isa - UK

intelligent speed adaptation

Results of Simulator Experiments

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UNIVERSITY OF LEEDS

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EXECUTIVE SUMMARY

This driving simulator study investigated how ISA might affect a driver's overtaking decisions on rural roads, by presenting drivers with a variety of overtaking scenarios designed to evaluate both the frequency and safety of the manoeuvres. Each driver completed two drives: in one of these 100% of the other traffic in the scene was equipped with ISA, whilst in the other only 50% was equipped. In half the overtaking scenarios, ISA was active and in the remained ISA was switched off. Thirty-two drivers took part in the experiment, balanced for age and gender. We modelled a rural road with a number of 2+1 road sections, thus allowing drivers a protected overtaking opportunity. The results indicate that drivers become less inclined to initiate an overtaking manoeuvre when the Mandatory ISA was active, and this was particularly so when the overtaking opportunity was short. In addition to this, when ISA was activated drivers were more likely to have to abandon an overtaking, presumably due to running out of road. They also spent more time in the critical hatched area — a potentially unsafe behaviour. The quality of the overtaking manoeuvre was also affected when ISA was active: although the overtaking initiation was comparable, when drivers pulled back in they did so more sharply with a smaller distance to the front of the lead vehicle. This suggests that drivers need to learn the limitations of their own vehicle in overtaking situations. Not only that, drivers need to be made aware of the potential for unexpected behaviours in a mixed fleet scenario.

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1. INTRODUCTION

The study reported here was designed to quantify how a mandatory ISA (with no opt-out function) might affect a driver's overtaking decisions on rural roads. The study was undertaken on a driving simulator and allowed the presentation of a variety of overtaking scenarios in a safe and controlled environment. The accident rate associated with UK rural roads is relatively high, compared to that of urban and motorway environments. Motorways are five times safer than the average single-carriageway road and twice as safe as dual-carriageways. This is often attributed to lower standards of road design and higher occurrences of overtaking and run-off-the road accidents. A system, such as ISA, that restricts the maximum may have general "calming" benefits for rural roads, however accidents are more commonly associated with poor overtaking decisions and inappropriate curve negotiation speeds (which are lower than the speed limit anyway). Reducing the number of erroneous overtaking is the preferred route, but we recognise that some drivers will always wish to engage in such behaviour, even when the perceived risk is relatively high.

There have been numerous on-road and simulator studies that have investigated whether drivers behave differently when their vehicle is equipped with ISA. Various effects have been reported and these usually relate to their speed choice or headway keeping. Little research has been carried out to evaluate if and how driver's overtaking behaviour alters when using an ISA system. If drivers understand the limitations placed on their behaviour by ISA they may choose to overtake less frequently. If, however, drivers fail to appreciate the nuances of ISA, they may continue to overtake and hence put themselves in risky situations.

If positive changes in behaviour are evident, such as a decrease in the propensity of risky overtaking, then safety benefits on rural roads may be accrued. Conversely, the fact that driver's maximum speed is limited, may mean that they spend more time in an overtaking situation, and thus increase the risk of colliding with oncoming traffic – driver's may not be able to learn to adapt their driving behaviour appropriately.

If drivers are unable to accurately forecast the amount of time required for a particular overtaking manoeuvre there is an argument for providing drivers with an opt-out function. This function would allow drivers to over-ride the ISA system in order to exceed the posted speed limit and thus complete their overtaking manoeuvre more quickly. Thus whilst exceeding the speed limit is obviously illegal, it may provide drivers with a mechanism for avoiding a head-on collision. This study therefore implemented both a Mandatory and Opt-out ISA in order to compare the effects of each on overtaking propensity and safety.[1]

Overtaking judgements are influenced by the perceived speed on oncoming and lead traffic. For example, relatively slow-moving traffic in front of a driver may encourage them to overtake more, as could slow, oncoming traffic. In this study, we chose not to vary the speed of the lead vehicles, nor did we include oncoming traffic. Instead we induced feelings of uncertainty by the conveyance of differing messages regarding the surrounding traffic. In half of the experimental drives, the participants were informed that all the surrounding traffic was equipped with ISA; in the remaining drives a mixed-fleet scenario was presented. In this mixed-fleet situation, participants were told that only half of the other traffic was equipped with ISA.

This driving simulator experiment allowed us to present a range of potential overtaking scenarios to the participants. By varying task difficulty, we ensured that all drivers would have the

[1] This version of the document only contains the results of the mandatory ISA trials

opportunity to overtake — from those who actively search for overtaking opportunities to those who only do so when they believe the associated risk to be zero (no oncoming traffic and clear sight distance).

2. METHODOLOGY

2.1 Experimental design

Drivers were assigned to one of two groups – Mandatory or Opt-out. Each driver was asked to complete two drives: in one of these 100% of the other traffic in the scene was equipped with ISA, whilst in the other only 50% was equipped. The order in which the driver encountered these two drives was randomised. Each of the drives contained 10 overtaking scenarios: in half of these scenarios ISA was available to the driver, in the other half ISA was not available. Again, this was randomised across drivers. An example can be seen in Table 1, where this particular driver encountered the 100% fleet situation first and within this first driver ISA was first switched off, then became available for the last five overtaking scenarios. In their second drive, the mixed fleet situation, the reverse ordering was presented.

Table 1: Example experimental design

Overtaking Scenario	Drive 1 100%	Drive 2 50%
1	ISA off	ISA on
2	ISA off	ISA on
3	ISA off	ISA on
4	ISA off	ISA on
5	ISA off	ISA on
6	ISA on	ISA off
7	ISA on	ISA off
8	ISA on	ISA off
9	ISA on	ISA off
10	ISA on	ISA off

2.2 Participants

Thirty-two drivers took part in the experiment, recruited from an existing database. Of the sixteen males who took part, half were 25-39 years old and half were 40-60 years. The age of the females was similarly distributed.

2.3 Driving simulator

The experiment was performed using the University of Leeds Driving Simulator, see Figure 1. The simulator's vehicle cab is based around a 2005 Jaguar S-type, with all of its driver controls fully operational. The vehicle's internal Control Area Network (CAN) is used to transmit driver control information between the Jaguar and one of the network of seven Linux-based PCs that manage the overall simulation. This 'cab control' PC receives data over Ethernet and transmits it to the 'vehicle dynamics' PC, which runs the vehicle model. The vehicle model returns data via cab control to command feedback so that the driver seated in the cab feels (steering torque and brake pedal), sees (dashboard instrumentation) and hears (80W 4.1 sound system provides audio cues of engine, transmission and environmental noise).

Figure 1: The Leeds Driving Simulator

The Jaguar is housed within a 4m diameter, composite, spherical projection dome. A real-time, fully textured 3-D graphical scene of the virtual world is projected on the inner surface of the dome. This scene is generated by three further dedicated PCs on the local network, each housing an nVidia FX4500G graphics card. Each PC is used to render two of the six visual channels at 60 frames per second and at a resolution of 1024x768. The PCs are frame-locked to avoid any "tearing" of the visual image.

The projection system that displays the visual information consists of five forward channel and one rear channel. The forward channels are edge-blended to provide a near seamless total horizontal field of view of 250°. The vertical field of view is 45°. The rear channel (40°) is viewed only through the vehicle's rear view mirror. The display resolution of all channels is 4.1 arcmin per pixel.

The simulator incorporates an eight degree of freedom motion system. High and medium frequency lateral accelerations (e.g. a lane change) are simulated by sliding the whole vehicle cab and dome configuration along a railed gantry. Low frequency, sustained cues (e.g. a long, sweeping curve) are simulated using the tilt co-ordination of a 2.5t payload, electrically-driven hexapod. The whole gantry can also slide longitudinally along tracks to mimic the vehicle's acceleration and braking. The 10m long rails and tracks allow 5m of effective travel in each direction. The motion-base enhances the fidelity of the simulator by proving realistic inertial forces to the driver during braking and cornering. It also provides lifelike high frequency heave, allowing the simulation of road roughness and bumps.

2.4 Road scenarios

Limitations in projection can mean that the speed and distance of approaching vehicles in the opposing lane are difficult to perceive. From past experience we were aware that drivers can be reticent to overtake due to these limitations. We therefore created a scenario that allowed drivers to perform overtaking manoeuvres without having to consider the gaps in the opposing traffic. This was achieved by modelling a 2+1 road section, thus allowing drivers a protected overtaking opportunity. However, drivers were still obliged to perform this safely, taking into account the speed of the lead traffic, their maximum achievable speed and the length of the 2+1 section.

The length of the 2+1 section was varied, based on extensive piloting. We wished to create scenarios that required drivers to make safety decisions, but that did not create floor or ceiling effects in the data (i.e. none or all drivers overtook). The range of overtaking sections can be seen in Table 2. Of the ten overtaking scenarios encountered, six were configured as 2+1 sections and the remaining four were 1+1 lane scenarios (1000m straight section) Of these latter four scenarios, two were marked with standard dashed centrelines (overtaking permitted), whilst the remaining two had solid double lining (overtaking prohibited).[2] The latter scenario was introduced to evaluate whether drivers previously limited by ISA, would choose to overtake in a prohibited situation. In these four sections, the speed of the lead car decreased and there was no opposing traffic to encourage drivers to search for an overtaking opportunity.

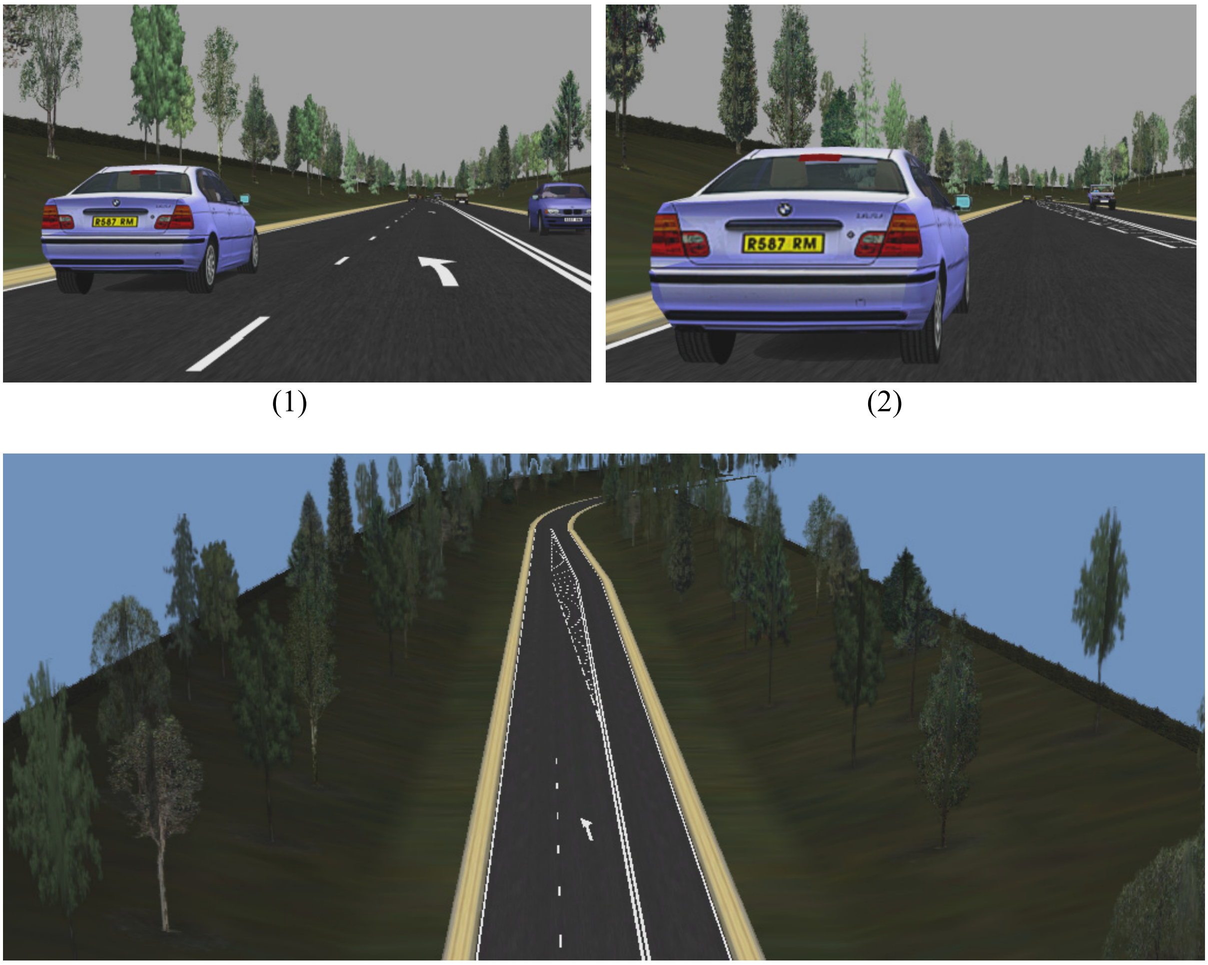
Table 2: Overtaking scenarios

Section	Lead car	2+1 length	comments
1	55mph	200	
2	45 mph	n/a	dashed centreline
3	55mph	350	
4	55mph	150	
5	45 mph	n/a	solid double centreline
6	55mph	200	
7	45 mph	n/a	dashed centreline
8	55mph	350	
9	55mph	150	
10	45 mph	n/a	solid double centreline

These overtaking scenarios were presented in the same order for each driver and were separated by filler sections of various lengths and curvature. All road sections, including the 2+1 overtaking section were modelled according to the UK Traffic Signs Manual, Chapter 5 (Road Markings).

Figure 2: Rural road scenes

[2] In reality there would be no reason to prohibit overtaking on such a long straight section of road.



(1) (2)

Plan view

Figure 3: Road scene showing the tapering down from two lanes to one

2.5 Measures

There were two main types of data of interest – the propensity of overtaking behaviour and the safety of any such behaviour. The following measures were recorded in each of the overtaking scenarios:

i. Overtaking outcome. A count was made of:
   a. The number of overtaking attempts made (no. of times the centre of gravity of the car crossed the centre-line)
   b. The number of successful overtaking (no. of cars passed, with no excursion into hatched area)
   c. The number of abandoned overtaking (no. of times they moved out of lane but abandoned the overtaking by moving back either before or after passing the lead car).
   d. If no attempt was made, this was also noted.

ii. Overtaking safety.
   a. Minimum distance (and time to collision) to the rear of the lead vehicle during the overtaking manoeuvre. This provided a measure of how sharply drivers pulled out from behind the lead vehicle.

b. Minimum distance to the front of the lead vehicle during the overtaking manoeuvre. This provided a measure of how sharply a driver pulled back in front of the lead vehicle
c. Time spent completing the overtaking manoeuvre
d. Maximum speed reached during the overtaking manoeuvre
e. Excursion into hatched area and the time spent in the hatched area

Additional data were collected in the filler sections – mainly to discover the effect of ISA on car-following behaviour. Here mean and minimum time headways were recorded.

Due to the non-parametric nature of some of the data (frequencies), chi-square tests were used to test any differences between overtaking behaviour when ISA was on, compared to when it was off. Elsewhere, paired t-tests and repeated measure ANOVA are used where appropriate.

3. RESULTS

3.1 Workload and acceptability

Previous research in the field has shown that drivers report changes in mental workload when driving with ISA. Increases in scores pertaining to "time pressure" and "frustration" have often been found (Comte, 2000; Várhelyi and Mäkinen, 2001). Acceptability scores tend to differ, depending on the type of ISA under investigation, but generally a mandatory ISA is less acceptable than a voluntary one. Instead of attempting to replicate these results, we used the workload and acceptability scores to evaluate whether drivers reported changes in workload under the differing traffic conditions (50% versus 100% ISA equipped).

The workload scores are shown in Figure 4. Paired t-tests performed on the individual components showed there to be no significant difference between the two traffic conditions.

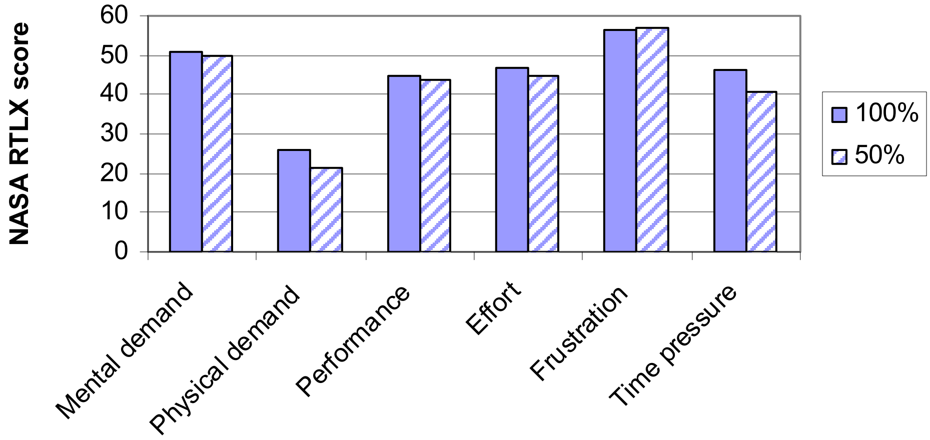


Figure 4: Mental workload scores

The acceptability scores similarly showed no differences in the two conditions, Figure 5, and as found in other studies, the Usefulness scores are higher than the Satisfaction one. This indicates that drivers can see the logic behind as ISA systems, in terms of its road safety benefits. However, when actually using ISA, they find the experience not as satisfying (although in this case not negative).

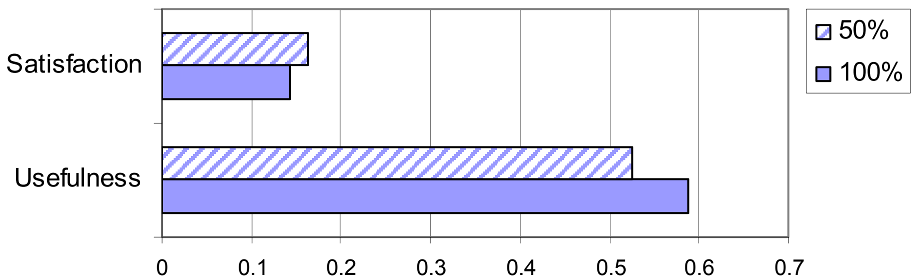


Figure 5: Acceptability scores

Together, these results suggest that either drivers did not comprehend the full implication of the mixed-fleet scenario or they deemed it no more or less demanding or acceptable than the 100% situation.

3.2 Overtaking propensity

Drivers encountered a total of twenty overtaking scenarios in the experiment. As can be seen in Figure 6, three drivers did not attempt to overtake at any point during the experiment. Most of the remaining drivers overtook in at least half of the scenarios.

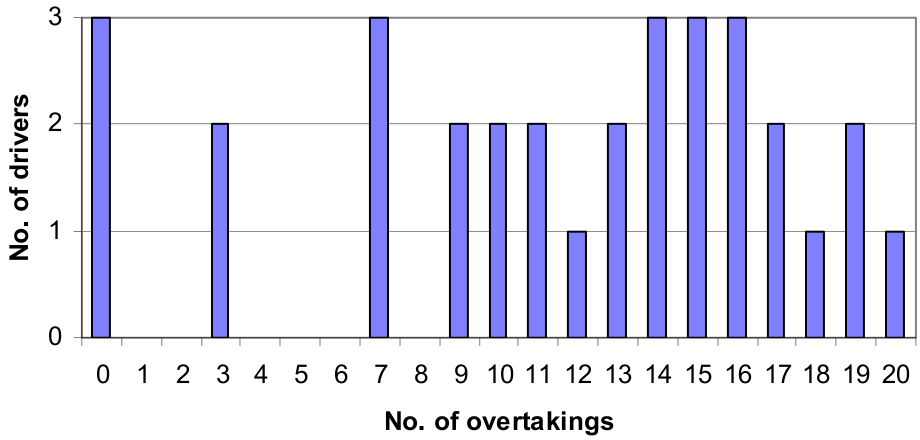


Figure 6: Frequency of overtaking manoeuvres

The number of drivers who attempted an overtaking manoeuvre in each of the scenarios is shown in Table 3. It can be seen that when ISA was off, most drivers attempted to overtake on the 2+1 sections and the permissible 1+1 section. When ISA was activated however, the number of attempts reduced, with only half the drivers attempting to do so in the shorter 2+1 sections. These differences were all significant at the 0.01 level. There was a strong correlation (r=0.8) between the number of overtaking each driver attempted in the ISA on/off scenarios – if a driver had a high propensity to overtake when ISA was inactive, this propensity remained (relatively) high when ISA was active. Figure 7 shows that most drivers reduced their overtaking attempts by up to 60%[3].

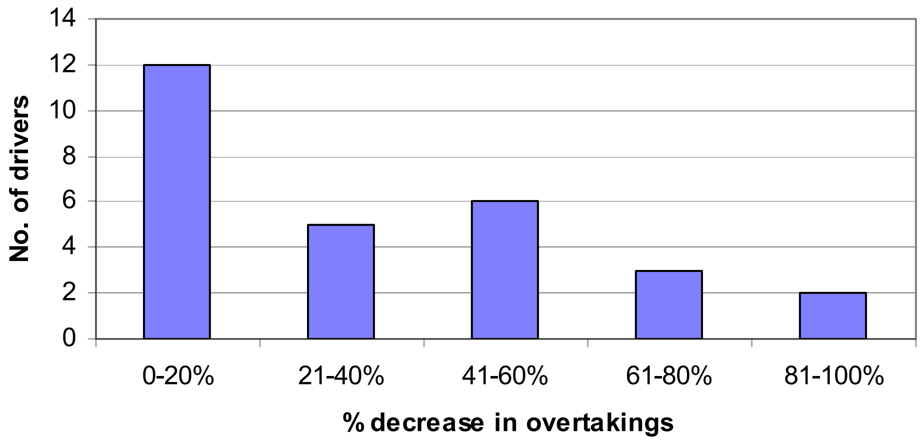


Figure 7: Percentage decrease in attempted overtaking with ISA active

There were no differences between the two traffic conditions (50% and 100%). Since the data showed this lack of variability in the rest of the measures, the datasets were combined.

[3] Three drivers exhibited no change and one driver increased the number of overtakings with ISA

Table 3: Number of drivers who attempted overtaking

	ISA on		ISA off	
	50%	100%	50%	100%
2+1 (150m)	18	16	23	25
2+1 (200m)	17	17	25	26
2+1 (350m)	20	14	26	27
1+1 (dashed)	24	23	25	25
1+1 (solid)	5	3	4	7

A number of drivers also attempted overtaking where double solid white lines were present. In the 100% ISA condition, twice the number of drivers overtook on this section when ISA was off – indicating that perhaps ISA had a calming influence on our drivers in this situation.

3.3 Overtaking outcome

The data presented above provide confirmation that drivers were able to discern differences in the difficulty of the overtaking scenarios. We were also able to measure the outcome of any attempted overtaking manoeuvres to establish whether drivers were more likely to abandon an overtaking manoeuvre when equipped with ISA. Figure 8 shows that successful overtakes (solid lines) were less likely when ISA was active and the number of abandoned manoeuvres higher. Both were significant at the 0.01 level.

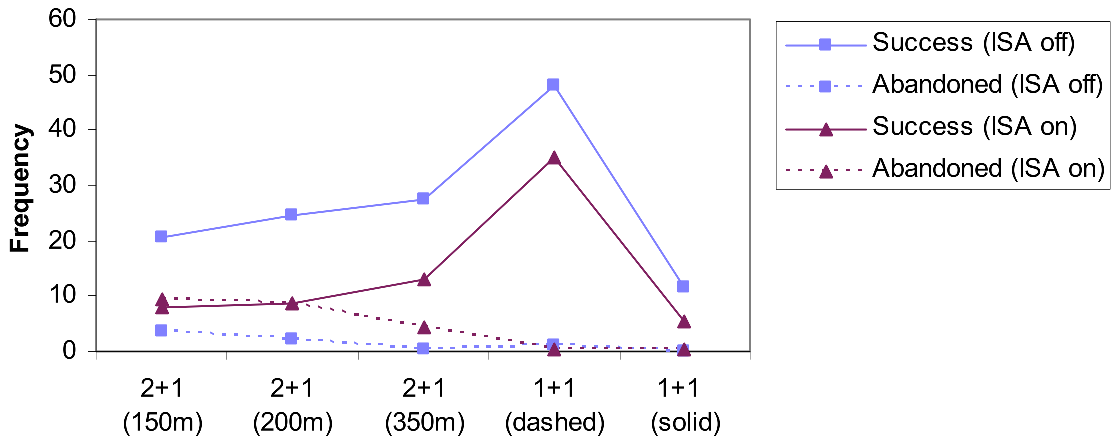


Figure 8: Overtaking outcome

The higher number of successful overtakes is a function of the number of overtaking attempts. More interesting is the ratio of the number of successful to attempted overtakes, Figure 9. In the 2+1 sections, the ratios are always higher when ISA is off. With ISA on, the ratios are approximately 0.5, except in the longer section, where this rises to almost the level of the ISA off condition.

It can be seen that in the 2+1 sections the ratios are always less than 1, whilst in the longer sections this increase to up to 2. This reflects the behaviour of a number of drivers who overtook multiple vehicles and hence whilst they attempted to overtake once at the beginning of the section, they successfully passed more than one vehicle.

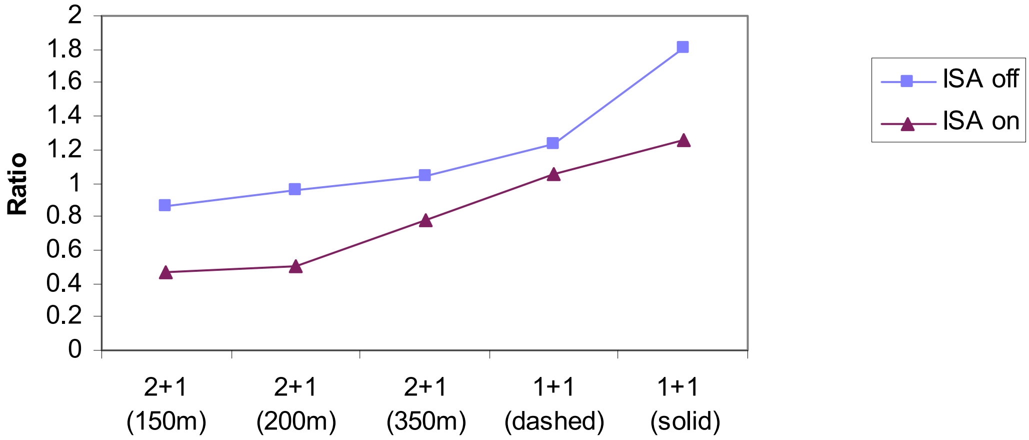


Figure 9: The ratio of attempted to successful overtaking

3.4 Safety of overtaking manoeuvres

Safety during overtaking is usually measured using indices of time-to-collision to oncoming traffic. As this experiment was designed using overtaking lanes, our measure of safety used the hatching at the end of the overtaking lane as the "critical object". If drivers encroached onto this hatching, we considered this to be poor planning, which in real-life could be safety-critical if oncoming traffic was present. Table 4 shows that the frequency of encroachments was comparable across conditions, with one-third of drivers doing so in the shorter 2+1 sections. However there were no statistically significant differences found here.

Table 4: Frequency of encroachments into hatched area

	ISA on		ISA off	
	50%	100%	50%	100%
2+1 (150m)	10	10	13	11
2+1 (200m)	6	8	4	7
2+1 (350m)	4	4	5	3

Figure 10 below shows seven drivers never encroached on the hatching and that most of the other drivers made only a small number of encroachments (there were 12 overtaking scenarios for each driver where encroachments could have occurred). Two drivers encroached in almost all scenarios.

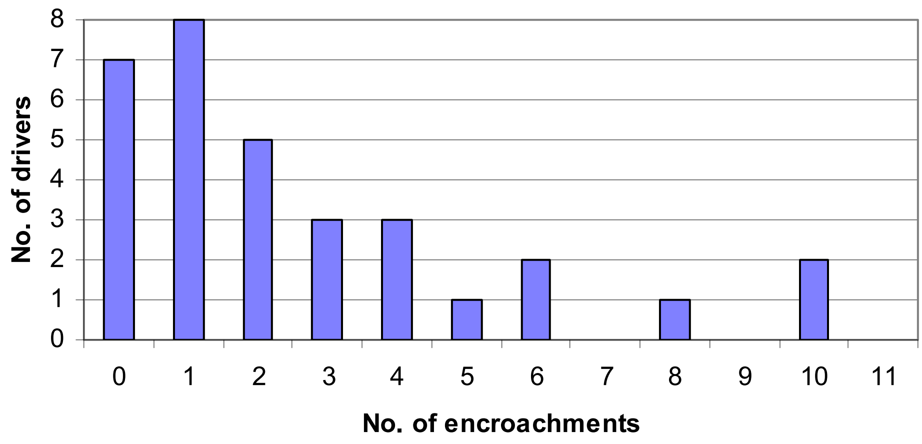


Figure 10: Frequency of encroachments

In addition, the amount of time spent in the hatched area was measured, as an index of severity, Figure 11. In general, when ISA was active, encroachments were more severe, with drivers spending an additional one second in the hatched area.

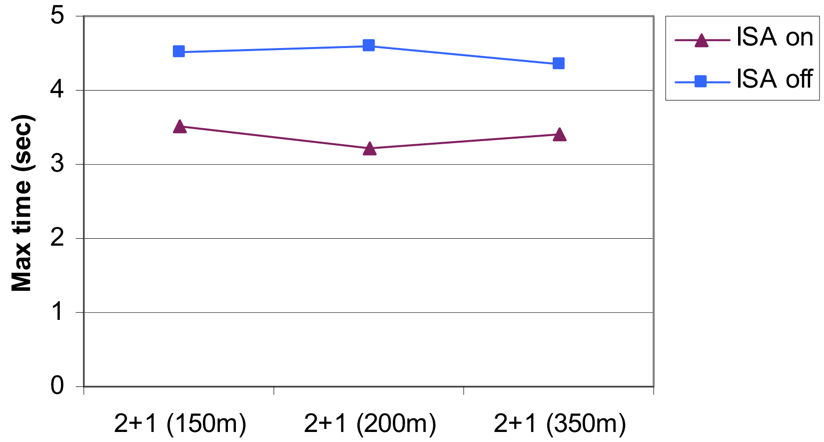


Figure 11: Severity of encroachment into hatched area

An additional measure of safety was gleaned from the separation distances between the driver and the lead vehicle whilst overtaking. As the driver instigated an overtaking manoeuvre, the minimum distance between the front of their vehicle and the rear of the lead vehicle was recorded. The minimum distance between the rear of the driver's car and the front of the lead vehicle was also recorded as the overtaking was concluded. These two measures of distance provide an indication of "cutting-in" and can be considered to be a measure of aggressiveness or lack of planning. Repeated measures ANOVA were carried out on the data pertaining to the 2+1 lanes only, due to their being multiple instances of overtaking in the 1+1 (dashed) overtaking scenario and scant data in the 1+1 (solid) scenario. The analysis showed there to be no significant difference between the conditions when commencing an overtaking manoeuvre ($F(1,8) = 3.57$, $p = 0.09$), Figure 12. However, there was a clear difference in behaviour when drivers pulled back into lane having completed the overtaking – with ISA active, drivers tended to cut in much more aggressively ($F(1,8) = 328.71$, $p = 0.03$) (see Figure 13).

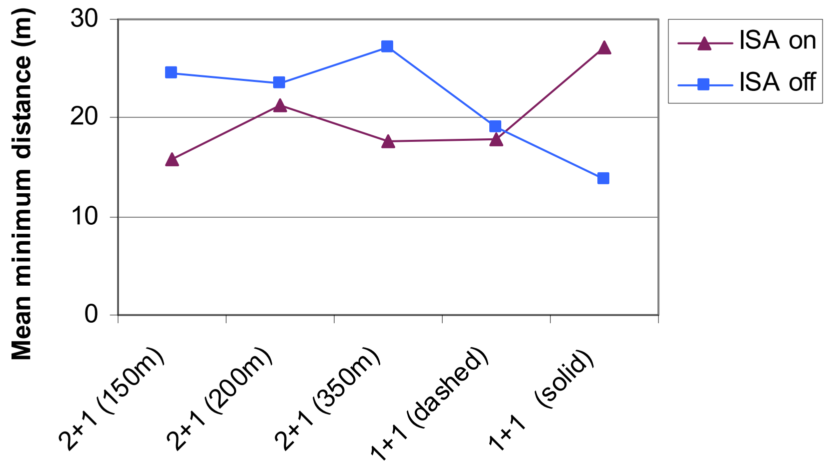


Figure 12: Mean minimum distance to the rear of the lead vehicle whilst overtaking

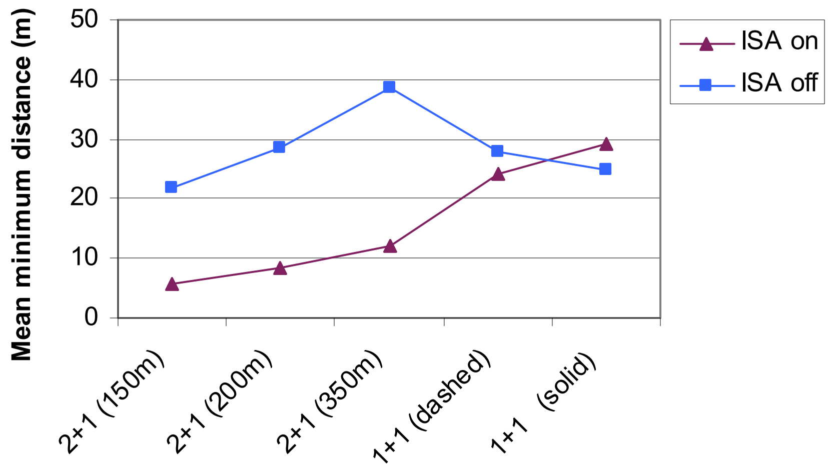


Figure 13: Mean minimum distance to the front of the lead vehicle whilst overtaking

Whilst overtaking, one would expect drivers to exceed the speed limit, in order to minimise their time in the overtaking lane. Maximum speed in the overtaking lane was calculated, and can be seen in Figure 14.

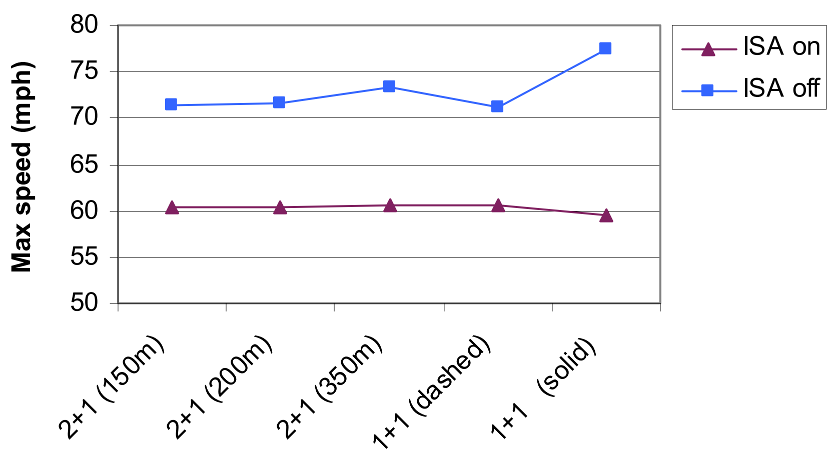


Figure 14: Maximum speed whilst overtaking

Whilst drivers with ISA were constrained to the speed limit of the road (60mph), those without ISA travelled at significantly higher speeds in order to pass the lead vehicles ($F(1,8) = 250.26$, $p = 0.001$). This was particularly noticeable in the prohibited overtaking section where the surrounding traffic was more unpredictable (50% condition).

3.5 Car following behaviour

Previous studies have reported changes in drivers' car following behaviour when driving with ISA. Persson et al (1993) reported increased following times in urban environments and Várhelyi et al (1998) found increases in urban situations but decreases in rural environments. Mean time headway was recorded during each of the filler sections, Figure 15. Whilst there were changes in headways depending on the filler sections, having ISA active or inactive made no difference ($F(1,34) = 0.05$, $p = 0.84$).

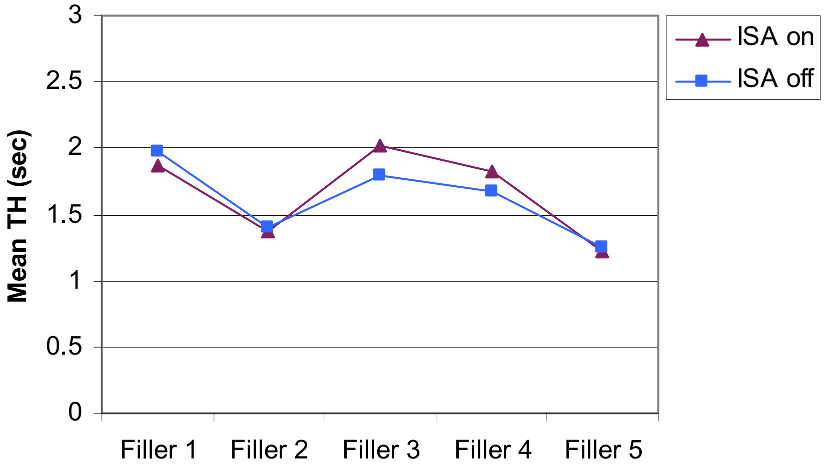


Figure 15: Mean time headway with the filler sections

3.6 Learning effects

As the two traffic conditions appeared to make no difference to the drivers' overtaking behaviour, the dataset was reanalysed using the run orders as the main experimental factor. It was possible that this would give different results as the order of the traffic scenarios was balanced and thus half the drivers encountered the mixed fleet scenario first (Run 1) and the other half encountered it second (Run 2). The number of overtaking attempts and success were compared in order to establish if experience with the ISA system impacted on their decision making, see Figure 16 shows the number of overtaking attempts, whilst Figure 17 shows the number of successful overtakes.

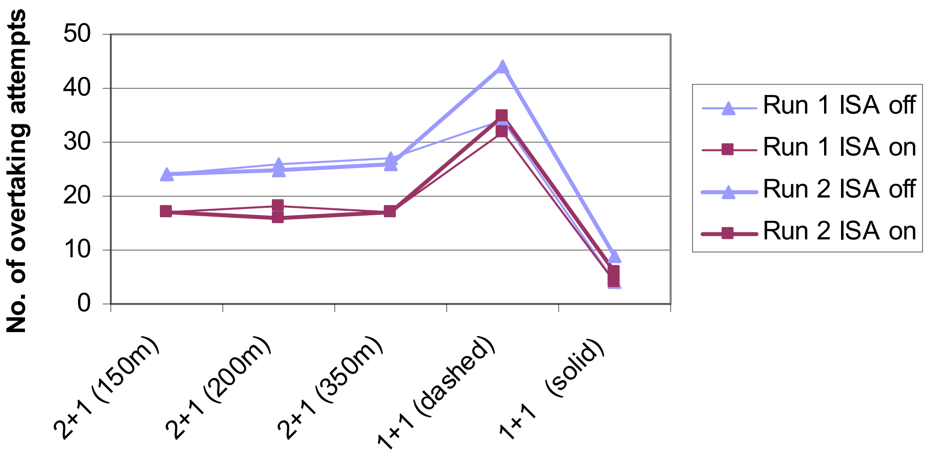


Figure 16: No. of overtaking attempts by run number

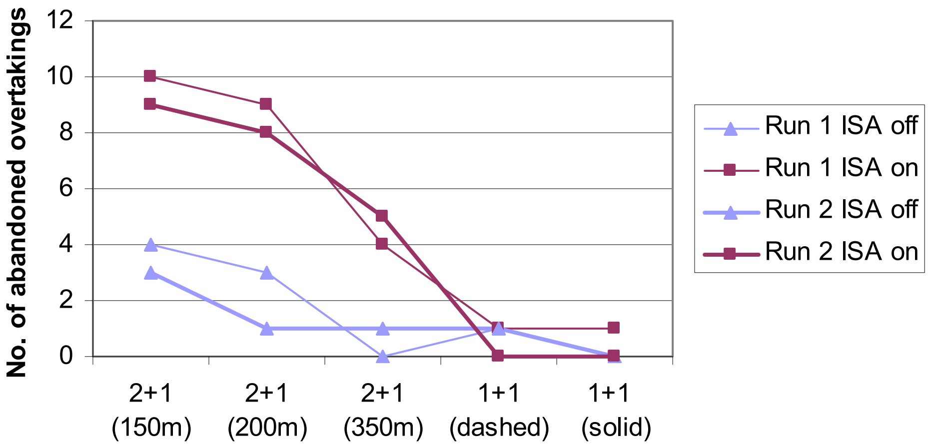


Figure 17: No. of abandoned overtaking by run number

It can be seen that drivers did not alter the number of overtaking attempts as their experienced increased, apart from in the 1+1 sections where overtaking was permitted: the number of overtaking increased by 30% in the second run. In addition, the number of abandoned overtaking manoeuvres also remained relatively stable with experience.

4. CONCLUSIONS

This simulator study allowed us to investigate whether drivers' overtaking behaviour changed when ISA was active. Almost all the drivers who took part in the experiment chose to overtake in at least some of the scenarios, despite not being primed to do so.

Overall the results indicate that drivers become less inclined to initiate an overtaking manoeuvre when the Mandatory ISA was active, and this was particularly so when the overtaking opportunity was short. In addition to this, when ISA was activated drivers were more likely to have to abandon an overtaking, presumably due to running out of road. Reassuringly, drivers were not inclined to carry on with an ill-timed overtaking and chose to drop back behind the lead car – they did not encroach on the hatched area more frequently than when ISA was inactive. More interestingly however, when the *amount* of time spent in the hatched area was considered, those with ISA active spent longer there. So whilst the frequency of poor planning was lower, the severity when it did occur was higher with ISA.

The quality of the overtaking manoeuvre was also affected when ISA was active – although the overtaking initiation was comparable, when drivers pulled back in they did so more sharply with a smaller distance to the front of the lead vehicle. This is presumably due to drivers running out of road length and ties in with the encroachment results presented above. With ISA inactive drivers overtook the lead car 10 mph faster and thus were able to rejoin the lane more quickly. Whether this represents a safety benefit is questionable as higher speeds could increase the frequency of loss of control accidents. However not being able to rejoin the inside lane swiftly brings its own risks. Under full implementation of ISA, drivers need to learn the limitations of their vehicle in overtaking situations. The opt-out function may provide a middle ground, whereby drivers travel at the appropriate speed when overtaking, but then opt-out to ensure they rejoin the inside lane in time. On the other hand, drivers may simply learn to use the opt-out function to disable ISA prior to an overtaking manoeuvre.

The results indicate that drivers behaved no differently when they were aware that only half the surrounding traffic was ISA equipped. They displayed no increased caution or reticence in overtaking. This is likely due to the fact that drivers require time and experience to understand the implications of this, and further research should establish how drivers react in situations where non-equipped traffic behaves erratically (sudden increases in speed of oncoming traffic, for example). We were not explicit in our instructions to the drivers, and we did not provide verbal descriptions of potentially critical situations that could arise as a result of the mixed fleet situation. As for all driver skills, experience is a key learning tool.

The study provides an overall picture of how drivers' overtaking behaviour when ISA was active. Whilst the propensity to overtake reduced, the quality of those manoeuvres undertaken also reduced. Most drivers continued to overtake with the same relative frequency when ISA was active, with only a few drivers dramatically altering their overtaking attempts.

5. REFERENCES

Comte, S.L. (2000). New Systems, new behaviour? Transportation Research Part F, 3, 95-111.

Persson, H., Towliat, M., Almqvist, S., Risser, R. and Magdeburg, M. (1993). Speed limiters for cars: a field study of driving speeds, driver behaviour, traffic conflicts and comments by drivers in town and city traffic. Report No. LUTDG/(TVTT-7128B)/1-114/(1993). Department of Traffic Planning and Engineering, Lund University, Sweden.

Várhelyi, A. and Mäkinen, T. (1998). Evaluation of in-car speed limiters: field study. EC FP4 project MASTER RO-96-SC.202. Working paper 3.2.2.

Várhelyi, A. and Mäkinen, T. (2001). The effects of in-car speed limiters: field studies. Transportation Research C, 9, 191-211.

APPENDIX A: KEY STATISTICS

Table 5: Overtaking outcome – Chi square results (p)

	Overtaking attempts	Overtaking successes	Overtaking abandons
2+1 (150m)	0.009	0.001	0.008
2+1 (200m)	0.001	0.001	0.002
2+1 (350m)	0.001	0.001	0.008
1+1 (dashed)	0.535	n/a	0.559
1+1 (solid)	0.455	n/a	0.315

Table 6: Mental workload – t test results (p)

Mental demand	Physical demand	Performance	Effort	Frustration	Time pressure
0.72	0.12	0.70	0.57	0.88	0.16

Table 7: ANOVA statistics

	Mean		F value	p	Effect size
	ISA on	ISA off			
Min distance to rear of lead car	14.95 m	18.72 m	3.57	0.09	0.31
Min distance to rear of lead car	8.88 m	39.36 m	328.71	0.003	0.99
Maximum speed when overtaking	60.54 mph	72.24 mph	250.65	0.001	0.98
Mean TH in filler sections	1.85 sec	1.88 sec	0.43	0.84	0.01