled drivers to be exposed to an ISA system more than once, thus allowing the opportunity of insight into novelty effects of the system. This design also provided data on a group of baseline drivers who never encountered the system, yet also completed the drive three times. This provided a reference to examine possible learning effects[1].

Table 8.1: Experimental design

Group	*Drive 1*	*Drive 2*	*Drive 3*	*n*
Baseline	Baseline	Baseline	Baseline	8
Driver Select	Baseline	Driver Select	Driver Select	8
Mandatory	Baseline	Mandatory	Mandatory	8

A number of (within subjects) comparisons were undertaken for each of the three groups (Table 8.2).

Table 8.2: Statistical comparisons

Comparison	*Drive 1*	*Drive 2*	*Drive 3*
System			
Exposure			
– short term			
– medium term			

These comparisons were carried out to discover firstly if there was an effect of ISA and secondly whether that effect was stable over time. These comparisons are described in more detail below.

8.2.3.1 System effect

The first comparison (System) used an orthogonal contrast (Helmert) to test the combined effect of Drives 2-3 against Drive 1. A significant difference would indicate that, overall, there was an effect of the ISA system. The analysis was carried out for the Driver Select and Mandatory Groups. The Baseline Group was excluded from this analysis due to the absence of system use.

8.2.3.2 Stability of behaviour

A second comparison (Exposure) was undertaken to test whether there was an effect of increased exposure to a system. A paired t-test was performed on Drives 2-3.

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[1] Throughout the rest of this chapter, Baseline data will be shown as shaded in tables.

Further pairwise comparisons (Short-term, Medium-term) tested for the presence of novelty effects, or whether changes in behaviour were only exhibited after repeated exposure. For example, if it was found that performance on Drive 2 differed to that on Drive 1, but that differences did not exist between Drive 3 and Drive 1, then it could be argued that a novelty effect occurred in Drive 2 (instability of behaviour). On the other hand if statistically significant differences (in the correct direction) were found in all three comparisons, then behaviour can be considered as stable.

This data analysis procedure was repeated for all three groups of participants (Baseline, Driver Select and Mandatory). These analyses were performed on the variables of mean, maximum and standard deviation of speed in a number of road environments.

8.2.4 Participants

The participants for the study were mostly drawn from an existing database. The sample was balanced for age and gender and participants were selected on the basis that they were regular drivers on all the road types incorporated in the test route. Participants were initially contacted by telephone and a brief experimental outline was given. If they were to be allocated to one of the experimental (Mandatory or Driver Select) conditions, an explanation of the system was also provided. The sample included 12 males between the ages of 20 and 58 [Mean= 27 years] with a reported annual mileage of between 6,000 and 22,000 miles [Mean= 11,500]. In addition, 12 females took part between the ages of 22 and 56 [Mean= 30 years] with a reported annual mileage of between 5,000 and 18,500 [Mean= 8,000].

Drivers were paid for their participation and this payment increased after each session to provide an incentive for their return. Drivers were allocated to each of the three groups as described above, to provide a balanced sample within each group regarding gender and age. The participants were scheduled to attend the three sessions over a period of three to four weeks. As far as possible, drivers completed each of their three sessions at roughly the same time of day.

8.2.5 The experimental route

The route was selected to include roads of varying speed limits and classes, and was approximately 42 miles in length (Figure 8.3). Speed limits varied from 30 to 70 mph and included urban roads with mixed traffic and large numbers of pedestrians, rural roads and a motorway section. The route was also thought appropriate as the traffic was mostly free-flowing and there were opportunities for drivers to exceed the speed limit.

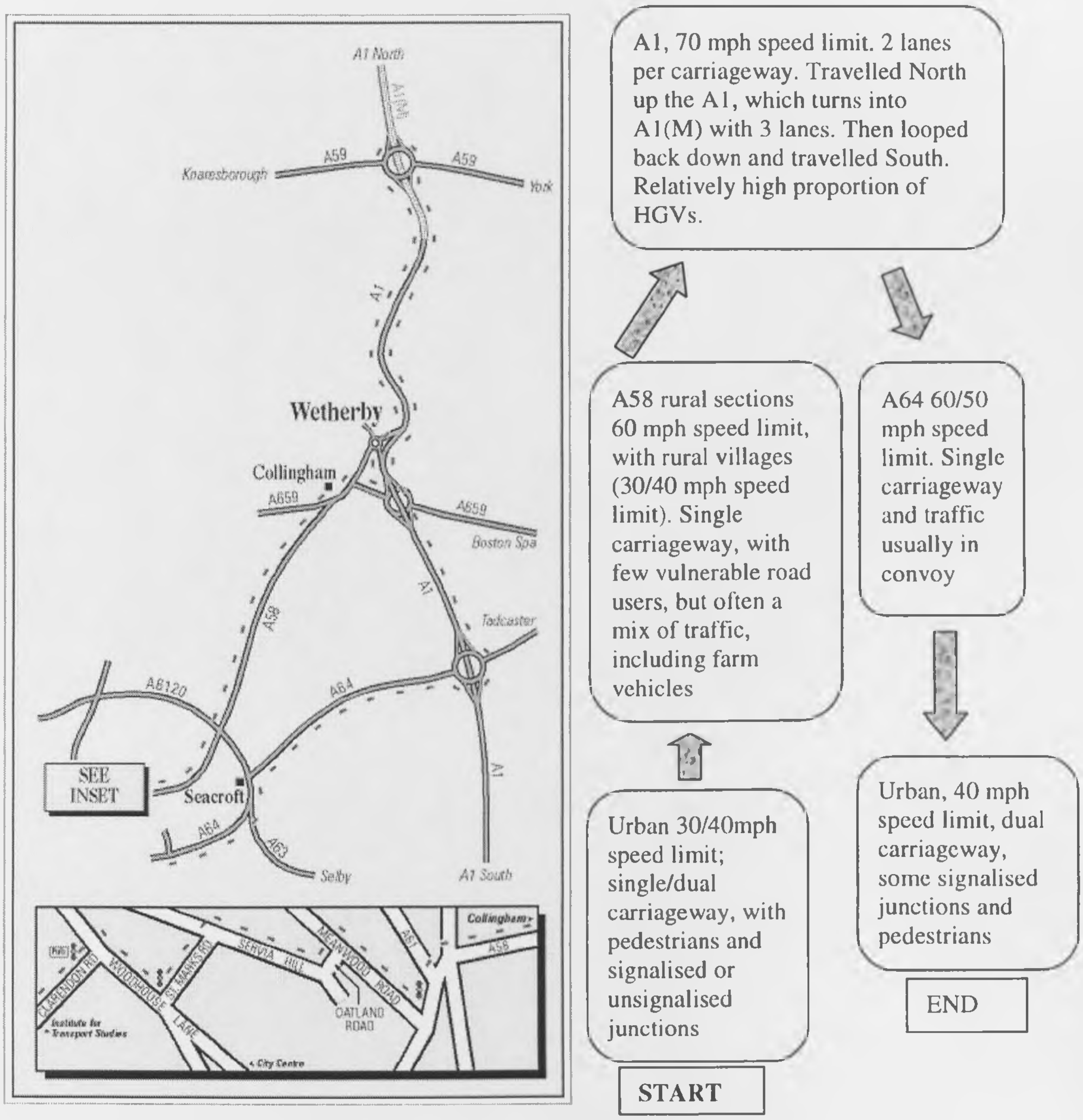

Figure 8.3: Map and description of the test route

The test route was divided into a number of sections, reflecting the various speed limits (Table 8.3).

Table 8.3: Description of road sections on the test route

Road section	Road type	Speed limit (mph)	Length (miles)
Harehills	Single carriageway way, 1\2 lanes	30	2.47
Upland Road	Dual carriageway, 2 lanes	40	1.83
Kentmere	Single carriageway	60	0.44
Shadwell	Single carriageway	40	0.25
Redhall	Single carriageway	60	1.77
Ling Road	Single carriageway	40	0.86
Wayside	Single carriageway	60	0.43
Church	Single carriageway	40	0.68
Keswick	Single carriageway	60	1.18
Collingham	Single carriageway	30	0.78
Collingham Out	Single carriageway	60	1.11
A1	2/3 lanes per carriageway	70	17.42
Roadworks	2 lane with roadworks	50	2.01
Roundabout	Single carriageway	30	0.54
A64	Single carriageway	60	2.75
A64	Single carriageway	50	1.92
Seacroft	Dual carriageway, 2 lanes	70	0.45
Crossgates	Dual carriageway 2/3 lanes per carriageway	40	4.65
A64 offramp	Single carriageway	30	1.00

As can be seen from Table 8.3, some of the sections were relatively short and most drivers were unable to attain any free flow speed on these sections. Therefore it was decided to omit a number of sections from the analyses. The eleven sections included in the analysis are shaded in Table 8.3 and provided a range of data from urban, rural and motorway road environments.

Harehills (30 mph speed limit) had a number of pedestrian crossings and junctions (both signalised and unsignalised). The traffic was varied in terms of composition and flow and buses and cyclists were often present. There was usually some congestion at the signalised junctions, but generally not more than two traffic light cycles. Halfway through this section, the single lane in each direction widened to two lanes.

Upland (40 mph speed limit) was a four-lane road. Traffic generally travelled faster than the posted speed limit and a downhill section also encouraged faster speeds.

Crossgates (40 mph speed limit) was a four-lane road with environmental and visual cues that encouraged drivers to exceed the speed limit where possible, with a high frequency of overtaking manoeuvres. Although the traffic was generally heavy in this section, much of the surrounding traffic travelled above the posted speed limit, especially in the final stretch.

Redhall to Collingham was a rural area comprising of a number of road sections. This section consisted of a single-carriageway road with one lane in each direction and a relatively low traffic flow. There were a number of speed limit changes, as there were three villages with speed limits of 30 or 40 mph incorporated in this section.

The *A64* was a rural section with a constant speed limit of 60 mph.

The *A1(M)* motorway section was approximately 17 miles in length and carried a large number of HGVs. This facilitated ample opportunity for overtaking manoeuvres but also limited the amount of unobstructed driving that occurred. As with some of the rural sections, driver speed was dictated by the surrounding traffic.

8.2.6 Data collection

Driver behaviour was recorded when driving both with and without the system activated. In order to examine thoroughly driver behaviour and attitudes, several data collection methods were employed. Such methods included quantitative data and the use of behavioural observations and questionnaires.

8.2.6.1 Quantitative data

Data were collected at 10Hz and stored on the PC in the boot of the car. The data files were saved at the end of each drive and stored in tab-delimited format. The variables collected included:

- *Speed* – wheel speed sensors recorded the speed (mph) of the vehicle. Due to limitations with the wheel speed sensors fitted to the vehicle, it was only possible to record speeds above 8 mph.
- *Distance* – this was calculated based on sample rate and wheel speed.
- *Retardation* – this represented the amount of engine retard applied for the ISA mechanism in order to keep the vehicle under the speed limit (range 0-91) and was used as a measure of drivers' resistance to the ISA system.
- *System use* – a record of when the driver has pressed the "system on" and "system off" buttons.

The data were post-processed and divided into appropriate sections, by speed limit, for analysis.

8.2.6.2 Behavioural observations

A technique known as the Wiener Fahrprobe (Chaloupka and Risser, 1995) was used to record behavioural observations throughout each drive. This technique requires the presence of two observers in the car, one in the front and the other in the rear. Each of the observers records a variety of different observations and the total set of variables recorded is intended to be a reflection of the observed driving behaviour or driving style. The Wiener Fahrprobe allowed four sets of variables to be collected:

- *Standardised variables* consist of those types of behaviour that can be specified and expected to appear in advance, e.g. speed choice.
- *Errors* were recorded e.g. exceeding the speed limit or poor lane discipline

- *Communicative aspects* of driver behaviour were recorded, especially in urban areas between car drivers and vulnerable road users, e.g. pedestrians. Both positive and negative communications were recorded.
- *Traffic conflicts* are situations where the driver and other road users are on a collision course and have to react in order to avoid an accident. Such conflicts may include rear-end or head-on conflicts, conflicts at turns, lane-change conflicts and conflicts with vulnerable road users.

The "coding observer" who was seated in the rear of the car recorded the standardised variables. One standardised observation sheet per road section was completed. The "free observer" in the front passenger seat recorded errors, communication and traffic conflicts. One coding sheet per error was recorded along with the name of the road section on which it occurred. Copies of the coding sheets can be found in Appendix E.

The drivers were asked to drive as they would normally and to try and ignore the presence of the observers. They were told that the observers were present in order to monitor the behaviour of the other traffic on the road. In order to familiarise themselves with the controls of the car and the ISA system, participants were allowed a 15 minute practise drive. This also allowed drivers to become accustomed to the presence of the observers.

It could be argued that the presence of two observers could have affected the way in which drivers behaved and how they interacted with the system (in particular the tendency to use the Driver Select system). Whilst the volunteer drivers were informed of the general purpose of the study, i.e. to test a new ISA system, they were not explicitly told which variables were being studied. Indeed drivers were under the impression that the observers were primarily interested in the behaviour of the surrounding traffic.

8.2.6.3 Performance ratings

In addition to the Wiener Fahrprobe, a number of anchored bi-polar scales were developed as a means of recording general impressions of driver behaviour. These scales were developed in the piloting stage of the experiment as a means of expressing overall driver performance in terms of critical driving skill. These skills indicated good performance and poor performance at either end. During piloting, the observers practised using these scales and in a debriefing session discussed how their observations translated into a score between 0 (poor performance) and 100 (excellent performance). Each observer completed this set of items independently immediately after each drive. A copy of the rating scale can be found in Appendix F.

8.2.6.4 Workload

Participants were asked to complete two mental workload scales after each drive. First, as a measure of global subjective mental workload, the NASA RTLX was administered. The second, the RSME (Zijlstra and Van Doorn, 1985) is a uni-dimensional measure of workload on a scale ranging from "absolutely no effort" to "extreme effort" (Appendix G). Four of the latter questionnaires were completed by drivers after each session, corresponding to four road classes, as it was thought that workload might vary according to the type of environment drivers experienced.

8.2.6.5 Acceptability

Prior to drivers experiencing the ISA system, an acceptability questionnaire (Van der Laan et al., 1997) was administered, designed to measure drivers' general attitudes towards the ISA system. This questionnaire was also administered after subsequent drives, thus providing an indication of how acceptability changed after experience with the system. In addition, a more detailed system evaluation form was given to participants after the final drive, consisting of both open and closed questions. This allowed drivers to comment on various aspects of the ISA system, including its likely contribution to road safety and their personal likes and dislikes about the system.

8.2.6.6 Driving style

Participants completed the Driving Style Questionnaire (West et al., 1991) before the experiment commenced. It was hypothesised that DSQ scores would correlate with system acceptability, such that those drivers who ordinarily choose to drive fast would exhibit lower scores on the acceptability questionnaire. In addition it was hypothesised that the fast drivers would be more inclined to disengage the Driver Select system. Age was also included as a correlate to investigate whether acceptability of ISA was age-related.

8.3 Results

Due to their size, the data files were compressed by a procedure of smoothing and sampling. This involved calculating a moving average of the data in the raw files and subsequently sampling every tenth data point. This resulted in a more manageable, less noisy data file. The resulting file was then segmented into the sections as described above to allow analysis of individual area with a single speed limit.

The data were analysed using the methods described in Section 8.2.2. The data were checked for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene tests respectively. Tests of sphericity were also included in the data-checking procedure.

8.3.1 Speed

Driving speeds were greatly affected by the traffic conditions on the road and, as it was not possible to isolate speeds in free-flowing traffic only, the reported mean speeds may be misleading. Where mean speeds indicate there may be a change in driving style, individual driver speed profiles are shown as demonstration.

Calculations were made of changes in mean, maximum and speed variance across sections of road. In addition, the change in the amount of time drivers spent above the speed limit was calculated; in each of the baseline drives this gave a rough indication of the amount of opportunity there was to speed on the individual road sections. The sections of road were characterised by speed limit. The results will be discussed separately for the Baseline, Driver Select and Mandatory groups. Where changes in speed are tabulated, significant values are shaded. For an overview of driver speeds, speed bins were used as a graphical representation of the distribution of speeds over a particular section.

8.3.1.1 Baseline group

It was anticipated that no changes in behaviour would occur in this group of drivers over the three drives.

Urban roads

The three urban areas were analysed separately. For each of them, there were no Exposure effects (Table 8.4).[2]

Table 8.4: Changes in speed measurements (mph) – urban areas (Baseline)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
Harehills (30)	0.73	-4.09	-0.65	0.43
Upland (40)	-1.01	-1.66	-0.31	1.94
Crossgates (40)	0.68	-0.44	-1.47	-2.50

Rural A-roads

Again, in general, there were no Exposure effects (Table 8.5).

Table 8.5: Changes in speed measurements (mph) – rural areas (Baseline)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
Redhall (60)	-1.70	-3.65	-1.15	-14.27
Ling (40)	-1.44	0.03	-0.32	-5.83
Wayside (60)	-1.55	-1.36	0.39	-3.19
Church (40)	-0.60	-1.70	-0.06	-11.94
Keswick (60)	-0.87	-2.01	-0.21	-6.19
Collingham (30)	0.45	-0.42	-0.50	-2.52
A64 (60)	0.97	1.16	0.10	-1.85

There were a couple of exceptions however. There was an Exposure effect in both Redhall [$F(1,7)=6.45$; $p<0.05$] and Church [$F(1,7)=5.02$; $p<0.05$] indicating there were decreases in the amount of time spent above the speed limit in both Drives 2 and 3 compared to Drive 1. These could be spurious results due to natural variation in traffic.

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[2] The change is calculated by subtracting the mean of Drives 2 and 3 from the value for Drive 1.

Motorway

Finally, the motorway data exhibited the same non-significant results (Table 8.6). There were no Exposure effects.

Table 8.6: Changes in speed measurements (mph) – motorway (Baseline)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
A1M (70)	-1.68	-1.05	0.025	-2.25

Overall in the Baseline group, despite natural variations in traffic there were mostly no changes in speed choice over the three drives. This implies firstly that no learning effects took place; secondly it is an indication that drivers were not displaying unnatural behaviour in their first drive. This is an important consideration when considering possible impacts of observers on behaviour.

8.3.1.2 Driver Select System

The speed measurements obtained from this group varied widely, both between participants and between road types. This was due to the different rates at which drivers chose to use the system. Whilst the speed data is presented below, the more interesting data on system use is presented in section 8.3.2.

Urban roads

Changes in speed measurements for each of these urban sections are shown in Table 8.7. There were no significant System or Exposure effects of the Driver Select system on mean speed in any of the urban areas.

Table 8.7: Changes in speed measurements (mph) – urban areas (Driver Select ISA)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
Harehills (30)	1.00	-4.01	-0.89	-3.16
Upland (40)	-1.31	-2.57	-0.63	-18.01
Crossgates (40)	0.81	-0.62	-1.21	-2.93

There was however a System effect on maximum speed in Harehills [$F(1,7)=5.42$; $p<0.05$] and Upland [$F(1,7)=4.61$; $p<0.05$] whereby speed was lower on Drive 3 compared to Drive 1. There was no effect of Exposure. There was a significant System effect of the Driver Select system on the percentage of time spent above the speed limit [$F(1,7)=13.98$; $p<0.01$], in Upland only. This is easily explained by the traffic volume on this road section: it was generally lower than in the other two urban areas, allowing drivers to exceed the speed limit. Thus the amount of time drivers spent exceeding the speed limit decreased from approximately 54% (in Drive 1) to 35% (in Drives 2 and 3). There were no effects of the System or Exposure on speed variation in any of the urban areas.

Rural A-roads

There were no System or Exposure effects in any of the rural areas (Table 8.8). The road geometry of the rural areas included several curves and there was often a mix of traffic, including farm vehicles. It was therefore usual for the drivers to be travelling at significantly lower than the posted speed limit.

Table 8.8: Changes in speed measurements (mph) – rural areas (Driver Select ISA)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
Redhall (60)	-2.27	-3.97	-1.09	-14.60
Ling (40)	-1.37	-0.02	-0.79	-5.85
Wayside (60)	-1.82	-1.91	0.31	-3.11
Church (40)	-0.73	-1.10	-0.46	-11.47
Keswick (60)	-0.81	-1.89	-0.11	-6.24
Collingham (30)	0.31	-0.36	-0.32	-2.73
A64 (60)	0.83	0.80	0.48	-1.92

There were System effects of the amount of time drivers exceeded the speed limit in Redhall [$F(1,7)=13.98$; $p<0.01$], Church [$F(1,7)=13.98$; $p<0.01$] and Keswick [$F(1,7)=13.98$; $p<0.01$].

Motorway

The data obtained are shown in Table 8.9. There were no effects of System or Exposure.

Table 8.9: Changes in speed measurements (mph) – motorway (Driver Select ISA)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
A1M (70)	-1.55	-3.57	-1.60	-0.14

Overall in the Driver Select group, there were few significant changes in speed, with a couple of exceptions. It is difficult to draw any firm conclusions about these results due to their apparent spurious nature. It is likely that drivers' choices about system use were influenced a great deal by traffic volume; hence natural variations in small sample sizes are bound to occur.

8.3.1.3 Mandatory System

It was hypothesised that the effects of the Mandatory system would be much more pronounced than those of the Driver Select system.

Urban roads

The changes in speed measurements are shown in Table 8.10. There were found to be System effects for mean speed in Harehills [$F(1,7)=4.18$; $p<0.05$], Upland [$F(1,7)=9.82$; $p<0.05$] and Crossgates [$F(1,7)=4.95$; $p<0.05$]. Mean speed in these urban areas was lower in both the drives where the system was active, compared to the baseline drive. There were no effects of Exposure.

Table 8.10: Changes in speed measurements (mph) – urban areas (Mandatory ISA)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
Harehills (30)	-1.27	0.00	-9.72	-1.65
Upland (40)	-3.15	0.71	-7.12	-2.17
Crossgates(40)	-2.51	0.00	-11.78	-2.22

There were also found to be System effects for maximum speed in Harehills [F(1,7)=63.27; p<0.001], Upland [F(1,7)=4.39; p<0.05] and Crossgates [F(1,7)=21.97; p<0.001]. Maximum speed in these urban areas was lower in both the drives where the system was active, compared to the baseline drive. There were no effects of Exposure.

Figure 8.4, a typical driver's speed profile through Harehills, shows the tendency for drivers to speed in this urban section when ISA was not available. This profile indicates that even with two observers in the car, participants in this study were quite prepared to exceed the speed limit, in this case by up to 50%.

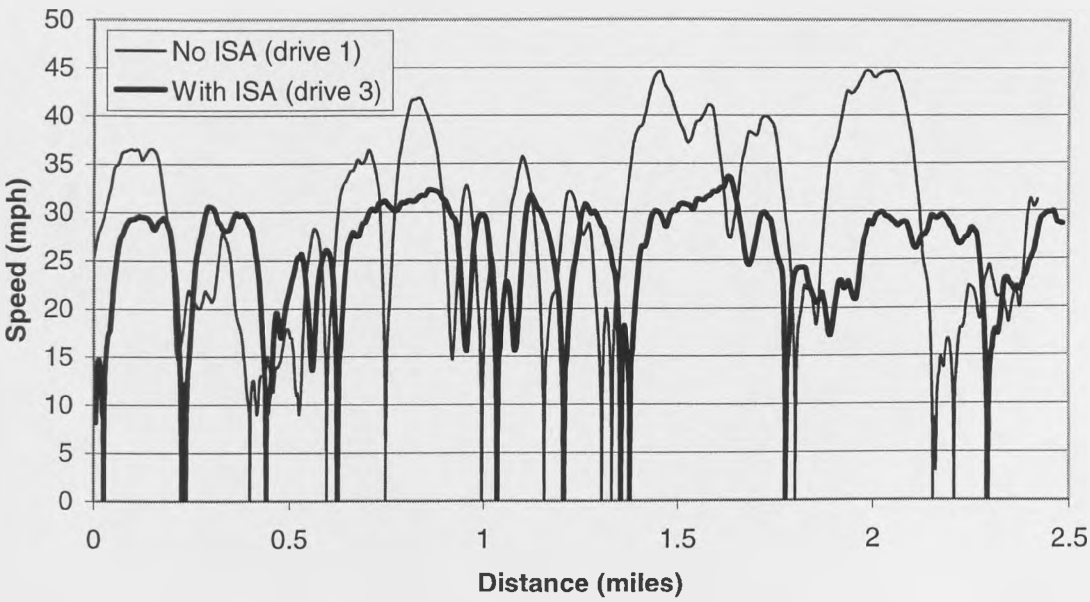


Figure 8.4: Speed profile [subject 13]: speed limit 30 mph (Mandatory ISA)

A secondary effect of Mandatory ISA is its possible impact on the distribution of speeds. In Chapter Three, two mechanisms that could affect the speed distribution under an ISA system were identified (Tate, 1998). Firstly, *Translation* of the speed distribution could occur whereby the shape of the speed distribution remains the same but the overall distribution is shifted downwards in terms of speed. Alternatively, *Transformation* or truncation of the speed distribution could occur whereby no vehicles exceed the speed limit. Figure 8.5 shows the distribution of speeds in Harehills for Drives 1 and 3. The high frequency of very low speeds reflects the congestion or waiting time at junctions along this stretch of road.

Not only is it useful to know how an ISA system impacts on maximum speeds, but also whether drivers develop a tendency to adopt faster speeds at the lower end of the distribution. For example, does ISA encourage drivers to try to "gain time" by attempting to drive closer to the speed limit. Related t-tests were performed on the amount of time spent in each of the speed bands for Drives 1 and 3. There was no change in the distribution of speeds at the lower end. However there was an increase in frequency of speed in the 25-30 mph speed band when ISA system was activated [$t(7)=3.94$; $p<0.01$].

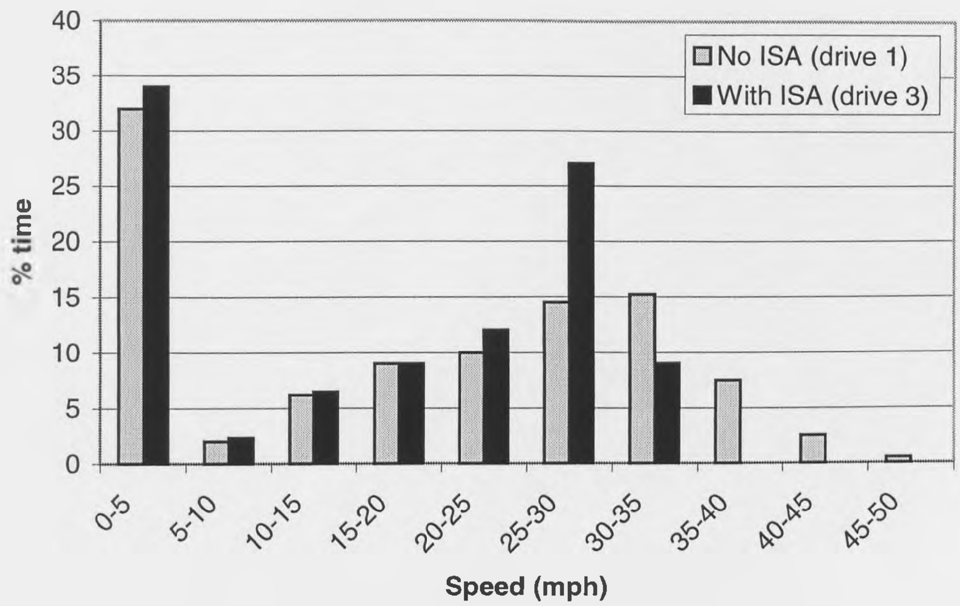


Figure 8.5: Speed distribution: speed limit 30 mph (Mandatory ISA)

Essentially, Figure 8.5 demonstrates transformation of the speed distribution. There was no indication that drivers were adapting their speed behaviour in any negative sense at the lower end of the speed distribution.

The next urban section, Upland, had a 40 mph speed limit. It comprised of a 2-lane road with a roundabout approximately half-way along the section. There was a tendency for the surrounding traffic to exceed the speed limit, particularly on a downhill straight. A similar result to Harehills was found, whereby there was little change observed in mean speed when driving with the ISA system. However there was a reduction in both maximum speed and the percentage of time spent above the speed limit (Figure 8.6).

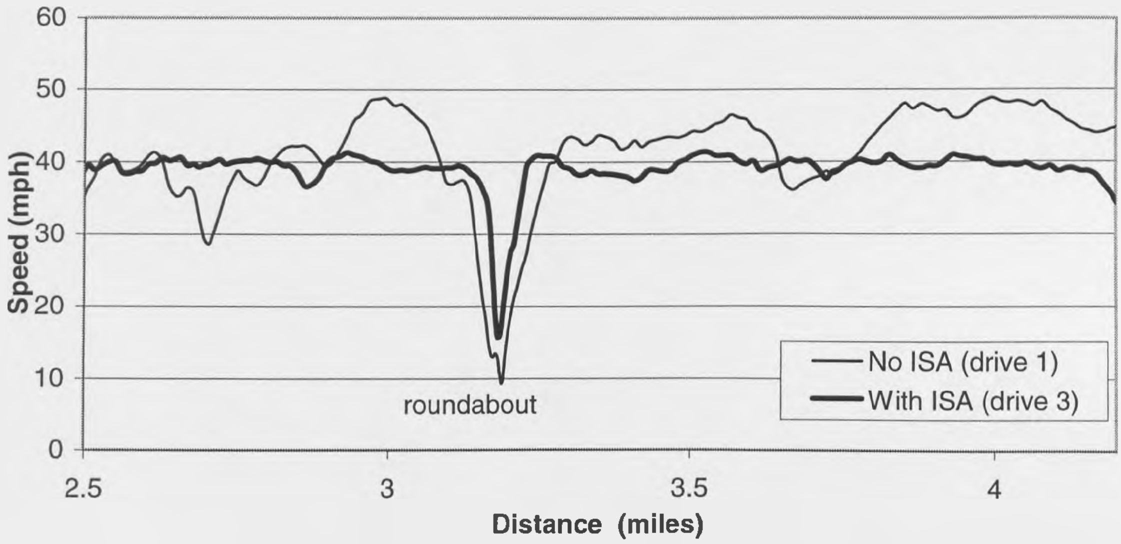


Figure 8.6: Speed profile [subject 13]: speed limit 40 mph (Mandatory ISA)

Again, as in the previous section, the speed distribution was transformed (Figure 8.7). Excessive speeds were abolished and there was an observed increase in the frequency of speeds in the 35-40 mph range [t(7)=4.76; p<0.01]. As in the previous section, there was no evidence of drivers adapting their speeds at the lower end of the speed distribution.

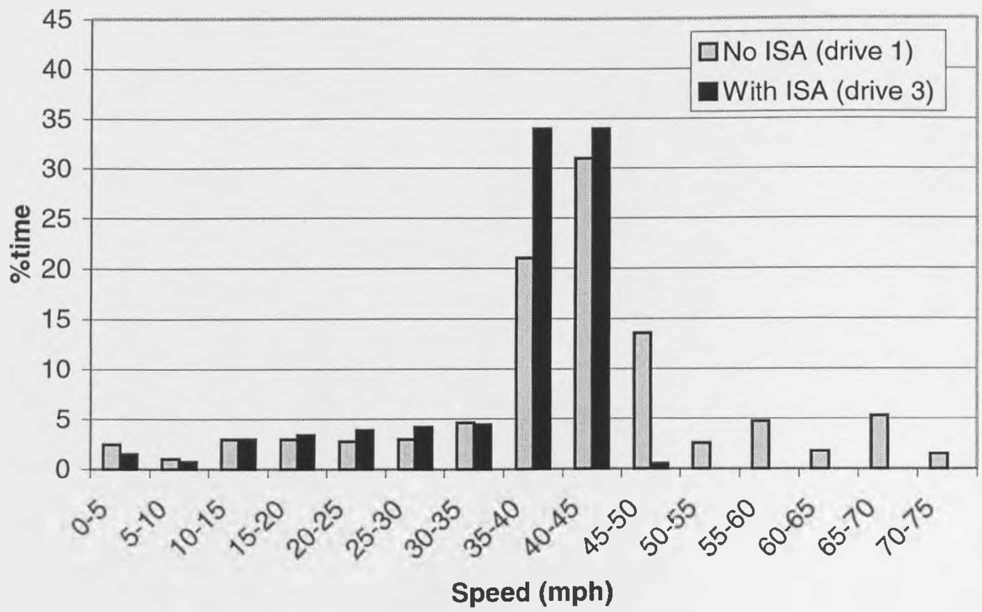


Figure 8.7: Speed distribution – urban area: speed limit 40 mph (Mandatory ISA)

The last urban section, Crossgates, was a dual-carriageway with two/three lanes per carriageway. With a 40 mph speed limit and widening to three lanes in parts, drivers travelled considerably faster than the speed limit. Maximum speed and the percentage of time spent above the speed limit reduced with ISA (Figure 8.8 and Figure 8.9).

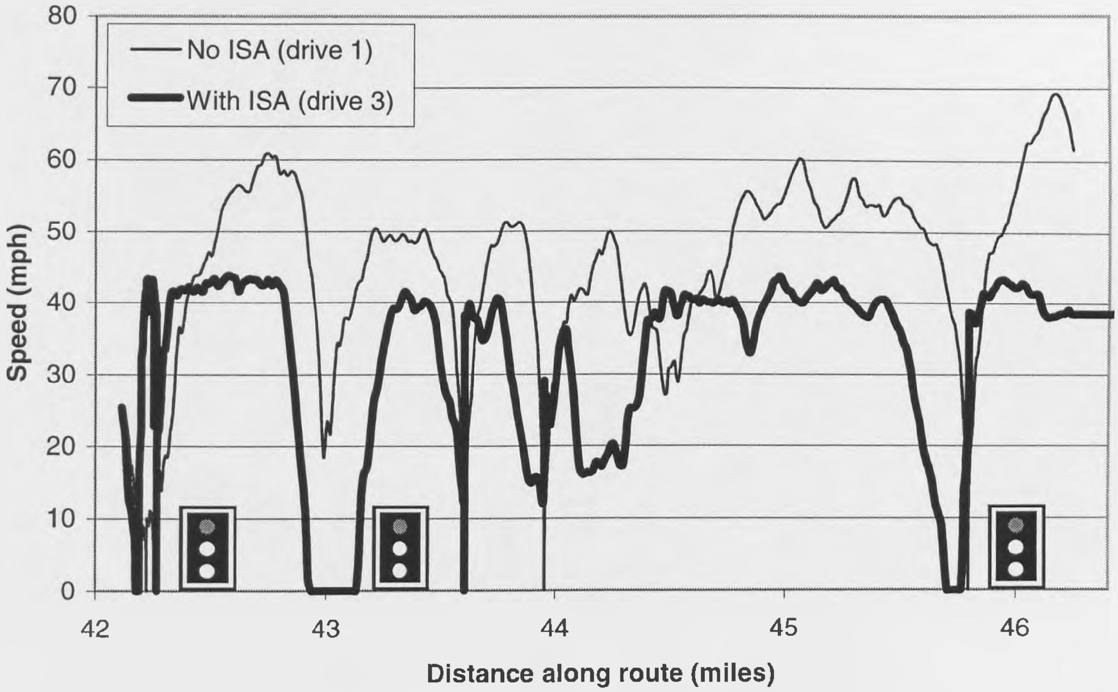


Figure 8.8: Speed profile [subject 16]: speed limit 40 mph (Mandatory ISA)

Again, the speed distribution was transformed. Excessive speeds were abolished and there was an observed increase in the frequency of speeds in the 40-45 mph range [t(7)=5.16; p<0.01]. This contrasts with the previous urban section where the increase in speed was seen in the 35-40 mph range. This is interpreted as drivers attempting to "fight" the system in this section in order to keep up with the surrounding traffic.

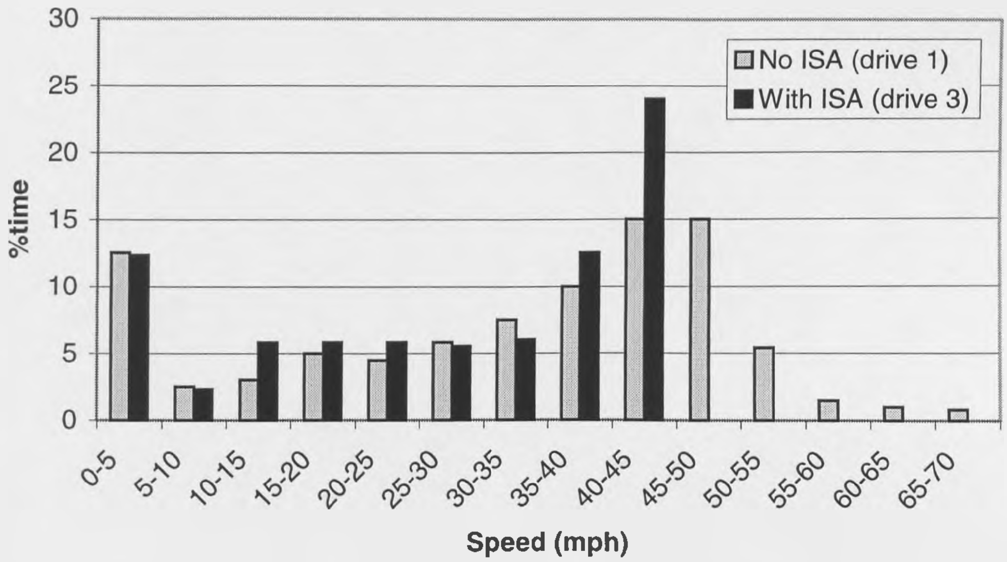


Figure 8.9: Speed distribution – urban area: speed limit 40 mph (Mandatory ISA)

Rural A-roads

The rural areas on the route required drivers to adapt their speed accordingly when entering the villages with lower speed limits. The changes in speed are shown in Table 8.11. The analyses showed clearly that there was a System effect for the Mandatory group such that it was effective at reducing mean speed in the lower speed limit areas of Ling [$F(1,7)=4.08$; $p<0.05$], Church [$F(1,7)=4.17$; $p<0.05$] and Collingham [$F(1,7)=8.33$; $p<0.01$]. Reduced maximum speeds in Ling [$F(1,7)=2.95$; $p<0.05$] and Church [$F(1,7)=3.15$; $p<0.05$] were also found. There was no effect of Exposure.

Table 8.11: Changes in speed measurements (mph) – rural areas (Mandatory ISA)

Section (speed limit)	Mean speed	SD speed	Max speed	% time spent above speed limit
Redhall (60)	0.25	-5.41	1.38	3.98
Ling (40)	-5.35	-3.59	-4.92	-22.38
Wayside (60)	-1.40	-5.39	-2.22	-14.38
Church (40)	-5.04	-4.47	-1.46	-21.49
Keswick (60)	3.89	1.49	2.28	3.96
Collingham (30)	-6.99	-2.30	-1.29	-23.86
A64 (60)	0.83	0.80	0.48	4.14

There were System effects for the amount of time spent above the speed limit in Ling [$F(1,7)=5.87$; $p<0.01$], Wayside [$F(1,7)=7.21$; $p<0.01$], Church [$F(1,7)=9.41$; $p<0.01$] and Collingham [$F(1,7)=15.91$; $p<0.01$]. There were no effects of Exposure.

There was no System effect for the Mandatory system in the higher speed limit areas. As can be seen in Figure 8.10, for this particular driver in free flowing traffic conditions, the ISA system has little effect in the 60 mph speed limit zones. This was due to the fact that higher speeds were rarely possible as a result of the traffic conditions and road geometry. ISA can be seen to have had a greater effect in the villages, where a reduction of approximately 15 mph was attained. Without ISA, this driver tended to travel at a relatively uniform speed through the whole rural area, demonstrating no marked reduction in speed through the village.

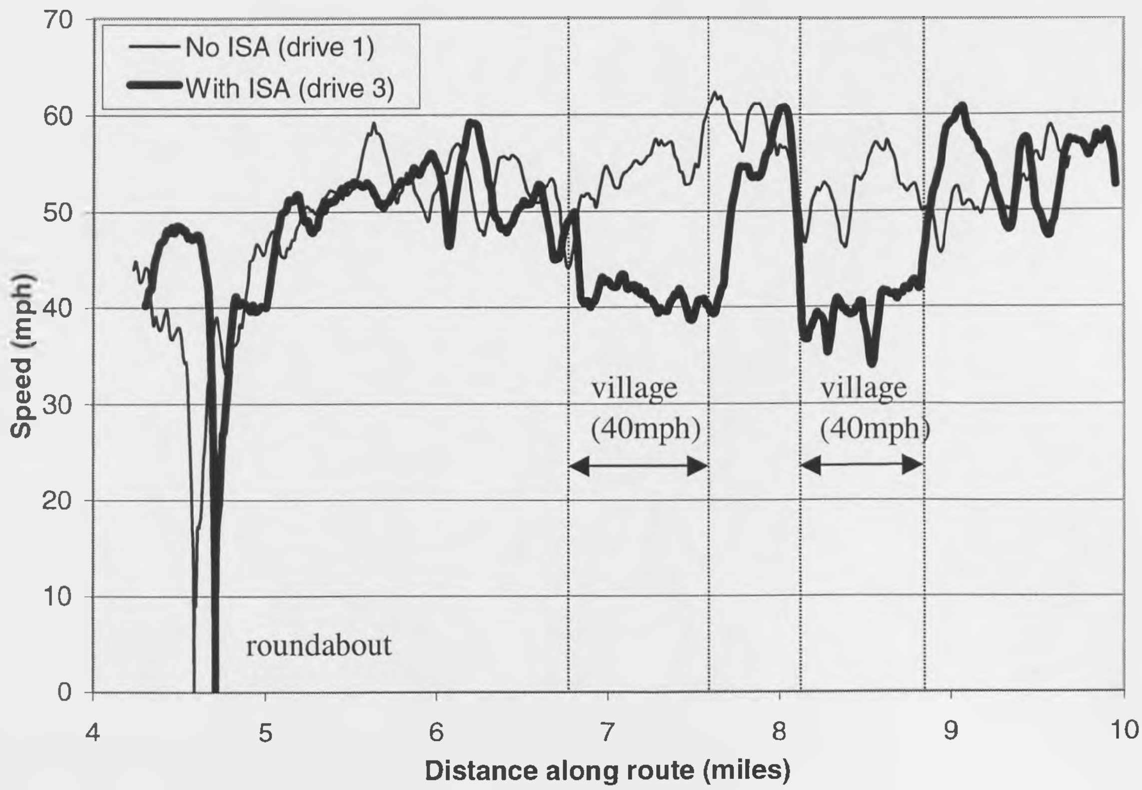


Figure 8.10: Speed profile [subject 15]: speed limit 60/40/60/40/60 mph (Mandatory ISA)

The speed distributions for the rural sections are too numerous to display. Statistical testing revealed however, no changes at the lower end of the distribution; transformation effects were present in some of the sections.

Motorway

No effects of System or Exposure were found (Table 8.12), probably due to the high traffic volume and large proportion of HGVs making it difficult to exceed the speed limit.

Table 8.12: Changes in speed measurements (mph) – motorway (Mandatory ISA)

Section (speed limit)	Mean speed	SD speed	Max Speed	% time spent above speed limit
A1M (70)	-2.77	7.68	-9.2	-8.40

Again, the speed distribution was transformed (Figure 8.11). Excessive speeds were abolished and there was an observed increase in the frequency of speeds in the 65-70 mph range [t(7)=6.76; p<0.01].

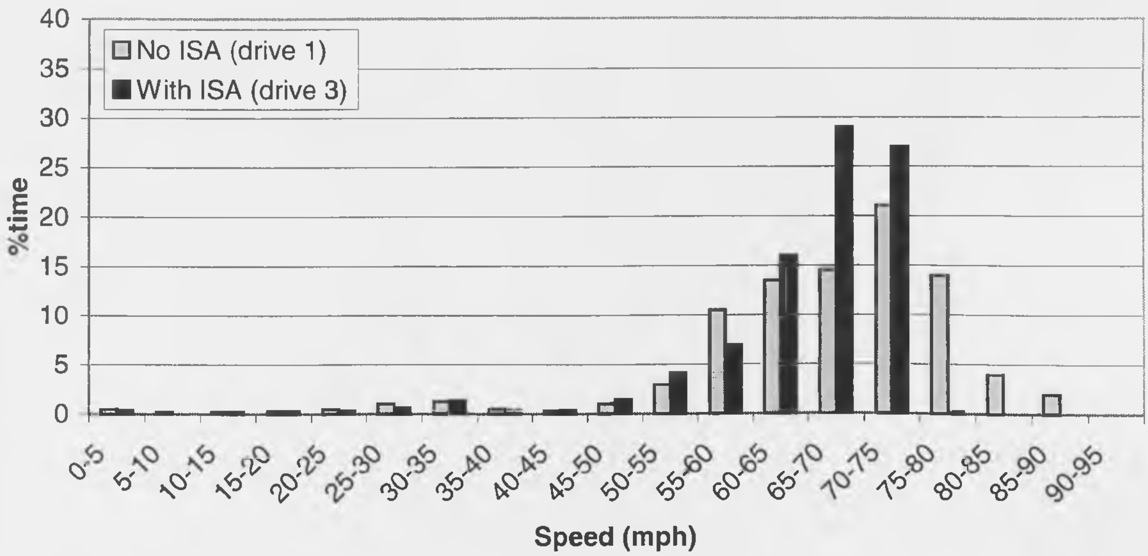


Figure 8.11: Speed distribution – motorway (Mandatory ISA)

8.3.2 System use

An additional aim of this study was to establish the propensity of drivers to use the Driver Select system. The percentage of time drivers activated the ISA system was calculated for each of the individual sections of the experimental road. It was thought sensible to analyse different speed limits separately, as there was likely to be variation in the use of the system in different road environments, as already noted in the simulator study reported in Chapter Seven. Each of the road sections is discussed separately below.

8.3.2.1 Urban roads

Use of the Driver Select system was higher in the 30 mph speed limit area compared to the two 40 mph speed limit areas. This was probably due to the fact that congestion in 30 mph zones prevented drivers exceeding the speed limit anyway, and thus there was no gain in disabling the system. This is also reflected in the proportion of time drivers spent exceeding the speed limit (Table 8.13). This was higher in the 40 mph areas (approximately 35%) compared to the 30 mph areas (approximately 20%).

Table 8.13: Use of the Driver Select System – urban areas

Section (speed limit)	Drive No.	% time system on	% time above speed limit
Harehills (30)	1	0.00	21.41
	2	89.72	22.20
	3	78.41	14.31
Upland (40)	1	0.00	53.90
	2	68.81	34.13
	3	61.02	37.66
Crossgates (40)	1	0.00	37.08
	2	58.58	34.95
	3	53.77	33.35

Between Drives 2 and 3, there were decreases of 11%, 8% and 5% in system use for the three respective urban sections. Related t-tests were performed to examine whether system use decreases from Drive 2 to Drive 3. They revealed statistically significant decreases in Harehills [$t(7)=6.26$; $p<0.01$], Upland [$t(7)=4.87$; $p<0.01$] and Crossgates [$t(7)=3.76$; $p<0.05$].

Whilst the percentage of time the system was engaged is interesting, additional analysis was undertaken to provide more insight. By itself, the "% time system on" figure is unrevealing because drivers may well leave the system on when they are unable to travel above the speed limit due to the road geometry or traffic volume (as noted in earlier sections). What is more interesting is the propensity for drivers to turn the system off and subsequently exceed the speed limit. Therefore a calculation was made of the proportion of time that the system was disengaged. This proportion was then divided into the time spent exceeding and not exceeding the speed limit.

Figure 8.12 and Figure 8.13 show the results for these calculations from Drive 2 and Drive 3 for each subject. A separate column represents each drive.

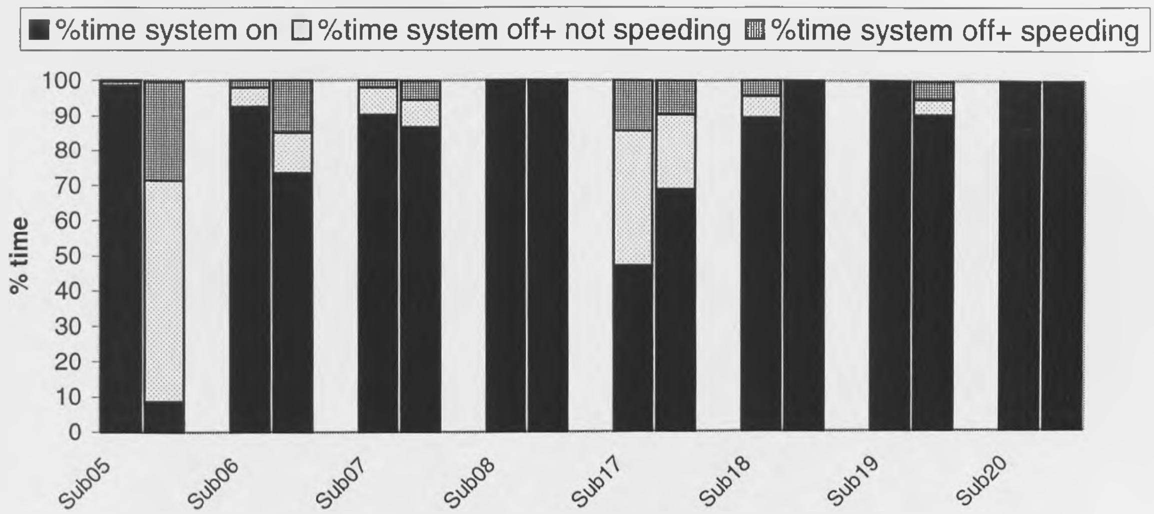


Figure 8.12: System use and speed choice: 30 mph speed limit (Driver Select ISA)

Figure 8.12 demonstrates that in Harehills, (the relatively congested urban section), drivers generally engaged the Driver Select system. In addition, although there were occasions when some drivers disarmed the system, the amount of time that they travelled above the speed limit was negligible (as indicated by the chequered portion of the graph).

In comparison, Figure 8.13 shows how drivers used the system in the urban area where traffic was free flowing and the surrounding traffic tended to travel above the posted speed limit. Where drivers were inclined to turn the system off (in particular drivers 5 and 6) they exceeded the speed limit for a large proportion of time. It should be noted that drivers 5 and 6 were both young male drivers.

In summary, the results suggest that drivers were willing to activate the system in road environments and traffic conditions that dictated a travel speed lower than the posted speed limit. However, in areas where the surrounding traffic generally exceeded the speed limit, the drivers were more likely to disengage the system. It is likely that these drivers wanted to maintain the traffic flow and not be subjected to close following from behind. Additionally, drivers tended to use the system less on their ultimate test drive in these urban areas than on their first drive with ISA.

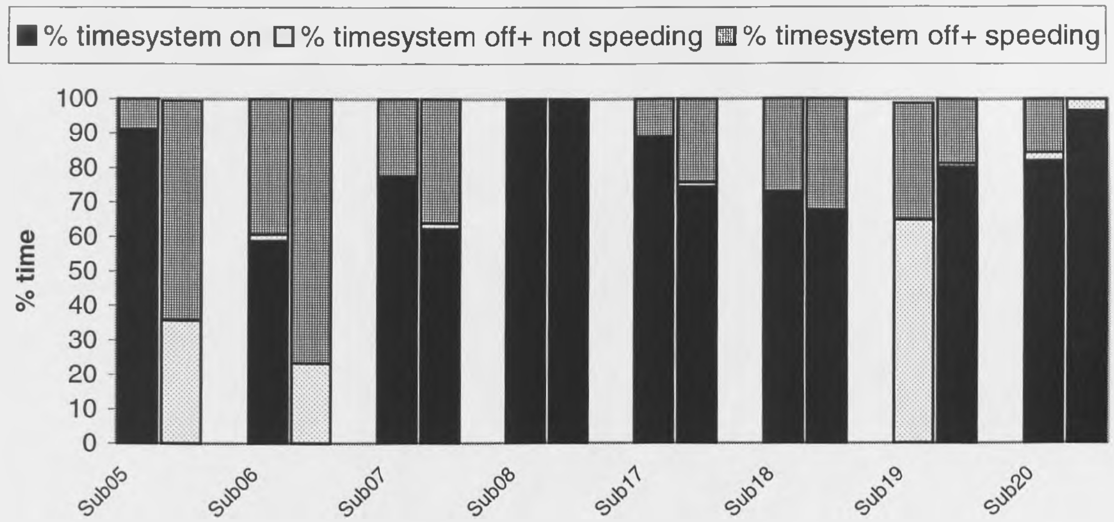


Figure 8.13: System use and speed choice: 40 mph speed limit (Driver Select ISA)

8.3.2.2 Rural A-roads

Use of the Driver Select systems was generally high in rural areas, although fell in the rural villages. Related t-tests ($p<0.01$) revealed that in all rural areas (apart from Keswick and Collingham), system use fell on Drive 3 compared to Drive 2 (Table 8.14).

Table 8.14: Change in system use – rural areas

Section (speed limit)	Change in system use (from Drive 2 to Drive 3)
Redhall (60)	↓26.80
Ling (40)	↓14.41
Wayside (60)	↓18.12
Church (40)	↓18.54
Keswick (60)	↑ 0.89
Collingham (30)	↑11.19
A64 (60)	↓19.47

Figure 8.14 shows how drivers used the system in a rural village. Drivers tended to turn the system off in order to exceed the speed limit. This is particularly true for drivers 5, 6 and 7 (all of whom were male drivers).

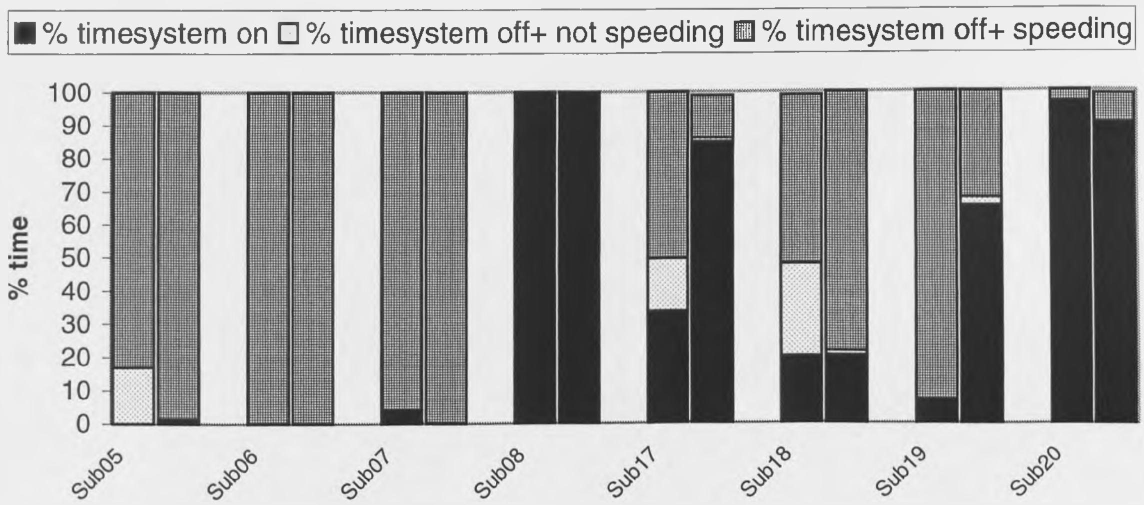


Figure 8.14: System use and speed choice: village 30 mph speed limit (Driver Select ISA)

Figure 8.15 shows how drivers used the system on the rural 60 mph roads. Here, the same drivers tended to have the system disengaged, even though they did not exceed the speed limit. This was probably due to the fact that the road geometry and the presence of other traffic prevented them from doing so, although maybe they have kept it disengaged in case there was an opportunity to overtake.

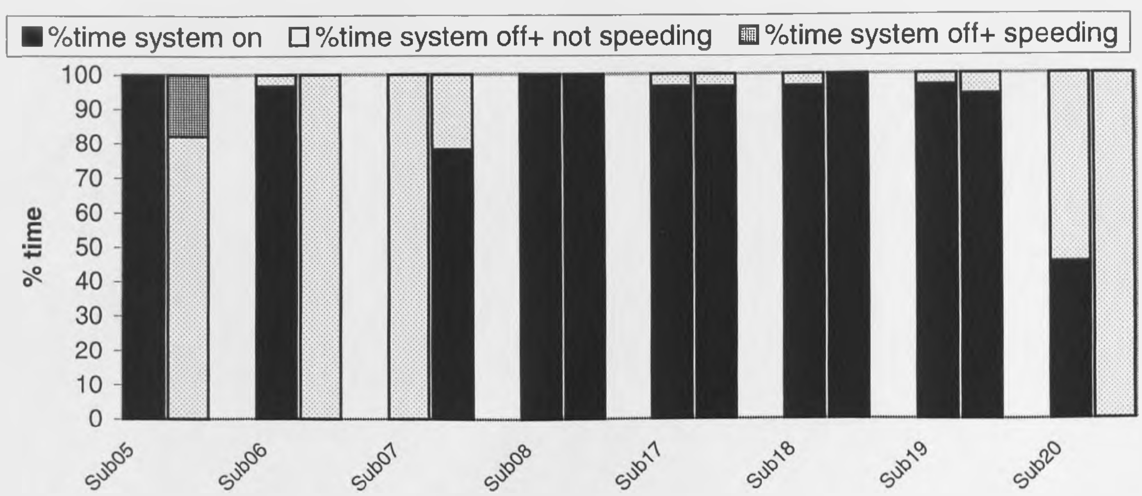


Figure 8.15: System use and speed choice: rural 60 mph speed limit (Driver Select ISA)

Where the ISA system would be most effective is in the rural villages. However it was in these areas that drivers were more inclined to switch the system off. These rural areas demonstrate the difficulty that some drivers have in adapting their speed at changes in the speed limit. These types of rural environments are notorious for speeding problems, and villages are often treated with traffic calming measures. In addition, the drivers who took part in this study were undoubtedly pressurised by the traffic behind them, and were inclined to switch the system off in order to maintain the traffic flow.

8.3.2.3 Motorway

The motorway provided the opportunity of discovering how drivers interacted with the system in a more dynamic environment, where they were required to maintain headway and overtake (Table 8.15).

Table 8.15: Use of the Driver Select System – motorway

Section (speed limit)	Drive No.	% time system on	% time above speed limit
A1M (70)	1	0.00	37.00
	2	66.37	38.00
	3	54.82	31.15

All but two drivers turned the system off at some point on the motorway (Figure 8.16). A related t-test revealed no change in system use from Drive 2 to Drive 3 [$t(7)=5.17$; $p<0.01$]. It can be seen that drivers did not necessarily exceed the speed limit when the system was disengaged. The drivers may have forgotten to switch the system back on or they may have left it off in case they needed to overtake.

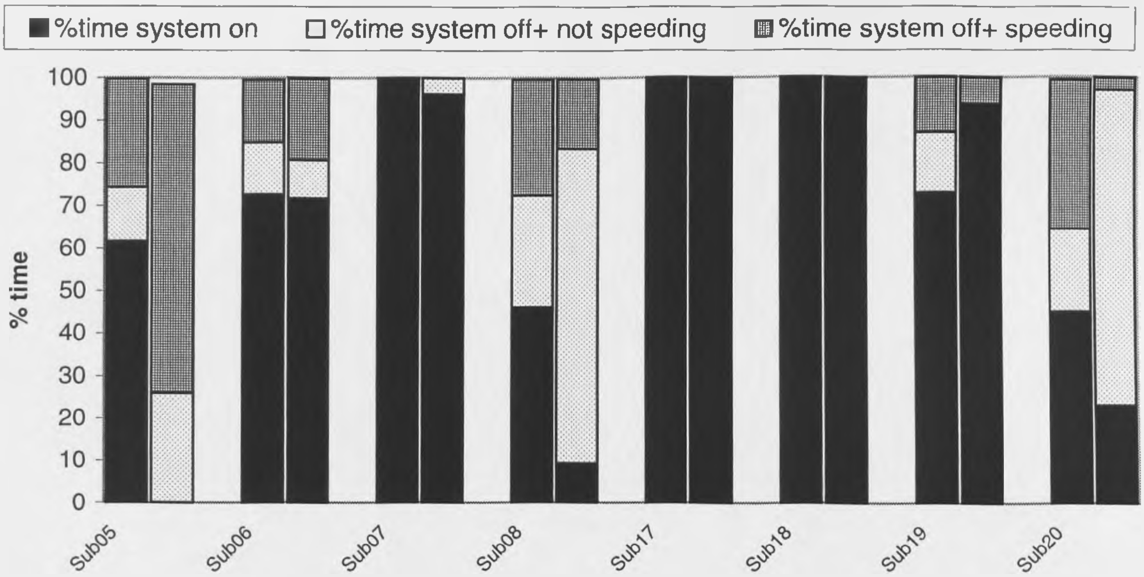


Figure 8.16: System use and speed choice: 70 mph speed limit (Driver Select ISA)

8.3.3 Retardation

A measure of the amount of retardation the ISA system applied (range=0-90) was recorded throughout the entire drive. Retardation provided an estimate of how drivers interacted with the system in terms of their desire to exceed the speed limit and "fight" the system. A measure of severe retardation, where a value of 45 was exceeded was also calculated. For clarity, only the results for the Mandatory system are presented. As can be seen in Table 8.16, drivers tended to fight the system in the urban areas, especially in the sections where the road environment encouraged excess speed (the 40 mph limit sections).

Table 8.16: Mean values of retardation – urban areas

Section (speed limit)	Drive No.	% time retardation active	% time severe retardation active (>45)
Harehills (30)	2	32.85	21.72
	3	27.73	18.51
Upland (40)	2	49.10	22.34
	3	59.80	35.58
Crossgates (40)	2	39.08	28.59
	3	39.61	26.47

This reflects the results found for the Driver Select system, as it was in these areas that drivers tended to disengage the system in order to exceed the speed limit. Likewise, drivers tended to have low values of retardation in the rural areas that had a higher speed limit. As discussed previously, this is due to the fact that the road environment and geometry meant that drivers were often unable to exceed the posted speed limit anyway. We can see, however, in Table 8.17 that in the rural villages (30 and 40 mph speed limit) drivers attempted to fight the system with regularity.

Table 8.17: Mean values of retardation – rural areas

Section (speed limit)	Drive No.	% time retardation active	% time severe retardation active (>45)
Redhall (60)	2	17.17	7.35
	3	12.93	3.42
Ling (40)	2	82.68	71.11
	3	75.39	60.12
Wayside (60)	2	20.68	7.97
	3	21.61	3.12
Church (40)	2	77.40	57.18
	3	78.58	49.79
Keswick (60)	2	11.74	0.84
	3	30.42	16.28
Collingham (30)	2	86.11	81.21
	3	79.26	67.03
A64 (60)	2	19.51	8.80
	3	6.80	0.85

On the motorway too, the retardation was less severe (Table 8.18).

Table 8.18: Mean values of retardation – motorway

Section (speed limit)	Drive No.	% time retardation active	% time severe retardation active (>45)
A1M (70)	2	24.75	7.63
	3	33.77	10.33

8.3.4 Behavioural observations

8.3.4.1 Negative interactions and conflicts

The Wiener Fahrprobe allowed the scoring of various interactions with other road users. Observations were made at both junctions and links. The following negative behaviours were scored:

- Unsafe merging/gap acceptance at junctions
- Incorrect lane changes
- Ignoring other road users e.g. by not adapting their speed
- Unsafe overtaking manoeuvres
- Adoption of short headways

A count was made of the total of these behaviours for each subject (Figure 8.17). Chi-square analyses revealed no differences in the numbers of negative interactions between the drives for any of the three groups.

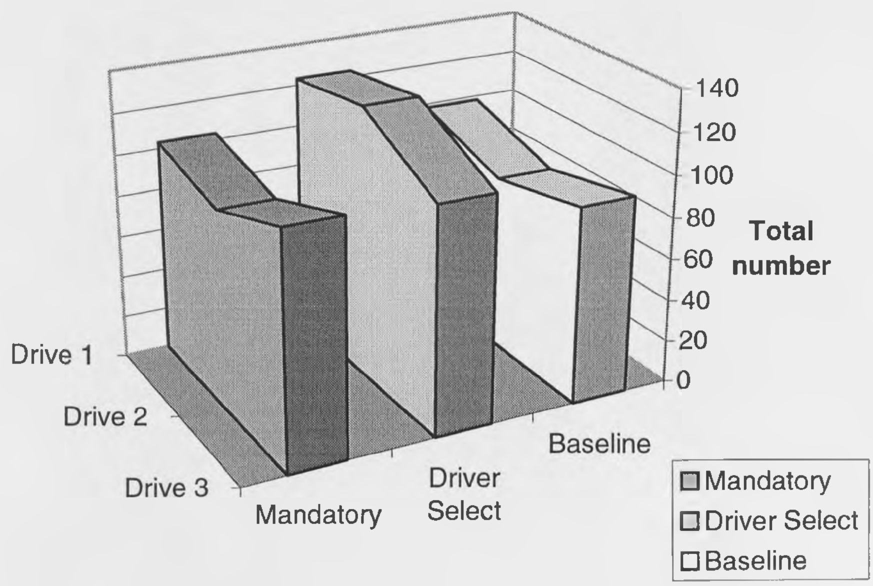


Figure 8.17: Total number of negative interactions

The second observer recorded critical events, such as those requiring intervention from the driver. Each time a critical event was observed, it was recorded and a note was made of the circumstances. The total number of critical events or conflicts is shown in Figure 8.18.

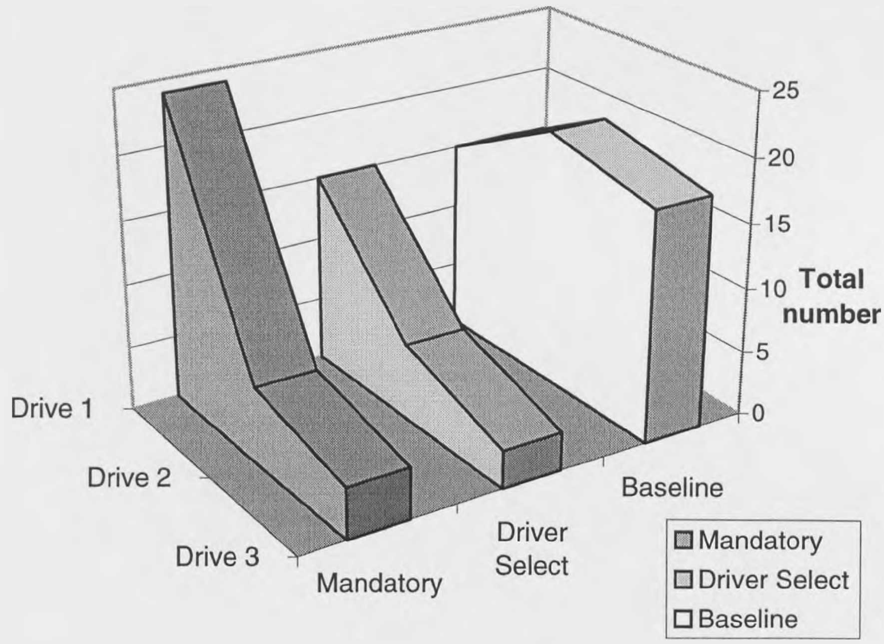


Figure 8.18: Total number of critical events or conflicts

It can be seen that critical events occurred less when ISA was active. In the Baseline condition, critical events increased slightly with increased familiarity of the route. Chi-square analyses indicated no significant changes in the Baseline group. In contrast, there were significant decreases in the total number of conflicts for the Driver Select [χ^2= 9.75 (df=2); p<0.01] and Mandatory groups [χ^2= 21.41 (df=2); p<0.01] when ISA was active.

8.3.4.2 Overtaking

One of the observers made a count of the number of times the driver overtook other vehicles and the number of times the driver was overtaken by other vehicles on each section of the route. It should be noted that this calculation of course depended on the traffic flow on each separate drive and thus the results should be treated with caution. There was no consistent pattern of change in overtaking behaviour exhibited by the volunteer drivers (Table 8.19). With the Driver Select system there was first a decrease in overtaking and then an increase. With the Mandatory system, there was first an increase and then a decrease. Chi-square analyses revealed no statistically significant differences for any of the groups, depending on the drive.

Table 8.19: Average no. of times driver overtook other vehicles

Group	Cars *[HGVs]*		
	Drive 1	**Drive 2**	**Drive 3**
Baseline	40 *[32]*	45*[27]*	50 *[35]*
Driver Select	30 *[29]*	20 *[25]*	37 *[25]*
Mandatory	22 *[36]*	29 *[26]*	16 *[28]*

However there is a clear pattern in terms of how the surrounding traffic on the road interacted with the volunteer drivers. Table 8.20 shows that the drivers were passed more often when they were driving with an ISA system. Chi-square analyses revealed significant differences in the number of times drivers were overtaken in both the Driver Select [χ^2= 42 (df=2); p<0.001] and Mandatory [χ^2= 48 (df=2); p<0.001] groups. The frequency of being overtaken was almost double when drivers were equipped with ISA. A similar result was found by Persson et al. (1993) where cars with ISA were passed 60% more frequently than cars without. As would be expected, there were no significant differences in the Baseline group.

Table 8.20: Average no. of times other vehicles overtook driver

Group	Cars *[HGVs]*		
	Drive 1	**Drive 2**	**Drive 3**
Baseline	52 *[8]*	61*[4]*	55*[6]*
Driver Select	45 *[5]*	83 *[6]*	70 *[4]*
Mandatory	43 *[5]*	87 *[7]*	75 *[4]*

This feeling of being overtaken more frequently than they would normally may have contributed to some of the negative opinions expressed in the questionnaires (see below). However, this is a characteristic of driving with ISA in a mixed traffic scenario and would undoubtedly be reduced if system penetration was higher.

8.3.5 Performance ratings

At the end of each driving session, the two observers independently completed the performance rating scales. On each of the dimensions, a score between 0-100 was given for performance, where 0 = poor performance and 100 = excellent performance. From these independent observer scores, an average score for each dimension across participants was calculated. An inter-rater correlation coefficient was also calculated for each of the dimensions as an indication of the amount of agreement between observers.

Figure 8.19 shows the average scores given on the nine dimensions for each of the three Drives. The inter-rater correlations, shown on the secondary y-scale, are generally high, indicating a good level of agreement between the observers. It can be seen that performance improves when drivers used the Mandatory ISA system on all dimensions, except those where the inter-rater correlations were relatively low (gap acceptance and junction preparedness). One-way ANOVAs performed separately on each of the performance indicators revealed that with Mandatory ISA, drivers selected more appropriate speed for the conditions [F(2,14)=8.45; p<0.01] and exhibited smoother braking [F(2,14)=7.17; p<0.01].

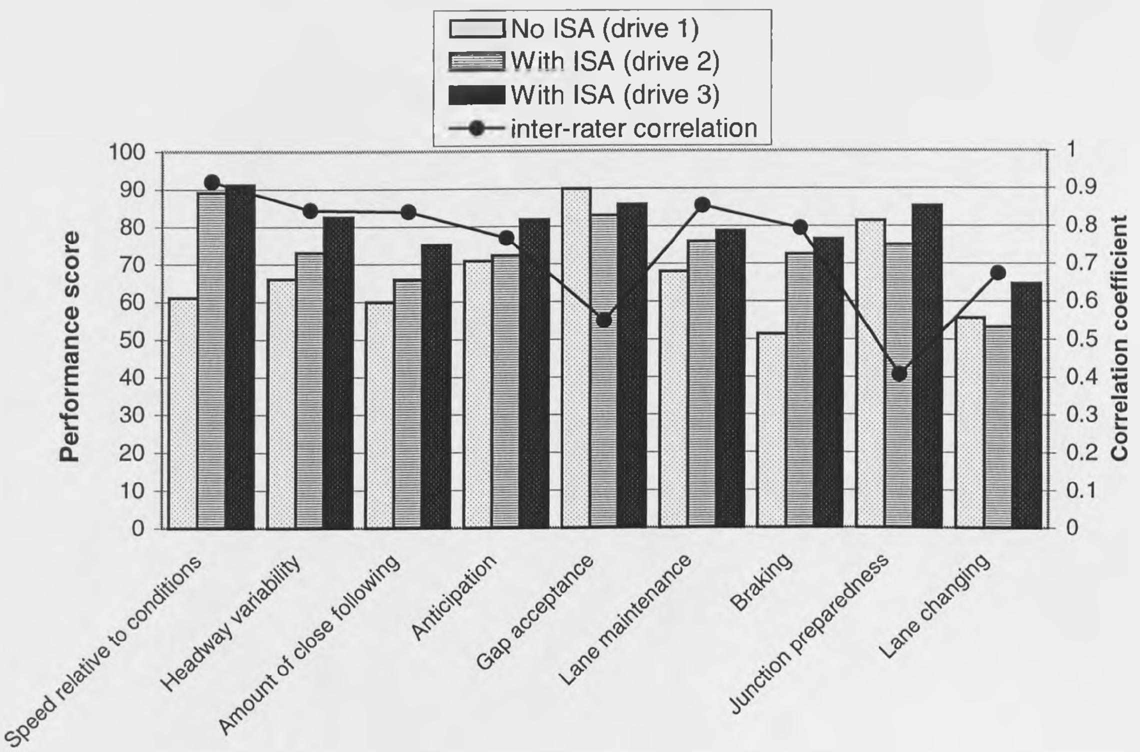


Figure 8.19: Driver performance ratings (Mandatory ISA)

In contrast, Figure 8.20 shows the scores obtained for the Driver Select system. None of the performance ratings changed over time.

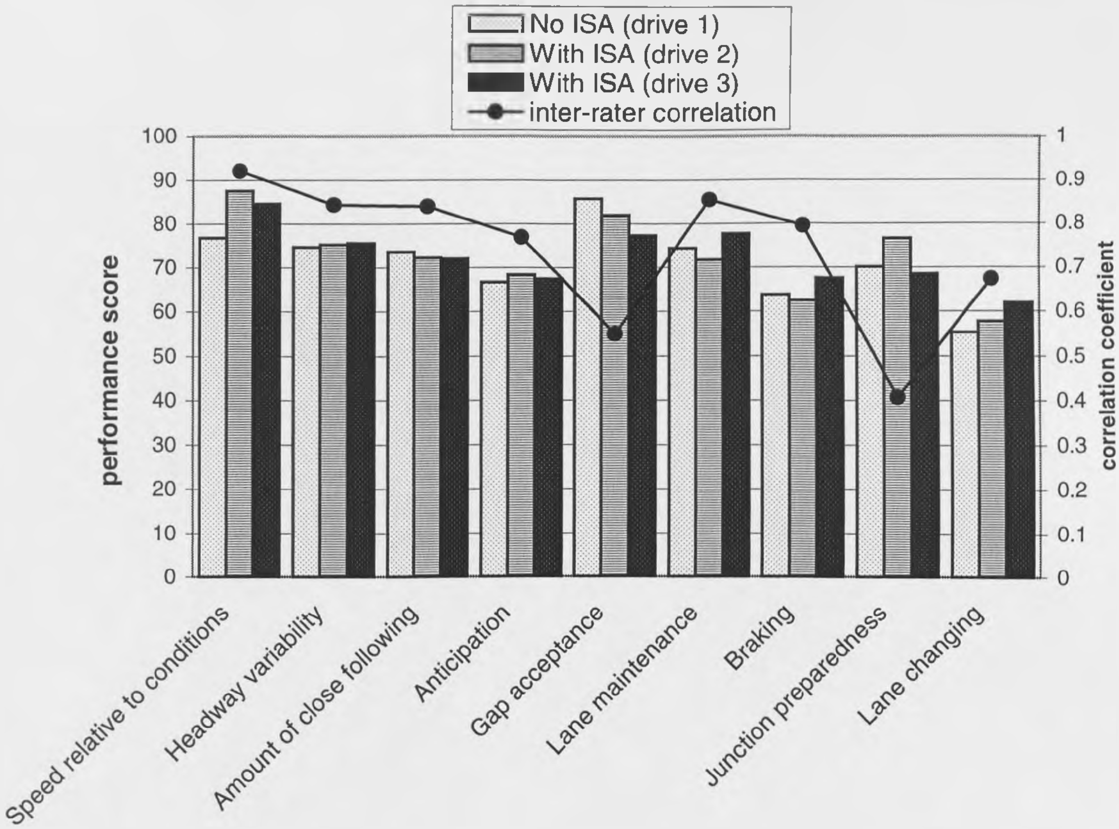


Figure 8.20: Driver performance ratings (Driver Select ISA)

Unlike the Mandatory system scores, there was no pattern of increase across the dimensions. Instead driver performance appears relatively stable across the three Drives.

8.3.6 Workload

Subjective mental workload was measured using two standard workload questionnaires. The first, the NASA RTLX used measurement on six dimensions of workload to obtain an overall score. This was administered after each drive in order to ascertain differences in reported mental workload when driving with and without the ISA system.

Figure 8.21 shows the workload scores obtained on the six dimensions of the NASA RTLX questionnaire for the Mandatory system. There were found to be System effects for time pressure [$F(1,7)=7.29$; $p<0.01$] and frustration [$F(1,7)=10.87$; $p<0.01$] such that scores increased on these dimensions when Mandatory ISA was active. There were no effects of Exposure suggesting that these increases were stable.

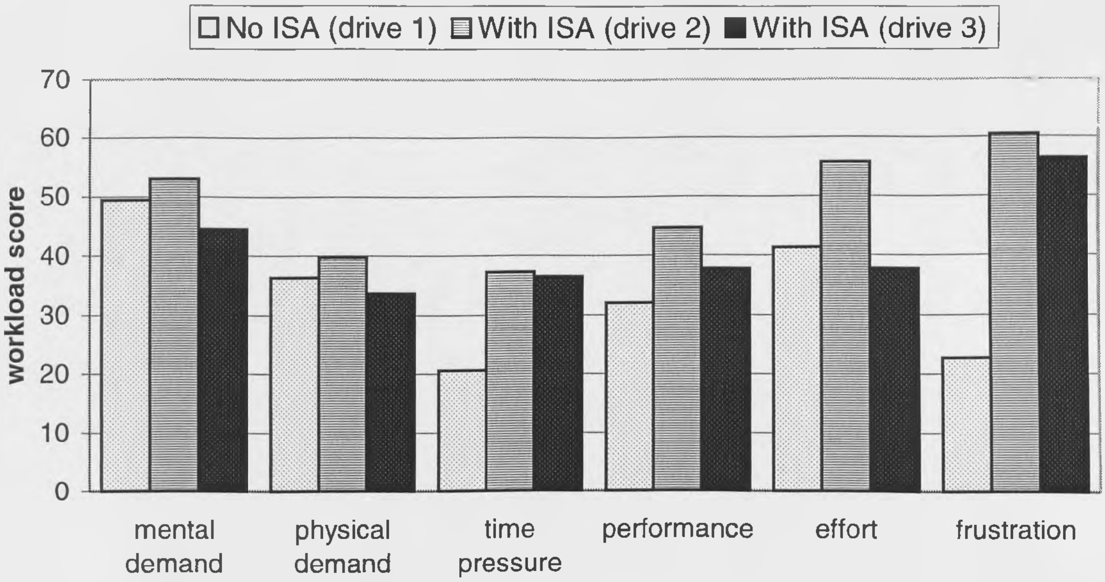


Figure 8.21: Mental workload scores: NASA RTLX (Mandatory ISA)

For the Driver Select group (Figure 8.22) there were found to be System effects for time pressure [$F(1,7)=5.71$; $p<0.05$] and frustration [$F(1,7)=9.34$; $p<0.01$] such that scores increased on these dimensions when Driver Select ISA was available. There was also an Exposure effect for these dimensions: the increases were only present on Drive 2. After Drive 3, the scores returned to their baseline level.

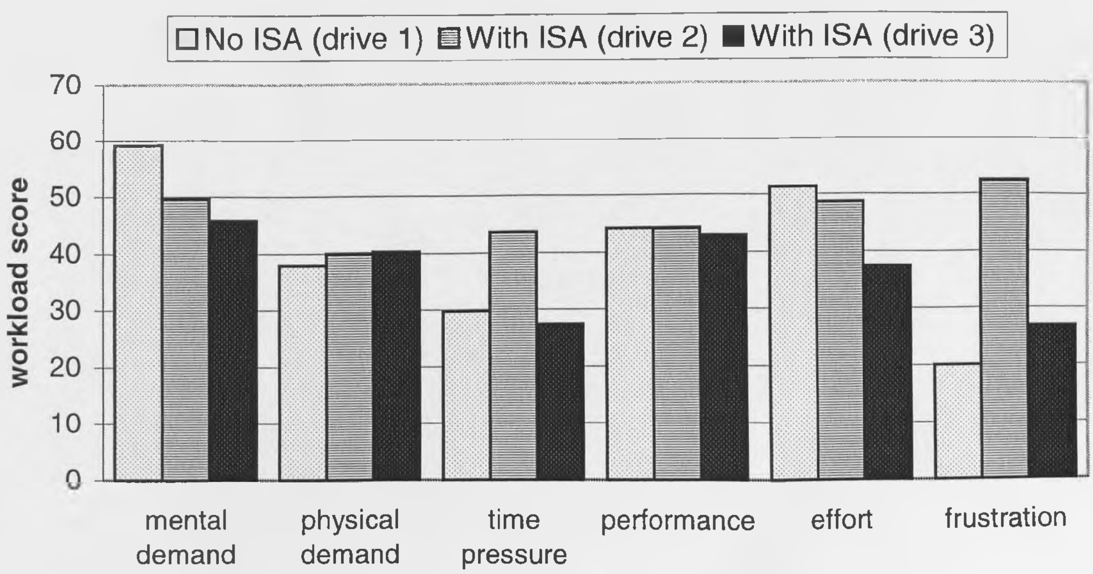


Figure 8.22: Mental workload scores: NASA RTLX (Driver Select ISA)

The second workload measurement questionnaire (uni-dimensional RSME) showed an increase in reported mental workload in the final urban section of road (Figure 8.23). A number of drivers commented that this was a difficult section of road to adapt to with the ISA system, due to the amount of fast traffic and necessary lane changes.

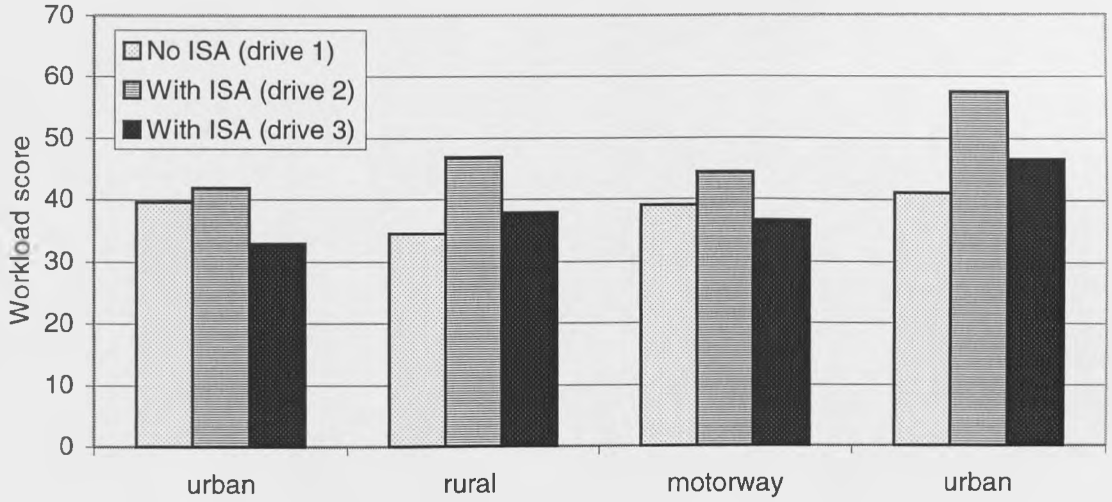


Figure 8.23: Mental workload scores for different road types: RSME (Mandatory ISA)

8.3.7 Acceptability

8.3.7.1 Rating scales

Driver acceptance of the systems was measured using an acceptability scale developed by Van der Laan et al. (1997). This allowed drivers in the study to express opinions about the systems in terms of "usefulness" and "satisfaction" using nine items. Scores were taken before drivers had experienced the system (the system was described to them with written instructions). In addition the questionnaire was administered after each test drive with the system activated. This served to indicate any preconceptions drivers might have about the system and demonstrate whether use of the system improved driver acceptability. An end-score for each subject on the two dimensions of "usefulness" and "satisfaction" was calculated for each system.

Figure 8.24 shows that drivers, in general, believed the Driver Select system to be more useful than the Mandatory system. There were no System or Exposure effects.

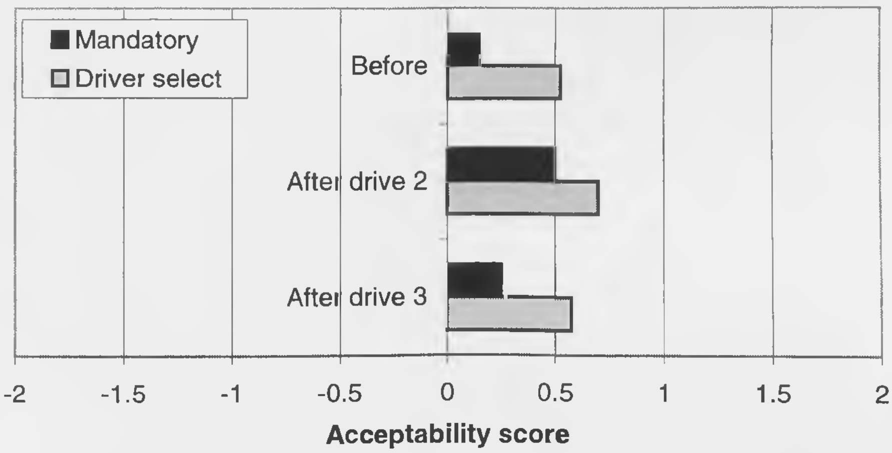


Figure 8.24: Acceptability ratings on the dimension of "useful"

Figure 8.25, shows that overall drivers thought the Mandatory system to be less satisfying, in terms of irritation and desirability, than the Driver Select system. Although these scores tended to decrease after use, there were no statistically significant effects of System or Exposure.

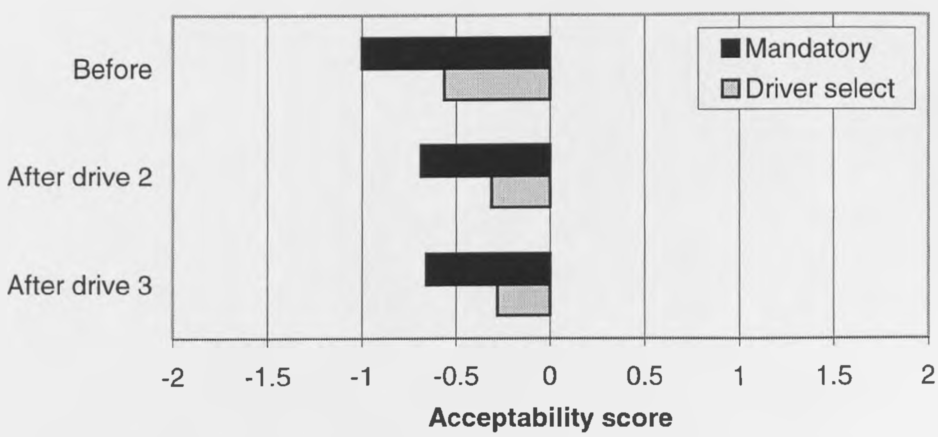


Figure 8.25: Acceptability ratings on the dimension of "satisfaction"

Additional attitudinal scores were obtained using a checklist of statements, both positive and negative, some of which were obtained during focus group discussions held previously (Comte et al., 2000). Drivers completed these ratings at the same time as the acceptability ratings reported above, thus providing three sets of scores each (Table 8.21).

Table 8.21: Driver opinion

I would view an ISA system as:	Agreement scores (1=disagree completely, 5= agree completely) Driver Select [Mandatory]		
	Before	After Drive 2	After Drive 3
A safety system	4.75 [3.63]	4.25 [3.50]	4.50 [3.50]
A driving aid	3.63 [3.75]	3.50 [3.25]	3.38 [3.13]
An interference to driving	3.00 [3.38]	4.00 [4.13]	3.63 [3.63]
A source of frustration	3.38 [4.00]	3.75 [4.00]	3.63 [4.00]
Useful in built-up areas	4.38 [4.38]	4.13 [4.00]	4.00 [3.63]
Useful in rural areas	2.75 [2.88]	3.00 [2.75]	3.13 [2.75]
Useful on motorways	3.25 [2.75]	3.50 [3.38]	3.25 [3.00]
Increasing driver comfort	2.75 [2.25]	2.88 [2.50]	3.25 [2.75]
Create difficulties when overtaking	4.00 [4.63]	4.50 [4.50]	4.13 [4.63]
Prevent acceleration out of danger	4.00 [3.63]	4.13 [4.00]	4.50 [4.25
Making the driver less vigilant	3.00 [2.63]	3.13 [2.50]	3.38 [2.38]
Exerting greater time pressure	3.50 [3.63]	3.63 [3.38]	3.38 [3.50]
Taking the fun out of driving	3.75 [3.13]	3.50 [4.50]	3.63 [4.50]

There were no statistically significant effects of System or Exposure for any of the items. In general terms, driver opinion about the systems changed little over the course of the trials. It did appear however that the Driver Select system was viewed as more of a safety system than the Mandatory was and less of a source of frustration. Both the systems were thought to be more useful in built-up areas as opposed to rural and motorway areas, but drivers also thought the systems would create difficulties when overtaking and prevent acceleration out of danger. These points were often mentioned in the focus group discussions as being possible negative safety effects, and it can be seen that even with use of the system, these preconceptions do not diminish, and the latter is actually slightly reinforced. Finally, it can be noted that drivers using the

Mandatory system became more of the opinion that it takes the fun out of driving as their experience with the system increased.

8.3.7.2 System evaluation

At the end of the experiment drivers were asked to complete a system evaluation form, containing both open and closed questions. Where possible, common themes in the open questions have been summarised.

Table 8.22: How would you describe your attitude to ISA?

Group	Very negative	Slightly negative	Neutral	Slightly positive	Very positive
Driver Select	1	1	0	5	1
Mandatory	1	3	1	2	1

As in the acceptability exercise, drivers expressed a more positive attitude towards the Driver Select than the Mandatory system, with half of those who used the Mandatory system reporting a "slightly" or "very" negative attitude. This negative attitude may be as a result of the amount of discomfort the drivers experienced, with half the sample reporting they felt the Mandatory system made driving "much more uncomfortable".

Table 8.23: Did using ISA make driving more or less comfortable?

Group	Much more uncomfortable	A little more uncomfortable	No change	A little more comfortable	Much more comfortable
Driver Select	1	4	2	0	1
Mandatory	4	2	0	1	1

The reasons for the discomfort included drivers feeling they were not "in control" of the car; the system disrupted "normal" driving habits (presumably speeding) especially when entering rural villages. The system also made them feel vulnerable as they were driving much more slowly than the surrounding traffic and felt this annoyed other drivers.

Table 8.24: Did using ISA make your driving more or less safe?

Group	Much less safe	A little less safe	No change	A little more safe	Much more safe
Driver Select	0	1	0	5	2
Mandatory	0	3	2	3	0

Drivers using the Driver Select system reported that they drove more safely, with those who reported feeling less safe with the Mandatory system stating that this was due to the fact that they were unable to accelerate to above the speed limit. These drivers felt they were at a disadvantage when attempting to overtake or merge into traffic. The responses partly reflected the fact that these drivers mentioned they were aware of close following traffic when they were unable to exceed the speed limit and this was therefore deemed as unsafe.

Table 8.25: Did you pay more or less attention to the other aspects of driving while using ISA?

Group	Much less attention	A little less attention	No change	A little more attention	Much more attention
Driver Select	0	3	3	2	0
Mandatory	0	0	2	4	2

Drivers with the Mandatory system felt they paid more attention to the driving task. They reported having to be more aware of upcoming hazards, for example, parked cars, and overtaking manoeuvres, so they could pull out in advance and avoid being blocked in. They also reported they felt they had more time to make decisions due to their lowered speed. Those with the Driver Select system reported a reduction in attention, the reason being that this was a result of having to interact with the Driver Select system, using the on/off buttons.

Table 8.26: In your opinion, would ISA make people drive more safely?

Group	Yes, definitely	Yes, probably	No, probably not	No, definitely not
Driver Select	2	5	1	0
Mandatory	1	5	2	0

Table 8.27: In your opinion, would ISA make people commit less driving offences?

Group	Yes, definitely	Yes, probably	No, probably not	No, definitely not
Driver Select	4	3	1	0
Mandatory	3	3	2	0

Table 8.28: Would you have this system installed in your own car on a voluntary basis if it cost in the region of £100?

Group	Yes, definitely	Yes, probably	No, probably not	No, definitely not
Driver Select	1	1	4	2
Mandatory	1	1	1	5

Drivers mostly agreed that ISA would make people driver more safely and commit fewer driving offences. However, drivers were resistant to the idea of actually owning one, especially if it was Mandatory. A summary of responses to the open ended questions is given in Appendix H.

8.3.8 Driving style

The scores for the three speed factors on the DSQ were combined for each driver. For the Mandatory group, correlation analysis was carried out on the variables of DSQ total score, age and acceptability scores (Table 8.29).

Table 8.29: Correlation analyses for DSQ (Mandatory ISA)

		Age	**Acceptability**
DSQ Total	Pearson's r	-0.80	-0.60
	Sig. (1-tail)	0.01	0.05
Age	Pearson's r		0.34
	Sig. (1-tail)		0.20

As would be expected, as DSQ scores rise (i.e. the propensity to speed increases) acceptability scores for the Mandatory system fall. The results indicate that DSQ scores decrease with age and that acceptability decreases with increasing DSQ scores. This suggests that younger drivers have a higher likelihood of speeding and that this leads to decreased acceptability of the ISA system. This seems logical given the fact that ISA prevents them from engaging in speeding behaviour.

An identical correlation analysis was performed for the Driver Select group, this time including the additional variable of system use. This was calculated as the average total time drivers engaged the system over the two drives. The results can be seen in Table 8.30.

Table 8.30: Correlation analyses for DSQ (Driver Select ISA)

		Age	Acceptability	System use
DSQ Total	Pearson's *r*	-0.02	-0.11	-0.72
	Sig. (1-tail)	0.48	0.40	0.02
Age	Pearson's *r*		0.75	0.05
	Sig. (1-tail)		0.02	0.45
Acceptability	Pearson's *r*			0.39
	Sig. (1-tail)			0.17

The correlation matrix indicates that, in contrast to the Mandatory group, acceptability increased as age increased. Therefore, although the acceptability scores were higher for the Driver Select group in general, only the older drivers were in favour of it. There was a negative correlation between system use and DSQ scores, i.e. those drivers who admit to speeding were less likely to engage the Driver Select system.

8.4 Predicted accident savings

The recent TRL work which modelled the relationships between speed and accident frequency (Taylor et al., 2000) concludes that the potential for achieving accident reductions on urban roads depends on the characteristics of the road in question. A national sample of A, B and C class urban roads were surveyed to included data on traffic flow, pedestrian activity, road geometry and visibility, amongst others. Using the accident data from the STATS 19, the relationship between accidents, road features and traffic flows was studied. The database was enhanced using speed measurements from a subset of 100 randomly selected links. A cluster analysis grouped the links according to their overall speed characteristics using various measures of the speed distribution. Four clusters were identified:

1. Congested roads in towns
2. Inner city link roads
3. Suburban link roads
4. Outer suburban fast roads

Some of the characteristics of these four clusters can be seen in Table 8.31.

Table 8.31: Average characteristics of road clusters (adapted from Taylor et al. 2000)

Road characteristic	Group			
	1	2	3	4
Mean speed (mph)	20.9	24.8	28.7	33.0
Proportion of speeders %	6	18	40	47
Total vehicle flow AADT	11038	9154	9927	9658
Pedestrian flow (12 hours)	7840	4935	2898	2094
Accidents per year	5.4	5.0	3.2	2.7

Using an urban accident model developed to predict the effects on accidents of changes in these explanatory variables, the combined effect of changes in both mean speed and speed variance on accident frequency was calculated for each of the four road groups. The resulting accident frequency versus mean speed curves are shown in Figure 8.26.

Each curve represents the combined effect of mean speed and speed variance on accident frequency, with all other factors held constant. The most noteworthy point with regards to speed management tools is that the data suggests that on roads with lower mean speeds, a change in the mean speed has a bigger effect on accident frequencies than on roads with higher mean speeds. The authors argue that:

"roads in Group 1 are characterised by being heavily congested, older town centre types of road while those in Group 4 are more modern, well engineered suburban types of road."

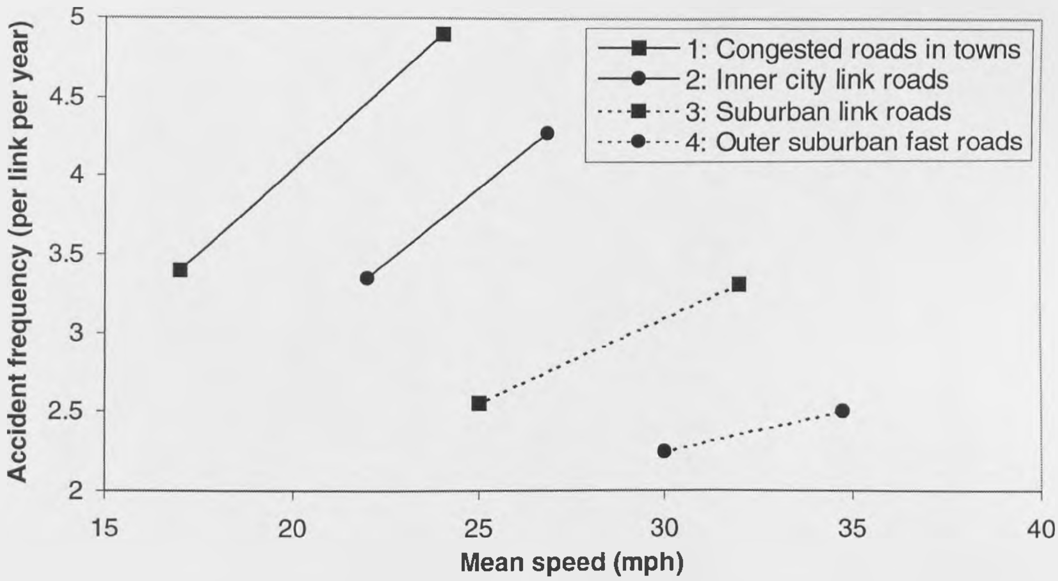


Figure 8.26: Accident frequency against mean speed for urban roads (from Taylor et al. 2000)

The expected percentage reduction in accident frequency per 1 mph reduction in mean traffic speed was then calculated (Figure 8.27). The authors conclude that on average for the slower urban roads with a mean speed of 20 mph, there is a potential accident saving of 7% in comparison to a 2% saving on roads with a mean speed of 34 mph.

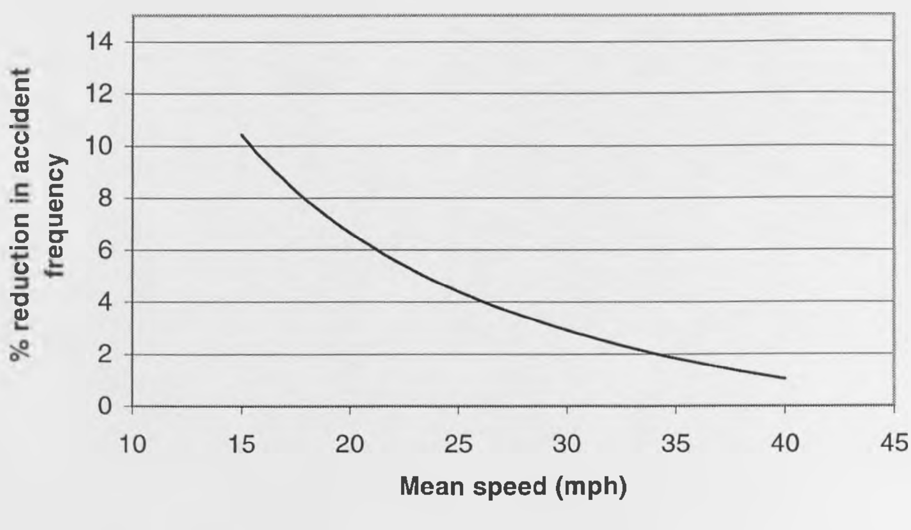


Figure 8.27: Predicted accident savings per 1mph reduction in mean speed (adapted from Taylor et al. 2000)

This model was used to calculate the likely accident savings to be obtained from implementing ISA on the roads in the on-road trials. Whilst it is noted that the data collected in the on-road trials reported in Chapter Eight is limited in terms of the number of vehicles involved, the data was collected over the whole length of the link, providing a certain amount of accuracy. The accident benefits have been calculated for both the Mandatory and the Driver Select ISA systems separately for each of the urban road sections discussed in Chapter Eight. The mean speeds observed for each road section without ISA (i.e. Drive 1) were used to classify the road in terms of the achievable accident reductions as defined in Table 8.25. This provided the likely accident reductions for each 1mph reduction in mean speed for that road. The observed reductions in mean speed with ISA (i.e. Drive 3) were then used to predict accident savings for the road in question. Table 8.32 shows the calculations made for the Mandatory ISA.

Table 8.32: Predicted accident savings from the on-road trials (Mandatory ISA)

Road section (speed limit)	Mean speed (mph)	Accident reduction (per 1 mph)	Reduction in mean speed (mph)	Predicted accident reduction (%)
Harehills (30)	17.66	8.15	1.83	14.92
Upland (40)	35.62	1.72	3.27	5.63
Crossgates (40)	28.30	3.36	3.13	10.51
Ling (40)	42.72	0.67	↑ 1.66	↑ 1.11
Church (40)	41.12	0.88	5.21	4.57
Collingham (30)	33.96	2.03	7.51	15.26

The on-road study was able to demonstrate substantial reductions in mean speeds in urban areas and rural villages. Whilst there were reductions in speed in areas such as Upland and Church, these roads are generally built to a higher standard and had a higher mean speed and lower pedestrian activity. The figures reported in Table 8.32 predict that areas such as Harehills, Crossgates and Collingham would benefit the most from speed management schemes, with Mandatory ISA promising a reduction in injury accidents in the range of 10-15%. This is broadly in line with the lowest predictions made by Carsten and Tate (2000). They estimated that with Mandatory ISA, a reduction of 10% in all accidents in non-built up areas would accrue.

Whilst there are some small reductions in predicted accident frequency with the Driver Select ISA system, for the data available from this on-road trial the relative benefits compared to a Mandatory system are less than half.

Table 8.33: Predicted accident savings from the on-road trials (Driver Select ISA)

Road section (speed limit)	Mean speed (mph)	Accident reduction (per 1 mph)	Reduction in mean speed (mph)	Predicted accident reduction (%)
Harehills (30)	17.05	8.61	0.26	2.24
Upland (40)	35.00	1.83	0.90	1.65
Crossgates(40)	26.85	3.79	$\uparrow$ 0.64	$\uparrow$ 2.42
Ling (40)	41.20	0.87	$\uparrow$ 3.39	$\uparrow$ 2.94
Church (40)	40.21	1.00	0.43	0.43
Collingham (30)	30.50	2.78	$\uparrow$ 0.07	$\uparrow$ 0.19

These results are hardly surprising given the observation that drivers tended to disengage the system when it would have been most safety beneficial.

8.5 Conclusions

This on-road study evaluated two types of ISA system in an instrumented car. The evaluation investigated the potential safety benefits and costs of a voluntary ISA system (Driver Select system) and a Mandatory system. Volunteer drivers were asked to drive a pre-selected route, once with the system off and twice with the system on. Speed data were collected continuously along the route and two in-car observers made behavioural observations. Participants were asked to complete questionnaires related to workload, acceptability and system evaluation. The experimental route included a variety of speed limits and differing traffic environments.

With the Driver Select system, it was important to discover how likely drivers were to actually use the system. The analysis showed that in congested areas drivers were happy to leave the system engaged, but when the opportunity to exceed the speed limit arose, they generally chose to disengage the system. Thus, it was exactly in the locations that the system would have had the most impact, i.e. the rural villages and urban roads where traffic generally exceeds the speed limit, that drivers were more inclined to switch the system off in order to break the speed limit. It was also noted that drivers used the system less on their second drive, indicating there may be changes in behaviour depending on the amount of exposure to the system.

The Mandatory system, as would be expected, had a far greater impact on driver behaviour. Large reductions in maximum speeds were noted on most road sections, especially in urban areas and rural villages. The data shows quite clearly that in the absence of the ISA system, drivers were poor at adapting to low speeds after travelling through a higher speed limit area. The effect of the ISA system was also obvious in the speed distributions that were measured, as there was a "translation" of the distribution whereby the top end of the distribution was eliminated and driver speed was more concentrated around the speed limit. There appeared to be no change in the distribution at the lower end, indicating that drivers were not increasing their speeds in order to regain perceived lost time, nor were they driving with their speed "set" by the system.

Using the Wiener Fahrprobe, it was possible to observe driver behaviour in a standardised manner. By scoring events where drivers engaged in negative interactions, an overall impression could be gained as to whether the ISA systems encouraged any compensatory behaviour. The results indicated that this was not the case as negligible differences were found between the groups. In fact, some undesirable behaviour such as close following decreased. However, when the total number of conflicts was scored for each system, it was found that the propensity to be involved in a critical situation (whether instigated by the volunteer drivers or other road users) decreased when the system was engaged. Thus due either to decreases in speed when using the ISA system or a heightened awareness of the surrounding traffic situation, safer driving behaviour was encouraged. In the questionnaires, drivers with the Mandatory system felt they paid more attention to the driving task, and as a result were more aware of upcoming hazards. They also reported they felt they had more time to make decisions due to their lowered speed.

Subjective rating scales, which described subsets of driver behaviour, were completed for each subject by two observers. The observers' responses correlated well on most of the dimensions and driver behaviour was seen to improve when the Mandatory system was engaged. These included improvements in use of appropriate speed and following distances and less abrupt braking. These are undoubtedly as a result of the reduced speed having secondary impacts on other characteristics of driver behaviour.

From both the questionnaires and the mental workload evaluation, it seems that drivers required an adjustment period in order to familiarise themselves with the capabilities of the car when the ISA system was engaged. Reported mental workload increased initially but then decreased on familiarisation. However in other respects, familiarisation with the system did not change more resistant opinions. For example, drivers were of the opinion that an ISA system would create difficulties when overtaking and prevent acceleration out of danger. These opinions did not diminish with use of the system.

In terms of driver acceptance, the Driver Select system was thought to be more useful than the Mandatory system. Generally, driver opinion about the systems changed little over the course of the trials. The interviews revealed that drivers regarded the Driver Select system as more of a safety system than the Mandatory, and less of a source of frustration. Drivers thought the systems would be particularly useful in built-up areas. However, even after use of the system, driver still thought the systems would create difficulties when overtaking and prevent acceleration out of danger. These comments are probably as a result of the fact that the volunteer drivers were driving in traffic that was not speed controlled. Drivers commented this sometimes made then feel vulnerable, especially when other drivers followed too close behind as a result of not being able to keep up with the traffic flow ahead. When driving with the Mandatory system, other vehicles overtook drivers approximately twice as much as when they drove without. This probably contributed to driver's feelings of vulnerability and increased frustration. Drivers remarked that the reason they liked the Driver Select system was that they could disengage the system in these sorts of situations and thus overtake or keep up with the traffic, as they desired.

When scores on the DSQ were correlated with the acceptability scores it was found that as DSQ scores rose (i.e. the propensity to speed increased) acceptability scores for the Mandatory system fell. In addition the results indicate that DSQ scores decrease with age and that acceptability decreases with increasing DSQ scores. This suggests that younger drivers have a higher likelihood of speeding and that this leads to decreased acceptability of the ISA system. This seems logical given the fact that ISA prevents them from engaging in speeding behaviour. This finding is important with respect to the way in which ISA might be marketed. For example younger drivers (who have a higher accident risk anyway) may need an additional incentive to purchase and use an ISA system such as reduced insurance premiums.

An identical correlation analysis performed for the Driver Select group also included the additional variable of system use. In contrast to the Mandatory group, acceptability increased as age increased. More interestingly, there was a negative correlation between system use and DSQ scores. The interpretation here is that those drivers who admit to speeding were less likely to engage the Driver Select system. This is an important finding when considering the mechanisms for implementing ISA: those drivers who would benefit most would be less likely to use a voluntary system.

In summary, this on-road study was able to demonstrate that although drivers were somewhat hostile to a Mandatory ISA system, it proved to be beneficial in terms of reduced speeds and negative interactions. The Driver Select system was more preferred but in terms of safety was not as beneficial particularly as drivers tended to disengage the system where it would have been most helpful. The results obtained should be considered in the light of the fact that the volunteer drivers were interacting with non-speed controlled vehicles and this is likely to have affected acceptability ratings and the low use of the Driver Select system.

Chapter Nine

Conclusions

9.1 Overview

This thesis has reported a series of experiments designed to evaluate the effect of an innovative speed management method, Intelligent Speed Adaptation, on driver behaviour and safety. A number of key deficiencies in the past research were outlined in Chapter Three along with new issues that required investigation. Each of the studies intended to address a separate deficiency or issue and thus a number of research methodologies were used.

The driving simulator experiments allowed the study of behaviour in a controlled environment and participants were exposed to the same, choreographed events. Using a driving simulator permitted the compression of driving experience such that drivers encountered a number of critical events designed to evaluate safety. However, such studies can lack face validity, particularly when a system such as ISA (which both interacts with and changes the driving task) is under evaluation. Therefore an on-road study was also undertaken to provide drivers with the opportunity of interacting with an implemented ISA system in a natural environment.

The findings reported in this thesis range from the effects of ISA on measures of speed and its derivatives, interactions with the surrounding traffic (gap acceptance, headway and overtaking) and lateral control. A common theme across the different studies was the evaluation of system acceptability and workload.

With regards to the questions posed at the beginning of this thesis, the following conclusions are offered.

- **How effective is ISA compared to other speed management methods?**

  As would be expected due to the design of the system, ISA surpassed all the other tested treatments. In terms of user acceptability however, ISA was least liked.

Encouragingly, all the "non-ISA" treatments significantly reduced speeds when activated with very few differences between them. Thus the low-cost measures (e.g. transverse bars) were just as effective as technologically advanced ones (e.g. Variable Message Signs).

- **Do different ISA variants have different effects?**

The range of ISA systems tested provided some interesting results. Drivers preferred an ISA system that either provided advice or the option of disengaging it in comparison to one that exerted physical control. However, the benefits in terms of speed reductions for the voluntary system compared to mandatory one were approximately half. Drivers were inclined to disengage the voluntary system where it would have been of most benefit. With regards to the Variable system, whilst the benefits of reduced speed at particular black-spots are obvious, acceptability for this system was low.

- **How do drivers react to driving with ISA on different road types?**

In summary, the studies showed that most benefits are seen on urban roads, although this was probably in part due to the fact that a low standard of road design was employed in most of the studies. The on-road study showed quite clearly that in free-flow conditions, drivers disengaged the Driver Select system on a regular basis. The Mandatory system was most beneficial in speed limit transition zones, where drivers regularly have difficulty in adapting to a lower speed limit.

- **Does behaviour change with increased exposure to ISA?**

Two studies allowed the investigation of novelty effects. Some effects were noted in the simulator study that may indicate that drivers "gave up" trying to push the car in front. Overall, though, few changes in behaviour were observed on extended use, although it is recognised that further work needs to be undertaken to increase exposure.

The results obtained reflect both safety beneficial and safety detrimental changes in behaviour when driving with ISA. The next section looks at these changes in detail to ascertain how these changes may affect overall risk (using the parameters defined in

Chapter Three). These conclusions are reported in the next section. This chapter then goes on to detail the implications that the results have for the implementation of ISA and discusses areas for future research.

9.2 Synthesis of the results

This section describes the results in more detail and relates them to possible safety benefits. The safety critical measures described in Chapter Three will be used as a basis for describing any improvement or degradation in safety that may occur as a result of implementing ISA.

9.2.1 Mean speed

The changes in mean speed found in the three studies reported in Chapters Six, Seven and Eight are reported in Figure 9.1. The changes are reported separately for the urban, rural and motorway sections and are based on average changes across drivers on each of the road sections. The changes in speed are reported separately for the Mandatory and Driver Select (or Advisory) systems.

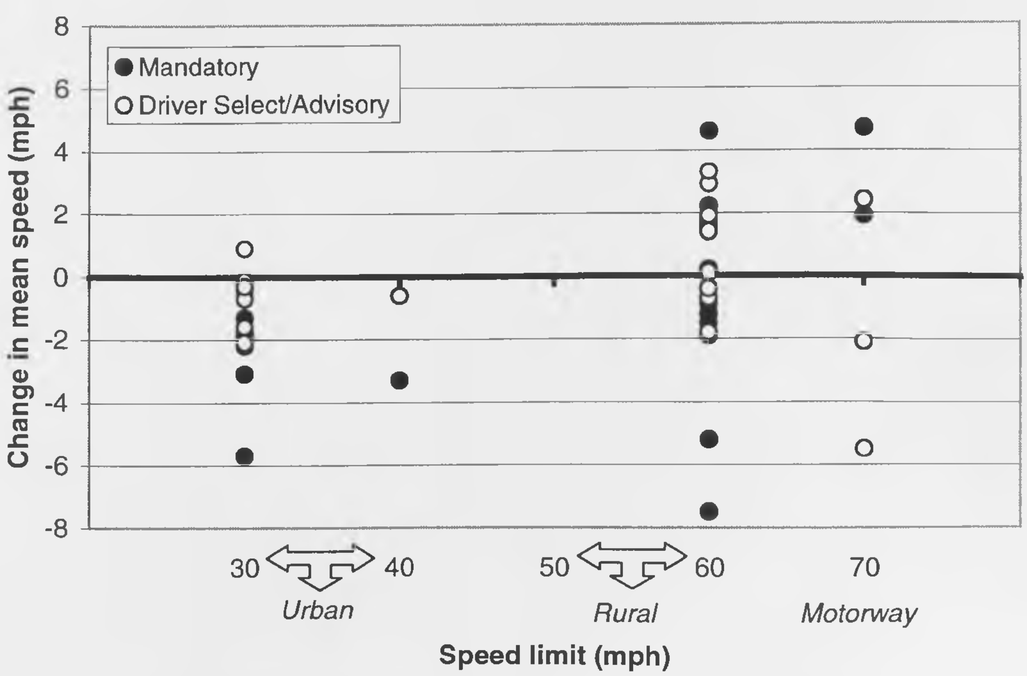


Figure 9.1: Change in mean speed when using ISA

The results from the three studies indicate general reductions in speed, particularly in the urban areas. Here, all the sites demonstrated decreases in speed with the

Mandatory ISA and most with a voluntary system. For the Mandatory system, this decrease was in the order of 3 mph, and with the voluntary system just over 1 mph.

With regards to the rural areas, reductions in speed were not so common with between 30-35% of sites showing average reductions in speed of 3 mph. However, this result is skewed by the inclusion of the large speed reductions (up to 5 mph) in the rural villages. Excluding these, the reduction is of the order of 1 mph. Some increases in speed were found, although these were generally small and not statistically significant.

Again, the results from the motorway data were mixed. The inconsistency in the results is probably due to the variation in traffic scenarios between the three studies and of course the between-subject variability.

9.2.2 Speed variance

As discussed in Chapter One, accident risk is likely to be related not only to the mean of the traffic speed but also its variance. A number of studies detailed in Chapter Three reported decreases in speed variation with ISA; the findings from the studies in this thesis are reported in Figure 9.2.

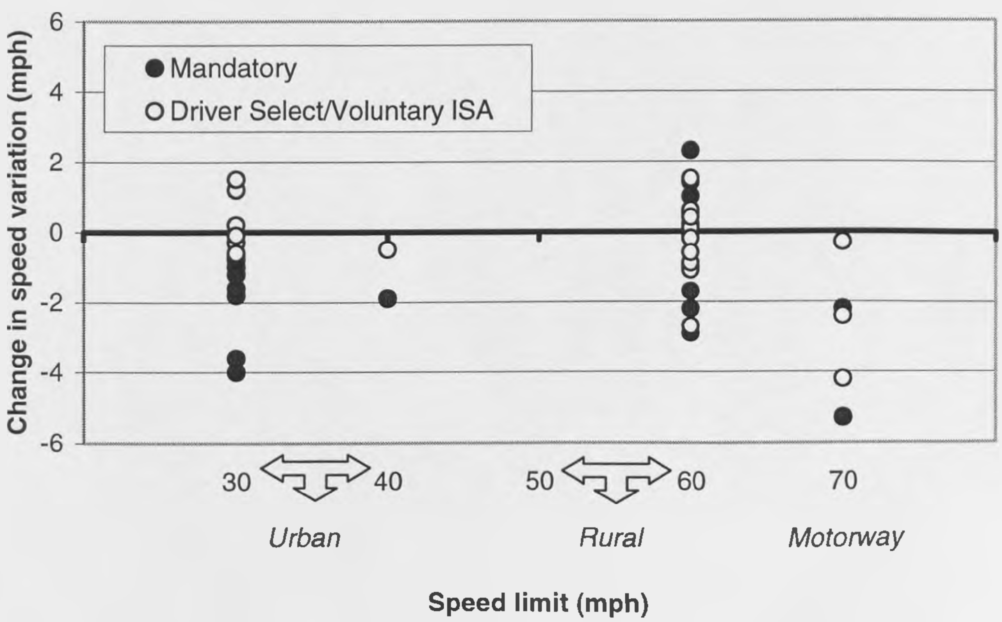


Figure 9.2: Change in speed variation when using ISA

In general the results reflect those of previous studies. The decreases in speed variation are most consistent in the urban areas with decreases in all but two road sections. The rural sections show mixed results with approximately half the road sections producing decreases in speed variation and the other half producing increases. These results are not unexpected given the road geometry on both the simulator and on-road trials; sharp curvature and overtaking were common which required decreases and increases in speed.

9.2.3 Car-following

Previous behavioural studies have used the measurement of headway as a risk indicator. Studies that report decreases in minimum headway tend to conclude that this implies *riskier* behaviour. Whilst in theory this is true, in practical terms *safety* may remain unaffected depending on the size of change in behaviour and whether this change is large enough to effect a change in safety.

The studies in this thesis reported changes in headway when driving with the Mandatory ISA system. The critical value of <1 second was used as identified by Evans and Wasielewski (1982) and the changes observed are reported in Table 9.1.

Table 9.1: Percentage of time spent at <1 sec headway with ISA on [and ISA off]

Study	Urban	Rural	Motorway
Chapter Four	8.76 [7.85]	-	-
Chapter Six	8.31 [0.47]	6.10 [0.00]	-
Chapter Seven	7.39 [4.58]	2.4 [0.67]	3.71 [2.41]
Average increase with ISA	*3.85*	*3.92*	*1.3*

The studies consistently show that in urban and rural areas drivers with ISA generally spent an additional 4% of their car-following time at less than one second headway. This represents a small increase in overall risk, considering that Olson and Sivak (1986) found that for an unexpected event the range of Perception Response Times was 0.8 - 1.8 seconds, with an average of 1.1 seconds. Therefore although for the average driver this increase in short headways may have little effect, those who are at the extreme end of the performance envelope or who suffer impairment may be exposed to more risk with ISA.

Whilst these results indicate that changes in headway behaviour have occurred, behavioural studies such as these are unable to estimate the overall effect in accident risk as a result of these changes. This is because accident risk in terms of headway keeping is dependant on the characteristics (speed, density) of the surrounding traffic and these studies looked at driver behaviour in isolation only. Results such as these are however a useful input into simulation modelling which can suffer from a lack of valid behavioural rules. Car following should be modelled accurately in order to be able to predict the effects of ISA that impact on driver behaviour.

9.2.4 Overtaking

As for headway, changes in overtaking with ISA and the impact of these changes on safety are difficult to quantify. Whilst the field studies showed no consistent pattern of change in overtaking behaviour, there was a clear pattern in terms of how the surrounding traffic on the road interacted with the volunteer drivers. The frequency of being passed was almost double when drivers were equipped with mandatory ISA. However it must be remembered that all the surrounding traffic was unequipped – a scenario that is unlikely to happen if implementation were to go ahead.

A mixed-traffic scenario would occur during implementation and, depending on the intensity of the roll-out procedure, there could be situations where increases in overtaking by non-ISA vehicles might cause safety problems. As the market penetration of ISA increased this would theoretically become less of a problem – as speed variation decreases and platooning increases. Some preliminary network modelling (Liu and Tate, 2000) simulated different levels of ISA penetration ranging from 0-100% and found that benefits in terms of speed distributions and journey time were relatively constant after 60% penetration. By the time penetration reaches this level the ISA equipped cars effectively control the speed of the surrounding traffic.

Studying overtaking at an individual level is therefore of little help in terms of safety prediction, except in terms of drivers' propensity to disengage a system in order to overtake. Whilst this was included as an area of interest in one of the simulator studies, the findings were inconclusive due to the small number of overtaking opportunities and learning effects of the simulator. Further studies should concentrate on overtaking scenarios and the results used to refine the behavioural rules for further microsimulation studies.

9.2.5 Gap acceptance

The studies reported in this thesis have consistently found changes in gap acceptance behaviour when driving with ISA. In the two studies that used this scenario (see Chapters Four and Seven) drivers accepted gaps that were approximately one second smaller when driving with ISA compared to their baseline behaviour (Table 9.2).

Table 9.2: Mean gaps (secs) accepted with ISA on [and ISA off]

	Driver Select	Mandatory	Variable
Chapter Four	-	3.9 [4.8]	-
Chapter Seven	7.5 [7.6]	5.2 [6.1]	5.0 [6.3]
Average reduction with ISA	*0.1*	*0.89*	*1.33*

Whilst it has only been possible to use the simulator to evaluate this behaviour, a field trial in Sweden reported similar results (Persson et al., 1993).

Darzentas, McDowell and Cooper (1980) defined a minimum acceptable gap as being 1.5 seconds, so the reductions in gap size presented above should not be cause for concern in terms of reduced safety. As far as the validity of the gap-acceptance results obtained in the simulator, on-road studies have found comparable results. Radwan, Shinah and Michael (1979) for example showed that gaps accepted by most drivers range from 3-11 seconds whilst Teply, Abou-Henaidy and Hunt (1997) reported average accepted gaps of 6.31 seconds.

The data still presents an interesting question. Why would a system that has no effect on the performance characteristics of the vehicle at low speeds have an impact on junction negotiation? In isolation, this finding at first glance seems illogical. However if this finding is considered in the context of other results, in particular headway keeping and mental workload, a tentative explanation can be offered. The headway results indicate a small but consistent shift towards closer car following behaviour with ISA in use. Taken with the gap acceptance results this could point to "time-saving" strategies employed by driving who perceive that ISA is increasing their journey times. These time-saving strategies are employed to maintain a high as speed as possible and reduce waiting time by following closer and accepting smaller gaps respectively.

Whilst this is a tentative conclusion, the mental workload questionnaires provide further insight. In all of the studies reported here, the NASA RTLX was used to assess subjective workload on six measures. It consistently showed that drivers reported increased time pressure and frustration when driving with Mandatory ISA. This result strengthens the argument that drivers were intending to save time by employing these strategies. Furthermore, whilst both subjective and objective (in terms of performance) data support this theory, the *actual* journey times were not affected. This perceived loss of time seems to be a preconception held by drivers (Comte et al., 2000) and should be taken into consideration if ISA were to be implemented. The general public will be more accepting of the system if research results indicate that no increase in journey will occur when driving with ISA (if indeed further research supports this) or indeed that with ISA some journey times are reduced because of improved network performance.

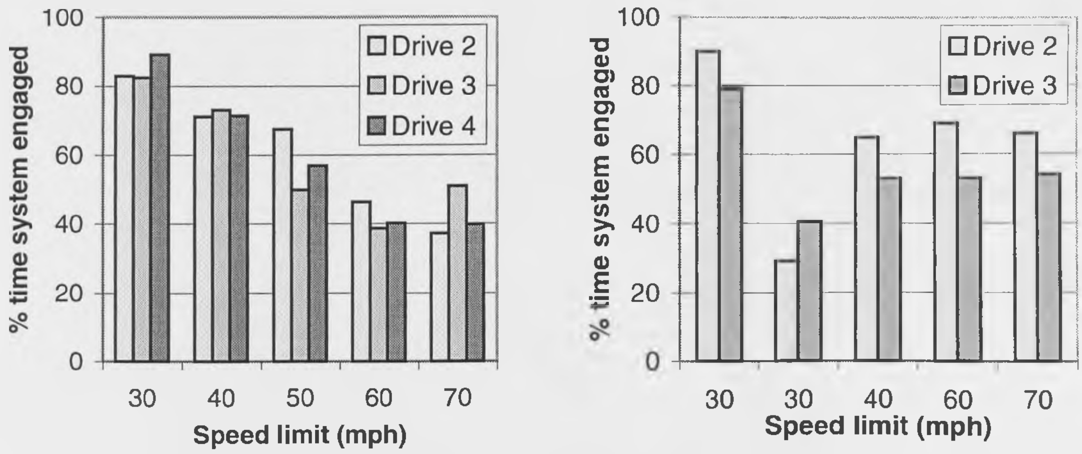
9.2.6 System Use

The studies reported here have generally found that drivers were more accepting of a voluntary ISA system. In calculating the relative safety benefits for the various types of ISA systems researchers have used an assumed value for compliance or system use. This thesis provides actual compliance levels and can be used as a preliminary estimate for relative benefits.

Estimation of compliance levels is not as straightforward as researchers have generally assumed. The studies reported in Chapters Seven and Eight both indicate that system use is dictated by the density and behaviour of the surrounding traffic (and undoubtedly by the degree of system penetration in the vehicle fleet). This reflects research that has suggested that drivers tend to influence one anothers speed (Åberg, Larsen, Glad and Beilinson, 1997) and that drivers choose their speed by comparing it to those of other drivers around them (Connolly and Åberg, 1993). Both the simulator study and the on-road trial indicated that drivers were willing to engage the system in low speed limit areas, where other speed-constraining factors existed. However, in both higher speed limit areas, particularly where traffic density was low, and in speed transition areas, drivers' propensity to engage the system was considerably less. This introduces an "unknown" into the equation of system compliance in that drivers' decisions are based on extraneous and changeable variables.

Despite this uncertainty, the results of the studies suggest that, as a rule of thumb, in urban environments drivers were willing to engage the ISA system for approximately 80% of time spent driving (Figure 9.3). The lower score in the on-road trials for one of the 30 mph areas is as a result of it being immediately after a 60 mph area. This inclined drivers to disengage the system due to pressure from following traffic.

In the simulator study, propensity to engage the system decreased as the speed limit increased, whilst in the on-road study it remained relatively constant. In any case, average use was approximately 50% in areas with a speed limit higher than 30 mph.



(a) Simulator study **(b) On-road study**

Figure 9.3: Use of the Driver Select system

However these results should be treated with caution due the small sample size and lack of extended interaction with the system. Furthermore, additional work needs to be undertaken to discover which driver types are more likely to use the system. The acceptability studies outlined here suggested that drivers who report higher preferred speeds also report lower acceptability scores. It is for these drivers that ISA would have the greatest benefits in terms of reduced mean speeds and it is particularly relevant for novice drivers. In a questionnaire to 800 U.K. car drivers, Stradling (2001) reported that Mandatory ISA was least favoured by male drivers under 45, those with the least driving experience and those with a high annual mileage.

9.2.7 Situation awareness

Previous studies on automating technologies (ACC, lane departure warning systems) have reported decreases in drivers' ability to maintain Situation Awareness (SA) and regain control after system failures. Critics have suggested this might also be the case for ISA. No evidence was found for this, except a slight increase in propensity to collide with a stationary queue of cars (Chapter Six). The secondary task chosen in the simulator study was probably too easy, resulting in a ceiling effect in the data.

The lack of decreased SA may also be the result of reported increases in mental workload. Such increases in mental workload may in turn increase arousal. Increases in arousal have been associated with improvements in task performance by increasing the availability of resources for sustained attention (Matthews, Davies and Holley, 1990). It should also be noted that there is evidence that this increase in attention is due to a perceptual narrowing (Baddeley, 1972). The SA task appeared in the forward view, thus requiring no monitoring of the periphery. Future work should employ a task in the visual periphery and also make use of some of the standard measures of SA. This was beyond the scope of the work reported in this thesis, especially as the majority of tools require disruption to the driving task.

9.2.8 Workload

Where increases in subjective mental workload were reported they were mostly confined to items pertaining to frustration and time pressure, a finding that replicates (Várhelyi and Mäkinen, 2001). It was suggested above that this may have contributed to the increases in time-saving strategies employed by drivers using ISA. Whilst it is true that drivers' maximum speeds were considerably reduced, there were indications in this research and others (Liu et al., 2000) that there is little or no effect on journey times. Drivers demonstrate a strong perception that ISA adversely affects trip times and this is an important area for future research.

9.2.9 Driver style

Two of the studies investigated the propensity of drivers to accept and use an ISA system (Chapters Seven and Eight). Drivers were asked to complete the Driving Style Questionnaire and a subset of the items, relating to speed behaviour, were correlated with acceptability scores and age. Whilst the DSQ only concentrates on breaking the speed limits (and thus does not address "appropriate speed"), there is evidence that violators of the speed limit have increased accident risk (Parker, Reason, Manstead and Stradling 1995).

It was hypothesised that lower acceptability scores would be associated with lower age and higher DSQ scores. In the simulator study, no such associations were found, even when analysed by system type. By contrast, in the on-road study, DSQ scores were negatively correlated with the acceptability scores for the Mandatory system. In addition the results indicate that DSQ scores decrease with age and that acceptability decreases with increasing DSQ scores. This suggests that younger drivers have a higher likelihood of speeding and that this is associated with decreased acceptability of the ISA system. With regards to the Driver Select group, there was a negative correlation between system use and DSQ scores such that those drivers who admitted to speeding were less likely to engage the Driver Select system. Those drivers who would benefit most would be least likely to use a voluntary system.

9.3 Implications for the implementation of ISA

This thesis raises a number of points relevant to the implementation of ISA.

- *Mandatory ISA provides the most safety benefits*: an advisory or voluntary system appears to be about half as effective.
- *Drivers dislike Mandatory ISA*: however when given the option of a voluntary system they disengage it in locations where it would be most beneficial.
- *Drivers display "selective recruitment"*: those drivers who would most benefit from ISA are those who choose to disengage the voluntary system.
- *Implementation of a Variable system requires careful consideration*: this was the least liked system, probably due to "patchy" implementation.
- *Behavioural adaptation may occur*: this was particularly evident in urban areas where changes in following behaviour and gap acceptance were observed.
- *Drivers perceive increases time pressure and journey times*: whilst no empirical evidence supports this, such perceptions will be an important part of any marketing strategy.

- *Small-scale implementation could be counter-productive*: not only do drivers report feelings of anxiety when driving ISA in isolation, traffic flow may become more unstable if overtaking by non-equipped cars increase.
- *No effects of reduced vigilance were found*: whilst this area requires further investigation, it contrasts with the results found in ACC trials.

These suggestions are of course tentative, although it should be noted that the studies were generally supportive of one another. Areas for future research are outlined below.

9.4 Further research

The studies reported here have used a number of evaluation methodologies and driver behaviour parameters. There is, however a large amount of scope for further work in this field as recognised by the number international projects that have been initiated in the last year or so. This thesis has outlined a number of important concepts including the possibility of negative behavioural adaptation, poor use of a voluntary system and the possibility of "selective recruitment" (Evans, 1985). The positive effects of ISA have been shown to be potentially dramatic in terms of accident reduction and accident severity using both theoretical relationships and behavioural studies. However, these must not overshadow the possible negative behavioural adaptations and future research should recognise this.

The research reported here has attempted to look at a wide range of scenarios in terms of system design and implementation strategies across different road types. Further longitudinal work needs to be carried out, whereby users can interact with a system over a much longer period of time than was possible in this programme of research. Only a snapshot of behaviour has been studied here and daily use of a system may have bigger impacts.

One of the limitations is the lack of face validity of the driving simulator in terms of its ability to replicate the deceleration characteristics of an ISA system and the possible lack of time pressure or motivation. It would be of interest to determine how drivers react if they were artificially put under time pressure to reach their destination for example by financial incentives. Such a study was performed by Bonsall, Cho, Palmer and Thorpe (1998); they reported that drivers engaged in riskier behaviour when subjected to time-based road user charging schemes. The lack of face validity may account for some of the differences found between the simulator and on-road studies (e.g. the DSQ results).

Another area that deserves more research is that of automation effects. No evidence was found of automation-induced complacency in the research reported here, but this could have been due to a flawed methodology (i.e. ease of the secondary task). Future evaluations should include peripheral tasks or those not dependent on the visual system. The combination of continual measurements of vigilance with on-line recording of mental workload may provide a clearer overview of the types of situations where drivers are affected by ISA in terms of either underload or overload.

This thesis has determined that a voluntary ISA system is used differentially according to driver type. An area of concern is that those drivers who would benefit the most from ISA would be less inclined to use it. This presents itself as an interesting future piece of research, not only to establish further reticent populations but also to investigate how their attitudes to ISA might be influenced. Further work should also be carried out to establish if different driver types react differently to a Mandatory system, i.e. in terms of increases in negative behavioural adaptation.

The results reported in this thesis indicate that drivers may be under the false illusion that their journey times increase when using ISA. Chapter Seven reported that *actual* journey times did not increase. In future studies it would be interesting to measure *perceived* journey times and correlate them with actual journey times. This may provide insight into the mechanisms behind the negative behavioural adaptation that was observed in some of the studies.

Finally, although the on-road studies revealed evidence that ISA reduced conflicts, this used a laborious behavioural observation technique – the Wiener Fahrprobe. Whilst this technique allows the collection of vast amounts of observational data, it is fundamentally a subjective method. As the two observers are rating different events there is no opportunity to gather information on the inter-rater and intra-rater reliability. This issue was tackled by Gully, Whitney and Vanosdall (1995) in a study that attempted to predict accident involvement using a Driver Performance Measurement test. They report high inter-rater and intra-rater reliability using a very simple checklist. However the method was still time-consuming in terms of observer training and analysis.

Remote data analysis techniques need to be developed that can identify the occurrence of a conflict. Some preliminary work has been carried out in this area. Nygård (1999) used a measure of "jerk" as a way of identifying traffic conflicts from speed profiles. He suggests that braking in response to a conflict differs from normal braking. Braking in serious traffic conflicts starts abruptly, resulting in a rapid change from positive acceleration to negative acceleration (deceleration). Thus he used the derivative of deceleration (jerk) to indicate the incidence of traffic conflicts. Further ISA evaluations should attempt to validate this concept.

These suggestions for further research are applicable to other types of systems. Controlled laboratory trials are essential to the understanding of drivers' interactions with systems and the development of critical scenarios of interest. On-road trials provide the researcher with the opportunity of studying naturalistic driving behaviour, but whilst they may offer increased face validity, do not allow systematic evaluation. Due to the financial input required, on-road trials require careful planning and data management to achieve rich and reliable research results.

9.5 Thesis summary

In summary, the simulator studies reported decreases in mean and maximum speeds for areas of interest such as curves and village entry points. The field studies on the other hand only found decreases in maximum speeds, probably due to the small sample and high variability in traffic conditions. However these decreases in speed were located in road environments where excessive speed is a problem; thus safety benefits would undoubtedly accrue with ISA.

With regards to system design, drivers were more accepting of an ISA system that allowed an override. When drivers used this type of system they were inclined to disengage it in situations where it would have had maximum safety benefit. This was particularly the case in the field trials, where acceptability for a Mandatory system was low; this can be partly due to the fact that the volunteer drivers were in the only ISA equipped vehicle on the road.

In general there was no evidence of reduced vigilance; this may be as a result of reported feelings of frustration and time pressure whilst driving with ISA that served to increase arousal. These increases in frustration and the perceived loss of time while driving with ISA may also explain the negative shift in gap acceptance behaviour and car following observed in the simulator.

The work contained in this thesis has indicated the possible positive and negative effects of an alternative speed management method. The research carried out was innovative in that the studies used tightly controlled designs to evaluate the behavioural effects of ISA both in the laboratory and in the real world. There were few existing studies in this area and it is hoped that this thesis has made a contribution to rectifying this situation. In addition it is hoped that this work will inspire future research projects in an attempt to understand comprehensively the likely contribution that ISA could have to road safety.

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Glossary

ABS	Anti lock Braking System
ACC	Adaptive Cruise Control
DETR	Department of the Environment, Transport and the Regions
DGPS	differential Global Positioning System
DRACULA	Dynamic Route Assignment Combining User Learning and microsimulAtion
DSQ	Driving Style Questionnaire
HUD	Head-Up Display
ISA	Intelligent Speed Adaptation
IWS	Incident Warning System
LCD	Liquid Crystal Display
MIRA	Motor Industry Research Association
NASA RTLX	NASA Raw Task Load indeX
OECD	Organisation for Economic Co-operation and Development
PRT	Perception Reaction Time
RSME	Rating Scale Mental Effort
SA	Situation Awareness
STATS 19	The UK accident database
SVDD	Speed Violation Detection/Deterrent system
TRL	Transport Research Laboratory, UK
TTC	Time To Collision
VMS	Variable Message Sign
VSL	Variable Speed Limit

Appendices

APPENDIX A

NASA-RTLX questionnaire (1)

The initials TLX stand for Task Load indeX and this questionnaire is designed to assess your own feelings and perceptions about the difficulty and mental workload associated with the experimental task.

The questionnaire divides workload into a number of contributing factors and all these factors add up to the total difficulty of the task. Please read the definitions of each factor carefully before completing the questionnaire.

Definition of 6 factors which describe the loads placed on an individual during the driving task

MENTAL DEMAND
This refers to the 'thinking' component of the driving task. For example, consciously making decisions about the traffic environment or deciding how to respond to the scenarios. How much of this type of thinking, deciding, calculating, remembering, looking, searching, etc. did you need to do? Was the task easy or demanding, simple or complex in this respect?

PHYSICAL DEMAND
How much physical activity was required (e.g. operating brake, clutch and accelerator, steering the vehicle, using the indicator, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous in this respect?

TIME PRESSURE
Did you feel you had enough time to adequately perform the experimental task?

PERFORMANCE
How satisfied were you with your performance in achieving the goals of the experimental task i.e. safe driving?

EFFORT
How hard did you have to work (mentally and physically) to achieve your level of performance? Did you feel stretched or comfortable during the task?

FRUSTRATION LEVEL
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the driving task?

NASA-RTLX questionnaire (2)

Please place a vertical line through each scale to indicate your level of workload on each of the six factors.

Mental Demand	LOW		HIGH
Physical Demand	LOW		HIGH
Time Pressure	LOW		HIGH
Performance	POOR		GOOD
Effort	LOW		HIGH
Frustration Level	LOW		HIGH

APPENDIX B

Acceptability questionnaire

Imagine driving your car if it was fitted with the speed advisory system. This system would display messages advising you of the appropriate speed for the particular area through which you are driving.

Please indicate how acceptable you would find such a system by ticking a box on every line on the scale below.

useful						useless
pleasant						unpleasant
bad						good
nice						annoying
effective						superfluous
irritating						likeable
assisting						worthless
undesirable						desirable
raising alertness						sleep-inducing

APPENDIX C

Driving Style Questionnaire

Please answer all of the questions below by ticking one of the boxes provided. These are intended to give a scale of frequency from never or very infrequently on the left to very frequently or always on the right. Meanings for each of the boxes are given below.

very infrequently — very frequently

1.Sometimes when driving, things happen very quickly. Do you remain calm in such situations?

2.Do you plan long journeys in advance, including places to stop and rest?

3.Do you dislike people giving you advice about your driving?

4.Do you exceed the 70 mph limit during a motorway journey ?

5.Do you ever drive through a traffic light after it has turned to red?

6.Do you exceed the limit in built-up areas ?

7.Do you ignore passengers urging you to change your speed?

8.Do you become flustered when faced with sudden dangers while driving?

9.How often do you set out on an unfamiliar journey without first looking at a map?

10.Are you happy to receive advice from people about your driving?

11.Do you drive cautiously?

12.Do you find it easy to ignore distractions while driving?

13.Do you drive fast?

14.Do you overtake on the inside lane of a dual carriageway if you have the opportunity ?

15.Is your driving affected by pressure from other motorists?

APPENDIX D

System functionality

Location of speed limits

In order for the ISA system to function, the vehicle had to receive information on the posted speed limit of the road on which it was travelling and on where the changes in the speed limit occurred. A number of mechanisms by which this information could be communicated to the vehicle were suggested at the planning stage. The original concept envisaged the use of small radio beacons mounted on speed limit signs or lamp posts. These would have been powered by rechargeable batteries, and transmitted a digital encoded signal with a range of about 100m. This mechanism was rejected on grounds of accuracy, cost, maintenance (regular battery changes), and the likelihood of vandalism.

A Global Positioning System (GPS) alleviates most of these problems, since it does not require road-side infrastructure. The accuracy of the base GPS system was limited by a randomising factor added by the American Military, in order to reduce the effectiveness when GPS is used by an aggressor. This results in the reported position of a stationary receiver changing by up to 100m over several minutes. To over come this inaccuracy, various base stations have been set up and surveyed to within a few millimetres. These receive the GPS data and broadcast a correction factor to mobile GPS units. This is known as Differential GPS (DGPS). The system used for the ISA system broadcast a correction factor on the sideband of Classic FM; so where Classic FM could be received in stereo, the corrections can also be received. A yearly subscription is paid to access this service. The DGPS increased accuracy to about 1m.

The GPS receiver originally selected was found to have a significant delay in updating the position of the car. This meant that the car could travel some distance from the reported position when travelling at speed. This factor, called latency, resulted in inaccuracies, so a faster GPS system was obtained. The new system had a latency of one tenth of a second, that is, it updated its location ten times a second. It was also more tolerant of loss of signal, and when combined with the Differential GPS, gave a reliable accuracy of about 1m, with a virtually instant update of position.

The position and value of every speed limit along the test route was stored in the laptop computer as a "virtual beacon". This virtual beacon could be moved and its radius altered according to where the ISA system should operate. For example, if the speed limit changed from 60 mph to 30 mph, the beacon was positioned so that the ISA system would engage before the speed limit change. This ensured that the ISA system was able to decelerate the car sufficiently so that the vehicle was travelling at the lower speed limit as it passed the speed limit sign. The software allowed great flexibility in moving the beacons so that overlapping was avoided.

The software constantly compared the position of the car with that of the beacons, and reacted to each beacon it passed through. If the car digressed from the test route for any reason, it continued to store the last speed limit it passed through. When it rejoined the route, it picked up the next beacon as normal. The software also had a plot function, allowing new routes to be easily set up, and existing routes to be edited.

Control of vehicle speed

In addition to the car's original Engine Control Unit (ECU) two auxiliary ECU's were modified from an after market traction control system. The signals from the car's original ECU were diverted through the auxiliary units en-route to the engine. The auxiliary ECU's could reduce engine power, but could not increase it.

The software was aware of the appropriate speed limit (as described above), and compared this with the car's actual speed, determined from the ABS wheel speed sensors. If the car was travelling below the speed limit, it behaved as a normal car. However, if the speed was above the limit, a signal was sent to the pair of auxiliary ECU's. These first reduced engine power by retarding the ignition for up to 30 seconds. The engine continued to run smoothly whilst the ignition was retarded, but would have overheated if it was retarded for prolonged periods. In order to provide a longer and/or greater reduction in power, the amount of fuel injected into the engine was progressively cut. Unfortunately, cutting the fuel injection results in a loss of refinement, and produced a sensation of jerkiness. This disappeared if the car was then slowed to at or below the speed limit. If the retardation and the fuel cut-off were insufficient, because the car is going down hill for example, the brakes were gently applied to decelerate the car to the speed limit. The braking system was composed of a small compressor, a valve that is normally open, and two pneumatic cylinders (Figure A).

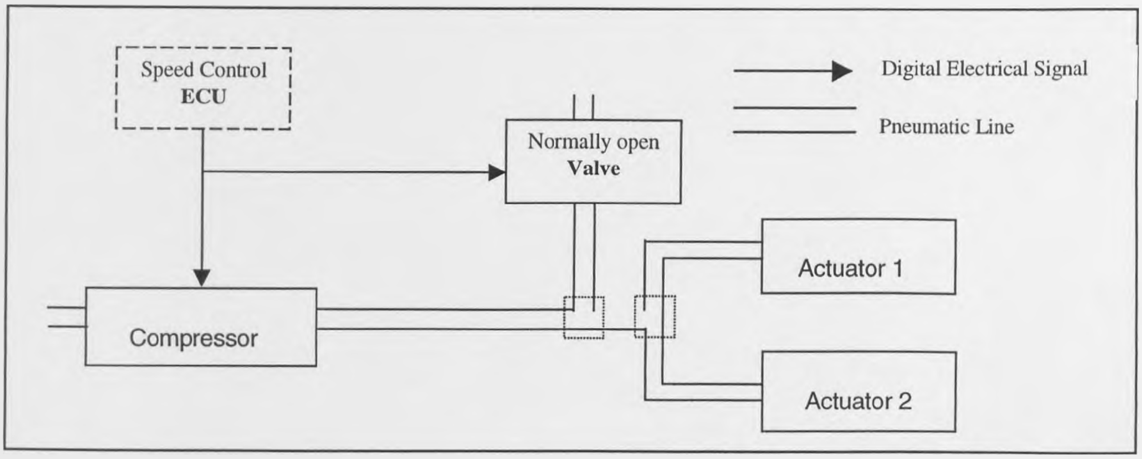


Figure A: ISA braking system schematic

When a signal was sent out by the auxiliary ECU, the compressor activated and the valve closed, thus supplying air to the cylinders that operate on the dual control brake pedal. When braking was no longer required, the compressor stopped, and the valve opened to release pressure. A built-in pressure switch in the compressor controls the amount of force applied.

Data logging

The laptop PC not only ran the ISA software but also recorded a wide range of data such as vehicle speed, current speed limit, amount of ignition retardation etc. The PC, GPS and auxiliary ECU's were concealed in the boot of the car, whilst other equipment was either under the bonnet or out of sight inside the car.

In general, the vehicle and the associated software performed well. Only rare occurrences of not registering changes of speed limit were detected and test data showed the car to be staying at the controlled speed without excessive deviations.

APPENDIX E

Wiener Fahrprobe

Free observer coding sheet

	Approaching a place of interaction
	checks the situation
	drives with anticipation
	does not drive with anticipation
	inappropriate speed
	inaccurate lane choice

Interaction			
	insists on right of way		does not insist on right of way
	does not allow to continue/merge		allows to continue/merge
	does not reduce speed		reduces speed
	presses other cars		
	obstructs others (e.g. at crossings)		
	others move into the safety distance of the subject		
	turns right near oncoming traffic		
	obstructs others when turning right		
	obstructs others when turning left		
	makes other road users decelerate		
	makes others accelerate		
	impedes cyclists/pedestrians		
	endangers cyclists/pedestrians		

	Overtakes or changes lane
	cuts up
	too small lateral distance
	Aborted

	Communication		comments
	Positive		positive
	Negative		negative

	Conflict
	subject provokes conflict
	subject does not provoke conflict

Description

Coding observer coding sheet

Standardised observation			
	Overtaking or		Speed
	lane change		Inappropriate
	Correctly		Inappropriate for road geometry
	not correct		too fast near VRUs
	in spite of oncoming traffic		in the platoon
	without sufficient vision		without platoon
	While forbidden		above the speed limit
	because of a stationary obstacle		at / below the limit
	lane change in time		considerably slower than the limit
	uses right lane mainly		brakes abruptly
	uses left lane mainly		unsteady speed
	Use of the indicator		Distance to the road user ahead
	indicates in time		correct
	Does not indicate		too short
	Does not indicate in time		Behaviour at traffic lights
	indicates ambiguously		drives against red
	Lane use		drives against amber
	inaccurate, weaving		does not start when it is green
	extremely on the right side of the lane		starts too early
	extremely on the left side of the lane		Checks the situation with respect to other road users
	cuts the curve		yes
	Lane choice for proceeding		no
	correct		Number of cars overtaking
	in time		
	at the last moment		
	Incorrect		
	Behaviour when merging		
	safe		
	Unsafe		
	with traffic		
	without traffic		
	inappropriate speed		

APPENDIX F

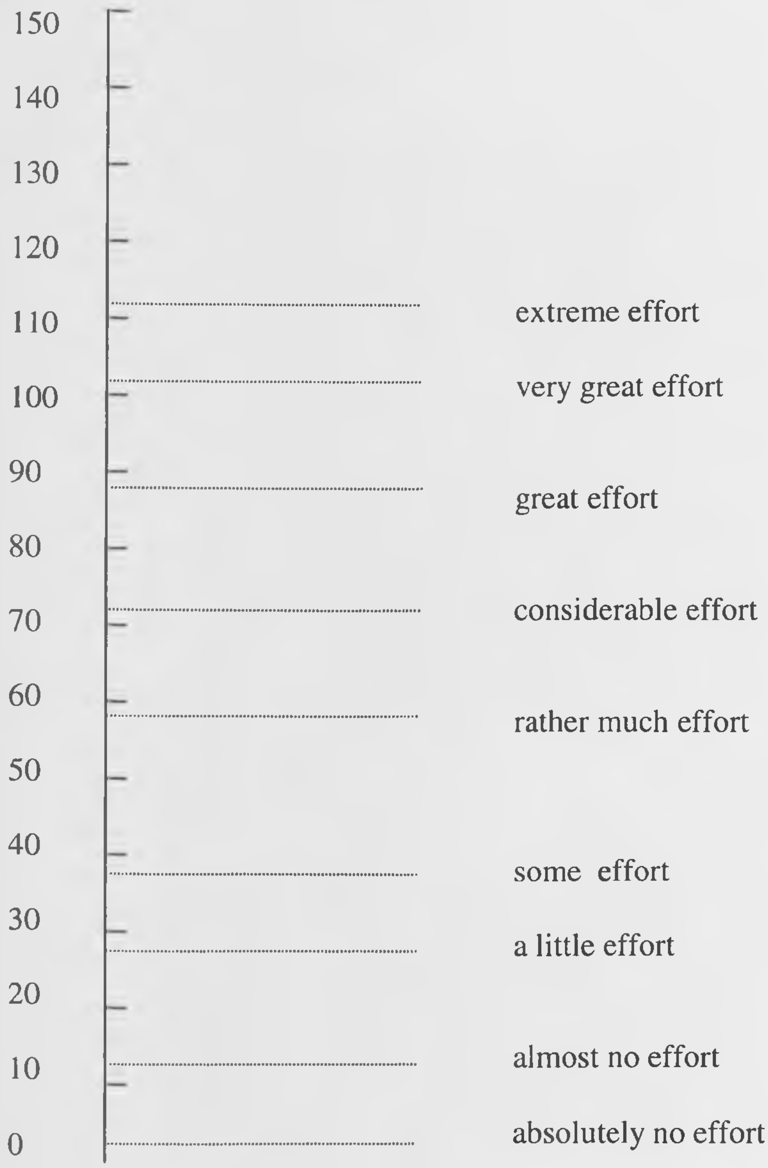
Performance rating scales

Speed relative to conditions	*Safe*	————————	*Unsafe*
Headway variability	*Low*	————————	*High*
Amount of close following	*Low*	————————	*High*
Anticipation	*Good*	————————	*Poor*
***Gap acceptance** (if applicable)*	*Safe*	————————	*Unsafe*
Lane maintenance	*Good*	————————	*Poor*
Braking	*Smooth*	————————	*Abrupt*
Junction preparedness	*Good*	————————	*Poor*
Lane changing	*Good*	————————	*Poor*

APPENDIX G

RSME rating scale

Please place a 'X' at the appropriate point on the scale below, to indicate how much effort was required to complete the task.



APPENDIX H

Responses to open ended questions

"What benefits do you think a speed control system would have for you?"

- Reminder of the speed limits
- Stop me from dangerous overtaking
- Stop me from speeding accidentally, e.g. when going down a hill
- Really good when there are pedestrians around
- Made me realise how fast I and others drive

"What benefits do you think a speed control system would have for society?"

- Calming of overall speeds, especially in built up areas and thus less accidents
- Make liability for accidents easier to assess
- Would alleviate burden on traffic police
- Improve traffic flow/reduce pollution
- Great if everyone had it

"What disadvantages do you think a speed control system would have for you?"

- Too regulated, would make motorway driving boring
- Lack of total control
- Don't have to worry about the police
- Would cause my performance at work to suffer, as I need to get from one place to the other efficiently
- Make safe overtaking difficult
- Less flexibility in driving necessitates more awareness

"What disadvantages do you think a speed control system would have for society?"

- frustration levels would rise
- too much like big brother
- how install and pay for it
- if it was voluntary, only law abiders would use it