What benefit does Intelligent Speed Adaptation deliver: A close examination of its effect on vehicle speeds

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ABSTRACT

Intelligent Speed Adaptation (ISA) is a driver support system which brings the speed limit information into the vehicle. This paper describes the UK ISA field trials taken place between 2004 and 2006 and presents evidence on how drivers’ choice of speed is altered. The ISA system was observed to have a distinctive effect in transforming the speed distribution from a conventional bell shape to an asymmetric distribution biased towards the high speed end. ISA not only diminished excessive speeding, but also led to a reduction in speed variation, prompting a positive implication to accident reduction. The use of an overridable ISA system also provided an opportunity to investigate where drivers would choose to have ISA based on observed behaviour instead of opinion. Evidence shows that ISA tends to be overridden on roads where it was perhaps needed most. Behavioural difference among driver groups also suggests that ISA tends to be overridden by those drivers who in safety terms stand to benefit most from using it, as with other safety systems.

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1. Introduction

Speeding is a universal road safety problem. It occurs to all types of drivers, and on all categories of roads. Statistical evidence shows that a high proportion of cars travelling over the speed limits, as illustrated in Fig. 1 (Department for Transport, 2009). Speeding has also long been the most common traffic offence dealt with by police action (Ministry of Justice, 2008). Furthermore, a recent one-week operation by police forces across 22 European countries as part of the European Traffic Police Network’s Lifesaver project also discovered that 636,038 drivers were detected breaking the speed limits (European Transport Safety Council, 2009).

In terms of why drivers exceed speed limits, Corbett (2000) argues that speeding is not seen as a crime by most drivers and is widely believed to be socially acceptable. A recent survey by the motor insurance industry seems to support such a view in that three-quarters of UK drivers admitted to regular speeding (CIS, 2008). Drivers’ personality (e.g., sensation seeking) and demographic characteristics (e.g., gender and age) also play a role in intentional speeding (Zuckerman and Neeb, 1980; Webster and Wells, 2000).

Drivers however might unintentionally exceed the speed limits simply due to the inherent difficulty in accurate speed perception. Drivers estimate their own travel speed by a variety of sensory inputs, including visual (Gibson, 1979), auditory (Matthews, 1978), and kinaesthetic (McLan and Wierwille, 1975) cues. Hence, for example, the presence of road environment, noise, and surface quality would all affect drivers’ estimation of their own travel speed. Transitions between high and low speed zones also present a problem in that drivers who have travelled in a high speed zone for a certain duration tend to underestimate their speed when driving into a lower speed zone (Denton, 1976; Casey and Lund, 1993).

The threat of speeding to road safety lies in its strong relation to accident occurrence and severity. It is a straightforward notion that the faster the vehicle travels, the less time the driver has to respond to incidents (i.e. principles of human performance), and the harder the vehicle collides (i.e. the laws of physics). The link between travel speed and accident occurrence and severity has been well documented (e.g. Nilsson, 1982; Baruya, 1998; Maycock et al., 1998; Quimby et al., 1999; Taylor et al., 2000, 2002; Elvik et al., 2004). The inclusion of contributory factors in UK’s official accident records since 2005 also shows that excessive speed and speeding are a major cause of accident occurrence as well as strongly influencing accident severity, as depicted in Table 1.

2. Intelligent Speed Adaptation

Intelligent Speed Adaptation (ISA) is a driver support system which brings the speed limit information into the vehicle. An ISA system can be configured in various ways depending on the desired level of intervention with the driver’s speed control task:
advisory/warning (no intervention), and intervening (either overridable or non-overridable) ISA (Carsten, 2002).

The idea of assisting drivers with their speed control task could in fact be traced to the early 1980s (Saad and Malaterre, 1982) in the form of an on-board speed limiter where the limit was set by the driver. During the 1990s, the research community started to investigate in-vehicle systems which would provide support to the driver according to prevailing speed limits. Large-scale trials took place in Sweden (Biding and Lind, 2002) where nearly 5000 cars equipped with various forms of ISA were tested. Most of these had an advisory ISA but nearly 300 vehicles were equipped with an intervening system which consisted of a haptic throttle known as an Active Accelerator Pedal (AAP) (Hjälmåhåll and Vårhelyi, 2004).

The UK began its research into ISA in 1997 (Carsten and Tate, 2000). Later on, various ISA trials took place across Europe, including the Netherlands (non-overridable ISA), Denmark (warning ISA), Finland (recording ISA), Belgium (dynamic ISA), France (intervening ISA), and Austria (advisory ISA), as well as outside Europe (e.g. Japan, Australia, and Canada) (Carsten, 2004).

3. The UK ISA project

The UK ISA project (2001–2006) developed an intervening ISA system, which was installed in a fleet of 20 vehicles for a two-year field trial with a total of eighty participants. The UK ISA project was unique in comparison with other ISA trials.

3.1. Sophisticated system design

The ISA system developed in this project was an overridable ISA system. It was linked to the vehicle’s powertrain as well as brake system. If the driver attempted to go over the speed limit, the ISA system would cease fuel supply and activate the vehicle’s brake where necessary (e.g. downhill, or a transition from high speed zone to low speed zone). The ISA interface was designed to blend into the vehicle’s existing interface to provide a non-intrusive integration. An additional LCD display was embedded into the dashboard providing speed limit and system status (e.g. whether the ISA control was active or not). The ISA system was by default enabled upon engine ignition but drivers could override the ISA control by pressing a button located on the steering wheel (i.e. the right button in Fig. 2). Once the system was overridden, the driver was able to go over the speed limit. The ISA control would be resumed when the vehicle’s speed dropped below the current speed limit, or the vehicle reached a new speed zone, or the driver voluntarily opted back in (by pressing the left button in Fig. 2). Once the ISA system was re-engaged, the driver would have to override it again in order to go over the speed limit. The occurrence of user overriding was logged. This process provided an ideal opportunity to demonstrate drivers’ interaction with the ISA system.

3.2. Extensive trial design

The field trial adopted an ‘A-B-A’ design with three distinct phases over a six-month duration, as illustrated in Fig. 3. The first month of driving served as a baseline for comparison with the ISA activated period, and the final month of driving provided the opportunity to identify any carry-over effect as a result of experiencing the ISA system.

A series of four trials took place, covering two distinctive geographic areas and different types of driver, as depicted in Table 2. The Leeds area consisted of a mainly city environment but also some outlying rural areas and villages. The Leicestershire area covered mainly rural single carriageways and small towns. The ISA system made use of a map-matching system using GPS and other sensors combined with on-board digital maps. The speed limit database covered the local area as well as the national trunk road network. The intention was to give drivers ISA support for almost all their regular driving during the ISA-active phase.

Eighty drivers participated in the field trials. Recruitment criteria included gender, age (17–39, or over 40 years old), as well as intention to speed or not to speed (screened by a questionnaire developed based on Theory of Planned Behaviour; Ajzen, 1985). A young male participant dropped out during the trial. Since the time remaining did not permit recruitment of a replacement driver,

Table 1
Proportion of road accident attributable to speed related factors.

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Serious</td>
</tr>
<tr>
<td>Exceeding speed limits</td>
<td>14%</td>
<td>7%</td>
</tr>
<tr>
<td>Excessive speeds</td>
<td>16%</td>
<td>33%</td>
</tr>
</tbody>
</table>


Table 2
Geographic characteristics and driver types in the UK ISA trials.

<table>
<thead>
<tr>
<th>Test area</th>
<th>Driver type</th>
<th>Private motorists</th>
<th>Fleet drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leeds (mainly urban environment)</td>
<td>Trial 1</td>
<td>20 participants</td>
<td>Trial 2</td>
</tr>
<tr>
<td>Leicester (mainly rural environment)</td>
<td>Trial 3</td>
<td>20 participants</td>
<td>Trial 4</td>
</tr>
</tbody>
</table>

Fig. 1. Percentage of cars exceeding the speed limit 1998–2008.

Fig. 2. The ISA HMI developed in the UK ISA project.

Fig. 3. Field trial phases.
there were in total 79 drivers whose data contributed to the final analysis. The categorisation of driver characteristics is shown in Table 3.

### 3.3. Comprehensive data collection

The on-board data logging system recorded a wide range of data at high resolution, which facilitated sophisticated data analysis of vehicle speed and drivers' overriding patterns against speed limits as well as road categories (i.e. Motorways, A roads, B roads, and unclassified roads).

### Table 3

<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intender</td>
<td>Non-intender</td>
<td>Intender</td>
</tr>
<tr>
<td>Young</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Old</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>20</td>
</tr>
</tbody>
</table>

Although the data were recorded at 10 Hz (i.e. 10 records per second), data used for analysis was distance-based rather than time-based. While time-based data is intuitively valid, it introduces undue weight to the data stream when vehicle speed is zero (e.g. the vehicle stops at junctions) or very low (e.g. the vehicle moves slowly on a congested road). Since accumulated travel distance within a trip was logged 10 Hz, the raw data were converted to distance based data by sampling a record per 5 metres of travelling distance.

### Table 4

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mph</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>30 mph</td>
<td>36.2</td>
<td>35.9</td>
</tr>
<tr>
<td>40 mph</td>
<td>14.8</td>
<td>15.0</td>
</tr>
<tr>
<td>50 mph</td>
<td>5.7</td>
<td>6.0</td>
</tr>
<tr>
<td>60 mph</td>
<td>14.8</td>
<td>15.2</td>
</tr>
<tr>
<td>70 mph</td>
<td>28.2</td>
<td>27.6</td>
</tr>
<tr>
<td>SUM</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Unit: percentage.

![Fig. 4. The impact of ISA on speed distribution.](image-url)
This data reduction process also filtered out records without a valid speed limit attached to them (e.g. the vehicle was driven outside the map boundary or on a private road). The reduced database ready for analysis contained over 110 million records across all four trials. Table 4 compares the proportion of distance driven among speed limit zones across trial phases and suggests that the majority of data were collected from 30 and 70 mph zones. The distribution of data among speed limit zones was remarkably similar across trial phase, which suggests that seasonal effect was minimal, and that participants had not altered their choice of route to a large extent across trial phases.

4. The impact of ISA on vehicle speed

The impact of ISA on speed distribution is illustrated in Fig. 4. It clearly shows that ISA imposes a dramatic effect in reshaping the speed distribution, except for the 60 mph zones, in which speeding behaviour had already rarely been recorded before ISA was activated (i.e. Phase 1); this is in line with the UK national data. The relatively low speeding figure observed on 60 mph roads is considered to be primarily due to the constraints on driving speed imposed by road geometry and traffic, as the 60 mph speed limit is generally applied on rural single-carriageway roads. It is worth noting that the ISA system developed within this project allowed some limited speed excursion before the system cut in, and therefore some driving clustered immediately above the speed limit. Another noticeable trend revealed in Fig. 4 is that the shapes of speed distribution from Phase 1 and Phase 3 were generally very similar, which implies that, although ISA effectively changed the speed distribution, the carry-over effect was not prominent.

Fig. 5 illustrates a comparison of the mean and the 85th percentile speeds across trial phases in each speed limit zone. A ‘V’ shape is observable across all speed limit zones; i.e. the mean or the 85th percentile speeds goes down from Phase 1 to Phase 2, and then rises again from Phase 2 to Phase 3. Repeated measures ANOVA reveals that the speeds from Phase 2 were significantly lower than Phase 1 and Phase 3 in most speed limit zones. The differences between Phase 1 and 3 were not statistically significant, which suggests that the carry-over effect was minimal. It is worth noting that the statistical significance where applicable was stronger for the 85th percentile speeds than for the mean speeds, which suggests that ISA is particularly effective in tackling speed violations at higher speeds.

Fig. 6 compares participants’ speeding behaviour across trial phases in terms of the percentage of distance travelled over speed limits. Again, a ‘V’ shape is observable across all speed limit zones, which suggests that ISA effectively reduces speeding. Results of repeated measures ANOVA confirm that speeding in Phase 2 was significantly less than Phases 1 and 3 in most speed limit zones.

The absence of statistical significance in the results from the 20 and 50 mph zones with respect to mean speeds was primarily due to the sample size; i.e. there were relatively less data collected from the two speed limit zones in comparison with other zones—not all participants drove in the two speed limit zones during the trial period. Attributing the small sample size, when the effect size is sufficiently large, it still demonstrates statistical significance as in the case of the 85th percentile speeds. Also, observed speeding was not significantly different between Phase 1 and 3, which again suggests that the carry-over effect of ISA was not prominent.

Fig. 7 shows a comparison of speed variability across trial phases, in terms of the coefficient of variation (CV). CV is a dimensionless measure that allows comparison of the variation of populations having considerably different mean values, which is of particular use for this analysis since the speed zones range from 20 mph to 70 mph. Speed variability derived from Phase 2 was consistently smaller than that from Phase 1 or 3 (i.e. a ‘V’ shape) across all speed limit zones. Noticeably, the reduction in speed variability appeared to more prominent in urban areas than on rural single-carriageways (i.e. the 60 mph zones) and motorways (i.e. the 70 mph roads).

5. Driver compliance with ISA

The use of an overridable ISA system provides an opportunity to investigate where drivers were willing to accept the support of
the ISA system and where they chose to override it. Fig. 8 shows that ISA was overridden most often on 70 mph roads. However, it is also of great concern that the 20 mph zone had the second highest rate of overriding, since here drivers are most likely to encounter vulnerable road users such as pedestrians and young children.

Overriding ISA support in fact presents a different picture from observed speeding (i.e. Fig. 7). Table 5 compares data collected from this project with official UK data on vehicle speeds. The average of percentage of cars exceeding speed limits on UK roads between 2004 and 2006 was used in order to provide comparable data since that is when the ISA trials were taking place. This comparison brings up two interesting points. First, speeding recorded in the ISA field trials was less than in the national data, and was far less in some speed limit zones. This is most likely to be a reflection of the survey protocols adopted by the UK Department for Transport. All automatic traffic counters are sited at selected points where traffic is not congested under normal conditions to minimise the impact of congestion, while data collected from the ISA trials included non-free-flow speeds. Second, there is a large difference between the percentages derived from when ISA was overridden and when the vehicle speed was over the speed limit, which is due to the ISA system allowing a small amount of over-speeding without deliberate overriding. This however highlights the value of ISA. When drivers wished to go over the speed limit, they had to deliberately override the system control. The need to overcome the natural behaviour of the system promoted driver compliance with speed limits.

Of all speed limit zones, the 30 mph zone is of particular interest, as it covers a variety of road layouts including residential streets and arterial roads (where roads are wider and often are dual carriageways, which could adversely encourage drivers to speed when traffic is light). Table 6 depicts a breakdown of the frequency of overriding and percentage of distance travelled with ISA overridden across road categories in 30 mph zones. It suggests that drivers indeed override more often and drove a larger proportion of distance with ISA overridden on urban arterial roads. Since a very large proportion of fatal and serious accidents (approximately 40% on average over the past five years; Department for Transport, 2008) occurred on A roads with a 30 mph limit and with the strong relationship between speed and accidents (i.e. Table 1), it could be argued that ISA was most by-passed where it was most needed.

Fig. 9 compares overriding behaviour by driver groups, and suggests that male drivers, young drivers, drivers who were intending to break speed limits, and private motorists tended to override the ISA system more often than their counterparts, although the difference between private motorists and fleet drivers was marginal. Fig. 10 further examines the extent of overriding of the ISA system on 30 mph roads which are typical of urban areas and 70 mph roads which are generally inter-city dual carriageways or motorways. It can be seen that the patterns by gender and age are the same for the two road categories. However, intenders and non-intenders demonstrated similar behaviour on urban roads but appeared to behave differently on 70 mph roads. There was a notable difference in behaviour between the private motorists and the fleet drivers: private motorists tended to override more frequently than fleet drivers on urban roads, while fleet drivers appeared to override more frequently than private motorists on 70 mph roads.

Table 5

<table>
<thead>
<tr>
<th>Speed limit</th>
<th>Overriding observed in this trial</th>
<th>Speeding observed in this trial</th>
<th>UK average between 2004 and 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mph</td>
<td>13.3%</td>
<td>42.4%</td>
<td>51%</td>
</tr>
<tr>
<td>30 mph</td>
<td>8.1%</td>
<td>34.9%</td>
<td>27%</td>
</tr>
<tr>
<td>40 mph</td>
<td>7.7%</td>
<td>23.8%</td>
<td>27%</td>
</tr>
<tr>
<td>50 mph</td>
<td>7.0%</td>
<td>24.0%</td>
<td>–</td>
</tr>
<tr>
<td>60 mph</td>
<td>1.3%</td>
<td>5.6%</td>
<td>11%</td>
</tr>
<tr>
<td>70 mph</td>
<td>16.3%</td>
<td>24.5%</td>
<td>55%</td>
</tr>
</tbody>
</table>

Table 6

<table>
<thead>
<tr>
<th>Road category</th>
<th>Percentage of distance travelled with ISA overridden</th>
<th>Mean frequency of overriding per 1000 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>A roads (urban arterial roads)</td>
<td>12%</td>
<td>228</td>
</tr>
<tr>
<td>B roads</td>
<td>6%</td>
<td>135</td>
</tr>
<tr>
<td>Unclassified roads (residential streets)</td>
<td>6%</td>
<td>133</td>
</tr>
</tbody>
</table>

Fig. 8. Comparison of overriding behaviour across speed zones.

Fig. 9. Comparison of overriding behaviour across driver groups.

Fig. 10. Comparison of overriding behaviour on 30 and 70 mph roads across driver groups.
6. Discussion

The ISA system was observed to have a distinctive effect in terms of transforming the speed distribution across all speed zones except the 60 mph zones. Speeds over the speed limit and in particular very high exceeding of the limit were curtailed. When ISA was switched on, a large proportion of the speed distribution previously spread over the speed limit was shifted to around or below the speed limit. Analysis of various statistics related to speed (mean and 85th percentile) revealed a ‘V’ shape across trial phases, i.e. the statistic went down from Phase 1 to Phase 2, then up from Phase 2 to Phase 3. This pattern is especially prominent with respect to high percentiles of the speed distribution, which are strong indicators of speeding behaviour. ISA not only diminished excessive speeding, but also led to a reduction in speed variation, which has been argued to be significantly correlated with accident occurrence (Taylor et al., 2000, 2002).

The use of an override-ISA system also provided an opportunity to investigate how drivers would choose to have such a support, based on observed behaviour instead of opinion. ISA was overridden the most on motorways, followed by built-up areas (20 and 30 mph zones). Urban environments are where drivers are most likely to encounter conflicts with vulnerable road users. Thus there was some tendency for ISA to be overridden on roads where it was perhaps needed most. In term of sub-groups within the driving population, male drivers and young drivers overrode the system more than their counterparts regardless of speed zones. Given that these two groups of drivers also drove faster and had a higher percentage of distance travelled over the speed limit than their counterparts, there is a pronounced tendency for ISA to be overridden by those drivers who in safety terms stand to benefit most from using it, as with other safety systems (e.g. seatbelts). The same tendency was observed by comparing overriding behaviour between drivers who intend to speed and not to speed. In addition, private motorists were more likely to override in built-up areas while fleet drivers more frequently overrode on motorways. This suggests that the need to comply with the speed limits on urban roads may have been instilled in the fleet drivers, but those same drivers feel little compunction about speeding on fast roads.

In conclusion, ISA demonstrates a very large potential for safety benefits, considering the strong relationships between speed and accident occurrence as well as severity. In addition, the potential of ISA to road safety would be further extended when it is incorporated into a network-wide traffic management system. For example, ISA could be configured to apply lowered speed limits where and when appropriate, such as roads outside schools within certain time periods, or on sharp bends at night time.

ISA could also be configured to apply speed limits dynamically depending on the provision of infrastructure. For instance, the traffic control centre could broadcast a lowered speed limit for roads with accidents, or for adverse weather conditions in certain areas of the network. In such a scenario, ISA would no longer just an autonomous system, but a co-operative system.

References

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