**Monograph:**
Comte, S.L. (1996) Response to automatic speed control in urban areas: A simulator study. Working Paper. Institute of Transport Studies, University of Leeds , Leeds, UK.

Working Paper 477

**UNIVERSITY OF LEEDS**
**Institute for Transport Studies**

*ITS Working Paper 477*

September 1996

# Response to automatic speed control in urban areas: A simulator study

**S L COMTE**

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## ABSTRACT

Speed affects both the likelihood and severity of an accident. Attempts to reduce speed have centred around road design and traffic calming, enforcement and feedback techniques and public awareness campaigns. However, although these techniques have met with some success, they can be both costly and context specific. No single measure has proved to be a generic countermeasure effective in reducing speed, leading to the suggestion that speed needs to be controlled at the source, i.e. within the vehicle. An experiment carried out on the University of Leeds Advanced Driving Simulator evaluated the effects of speed limiters on driver behaviour. Safety was measured using following behaviour, gap acceptance and traffic violations, whilst subjective mental workload was recorded using the NASA RTLX. It was found that although safety benefits were observed in terms of lower speeds, longer headways and fewer traffic light violations, drivers compensated for loss of time by exhibiting riskier gap acceptance behaviour and delayed braking behaviour. When speed limited, drivers' self-reports indicated that their driving performance improved and less physical effort was required, but that they also experienced increases in feelings of frustration and time pressure. It is discussed that there is a need for a total integrated assessment of the long term effects of speed limiters on safety, costs, energy, pollution, noise, in addition to investigation of issues of acceptability by users and car manufacturers.

# 1. INTRODUCTION

## *1.1 Speed and Accidents*

In 1994, the Department of Transport reported the annual number of road traffic casualties as being 315,189 (all road users) of which 3,650 were fatalities. With the estimated cost of each fatality at £784,090 (includes lost output, medical and ambulance costs and human costs), it can be seen that the total cost of fatal accidents is enormous. Empirical evidence suggests that driving too fast for the conditions is a major factor in accident causation. Sabey and Taylor (1980) reported that 22-23% of accidents have speed as a contributory factor. Likewise, the Federal Office of Road Safety noted excessive speed to be at least a contributing factor in up to 30% of fatal crashes in Australia during 1991/2. A TRL review of the literature on the effect of speed concluded that a 1mph reduction on traffic speed produced a 5% reduction in accidents (Finch, Kompfner, Lockwood and Maycock (1994). The Department of Transport's 1994 speed survey reports that 47% of cars were exceeding the 70mph speed limit on motorways, 31% were breaking the speed limit in 40 mph zones and 69% were breaking it on 30 mph roads. It is likely that drivers adopt a speed which they perceive as being appropriate to the conditions with little regard for the posted speed limit (Garber and Gadiraju, 1989).

There exists a complex relationship between speed and accident rates. Early research (Solomon, 1964) reported a relationship between crash involvement and speed. It was suggested that the cause of speed in road crashes was variance from the speed of the rest of the traffic, rather than absolute speed itself. The U-shaped hypothesis claimed that both slow and fast travel speeds relative to the mean speed were crash inducing. Munden (1967) also reported a U-shaped relationship between crash rate and relative speed in the UK, similar for that reported by Solomon in the USA. He suggested that vehicles travelling more than one standard deviation above or below the mean speed had an inflated crash rate. More recently, the studies by Kimber (1990) and O'Neill (1990) on the relationship between speed, accidents and injury in Britain and the USA reveal that a reduction in the posted speed limit results in a reduction in speeds, accident rates and accident severity. A recent study by Fildes, Rumbold and Leening (1991), although supported Solomon's claims regarding speed variance, failed to show any evidence that slow travel was associated with increased crashes.

As 69% of all casualties occur in built-up areas (Department of Transport, 1995), a statistic that is recognised in the Department of Transport's target to reduce casualties by a third by the year 2000 compared with the 1981-1985 level, a reduction in speed on urban roads should result in a reduced accident rate. Mackie, Hodge and Webster (1993) examined the effect of the introduction of 20mph zones on accident data and reported that the annual frequency of accidents was reduced initially by 70%, falling off to 56% in the medium term.

## 1.2 Reducing speed

The major safety benefits of reducing speed are thought to be diminished crash frequency and severity. Various interventions to achieve compliance with speed regulations have been implemented. These include:

**(i) traffic calming**

Various traffic calming measures have been implemented to encourage drivers to reduce their speed. These include the alteration of the vertical profile of the road (e.g. road humps and raised junctions) or the creation of horizontal deflections such as pinch points and chicanes. Engineering the road and its immediate environment has been shown to have long-term effects on changing driver behaviour (Russam, 1979; Silcock and Walker 1982; Wright and Boyle 1987). However, road humps can cause problems and inconvenience primarily for emergency services and bus operators. Also, vehicles traversing these devices, particularly those that interrupt vertical alignment, can produce noise and vibration, seen as detrimental to both road user and local residents. It is also possible that the installation of traffic calming measures on isolated roads causes local diversions onto other roads and thus create accident migration. The measures should be implemented as part of an overall Urban Safety Management Strategy and they need to be viewed in terms of the whole transportation system. Traffic calming may have the potential to stem the flow of traffic in local environments, but if the arterial and collector roads are incapable of carrying the excess traffic, there will be no overall gain to the system.

**(ii) feedback**

A number of studies have been carried out using mobile roadside speedometers which consist of a speed limit sign, a Doppler radar emitter and receiver to measure speeds and a display that indicates the speed of an approaching vehicle. Thus drivers are able to observe the posted speed limit and their own speed simultaneously. Casey and Lund (1993) conclude that mobile roadside speedometers can be used to help reduce urban traffic speeds, but only in the short-term. They suggest that occasional police enforcement in the vicinity of mobile roadside speedometers could extend the system effects over longer periods, and that their use may be limited to specific sites where speeding traffic is particularly hazardous (e.g., school zones and construction sites).

The use of Variable Message Signs to display alternative types of feedback to drivers have also been evaluated. Some researchers (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 using feedback signs which display the percentage of vehicles not speeding in the previous day or week. The effects were apparently 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.

**(iii) enforcement**

In addition to reducing speed, it is thought that speed enforcement may bring about increased levels of driver vigilance (in the hope that early sighting of police will reduce the likelihood of detection and punishment) and that these increased levels of vigilance will have inherent safety benefits. Galizio and Jackson (1979) measured the effect of several variables on speed including the presence or absence of a speed limit sign, a radar enforced sign and a marked police vehicle. Only in the presence of the marked police vehicle did significant reductions in speeds occur. The authors conclude that driving speed is controlled more by threat of punishment than by the acceptance of the value of safe driving. However the costs related to this type of enforcement are extremely high and are thus impractical.

Even if the necessary funds were available to increase the level of enforcement, there is evidence to suggest that the reduction in speed is not long-lasting (absence of time-halo). In addition, if enforcement were more stringent it would be likely that the prevalence of radar detectors in cars would rise. Teed, Lund and Knoblaunch (1993) found that drivers with radar detectors slow only briefly when alerted to the presence of police and that one mile after exposure, nearly half the reduction was recovered (absence of distance halo). These results are consistent with other studies using a variety of enforcement techniques, also demonstrating the absence of time and distance halo effect, e.g. Hauer, Ahlin and Bowser (1982).

Speed cameras, which achieved legislation in 1994, are employed by about half the police forces in the UK. A trial in 1992 in London achieved fatal and serious accident reductions of 36% on roads which were fitted with speed cameras (Winnett 1994). However, again, the effect is localised, and thus they may be more usefully employed not as a general speed reduction measure but only at accident blackspots.

**(iv) public awareness campaigns**

The use of public awareness campaigns have operated by trying to alter public attitudes towards speed (e.g., Kill your speed, not a child). Elliot (1993) conducted a meta-analysis examining the characteristics of successful and unsuccessful road safety campaigns. Campaigns were more effective when they were persuasive (rather than educative), if they were based on qualitative and quantitative research, contained simple and identifiable language and characters, were emotional (rather than rational) and had legislative support. According to Andersson (1978), the problem can be divided into three parts :

(i) The recipient must be motivated

(ii)The material must clearly communicate to the recipient what informational, attitudinal and behavioural changes are necessary

(iii)The recipient must make those changes.

It seems that many campaigns e.g. Glad (1986) and Downing and Spendlove (1981) fail to meet these criteria. The above criteria also rely on the assumption that behavioural change will arise as a result of attitudinal change, however this correlation has been shown to be weak (Fishbein and Ajzen, 1975). Publicity campaigns are difficult to evaluate; evaluations are often before-after studies with no proper control condition. Elliot (1993) suggests that publicity may help create a desirable supportive climate of opinion in which other measures can operate.

**(v) perceptual countermeasures**

Perceptual countermeasures attempt to alter the sensory scene available to the driver in order to reduce travel speed. The measures include special signing, transverse road markings and centre and edge line markings. Carsten, Tight, Pyne and Dougherty (1995) found significant decreases in mean speed and speed variance using lane narrowing techniques in a simulator based study. Such interventions have the advantage that they are relatively low cost and long-term, however, many other perceptual countermeasures have not been tested fully and it has been suggested that they are site dependent.

**(vi) automatic speed control**

The lack of success and consensus regarding the above speed reducing measures has led to the suggestion (e.g. Fildes and Lee 1993) that controlling speed at its source, i.e. within the vehicle, would be the next logical step in attempting to reduce the number of road accidents with speed as a contributory factor. British and European legislation since March 1988, has made it compulsory for coaches and most heavy goods vehicles to be fitted with speed limiters. Coaches are generally limited to a top speed of 65 mph and lorries are limited to either 56 mph or 60 mph. The Department of Transport report that the percentage of articulated lorries exceeding their 60 mph speed limit on motorways decreased from 43% in 1991 to 25% in 1994. However the percentage exceeding the 50 mph limit on dual carriageways rose from 72% in 1991 to 78% in 1994. So the top speed limiter enforces the speed limit on motorways but on other types of roads where accident rates are higher anyway, this sort of speed limiter is of little use.

Almqvist, Hydén and Risser (1991) carried out a small self-observational study in Lund and cite the following advantages in installing speed limiters in cars:

- Drivers may speed unintentionally due to difficulties in accurately judging their own speed and so the speed limiter would effectively take over the task of monitoring speed.
- Speeding due to social pressure to keep up with the traffic will be decreased.
- Irrational or emotional driving causing inappropriate speed choice would be limited.
- Environmental benefits such as reduction in fuel consumption, air and noise pollution would ensue.

However they also point to several possible disadvantages:

- When the freedom to choose ones own speed is abolished, compensatory behaviour such as red light violations may arise.
- As a result of lost time, frustration may lead to increased speed in normally low-speed situations (e.g. turning manoeuvres).

Hogema, van de Horst and Janssen (1994) carried out a simulator evaluation of different forms of Intelligent Cruise Control (ICC). The ICC regulated vehicle speed and following distance, and there resulted in a reduction of the proportion of short headways and high speed in the controlled area; however it was found that a compensating mechanism meant that by actively reducing driver's speed on a few limited sections made them drive faster in other areas. A second negative impact on safety was also discovered; it appeared that braking reactions were somewhat later, possibly due to either a decrease in driver vigilance as a result of autonomy, or to over-confidence in the system. This effect was also found in Becker and Sonntag's (1993) study on Autonomous Intelligent Cruise Control.

Plowden and Hillman (1996) recommend that speed limits should be enforced by fitting cars with variable speed limiters which are set by drivers to prevent vehicles travelling above the speed limit. The authors suggest that "The adoption of lower speed limits, enforced by variable speed limiters, will save lives and make our towns safer for all road users, especially children and old people. It will also reduce pollution and fuel consumption, weaken still further the case for major new roads, and minimise the need for police involvement in enforcement. Speed control is an immensely powerful instrument of transport policy which has so far been little exploited."

Intuitively, one would think that the introduction of automatic speed limiters, would result in immediate safety benefits, in terms reduction in accident rate and severity. However, to date there has been no detailed research undertaken to evaluate exactly how drivers react to being speed limited. Thus the present study, ***Response to automatic speed control in urban areas,*** was designed to evaluate the effects of automatic speed limiters on driver behaviour.

### *1.3 Response to automatic speed control in urban areas*

This study, carried out on the University of Leeds Advanced Driving Simulator, attempts to quantify some of the safety benefits and costs of the installation of an automatic speed limiter. The study focused on the two major issues of behavioural adaptation and the identification of problems that may arise in the transitional phase that would naturally occur if speed limiters were to be introduced onto the market. In addition, subjective measures were recorded in order to evaluate whether speed limiters were beneficial or detrimental in terms of drivers' mental workload. In this study the speed limiter works by permanently restricting the top speed of the car; a pilot study produced the technical characteristics of the speed limiter (i.e. deceleration rates). In a real-world implementation it would more likely involve the installation of a roadside sender at every change of speed limit. This sender would emit impulses and each vehicle would be equipped with a receiver able to receive these impulses, automatically limiting the vehicle's maximum speed to the speed limit in question.

The study was designed to enable the investigation of different levels of system penetration and alternative types of speed limiters. Three levels of system penetration were implemented; the control condition where neither the subject nor the any of the other vehicles on the road were speed limited; a 'mixed fleet' scenario where half of the other cars on the road were speed limited; and finally the full implementation phase where all cars were speed limited. The 'mixed-fleet' scenario is an important consideration because if speed limiters were introduced onto the market the uptake would be gradual and problems may arise due to the unpredictability of the other traffic.

In addition, two types of speed limiter were evaluated. The first, referred to as the 'general speed limiter', constantly restricted the driver to a maximum speed of 30mph. The second, referred to as the 'secondary speed limiter', was only activated in the vicinity of junctions, where it automatically restricted the driver to 25mph It is referred to as a secondary device as it is only conceivable as a second stage implementation. Appendix A contains the technical details of the speed limiter. It was decided that this was a potential area of interest as in built-up areas, almost two-thirds of fatal or serious accidents take place at junctions (Road Accidents Great Britain 1994), and thus to reduce the speed of vehicles around junctions maybe beneficial in terms of accident reduction and severity involving cars both on the minor and major road.

Using the University of Leeds Advanced Driving Simulator permitted the subjects to be exposed to carefully controlled conditions without personal risk. A subset of behaviours that were deemed to be important in the causality of accidents were selected for investigation. These were junction approach and negotiation, following behaviour and traffic light violations.

Subjective measurements of driver behaviour were also recorded. With the increasing technology available to the driver, there is interest in the assessment of changes in driver's mental workload attributable to the technology. Both increases and decreases in mental workload are of concern; increases may lead to a reduction in the driver's ability to control the vehicle due to excess demands made by technology. Equally, the presence of telematics applications that take over part of the driving task may result in decreases in mental workload, thus inducing monotony and decreased vigilance. The pilot study allowed the evaluation of different types of subjective measurement (Anderson, 1996). It was decided that the NASA RTLX (adapted from Byers 1989) would be an appropriate tool to use. The NASA RTLX contains the same elements as the TLX but does not require the operator to complete the paired comparisons stage, which can often be a lengthy process, and difficult carry out inside a vehicle. Fairclough (1991) adapted the TLX to measure driver mental workload and reported that the RTLX is just as, if not more sensitive, than the TLX, yet is easier and quicker to administer. See Appendix B for a copy of the questionnaire used.

## 2. METHOD

### 2.1 Subjects

The subjects who participated in the experiment were all members of an existing subject panel. All the subjects had driven the simulator at least twice in previous other research projects and were thus considered to be competent in its handling. In addition to reducing the amount of familiarisation and training needed, the use of experienced subjects considerably reduces drop-out rate due to simulator sickness. (See Appendix C for drop-out rates).

30 subjects participated in the experiment. There were 15 males between the ages of 23 and 54 (mean 37 years) with a reported annual mileage of between 7000 and 40000 miles (mean 17600 miles); and 15 females between the ages of 24 and 49 (mean 37 years) with a reported annual mileage of between 6000 and 25000 miles (mean 15200 miles). Approximately half the males were under 35 and half were over 35 and that females were similarly distributed. Appendix D contains the cross-tabulations of sex by age group and annual mileage.

The four experimental conditions were randomly ordered and subjects were assigned at their convenience. The total time for the experiment to take place was approximately 75 minutes for each subject including briefing, short breaks between experimental trials, debriefing and payment.

### 2.2 Experimental Design

The study allowed the investigation of two types of system implementation (general and secondary) 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 control scenario, would result in 7 experimental conditions. To test the complete set of permutations using a within subjects design would require subjects to drive for approximately 2 hours on the simulator, and 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. Firstly, by asking subjects to return on a second occasion a higher drop-out rate is likely to be encountered. Secondly, according to the risk compensation literature (e.g. Streff & Geller 1988), adjustments in risky behaviour are only observed in within subjects design, probably due to the fact that the occurrence of risk compensation is dependant on individuals being able to compare the sensations of the two conditions (risk compensation did occur in a comparative between subjects design). It was therefore felt that a within subjects design would be more practical and powerful.

The high number of treatment conditions was reduced by selecting those which would be logically encountered in real world implementation. Subjects encountered the following four conditions. For ease the following condition names will now be referred to in this document. Each of the condition names appears in the format: "X/Y", where the first half of the name (here X) refers to the speed limiter implementation in the subject's car (the simulator); the second half (here Y) refers to the speed limiter implementation in the other vehicles on the road. The four conditions were randomised to reduce practise effects.

| | |
|---|---|
| NSL/NSL | This is the control condition. Neither the simulator nor any of the other cars on the road are fitted with a speed limiter. |
| NSL/50SL | This condition represents the 'mixed-fleet' scenario. The simulator is not fitted with a speed limiter but approximately 50% of the other cars on the road are. |
| SL/SL | Here the full implementation stage has been reached. Both the simulator and all the other cars on the road have been fitted with a speed limiter. |
| SL+/SL+ | Both the simulator and all the other cars on the road have been fitted with a speed limiter. The secondary speed limiter is also present in all cars. |

## *2.3 Apparatus and materials*

### 2.3.1 The University of Leeds Driving Simulator

The experimental trials were conducted on the University of Leeds Advanced Driving Simulator. This facility is a sophisticated, static-base simulator built around a Silicon Graphics Reality Engine workstation. The "driver" sits in a complete car, with all the basic controls and dashboard indicators fully operational. The car is situated directly in front of a projection screen with the driver's seat aligned with a video projector. The workstation continuously receives information on driver activation of the vehicle controls and re-calculates the vehicle position using a complex vehicle handling model. The current position is continuously passed to the visualisation software, which calculates the resulting driver view and projects it onto the screen in front of the car. All this takes place in real time to provide smoothly flowing images. Shortly before the project began, there was a significant upgrade in the main graphics workstation to provide fully textured images for increased realism and enhanced graphics performance. A detailed description can be found in Carsten and Gallimore (1993). The scenarios under investigation were incorporated into a continuous road network, allowing natural movement from one scenario to the next. A full description of the road network is contained in Appendix E.

### 2.3.2 NASA-RTLX

Following each experimental trial subjects were asked to complete the NASA RTLX, a standard measure of mental workload. This requires subjects to rate the task they have just completed in terms of mental demand, physical demand, time pressure, performance, effort and frustration level. Each of these items were represented by a bipolar scale; subjects placed a line on the scale between the two extremes of the item to indicate the strength of the attribute. The individual scales are then averaged to give a total workload score.

## 2.4 Independent Variables

The independent variables were the presence and type of speed limiter fitted on the simulator and other cars on the road. Between subjects factors of age (under 35 and over 35 years of age) and sex were also incorporated into the design.

## 2.5 Dependent Variables

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. The following data was collected :

| *Left turns* | *Right turns* | *Curves* | *Car following* | *Traffic lights* |
|---|---|---|---|---|
| approach speed | gap accepted | speed | time headway | violations |
| braking point | | speed variation | | |
| turn speed | | | | |

More details of data measurement and collection are contained in Appendix F.

## 2.6 Procedure

### 2.6.1 Subject briefing

Subjects were told that they would first be allowed to drive the practise route, after which they would take part in four experimental trials. Subjects were told that in some of the trials they would be automatically speed limited and that before each trial began they would be told whether they were limited in that particular condition. In addition they were reminded that some people experience simulator sickness and were advised of the symptoms. They were told that if they experienced any discomfort, however slight, they should immediately stop driving. They were asked to complete a form detailing their driving history and sign the consent form agreeing to take part in the experiment. A complete set of subject instructions is provided in Appendix G.

### 2.6.2 Practise session

Subjects were informed that they would be given a 5-10 minute practise road in order to familiarise themselves with the controls of the car and to practise all the scenarios which were to follow in the experimental trials. When they had completed the practise session they were asked if they wanted to continue, and if they did the experimental trials began.

### 2.6.3 Experimental trials

The subjects were then read the instructions referring to the particular trial they were about to undertake. Subjects 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 subjects were instructed to start driving when they were ready. At the end of each of the experimental trials, subjects were given the opportunity to stretch their legs and have a drink of water. They were then asked to complete the NASA RTLX. They were told that when they were ready they should take the driver's seat ready for the next trial.

## 3. RESULTS

Analyses were carried out to establish differences between the four experimental conditions for all the dependent variables. It was apparent that the 'mixed-fleet' scenario was not perceived by the subjects as different from the control condition, and that any additional effect of the secondary speed limiter would only be observed in areas around the junctions.

### *3.1 Approach to junctions*

From the data that was collected, a mean value was obtained for each 10 metre section on approach. Figure 1 shows the means of speed profiles on approach to left hand turns for all conditions.

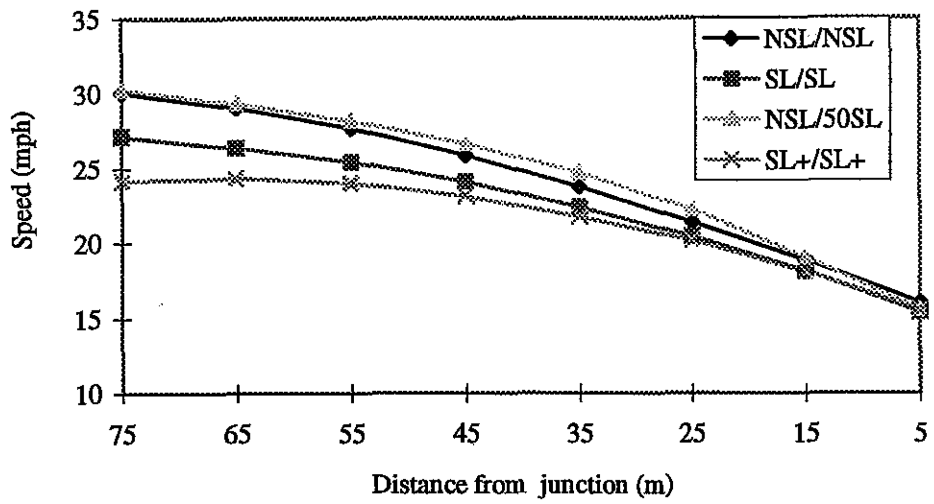



**Figure 1 Approach speeds to junctions**

The data were analysed with multi-factorial analysis of variance to determine the effect of two between subjects factors (Sex and Age) and two within subjects factors (Condition and Approach) on speed. There was a main effect of condition (F(3,87)=50. 87; p <. 001 indicating that both the speed limiter conditions produced lower average approach speeds than both the non-speed limited conditions. A significant interaction between Condition and Approach, F(21,609)=2. 83; p <. 001 suggests that the effect of Condition type is not stable across the different approach distances. Post-hoc analyses subsequently revealed that the reduction in speed is 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. So although speeds were lower on approach when drivers were speed limited, they were very similar for the main deceleration profile on the immediate approach to the junction. No additional effects of the secondary speed limiter were observed.

A significant main effect of Age was found such that those subjects under the age of 35 drove faster on overall approach than those over the age of 35 F(1,29)=47. 96;p <. 001 A significant interaction between Condition and Age F(3,87 )=3. 84;p <. 01 indicates that the effect of age is not consistent across conditions. As can be seen in Figure 2 the reported higher speeds for younger drivers are not observable in the conditions in which they are speed limited.

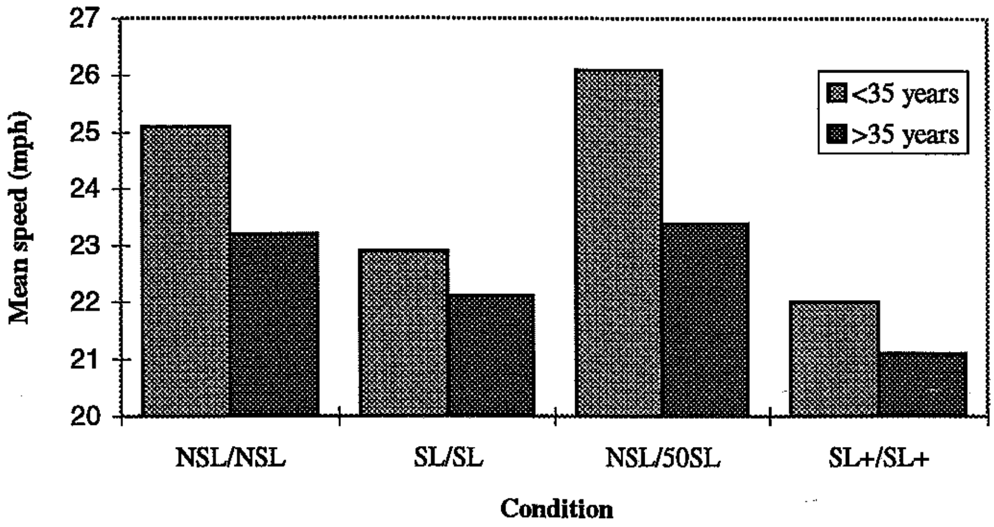



**Figure 2 Mean approach speeds by age**

The point at which the subjects first began to brake was recorded (within 80 metres of the junction). The mean values are shown in Table 1.

**Table 1 Mean braking point in each condition**

| *Condition* | *NSL/NSL* | *SL/SL* | *NSL/50SL* | *SL+/SL+* |
|---|---|---|---|---|
| *Braking point (m)* | 45. 19 | 38. 51 | 43. 64 | 23. 22 |

An average braking point for all left turns was calculated for each subject. The data were analysed using analysis of variance. There was a significant main effect of Condition on braking point, $F(3,29)=9.892$; $p < .001$. From Table 1 it can be seen that when the subjects were speed limited they tended to brake later.

### *3.2 Traffic light violations*

The number of red light violations that subjects committed in each condition was calculated and the numbers of violations in each condition are shown in Table 2.

**Table 2 Red light violations**

| *Condition* | *NSL/NSL* | *SL/SL* | *NSL/50SL* | *SL+/SL+* |
|---|---|---|---|---|
| *No. of violations* | 7 | 2 | 9 | 5 |

A chi-square test for independence between speed limited and non speed limited conditions revealed a significant difference in the number of traffic light violations committed ($p < 0.05$). Thus when drivers were speed limited, they tended to commit fewer traffic light violations.

### *3.3 Following behaviour*

Headway was recorded at 2 metre intervals along a 600 metre stretch of straight road where subjects were required to follow a lead vehicle. The presence of traffic on the approaching carriageway made it difficult for the subjects to overtake, however when this did occur, these instances were excluded from the analysis as the close approach to the lead vehicle during overtaking would skew the headway values. There were four occasions on which subjects were required to follow a lead vehicle; the following analyses refer only to one of those occasions. In this scenario, the lead car was travelling at a speed of 25 mph, and thus it was physically possible for subjects, even when speed limited, to adopt very short headways if they wished to.

For each subject, the percentage of driving time occupied in each half second unit between 0-6 seconds was calculated. A mean percentage was then derived across subjects in each condition. The distribution of headways is shown in Figure 3.

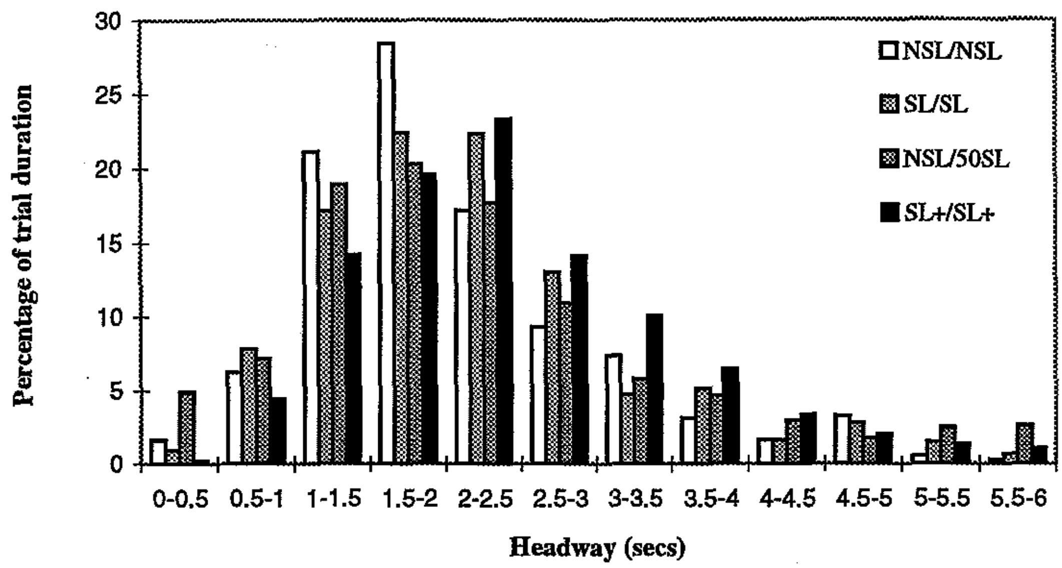



**Figure 3 Mean headway exposure for each condition**

The above distribution exhibits the following characteristics:

**Table 3 Headway distribution characteristics**

| *Condition* | *NSL/NSL* | *SL/SL* | *NSL/50SL* | *SL+/SL+* |
|---|---|---|---|---|
| *Skew* | 1.28 | 0.88 | 0.92 | 0.79 |
| *Kurtosis* | 0.68 | -0.81 | -0.83 | -0.65 |

From the above it can be seen that as the speed limiter is gradually introduced there is a trend towards reduced positive skewness, i.e. following behaviour is becoming safer by there being less tendency to follow at short headways.

### *3.4 Speed on curves*

The data were analysed with multi-factorial analysis of variance to determine the effect of two between subjects factors (Sex and Age) and one within subjects factors (Condition) on speed. There were no effects of Condition on entry, apex or exit speeds on curves, however a main effect did exist for speed variance over the whole, $F(3,87)=3.29; p<.05$, indicating that speed variance is lower when subjects are speed limited. The means are displayed below in Table 4.

**Table 4 Speed variance on curves**

| *Condition* | *Speed variance (mph)* |
|---|---|
| *NSL/NSL* | 1.28 |
| *SL/SL* | 0.63 |
| *NSL/50SL* | 1.11 |
| *SL+/SL+* | 0.72 |

### *3.5 Gap acceptance*

A mean value was calculated for all right hand turns for each subject. The means are displayed in Table 5 and Figure 4 below.

**Table 5 Mean gap accepted (metres)**

| | *Male* | | *Female* | | |
|---|---|---|---|---|---|
| *Condition* | <35 | >35 | <35 | >35 | *Mean* |
| *NSL/NSL* | 55.22 | 50.06 | 54.72 | 56.68 | ***54.15*** |
| *SL/SL* | 45.84 | 35.88 | 47.99 | 47.07 | ***46.69*** |
| *NSL/50SL* | 56.42 | 49.03 | 52.11 | 57.95 | ***53.87*** |
| *SL+/SL+* | 45.38 | 40.21 | 47.65 | 53.86 | ***46.78*** |
| *Mean* | 50.72 | 43.79 | 50.62 | 53.87 | |

The data were analysed with multi-factorial analysis of variance to determine the effect of two between subjects factors (Sex and Age) and one within subjects factor (Condition) on size of gap accepted.

There was a main effect of Condition, $F(3,87) = 6.23$, $p<0.01$. Post-hoc analyses revealed that subjects accepted smaller gaps when they were speed limited (both SL/SL and SL+/SL+ conditions) than when they were not speed limited (both NSL/NSL and NSL/50SL conditions). There were no differences in gap acceptance behaviour between the two speed limited conditions or between the two non-speed limited conditions. There was also a significant main effect of Sex on mean gap accepted, $F(1,29) = 6.27$, $p<.01$. Males accepted smaller gaps than females and that there is a significant interaction between Age and Sex, $F(1,29)$, $p<.01$, such that although there is only a slight increase in the size of gap taken for older females compared to younger ones, it appears that males in the higher age bracket accept significantly smaller gaps.

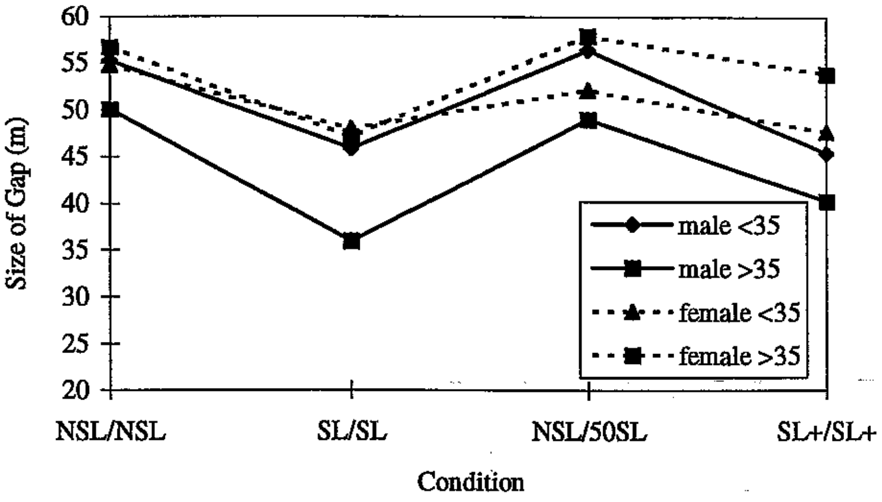



**Figure 4 Mean gap accepted**

### *3.6 Mental workload*

There were main effects of Condition on the following factors on the NASA-RTLX, the means are shown below in Table 6.

**Table 6 Mean mental workload scores**

| *Condition* | *NSL/NSL* | *SL/SL* | *NSL/50SL* | *SL+/SL+* |
|---|---|---|---|---|
| *Physical Demand* | 32.93 | 27.77 | 37.33 | 33.23 |
| *Performance* | 46.8 | 37.97 | 48.57 | 44.77 |
| *Time Pressure* | 27.6 | 35.97 | 32.5 | 40.57 |
| *Frustration Level* | 30.43 | 43.57 | 34.73 | 58.07 |

Compared to the control condition, subjects reported they experienced less physical demand, and that their driving performance improved when the car was fitted with a general speed limiter. The scores also indicate that subjects thought physical demand rose when the secondary speed limiter was introduced and that subsequently their performance deteriorated. In addition they reported that their frustration level rose from the control condition to the general speed limiter condition and that the level rose again when the secondary speed limiter was introduced. Finally they reported an increase in time pressure when the secondary limiter was implemented.

## 4. Significance of results

The results in general indicate that driver behaviour does change when speed limiters are in use. However it was noted that these changes were bi-directional, i.e. both safer driving and riskier driving were observed and these will be discussed separately.

### *4.1 Safety benefits*

The results suggest that driver's behaviour was sometimes more safe when speed limited. In car following scenarios there appears to be a shift towards safer behaviour whereby less time was spent at short headways. This can not be attributed to a system effect, as the lead car was only travelling at 25 mph, and therefore subjects were capable of adopting short headways if they wished (as they were limited to 30 mph). It is more likely that being speed limited prevented subjects from pulling up close to the car in front and then dropping back in an attempt to overtake. Summala (1980), in a study where overtaking was prohibited along a stretch of road, found that when drivers passed the prohibitory sign, if they were close following another car they increased their following distance. Where subjects were not speed limited they could not overtake, due to oncoming traffic, but in the process of attempting to, drew close to the car in front and thus increased the incidence of short headways. The results suggest that if drivers are waiting for an opportunity to overtake, accident risk increases by inducing shorter following distances.

In addition, the frequency of traffic light violations decreased when drivers were speed limited. The frequency is attributable to a system effect, as being speed limited meant drivers were travelling slower and thus had more time to make the decision as to whether to run the red light or not. The slower the driver is going, the more time they have from the onset of the amber light to make the decision, the more time they have to make the decision the more likely they are to stop.

Finally, it was observed that driver's who were speed limited tended to exhibit less variation in speed on curves. Total homogeneity i.e. a flow without speed variance, would theoretically eliminate many accidents (especially rear end collisions). Garber and Gadiraju (1988) found that accident rate did not necessarily rise with an increase in mean speed, but did rise with an increase in speed variance.

It is likely that the drivers in this experiment were aware that the speed limiter was encouraging them to drive more safely as in their subjective mental workload scores they reported their driving performance had improved.

### *4.2 Safety costs*

The results of the mental workload index indicate that feelings of frustration and time pressure increased when drivers were speed limited. This increase in time pressure is reflected in the riskier gap acceptance behaviour that was observed in the speed limited conditions. Drivers who were speed limited could be reducing their waiting time at junctions in order to make up for time lost elsewhere. This finding has important implications for safety at junctions.

In addition drivers tended to brake later on approach to junctions, however, the onset of braking is a function of speed on approach to junctions. Therefore drivers who were not speed limited were travelling faster on approach to junctions and thus were required to engage in earlier braking behaviour than drivers who were speed limited. This indicates that drivers who were speed limited were happy to allow the system to control their approach to the junction. Although this does not seem to be causing drivers to lose control of the car around the junction, it is impossible to predict how this system reliance may change as drivers become more used to the system. As familiarity with the system increased, drivers may become more reliant on the system, vigilance may decrease and accident propensity may increase.

## 5. PRINCIPAL CONCLUSIONS

This study examined the impact of automatic speed limiters on driving style, using the University of Leeds Advanced Driving Simulator. An urban environment was simulated using appropriate traffic and road variables to allow driver behaviour to be monitored. Various levels of system penetration were implemented and two types of speed limiter were evaluated. Behaviour, in terms of safety measures such as headway, gap acceptance and traffic light violations were measured, and mental workload was assessed using the NASA RTLX. It was hypothesised that although system effects would be observed in the form of speed reduction, drivers may undertake compensatory behaviour in order to attempt to regain lost time. The results in general indicate that driver behaviour does change when speed limiters are in use. However it was noted that these changes were bi-directional; i.e., both safer driving and riskier driving were observed. The benefits were observed on both links and at signals, and the reduction in speeds for younger drivers are particularly encouraging. On the other hand, the acceptance of smaller gaps at junctions is particularly worrying, since junctions account for 70 percent of accidents on urban roads.

The implementation of such a speed control measure requires careful prior consideration of issues such as practicality, acceptability and reliability. With regards to practicality the speed limiter could be installed in the car, using a mechanism similar to that of cruise control, and be operated by the driver. Alternatively the limiter could be controlled at the roadside. The first option is relatively simple and may be more acceptable to the driver as they still have some sense of personal control; but a system like this would be open to abuse. The second however, is dependant on a reliable and complete network of roadside technology.

Issues of acceptability apply to both car manufacturers and end-users. Car manufacturers market their products using speed and acceleration figures and it is likely that resistance to the introduction of speed limiters would be strong. Public opinion would have to be sought and incorporated into design and implementation. Over the years, the value of time for leisure and works trips has increased; it is therefore necessary to evaluate thoroughly any measures that might lengthen travel time. Typical reactions from subjects in this investigation included reference to the fact that sometimes it is necessary to accelerate above the speed limit to avoid dangerous situations. On urban roads this is unlikely, as probably the natural reaction is to brake rather than accelerate, however in faster moving traffic where overtaking is more common, this may be an issue, especially in a mixed fleet scenario where the traffic is relatively unpredictable.

Further research is necessary to establish long-term adaptation effects of speed limiters. The results produced in the above investigation are only applicable to short term effects and are not generalisable to a situation where a speed limiter has been in operation for a longer period of time. It may transpire that maladaptive behaviour disappears as lower speeds become more acceptable; on the other hand as people are constrained to lower speeds for longer and longer periods of time, compensatory behaviour may become more evident. Only by conducting long-term studies can these effects be monitored, e.g. the feasibility study in preparation in the Netherlands ( Diepens and Okkema) which aims to establish the benefits and costs of implementing intelligent speed limitation in a new neighbourhood in Tilburg. Issues to be tackled include hardware availability and applicability, town planning and design, co-operation of inhabitants, legal issues and financial consequences.

Incorporated into this research should be the ability to study behaviour in the mixed fleet situation. Although no effects were discovered in the present study it is likely due to the difficulty in simulating this type of interaction in the simulator, rather than the absence on effects per se. The unpredictability of traffic in a mixed fleet scenario may not only result in problems for other drivers, but also for other road users, in particular pedestrians. Another area which was outside the capability of this investigation due to limitations in the field of view on the simulator, was the consideration of how drivers of vehicles on a minor road may adapt their behaviour on approach to the junction with a major road. As in the example of vulnerable road users above, drivers may exhibit riskier merging behaviour due to their expectancy that cars will be travelling at or below the speed limit.

In conclusion, the results from this study indicate that automatic speed limiters may be both beneficial and detrimental to road safety. It is apparent that there is a need for a total integrated assessment of the effects of a speed limiter on safety, costs, the environmental and acceptability issues.


## ACKNOWLEDGEMENTS

Acknowledgements to Oliver Carsten and Mark Dougherty, grant-holders of the EPSRC funded project under which this study was carried out; Hamish Jamson and Stephen Gallimore for the creation of the road network and data collection software on the driving simulator, and Monica Anderson for the piloting of the mental workload questionnaires.

## REFERENCES


Almqvist, S. , Hydén, C. and Risser, R (1991). Use of speed limiters in cars for increased safety and a better environment. *Transportation Research Record* **1318,** pp34-39.

Anderson, M. E. (1996). Development of a questionnaire on workload for response to automatic speed control in urban areas project. *ITS Technical Note 398,* Institute for Transport Studies, University of Leeds, Leeds.

Andersson, J. W. (1978). The effectiveness of traffic safety materials in influencing the driving performance of the general driving population. *Accident Analysis and Prevention* **10,** pp81-94.

Becker, S. and Sonntag, J. (1993). Autonomous Intelligent Cruise Control. Pilot study conducted by the Daimler Benz and Opel demonstrators. TÜV Rheinland. Institute of Traffic Safety.

Byers, J. C. , Bittner, A. C. and Hill, S. G. (1989). Traditional and raw task load index (TLX) correlations: Are paired comparisons necessary? *In:* Advances in Industrial Ergonomics and Safety I Mital, A. , (ed) pp 481-485.

Carsten, O.M.J., Tight, M.R., Pyne, H.C. and Dougherty, M.S. (1995). Speed on Rural Arterial Roads. EPSRC Final Report GR/J48870.

Casey, S. M, and Lund, A. K (1993). The effects of mobile roadside speedometers on traffic speeds. *Accident Analysis and Prevention* **25**(5), pp 627-634.

Department of Transport (1995). Vehicle speeds in Britain, 1994. Department of Transport Statistics Bulletin (95) 32.

Diepens and Okkema (study to commence in 1998). A feasibility study of Intelligent Speed Limitation. On behalf of Ministry of Traffic, the Netherlands.

Downing, C. S and Spendlove, J. (1981). Effectiveness of a campaign to reduce accidents involving children crossing roads near parked cars. *TRL Laboratory Report 986.* Transport and Road Research Laboratory, Crowthorne.

Elliot, B. (1993). A meta-analysis of road safety mass media campaigns, unpublished report.

Evans, L. and Wasielewski, P. , (1983). Risky driving related to driver and vehicle characteristics. *Accident Analysis and Prevention* **15,** pp121-136.

Fairclough, S. H. (1991). Adapting the TLX to measure driver mental workload. DRIVE Project V1017 (BERTIE). Report no. 71. HUSAT Research Institute.

Fildes, B. N. and Lee, S. J. The speed review: road environment, behaviour, speed limits, enforcement and crashes. Report CR 127, Monash University, Accident Research Unit. Prepared for Federal Office of Road Safety.

Fildes, B. N. , Rumbold, G. and Leening, A. C. (1991). Speed behaviour and drivers' attitude to speeding. Report 16, Monash University, Accident Research Centre, Prepared for VIC ROADS, Hawthorn, Victoria.

Finch, D. J. , Kompfner, P. , Lockwood, C. R. , and Maycock, G. (1994). Speed, speed limits and accidents. *TRL Project Report 58*, Transport and Road Research Laboratory, Crowthorne, UK.

Fishbein, M and Ajzen, I. (1975). Belief, attitude, intention and behaviour: an introduction to theory and research. Addison-Wesley. Reading, MA.

Galizio, M. , Jackson, L. A. , and Steele, F. O (1979). Enforcement symbols and driving speed: the overreaction effect. *Journal of Applied Psychology* **64**(3) pp311-315.

Garber, N.J. and Gadiraju, R. (1988). Speed variance and its influence on accidents. AAA Foundation for Traffic Safety. 1988/07 pp 63. Report No. HS-040559.

Garber, J. P. and Gadiraju, R. (1989). Factors affecting speed variance and its influence on accidents. *Transportation Research Record,* **1213**, pp64-71.

Glad, A. (1986). Aksjonen "Bedre bilist-85", Resultater av en evaluering av aksjonen. Transportökonomisk institutt. Oslo.

Hauer, E. , Ahlin, F.J. and Bowser, J.S. (1982). Speed enforcement and speed choice. *Accident Analysis and Prevention.* **14** (4)267-278.

Hogema, J. H. , van de Horst, A. R. A, and Janssen, W. H (1994). A simulator evaluation of different forms of Intelligent Cruise Control. TNO Human Factors Research Institute. Report No. TNO-TN 1994 C-30.

Janssen, W. and Nilsson, L, (1993). Behavioural effects of driver support. *In:* Parkes, A. M. and Franzen, S. (Eds) *Driving Future Vehicles*, London : Taylor and Francis.

Kennedy, R. S. and Frank, L. H. (19860. Review of motion sickness with special reference to simulator sickness. *Transportation Research Record* **1059**, pp75-80.

Kimber, R. M. (1990). The relationship between speed, accidents and injury: Appropriate speeds for different roads and conditions. Proceedings of the PACTS conference on Speed, Accidents and Injury: Reducing the Risks pp17-28.

Lassarre, S. (1986) The introduction of variables "traffic volume", "speed" and "belt-wearing" into a predictive model of the severity of accidents. *Accident Analysis and Prevention.* **18**(2), pp129-134.

Mackie, A. M, Hodge, A. R. and Webster, D. C. (1993). Traffic Calming- design and effectiveness of 20mph zones. In Traffic Management and Road Safety, PTRC 21st Summer Annual Meting. Proceedings of Seminar C. London:PTRC.

McDowell, M. R. C. , Darzentas, J. and Wennell, J. (1981). Driver gap acceptance as a measure of accident risk. *In:* Road Safety: Research and Practice. Foot, H. C. , Chapman, A. J. and Wade, F. M. (eds). Praeger, UK.

Munden, J. W. (1967). The relation between a driver's speed and his accident rate. *TRL Laboratory Report 88,* Transport and Road Research Laboratory , Crowthorne , UK.

O'Neill, B. (1990). The relationship between speed, accidents and injury: Experience with speed limits in the USA. Proceedings of the PACTS conference on Speed, Accidents and Injury: Reducing the Risks pp11-18.

Philips, G. E. and Maisey, N. G. (1989). The effects of posted feedback on speeding behaviour. Western Australia Police Department Research and Statistics Section, Perth.

Plowden, S. and Hillman, M. (1996). Speed Control and Transport Policy. Policy Studies Institute, London.

Ragnarsson, R. S. and Bjorgvinsson, T (1991). Effects of public posting on driving speed in Icelandic traffic. Journal Applied Behaviour Analysis 24 pp 53-58.

Road Accidents Great Britain 1994. The Casualty Report. Department of Transport. London :HMSO.

Roqué,G. M, and Roberts, M. C. (1989). A replication of the use of public posting in traffic speed control. *Journal Applied Behaviour Analysis* **22** pp 325-330.

Russam, K. (1979). Improving user behaviour by changing the road environment. *The Highway Engineer,* August/September 1979, 18-24.

Sabey and Taylor (1980). The known risks we run: the highway. *TRRL Supplementary Report 567.* Transport and Roads Research Laboratory, Crowthorne.

Silcock, D. T. and Walker, R. T. (1982). The evaluation of accident countermeasures for application in residential streets. Research Report No.44, Transport Operations Group, University of Newcastle upon Tyne, UK.

Solomon, D. (1964). Accidents on main rural highways related to speed, driver and vehicle, US Department of Commerce, Bureau of Public roads, Washington, DC.

Streff, F. M. and Geller, E. S. (1988). An experimental test of risk compensation: between-subject versus within-subject analyses. *Accident Analysis and Prevention* **20**(4) pp277-287.

Summala, H. (1980). How does it change safety margins if overtaking is prohibited: a pilot study. *Accident Analysis and Prevention* **12**(1) pp95-103.

Teed, Lund and Knoblaunch (1993). Reductions in speed attributable to radar detectors. *Accident Analysis and Prevention* **25**(2) pp131-137.

Van Houten, R. and Nau, P. A. (1981) A comparison of the effects of posted feedback and increased police surveillance on highway speeding. *Journal Applied Behaviour Analysis* **14** pp 261-271.

Van Houten, R. and Nau, P. A. (1983) Feedback interventions and driving speed. : A parametric and comparative analysis. *Journal Applied Behaviour Analysis* **16** pp 253-281.

Van Houten, R. , Rolider, A. , Nau, P. A. , Friedman, R. , Becker, M. , Chalodovsky, I, and Scherer, M. (1985). Large-scale reductions in speeding and accidents in Canada and Israel: A behavioural ecological perspective. *Journal Applied Behaviour Analysis* **18** pp 87-93.

Winnett, M. A. (1994). A review of speed camera operations in the UK. PTRC summer annual meeting 1994.

Wright, C. C. and Boyle, A. J. (1987). Road accident causation and engineering treatments: a review of some current issues. *Traffic Engineering and Control.* **28** p475-479.

## Appendix A : The speed limiter

### 1. Technical details

Using the logical road network, each individual section of road can be given a speed limit which the drone cars will, if required, adhere to. If the speed of the drone exceeds the speed limit, it is decelerated by the formula:

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

where $a$ = drone's acceleration (m/s²)

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

$v$ = current speed of the drone (m/s)

$T_c$ = time constant of this first order system (1.5s).

### 2. Driver experience

(a) general speed limiter

- If the subject is driving the simulator at 30 mph or less then the speed limiter is inactive.

- If the subject attempts to accelerate to above 30 mph 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 of 10 bar. Thus even if the driver depresses the accelerator to its full extent there results in no increase in speed.

(b) secondary speed limiter

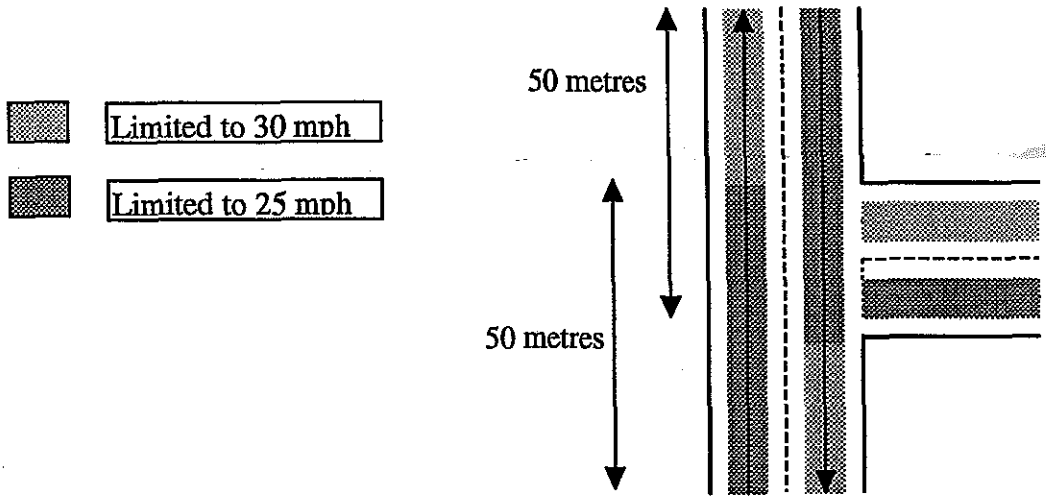
If the subject is driving the simulator when it also has the secondary speed limiter fitted, in addition to being limited to 30 mph, they are additionally speed limited around junctions. A junction is defined as an area of road where a minor road joins the major road on which the subject is travelling. As subjects approach the junction the secondary speed limiter comes into operation. At a distance of 50 metres before the junction the simulator is automatically slowed down to 25 mph (if the subject is currently exceeding that speed). They can only accelerate to 30 mph once they have passed the junction.

When the driver enters the junction zone (i.e. 50 metres before the junction) :

- If the subject is driving the simulator at 25 mph or less then the speed limiter is inactive.

- If the subject is travelling at more than 25 mph then the speed limiter is employed as described earlier by the vehicle dynamics model until the vehicle's speed has been reduced to 25mph.

If the subject attempts to accelerate to above 25 mph the speed limiter automatically prevents any further increase in speed as before. It is referred to as a secondary device as it is only conceivable as a second stage implementation,see diagram below.




When the driver enters the junction zone (i.e. 50 metres before the junction) :

- If the subject is driving the simulator at 25 mph or less then the speed limiter is inactive.
- If the subject is travelling at more than 25 mph then the speed limiter is employed as described earlier by the vehicle dynamics model until the vehicle's speed has been reduced to 25mph.
- If the subject attempts to accelerate to above 25 mph the speed limiter automatically prevents any further increase in speed as before.

## Appendix B : NASA RTLX

The following questionnaire was administered after each condition; subjects were permitted to consult the definitions of the factors given below.

Please place a line through each scale that represents the magnitude of each factor on the task you just performed. The factors are explained in more detail on the following page.

| | | | |
|---|---|---|---|
| **Mental Demand** | LOW | |_____________________| | HIGH |
| **Physical Demand** | LOW | |_____________________| | HIGH |
| **Time Pressure** | LOW | |_____________________| | HIGH |
| **Performance** | POOR | |_____________________| | GOOD |
| **Effort** | LOW | |_____________________| | HIGH |
| **Frustration Level** | LOW | |_____________________| | HIGH |

**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 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?

## APPENDIX C : Drop-out rate due to simulator sickness by sex and age

| | *Males <35* | *Males >35* | *Females <35* | *Females >35* |
|---|---|---|---|---|
| *Frequency* | 0 | 1 | 0 | 1 |

**Symptoms and onset**

Male >35: After approximately 5 minutes of driving the simulator, subject was physically sick. Described as a very sudden reaction to possibly driving round a left hand bend. Recovery was quick and the subject felt able to drive home after about an hour.

Female >35 : After approximately 30mins of driving the subject complained of feeling slightly warm, a little disoriented and mildly nauseous. Recovery was quick after some tea and air.

## APPENDIX D : Subject details

| *S no.* | *Sex* | *Age* | *Annual mileage* | *S no.* | *Sex* | *Age* | *Annual mileage* |
|---|---|---|---|---|---|---|---|
| *1* | Male | 26 | 40000 | *16* | Female | 35 | 15000 |
| *2* | Male | 35 | 10000 | *17* | Female | 32 | 20000 |
| *3* | Male | 23 | 30000 | *18* | Female | 26 | 8000 |
| *4* | Male | 26 | 12000 | *19* | Female | 25 | 8000 |
| *5* | Male | 30 | 15000 | *20* | Female | 30 | 12000 |
| *6* | Male | 33 | 15000 | *21* | Female | 30 | 16000 |
| *7* | Male | 32 | 12000 | *22* | Female | 31 | 25000 |
| *8* | Male | 37 | 15000 | *23* | Female | 43 | 12000 |
| *9* | Male | 43 | 20000 | *24* | Female | 48 | 15000 |
| *10* | Male | 54 | 9000 | *25* | Female | 49 | 6000 |
| *11* | Male | 38 | 28000 | *26* | Female | 48 | 15000 |
| *12* | Male | 46 | 7000 | *27* | Female | 43 | 20000 |
| *13* | Male | 44 | 18000 | *28* | Female | 48 | 18000 |
| *14* | Male | 47 | 13000 | *29* | Female | 47 | 17000 |
| *15* | Male | 48 | 20000 | *30* | Female | 24 | 21000 |

## APPENDIX E : The road network

The road network consisted of T-junctions and cross-roads, both approached from the major road only, due to the limitations of the field of view on the simulator, i.e. it is not possible for the driver to emerge from a minor road. The junctions were either signalised or unsignalised. All the junctions were at right angles and were separated by straight and curved lengths of road. In each experimental road subjects were required to manoeuvre round four right turns and six left turns. In addition they had to negotiate 4 circular curves and five sets of traffic lights. Speed limit signs were posted at the beginning of each network. Subjects found their way through the network by following signposts which directed them to Otley. Road markings and signs were 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.

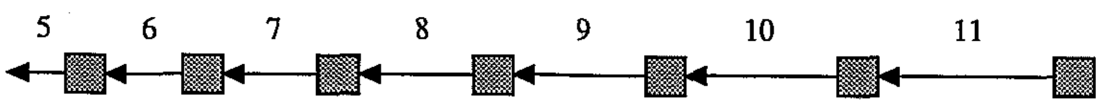
The other traffic on the road served two purposes. First, although they may not be crucial to the data collection, they add a sense of realism to the simulator. Second, they create scenarios which allow the investigation of certain driver behaviour, such as gap acceptance and headway distance. The other cars engaged in pre-programmed rule-based behaviour allowing the repetition of certain scenarios. This allows replication of traffic scenarios within experimental trials (allowing more data to be collected), between experimental trials (allowing manipulation of only one independent variable at a time) and between subjects (reducing the amount of between subject variability).

The following scenarios were simulated.

***Left turn manoeuvres*** Data was collected at four left turns in each experimental condition. Where the driver had to make a left turn manoeuvre all the junctions were identical in layout. The junctions were unsignalised and did not require the driver to give way to any other traffic. Each left turn required the subject to turn 90 degrees from the major road to minor road on the left. The junctions were designed so that 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.

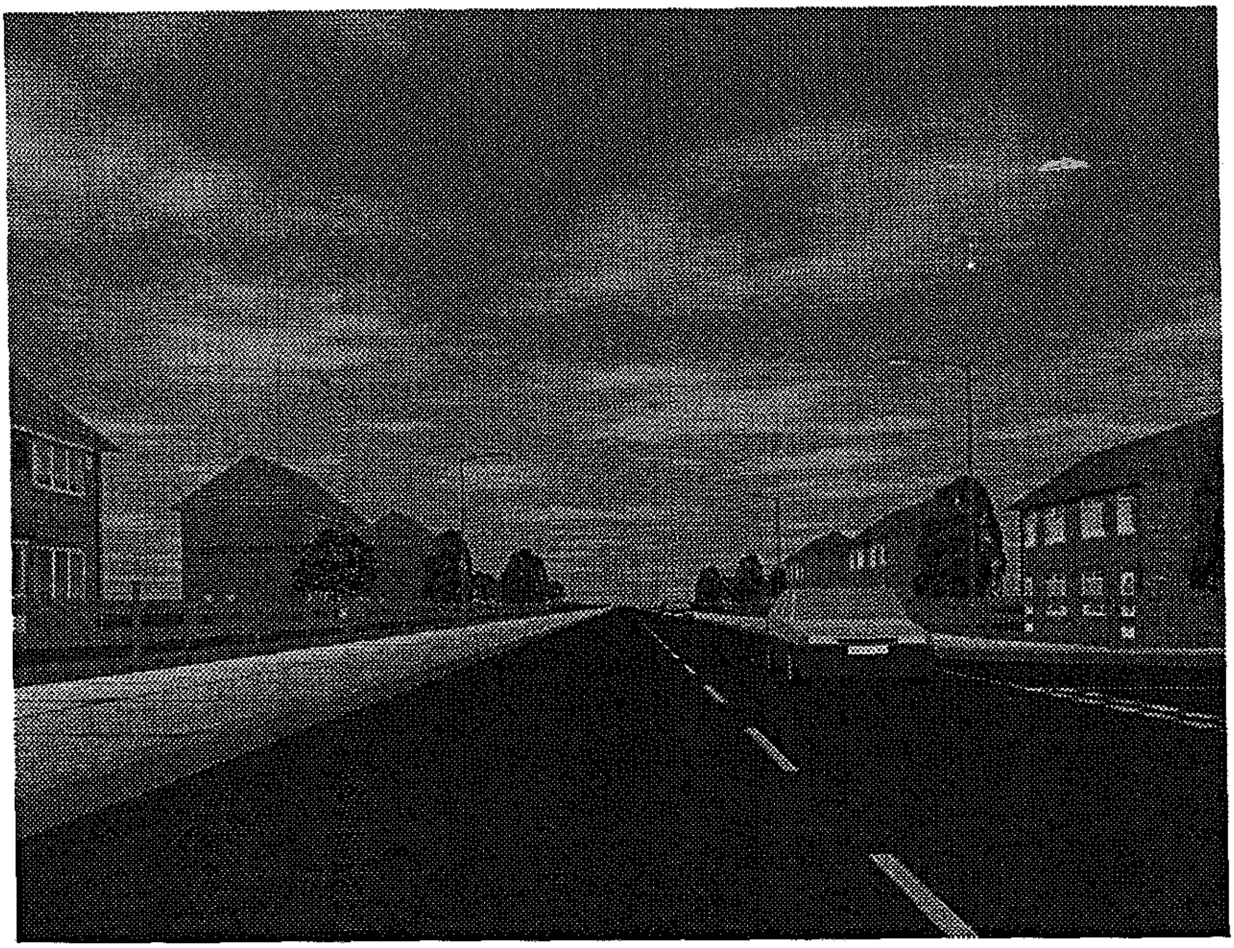
***Right turn manoeuvres*** Subjects were required to make a right hand crossing manoeuvre at four unsignalised T-junctions. Two directional sign-posts were displayed at the roadside, the first approximately 150 metres before the left hand turn, and another at 50 metres before the junction. On approach to these junctions it was clearly visible to subjects that there was oncoming traffic and that they would be required to undertake gap acceptance behaviour. There were 11 oncoming cars at each junction. These cars were programmed to maintain a constant speed and headway to the car in front, however the gaps between the cars varied. The oncoming traffic was deliberately designed to force the subject to come to a halt at the junction. This was achieved by the presence of four cars having gaps of three seconds between them. In a pilot study none of the subjects attempted to accept a gap of this size.

Behind these were an additional seven cars which maintained the following gaps (in seconds) :



This pattern was repeated for each right turn; the speed of the oncoming cars was 30 mph except in the condition where the secondary speed limiter was fitted (because the cars are within 50 metres of the junction and are thus slowed down to 25mph).

**Image 1 Driver waiting to turn right across oncoming traffic**

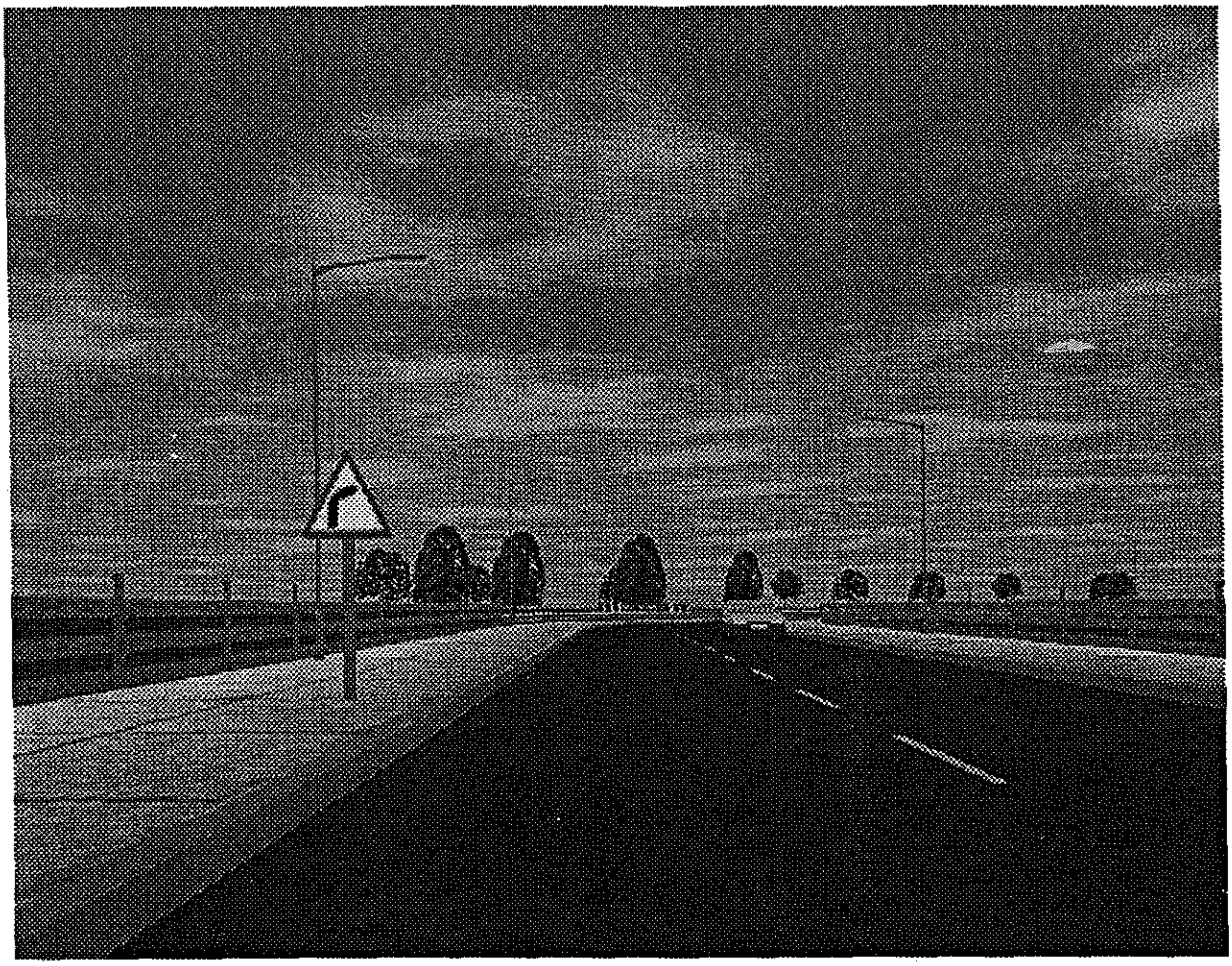


***Curve negotiation*** In each condition subjects were required to negotiate four bends. The geometric design of the curves were as follows :

| | *Radius (m)* | *Length(m)* |
|---|---|---|
| ***Bend 1*** | 300 | 200 |
| ***Bend 2*** | 63 | 100 |
| ***Bend 3*** | 63 | 100 |
| ***Bend 4*** | 300 | 200 |

The pilot study indicated that bends with a radius of less that approximately 70 metres encouraged subjects to drive at a maximum speed of approximately 25 mph. Therefore it was this type of bend (i.e. bends 2 and 3) that are of interest as it was theoretically possible for subjects to drive faster with the speed limiter fitted if they so wished. The longer shallower bend was included in the road network for realism's sake and was excluded from the statistical analyses.

**Image 2 Approach to sharp bend**



***Car Following*** The network was designed to allow the subject to engage in car following behaviour four times in each experimental trial. Each of these stretches of road were 700 metres in length, with a preceding section of 100 metres to allow the subject to alter their headway accordingly. In the first two situations there appears a curve in front of the subject and the car which they are required to follow is concealed round this bend. The cars movement is triggered by the subject's approach. In the third situation, subjects are required to stop at a set of traffic lights. A car pulls out from a side road and it is this car that the subject follows. Finally, in the fourth situation, the subject manoeuvres round right corner and triggers a car waiting there, which they then proceed to follow.

***Traffic lights*** There were five sets of traffic lights in each network. 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. In each experimental trial subjects encountered one situation where they were required to make a rapid stop/go decision at a set of traffic lights. The position of this set of lights was varied across conditions to reduce the effect of learning. The remaining traffic lights displayed various other behaviour. The order of traffic light sequences in the four experimental conditions are below.

| *Junction* | *NSL/NSL* | *SL/SL* | *NSL/50SL* | *SL+/SL+* |
|---|---|---|---|---|
| *4* | D | A | A | B |
| *9* | A | A | B | D |
| *15* | B | D | D | A |
| *19* | C | C | C | C |
| *25* | C | B | A | A |

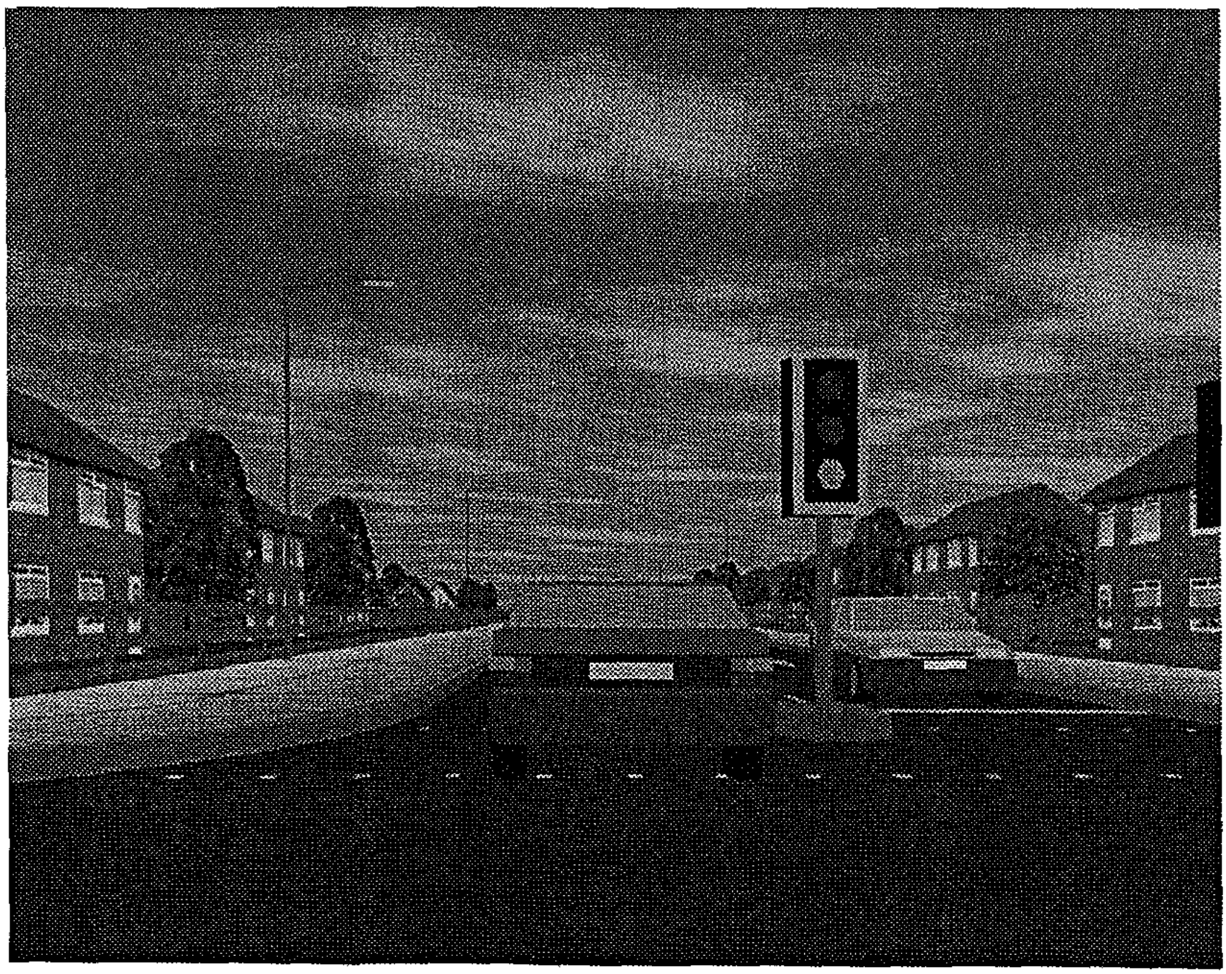
A When the subject first see the lights they are green
As they approach the lights they are green
They remain green.

B When the subject first see the lights they are green
As they approach the lights they are green
They change to red when the subject is approximately 30 metres from the lights.

C When the subject first see the lights they are red
As they approach the lights they are red
They remain red. Subject is required to stop.

D When the subject first see the lights they are red
They change to green when the subject is approximately 50 metres from the lights.

**Image 3 Driver engaging in car following after a set of traffic lights.**



## APPENDIX F : Data collection

*Left turn manoeuvres*
The data collected in a pilot study indicated that on the whole subjects were beginning to brake within a 80 metre distance before the turn. It was therefore decided to record the following data on the 80 metre approach to the junction.

(i) *Braking point (metres).* The distance from the junction at which the driver first started braking.
(ii) *Braking profile (bars).* Once an initial braking point had been recorded, the subsequent braking profile was measured.
(iii) *Speed (metres/sec).* Recorded for 80 metres before the junction.
(iv) *Longitudinal acceleration/deceleration (metres/sec $^2$).* Recorded for 80 metres before the junction.
(v) *Turn speed (metres/second).* An average value was obtained to indicate mean speed at the actual turning manoeuvre.
(vi) In addition the following data were collected over a distance of 30 metres after the junction.
(vii) *Speed (metres/second).*
(viii) *Longitudinal acceleration/deceleration (metres/sec $^2$).*

The data was collected every metre.
As junction layout was identical in nature it was considered appropriate to carry out analyses on the average measurements at the four junctions.

*Right turn manoeuvres*
At each right turn, the size of the gap that subjects accepted was recorded. This was calculated by measuring (in metres) the distance between the centre of gravity of the subject's car and the centre of gravity of the oncoming car as the subject manoeuvred the right hand corner.

*Curve negotiation*
The following measurements were taken :
(i) Speed (mph) at entry, apex and exit to the curve
(ii) Speed through the whole curve
(iii) Lateral position

*Following behaviour*
Once the subject had been following the lead car for 100 metres, the measurements taken were
(i) speed (mph)
(ii) distance from front of subject's car to rear of lead car (metres)
(iii) from the above two a measure of time to collision was derived (speed/headway)

*Traffic lights*
The colour of the traffic lights when the subject passed them was recorded.

## APPENDIX G : Instructions to subjects

**Briefing**

Thank you for volunteering to take part in this study. The purpose of the experiment is to discover how you drive if a speed limiter is fixed to the simulator. The speed limiter works in a similar way to those which are fitted to some HGVs and coaches. It restricts the driver to a certain maximum speed. First of all today I will be asking you to refamiliarise yourself with the controls of the simulator and get used to interacting with the types of traffic you are going to meet. This will take about 5-10 minutes. Once you feel comfortable with driving the simulator the experimental trials will begin. There will be four trials; sometimes you will be seed limited and sometimes you won't. Likewise sometimes the other cars on the road will be speed limited and sometimes they won't. I will tell you more details at the beginning of each trial. At the end of each trial you will have the opportunity to stretch your legs and have a drink of water if you wish to. Each trial lasts approximately 10 minutes, so we should be finished in just over an hour.

As I have explained on your previous visits to the simulator, some people have the tendency to suffer from 'simulator sickness'. Some of the symptoms include feeling warm, sweating, headaches and nausea. If you experience any of these symptoms or indeed feel any other discomfort, please stop driving straight away. We prefer for you to tell as soon as possible as usually the symptoms do not go away if you continue driving. The only cure is to stop driving.

If you still wish to proceed with the experiment please sigh the consent form and make yourself comfortable in the driver's seat.

**Practise session**

The purpose of this part of the experiment is to allow you to refamiliarise yourself with the simulator. I am going to ask you to drive along the practise road; it is about 7 minutes long. If after you have come to the end you do not feel completely comfortable you may ask to drive the practise road again. The road is a 30 mph zone and you are not speed limited, i.e. you can exceed the speed limit if you wish to. We want you to drive as naturally as possible and interact with the other traffic on the road as you would in real life.

I would like you to follow the signs to Otley. There are no other signs to worry about. By following the signs you will be taking left and right hand turns and interacting with traffic lights. You have already met on previous occasions all the scenarios you are going to meet. When you are at a right hand junction remember there is a lot of traffic approaching you and it is your task to cross when you feel it is safe to do so. Remember to position yourself a little further back from the junction than you would in real life, due to the limitations in the field of view. It is easier to complete the manoeuvre if you can keep the junction exit in view the whole time. When you reach the end of the practise road there will be a church directly in front of you, please drive up to the church and the screen will go off automatically.

Do you have any questions?
When you are ready, please begin.

**Experimental trials**

*NSL/NSL*
In this trial you are not speed limited and neither is any of the other traffic. So this is an everyday driving situation. I would like you to drive through this road network which will take you approximately 10 minutes. Please follow the signs to Otley and drive as if this is a normal 'on the way to work' or similar time pressured journey. I don't mean that you should go as fast as possible but please don't treat this as a 'Sunday drive'.

You have already encountered all the traffic scenarios that you are going to meet, there is nothing new for you to cope with. Please remember if you want to stop at any time please do so.

*SL/SL*
In this trial you are speed limited to 30 mph the whole way through the network.
This means that you are not able to accelerate to above 30 mph even if you have your foot flat on the floor. Of course you are able to go under 30 mph at any time. All the other traffic on the road is also speed limited to 30 mph. I would like you to drive through this road network which will take you approximately 10 minutes. Please follow the signs to Otley and drive as if this is a normal 'on the way to work' or similar time pressured journey. I don't mean that you should go as fast as possible but please don't treat this as a 'Sunday drive'.

You have already encountered all the traffic scenarios that you are going to meet, there is nothing new for you to cope with. Please remember if you want to stop at any time please do so.

*NSL/50SL*

In this trial you are not speed limited. However we want you to imagine that this is a transitionary phase and approximately half of the other cars on the road have a speed limiter fitted. You will not be able to tell which ones are fitted . I would like you to drive through this road network which will take you approximately 10 minutes. Please follow the signs to Otley and drive as if this is a normal 'on the way to work' or similar time pressured journey. I don't mean that you should go as fast as possible but please don't treat this as a 'Sunday drive'.

You have already encountered all the traffic scenarios that you are going to meet, there is nothing new for you to cope with. Please remember if you want to stop at any time please do so.

*SL+/SL+*

In this trial you are speed limited to 30 mph the whole way through the network.
This means that you are not able to accelerate to above 30 mph even if you have your foot flat on the floor. Of course you are able to go under 30 mph at any time. In addition, there has been fitted to the car a secondary speed limiter which operates in the following way. As you approach a junction the secondary speed limiter comes into operation. A junction is defined as an area of road where a minor road joins the major road on which you are travelling. At a distance of 50 metres before the junction your car is automatically slowed down to 25 mph (if you are currently exceeding that speed). You can only accelerate to 30 mph once you have passed the junction.
I would like you to drive through this road network which will take you approximately 10 minutes. Please follow the signs to Otley and drive as if this is a normal 'on the way to work' or similar time

pressured journey. I don't mean that you should go as fast as possible but please don't treat this as a 'Sunday drive'.

You have already encountered all the traffic scenarios that you are going to meet, there is nothing new for you to cope with. Please remember if you want to stop at any time please do so.

**NASA-RTLX**
(completed after each experimental trial)

This questionnaire requires you to specify how difficult you thought that last task was.
It is divided into 6 factors, which when combined indicate the total difficulty of the task. Please read the definitions of the factors on the attached sheet carefully. Then put a vertical line through each of the six factors to indicate the level of workload experienced on the task you have just completed.

**Debriefing**
Thank you for taking part in this experiment. As you have probably guessed we are looking at the effects of being speed limited on driver behaviour. We were recording general measurements such as speed, and also your interactions with other vehicles on the road.

Do you have any questions?