INTRODUCTION

The External Vehicle Speed Control (EVSC) project, funded by the Department of the Environment, Transport and the Regions (DETR), has investigated a wide range of issues concerning intelligent speed adaptation (ISA), including the technologies that can be used, attitudes towards such systems, the predicted safety benefits, network effects, and costs and benefits. This paper summarises the work predicting the safety impacts of ISA/EVSC and provides an overview of the studies of driver behaviour with ISA/EVSC.

SYSTEM VARIANTS

The generic EVSC concept is shown in Figure 1. The car knows in position from a differential GPS (dGPS) system, to an accuracy of about 2 metres. On board the car is a digital road map, which includes information on the speed limit for a particular road. With the consequent knowledge of location and speed limit, it is possible, through the engine controls and braking, to limit the vehicle’s top speed to the current speed limit.

There are a number of variants of EVSC. One important dimension is how intervening the system is. Here there are three major variants:

1. Advisory EVSC: here information is provided to the driver on speed limits, but there is no use of this information to limit vehicle speed automatically.

2. Driver Select EVSC: this is a voluntary system in which information on the speed limit is linked to the vehicle controls, but the driver has the option of enabling and disabling the control of maximum speed at will.

3. Mandatory EVSC: here the vehicle maximum speed is always limited automatically.

Figure 1: External Vehicle Speed Control system
It is also possible to have various kinds of speed limit. The typology used by the project is:

1. **Fixed EVSC**: an EVSC system with knowledge of the posted speed limits.
2. **Variable EVSC**: fixed EVSC enhanced to provide slower speed limits at particular geographic points in the road network, in particular for sharp horizontal curves.
3. **Dynamic EVSC**: an EVSC system enhanced to provide lower speed limits in response to current conditions of the road network (it is assumed that the system will also have the capability of Variable EVSC). The system would respond to the presence of incidents downstream as well as to congestion and to environmental conditions such as fog or ice.

Variable EVSC could be introduced by means of enhanced digital road maps, but dynamic EVSC would require a broadcast system for the provision of the variations from the normal speed limits.

**PREDICTION OF ACCIDENT SAVINGS**

The modelling approach used to make predictions about the accident savings from the various forms of EVSC has started with the presumption that reduced speeds will directly influence both the probability and the severity of accident occurrence. The relationships used have been derived from the best empirical evidence available, as established by a detailed literature review.

The numbers used for the relationship between changes in mean speed and accident risk were that, for each 1 mph change in mean speed the change in accident risk was as follows (derived from Finch et al., 1994):

- **Low estimate**: 3.75%
- **Best estimate**: 5.00%
- **High estimate**: 9.70%

The above numbers were applied to create the estimates for **Advisory** EVSC. Based on findings from Finch et al. (1994), the change in accidents was capped at 25%. For **Mandatory** EVSC, an additional element was introduced, namely the fact that such a system transforms the distribution of speeds by cutting off all speeds in excess of the limit and therefore reduces speed variance. The formula applied for the relationship between speed variance and risk was derived from West and Dunn (1971) and was:

\[ y = 0.0139x^2 + 0.0140x \]

where \( y \) is relative risk
and \( x \) is speed difference of a vehicle from mean speed in mph

Table 1 shows the best estimates of the accidents savings for Great Britain at various levels of accident severity, for the permutations of EVSC. EVSC systems are divided into the broad classes of Advisory, Driver Select, and Mandatory systems. Each broad class can have speed limits in fixed, variable or dynamic forms (where dynamic also includes variable capability). The prediction is that the most powerful and versatile form of EVSC, the Mandatory Dynamic system, will reduce overall injury accidents by 36%, fatal and serious accidents by 48% and fatal accidents by 59%.
Table 1: Best estimates of accident savings by EVSC type and by severity

<table>
<thead>
<tr>
<th>System Type</th>
<th>Speed Limit Type</th>
<th>Best Estimate of Injury Accident Reduction</th>
<th>Best Estimate of Fatal and Serious Accident Reduction</th>
<th>Best Estimate of Fatal Accident Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advisory</td>
<td>Fixed</td>
<td>10%</td>
<td>14%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>10%</td>
<td>14%</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>13%</td>
<td>18%</td>
<td>24%</td>
</tr>
<tr>
<td>Driver Select</td>
<td>Fixed</td>
<td>10%</td>
<td>15%</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>11%</td>
<td>16%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>18%</td>
<td>26%</td>
<td>32%</td>
</tr>
<tr>
<td>Mandatory</td>
<td>Fixed</td>
<td>20%</td>
<td>29%</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>22%</td>
<td>31%</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>36%</td>
<td>48%</td>
<td>59%</td>
</tr>
</tbody>
</table>

SIMULATOR STUDY

The aim here was to evaluate behaviour with the three EVSC systems (Driver Select, Mandatory and Variable) in a controlled environment on the Leeds Advanced Driving Simulator (Carsten and Gallimore, 1996). The simulated road included urban, rural and motorway sections, providing a range of speed limits between 30 and 70 mph. It was 22 miles long. Other cars in the scene provided the opportunity to study overtaking scenarios, gap acceptance tasks and car-following situations. The road environment also featured traffic lights and pelican crossings in order to instigate possible violations; and sub-standard curves were included in both the urban and rural sections. Workload and acceptability were also monitored. Forty members of the public attended the simulator on four separate occasions. Thirty drove the car once without an EVSC system and the following three times with one version of the system (10 with the Driver Select version, 10 with the Mandatory one, and 10 with the Mandatory plus Variable one). The other 10 participants drove four times with the system off, to provide a baseline. There were thus 160 drives in all.

Speed measurements were taken every 10 metres along the road network. The results suggest that the EVSC systems had little impact on mean speeds, but, as expected, reduced maximum speeds. The effects of the EVSC systems were most prominent at specific locations, such as village entry, where drivers find it difficult to adapt their speed to the lower speed limit. Figure 2 shows the speed profiles across systems for one village entry.
Table 2 shows maximum speeds in one of the villages on the route. From Table 2, it can be seen that with Mandatory EVSC maximum speed was substantially lower, as compared both with the initial run with no EVSC and with the speeds in Runs 2–4 of the drivers in the baseline condition. The same effect is found in the Variable situation (the Variable system operates here like the Mandatory one, but was operational on one curve). With the Driver Select system, maximum speeds are in between those with the Mandatory system and those with no EVSC.

**Table 2: Maximum speed in 30 mph village (averaged across drivers)**

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>Run 1 (baseline)</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>33.52</td>
<td>35.21</td>
<td>34.12</td>
<td>35.21</td>
</tr>
<tr>
<td>Driver Select</td>
<td>33.24</td>
<td>32.12</td>
<td>32.56</td>
<td>31.27</td>
</tr>
<tr>
<td>Mandatory</td>
<td>34.15</td>
<td>29.15</td>
<td>29.56</td>
<td>29.54</td>
</tr>
<tr>
<td>Variable</td>
<td>32.58</td>
<td>28.74</td>
<td>29.31</td>
<td>29.07</td>
</tr>
</tbody>
</table>

*Note: Shaded cells show drives without EVSC*
There were several changes in behaviour noted in the experiment. It was found that, when using an EVSC system, gap acceptance behaviour altered. The mean gaps accepted and the minimum times to collision reduced in size, suggesting that drivers were exhibiting riskier behaviour. Figure 3 shows the results for a left turn with traffic approaching from the right.

![Figure 3: Mean gap accepted and minimum time to collision on left turn merge](image)

Drivers using either the Mandatory or Variable systems may have become increasingly frustrated on increased exposure to the system. There were also observed changes in car following behaviour. Safety-critical close following (less than 1 second) increased in both urban and rural areas. When driving behind a slow moving vehicle (with no opportunity to overtake), drivers using an EVSC system were more likely to want to engage in close following. Figure 4 compares the amount of close following for drivers who experienced the Mandatory system. The figure compares behaviour on Run 1 (no EVSC) with that on Runs 2 through 4 (with EVSC).
Subjective mental workload scores were obtained and, as in previous studies, both time pressure and frustration significantly increased as drivers used the system more and more (see Figure 5). This perceived time pressure does not translate into actual loss of time, as there was little change in total journey time for each of the progressive runs. Thus this increased time pressure is only imaginary, not actual. From the acceptability questionnaires, it was found that drivers preferred the Driver Select system. Generally, drivers valued all EVSC systems more highly after having experienced one, with the Driver Select system demonstrating the greatest improvement in acceptability ratings.

*Figure 4: Time headway on urban roads for drivers with Mandatory system*
In summary, it can be seen that the experiment confirms the potential benefits of EVSC systems, with reference to reduced maximum speeds and improved speed adaptation in speed limit transition zones. This experiment, however, also highlighted the fact that any prediction about safety benefits should perhaps be modified in the light of the secondary effects that were found. Such secondary effects, including the propensity to adopt riskier driving behaviours, may not outweigh any benefits gained under speed control, but the possibility of their occurrence should be noted. Further evaluations of EVSC systems should include appropriate methods of gauging the extent of both positive and negative effects of the system, with particular emphasis on observing behaviour in long-term use.

**ON-ROAD STUDY**

This study required drivers to drive a predetermined route in a car equipped with an External Vehicle Speed Control (EVSC) system. A Ford Escort was specially modified and equipped with two versions of EVSC, Driver Select and Mandatory. Using differential GPS, the position of the car could be monitored with an accuracy of about 1m and with a normal update rate of once per second (a dropout of the GPS or the differential signal could result in slowing the update to 3 seconds). The position and value of every speed limit along the test route was stored in a laptop computer as a “virtual beacon”. The EVSC software compared the appropriate speed limit with the car’s actual speed. If the car was travelling below the speed limit, it behaved as per a normal car. However, if the speed was above the limit, a signal was sent to a pair of auxiliary Electronic Control Units. These first reduced engine power by retarding the ignition for up to 30 seconds. In order to provide a longer and/or greater reduction in power, the amount of fuel injected into the engine was progressively cut. If the retardation and the fuel cut-off were insufficient, because the car was going down hill for example, the brakes were gently applied to decelerate the car to the speed limit. The automatic deceleration was in the region of 0.2g.

The test route was selected to include roads of varying speed limits and classes, and was approximately 42 miles in length. Speed limits varied from 30 to 70 mph, and included urban roads with mixed traffic and a high number of pedestrians, rural roads and a motorway section. In total there were 18 speed changes on the test route. Data were collected at

![Figure 5: Mental workload (NASA-TLX)](image)
10Hz and stored on the PC in the boot of the car. Variables collected included speed, braking, amount of retardation imposed by the system, and system state. Behavioural observations were made by two in-car observers with regards to driving errors, interaction with other drivers and conflicts. Workload and acceptability were assessed using questionnaires. There were 24 participants in the experiment. They drove on three separate occasions; 16 drove the car once without an EVSC system and the following two times with one version of the system (eight with the Driver Select version and eight with the Mandatory one). The other eight participants drove three times with the system off, to provide a baseline. There were thus 72 drives in all.

With regard to the Driver Select system, drivers were generally happy to leave the system engaged, but as soon as the opportunity to exceed the speed limit arose, they chose to disengage the system. Figure 6 shows the use of the system and speeding behaviour for an uncongested urban stretch. For each subject, the left bar shows behaviour on the first drive with the system (Run 2) and the second bar show behaviour on the second drive with the system (Run 3). Figure 7 shows the same data for a rural village. It can be seen that drivers are inclined to switch the system off precisely in the locations where the system would have had the most impact, i.e. the rural villages and urban roads where traffic generally exceeds the speed limit, and that they do deliberately in order to exceed the speed limit. From the overall analysis of system use with Driver Select, it was also noted that drivers used the system less on their second drive, indicating there may be shifts in behaviour depending on the amount of exposure to the system.

![Figure 4: Use of Driver Select system and associated speed choice on a 40 mph uncongested urban road](image-url)
The Mandatory system, as would be expected, had a far greater impact on driver behaviour. Large reductions in maximum speeds were noted on most road sections especially in urban areas and rural villages, as can be seen from Figure 8.

In the absence of the EVSC system, drivers were poor at adapting to low speeds after travelling through a higher speed limit area. The effect of the EVSC system is also obvious in the overall speed distributions that were measured for each speed limit, as there was a “transformation” of the distribution whereby the top end of the distribution was virtually eliminated by the system and driver speed was more concentrated around the speed limit. This effect can be seen in Figure 9 which shows the changes in the percent of driver time spent at different speeds for a section of 40 mph urban roads. From the same Figure, it can
also be seen that there was to be no change in the distribution at the lower end, indicating that drivers were not increasing their speeds in order to regain perceived lost time.

The results from the behavioural observations also indicated that no negative compensatory behaviour was occurring, and in fact some undesirable behaviour such as close following decreased. The finding on close following was largely an artefact of the traffic situation: with other vehicles able to exceed the speed limit, there was a tendency for the vehicles in front to speed away from the EVSC car. In addition, when the total number of conflicts was scored for each system, it was found that the propensity to be involved in a critical situation (whether instigated by the volunteer drivers or other road users) decreased when the system was engaged, indicating improved safety. This can be seen from Figure 10, which shows the conflicts scored by the observers for each run. With EVSC, performance improved; without EVSC, drivers tended to have more conflicts with increasing familiarity with the route. From the questionnaires, drivers with the Mandatory system felt they paid more attention to the driving task, and as a result were more aware of upcoming hazards. They also reported they felt they had more time to make decisions due to their lowered speed.
Subjective rating scales, which described subsets of driver behaviour, were completed for each subject by two observers. Driver behaviour was assessed as better when the Mandatory system was engaged. The improvements were in use of appropriate speed, better following behaviour and less abrupt braking. These are undoubtedly as a result of the reduced speed having secondary impacts on other aspects of driver behaviour.

From both the questionnaires and the mental workload evaluation, it seems that drivers required an adjustment period in order to familiarise themselves with the capabilities of the car when the EVSC system was engaged. Reported mental workload increased initially but then decreased on familiarisation. However in other respects, familiarisation with the system did not change some of the more hostile opinions. For example, drivers were of the opinion that a speed control system would create difficulties when overtaking and prevent acceleration out of danger. These opinions did not disappear with use of the system. Drivers remarked that the reason they liked the Driver Select system was that they could disengage the system and thus overtake or keep up with the traffic, as they desired.

In summary, the Mandatory system tested in this experiment successfully reduced excessive speed, particularly in areas where drivers are renowned for being poor at adapting their speed, for example in rural villages. Although the use of the Driver Select system was relatively high, drivers were prone to disengage the system at locations where speeding was the norm for the surrounding traffic. This is partly attributable to the fact that drivers preferred to be in control of the system operation and turn it off when they felt vulnerable or under pressure from other drivers. This is a symptom of a mixed traffic environment, and with higher system penetration in the traffic as a whole, drivers may be more inclined to use the system. There were no negative behavioural compensation effects, even though reported time pressure and frustration levels rose when using the system. In fact, some undesirable behaviours and conflicts or critical situations decreased in occurrence when the system was engaged. Drivers were initially unfavourable towards the Mandatory system, but they reported that driving with the system was safer due to enhanced awareness of potential hazards.
CONCLUSIONS

Some of the simulator results were not replicated in the real-road driving. In particular, it was only in the simulator that there was evidence of increased frustration leading to more close following and the acceptance of smaller gaps at intersections. On the real road, being speed limited meant that the traffic in front tended to move away from the EVSC car. It was also not possible to observe a change in behaviour at intersections, perhaps because traffic conditions could not be controlled as they were in the experimental situation.

In spite of the different results between the two studies, there were also important similarities in the results. One aspect that deserves is that speed is always dictated predominantly by the road layout, by road features such as traffic lights and by traffic conditions. This was confirmed in both studies. In both studies too the overall behavioural findings were favourable to EVSC. Both on the simulator and on the real roads, driver speed choice was generally more appropriate with EVSC (that is after all the objective of the system). This was particularly true with the Mandatory system; with the Driver Select system drivers tended to be manipulative and keep it on when it would have little effect and turn it off when it would be restrictive. One important finding is that there was no confirmation of any “out of the loop” behaviour: speed in the lower range did not become faster with EVSC and drivers were observed to be more attentive to the road and traffic situation with EVSC. It is possible that the short-term negative effects found in the simulator drives would be eliminated with longer-term acquaintance with EVSC. This can only be investigated in the context of longer trials.

Neither of the behavioural studies — that on the simulator and that on the real road — would lead to any qualification in the accident prediction. A system that can save 36% of injury accidents and 59% of fatal accidents in Great Britain can almost certainly save even higher proportions in countries where excessive speed is more of a problem, including developing countries. And there is a kind of justice in making the car owner pay for a technology that can drastically reduce the social harm associated with car use. This has long been the principle in terms of emissions reduction; now the technologies are available to do the same in the area of accident reduction.

REFERENCES

