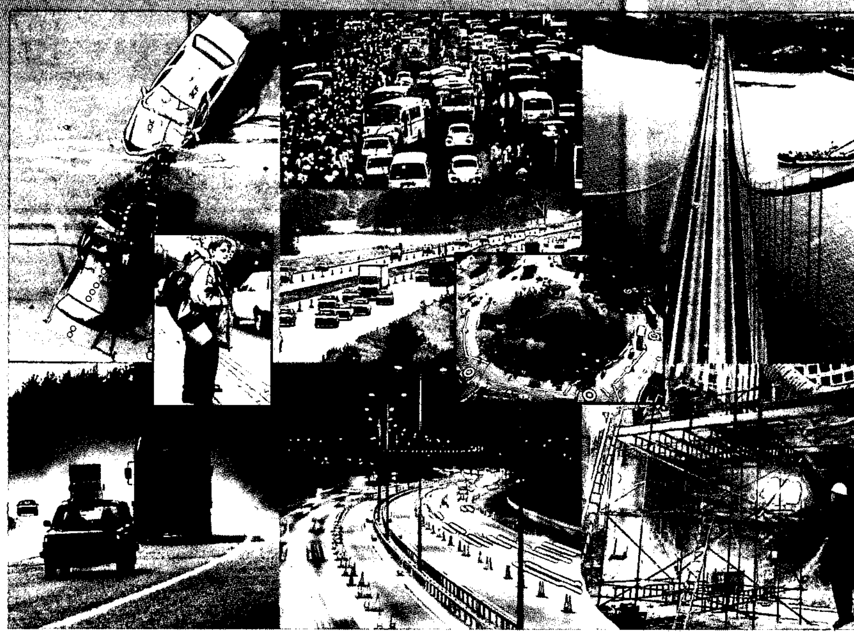

Using the TRL driving simulator to evaluate traffic calming measures

by C R Lockwood

TRL Report 245

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TRANSPORT RESEARCH LABORATORY

Using the TRL driving simulator to evaluate traffic calming measures

Prepared for Driver Information and Traffic Management Division, Department of the Environment, Transport and the Regions

C R Lockwood

TRL REPORT 245

First Published 1997
ISSN 0968-4107

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(continued)

EXECUTIVE SUMMARY

The study

It can be expensive and difficult to trial traffic calming measures on the public roads. One way of overcoming some of these difficulties might be to use a Driving Simulator. This could allow a range of alternative measures and layouts to be tested quickly using a cross-section of drivers ('subjects') who would drive through computer-generated schemes without any risk to themselves or other road users. However, it is recognised that, as with any kind of simulation, it is necessary to demonstrate that it can reproduce effects that are sufficiently close to reality to make the exercise representative and worthwhile. The report describes a pilot study on the TRL driving simulator, designed to investigate the use of this technique, and to confirm its validity by comparing results with those of corresponding public road trials. The work was funded by Driver Information and Traffic Management Division, the Department of the Environment, Transport and the Regions.

Three real villages with signing/marking measures at the entrance were selected: one site where very large reductions in speed had been observed (Craven Arms), one with small reductions (Hermitage), and one site which gave reductions which were greater than had been expected (South Warnborough). The measures included enhanced speed limit signs, patches of coloured road, and innovative markings. The approach and one entrance to each of these villages were modelled on the simulator. Several simulated versions of each village were generated - one with the traffic calming measures used in real life; one representing the village before the measures were installed; and various intermediate versions. Chicanes and road humps were included in some versions of the villages. Four test routes were compiled; each consisted of 40 miles of rural road with 20 simulated villages, but the order of the villages varied between routes. Sixteen subjects were used; each route was driven by four subjects. After their drive, subjects were asked about the realism of the trial.

The results

Table 1 shows the speed changes observed in the simulator between uncalmed and calmed versions of the villages, compared to those observed on the public roads. The simulator successfully distinguished the very effective scheme at Craven Arms from the less effective scheme at Hermitage. Speed reductions on public roads are subject to some uncertainty and, given this, there are no large discrepancies between simulated and real speed reductions.

Versions of Craven Arms which contained only one traffic calming measure were tried. It was clear that more subjects would have been needed to detect differences in speed reductions between individual measures.

In the simulator, 'countdown signs' on the village approach slowed drivers earlier than measures at the gateway itself, as would be expected. The results also suggested that signing/marking measures at the gateway alone have little effect on the speed 200m down-stream (in the village). Again this is consistent with effects observed on the public roads.

Table 1 Comparison of speed changes on the public roads and in the simulator

Speed changes (mph)	*Public road*	*Simulator*
Traffic calming at Craven Arms	–8.5	–8.5
Traffic calming at Hermitage	–0.7	–3.4
Traffic calming at South Warnborough		
— at the entrance	–5	–4.3
— at 'Site 2'	–3	–3.4
— at the pinch point	–7	–3.9

In one version of Craven Arms, the traffic calming measure from Hermitage was used, and *vice versa*. Speed reductions depended more on the features used, rather than the village they were in.

At the chicanes and humps, the behaviour of subjects was broadly comparable with that observed on public roads. However, the simulator cannot fully reproduce the physical forces experienced when speeding through chicanes and humps (which is why this trial concentrated on signing/marking measures). It is thus possible that the drivers' behaviour was governed mainly by habit, and that simulator drivers might not respond realistically to an innovative design of hump/chicane. The modelled chicane and hump worked quite well in this trial, so this suggests that it might be possible to test innovative *combinations* of measures that include these 'ordinary' chicanes or humps.

It was feared that speeds might be affected by the order in which villages were placed along the route, distorting the results, so possible 'order' effects were examined. The most serious effect identified was when a subject drove through the same village several times in succession, when they seemed to become less sensitive to traffic calming. There is therefore a case for avoiding this in future experiments, by ensuring the order of the villages changes frequently in each test route.

Most subjects rated the scenery and calming measures 'Good' or 'Adequate' in realism.

Conclusions

The pilot trial has demonstrated that the effects of signing/marking measures can be broadly reproduced in the simulator. This, and drivers' opinions, indicate that the quality of the images generated are sufficiently good for this kind of application.

It is considered that simulator trials will be valuable in supplementing the results of road trials - in particular for comparing the effects of a wider range of measures. The simulator also offers additional data not easily obtainable from conventional road trials (for example, speeds at a large number of points). In addition it could help by sifting out ineffective measures prior to road trials.

1 Introduction

1.1 Background

Several projects have been undertaken by TRL for the Driver Information and Traffic Management Division (DITM) of the Department of the Environment, Transport and the Regions, to investigate the design and effectiveness of innovative traffic calming measures. These cover residential and distributor roads in urban areas and major roads through villages. The traffic calming measures include road humps, speed cushions, chicanes, other horizontal deflections and novel signs. A limitation on the knowledge that can be obtained is the difficulty and cost of mounting trials, particularly on the public roads. For example, Highway Authorities are reluctant to apply measures which are not tried and tested because of the likelihood of adverse local reaction. Once a scheme has been designed and implemented, only minor modifications are generally feasible and it is not possible to establish what might have happened if alternative configurations of measures had been adopted.

One way of overcoming some of these difficulties might be to use a Driving Simulator. This could allow a range of alternative measures and layouts to be tested quickly using a cross-section of drivers ('subjects') who would drive through computer-generated schemes without any risk to themselves or other road users. However, it is recognised that, as with any kind of simulation, it is necessary to demonstrate that it can reproduce effects that are sufficiently close to reality to make the exercise representative and worthwhile. Therefore a pilot study was carried out, and it is this that is described in the present report.

The study attempted to replicate a number of existing public road calming schemes which had already been monitored to determine their 'real' effects on drivers. The key questions which it aimed to address were:

i) can sufficiently realistic images be generated in the simulator, both of the calming measures under investigation (signing and marking) and of the surrounding scenery?

ii) are the driving/handling characteristics of the simulator sufficiently reliable and realistic to examine small changes in driving speed, and the line taken by the vehicle?

iii) is the relative effect of different measures on driver speed similar in the simulator to what has been found on the public roads?

A number of other avenues were also explored, including the capability of the simulator to represent physical measures, and the issues important in the design of a robust trial.

Providing signing/marking measures could be correctly ranked according to their speed reducing effect, it was not thought essential to obtain in the simulator the same absolute speeds obtained on public roads.

The next sub-section in this report summarises previous relevant research. Section 2 describes the TRL driving simulator and section 3 describes the pilot study that was undertaken. Results of this study are presented in section 4 and summarised in section 5.

1.2 Previous research

A trial relevant to the present study was carried out on the Daimler-Benz simulator (Riemersma, van der Horst, Hoekstra, Alink and Otten, 1990). The Daimler-Benz simulator has a much more elaborate hydraulic system than the TRL simulator (described in section 2). Different configurations of gateway measures for the village of Weiteveen in Holland were tested in a full-scale experiment. Subjects were asked how realistic they considered the experiment to be and speed results were compared with some obtained through monitoring of the real situation. The results of the questionnaire indicated that participants considered the simulated road surroundings sufficiently realistic to be able to make proper estimates of the speed at which they were travelling. Comparison of the driving behaviour observed during field-trials and that observed in the simulator showed *qualitative* agreement. A lack of *quantitative* agreement between the results was noted but several reasons concerning the experimental design were put forward for this. The conclusion was that the study had demonstrated the feasibility of using the Daimler-Benz simulator to analyse the effectiveness of speed-reducing measures applied either separately or in combination. There was no examination of measures (such as humps and chicanes) that were not purely visual.

Pyne, Carsten and Tight (1995) have recently assessed traffic calming measures using the Leeds University driving simulator. 17 possible influences were tried at village entrances. The lowest mean speed recorded with any measure was 2.26 mph slower than the control site, and the highest was 1.23 mph faster than the control site. This suggests that a simulator study will need to be capable of detecting quite small differences in speed. Their paper does not mention any validation exercise against real sites.

2 The TRL driving simulator

The TRL driving simulator consists of a room, within which is a real car (Rover 414) with screens in front of it and on either side. Images projected on these screens provide a driver in the car with forward and side vision, over 210 degrees. (An image can be provided on a rear screen as well, so the 'driver' can use the rear-view mirror, but this was not used during the present experiment). The images are generated by computer, and respond to the steering, gears, and pedals of the car. The speed of the car (and other variables) can be continuously recorded.

The choice of measures tried in this study was influenced by the simulator technology. The simulator principally reproduces the *visual* aspects of driving. Although hydraulic equipment provides some pitch, roll and heave, the simulator cannot reproduce the full range of forces that occur, for instance, when driving through a chicane at speed. Reproducing chicanes also presents other problems. For example, no shock is felt if a wheel runs over a kerb, and when the steering wheel is turned to negotiate a *sharp* bend, there is a small but noticeable delay before the simulator responds. Simulated humps present the difficulty that the subject does not feel a sufficiently large jolt when speeding over them, although there is a visual jerk. Consequently it seemed more promising to examine purely visual measures, such as signing, than measures that involved substantial physical deflections. In this pilot trial, most of the measures examined involved signing/marking, though humps and chicanes were also tried.

An additional projector was used to back-project an image onto the part of the screen immediately in front of the driver, with a much higher resolution than the images on the rest of the screen. Although only part of the screen can be provided with high resolution images, it is the part towards which the driver is looking for the vast majority of the time. In use, the high-resolution projector provided the images only for roadside signs. The main projector provided the images for all objects except the roadside signs near the centre of the screen, and for all objects near the edge of the screen. The effect can be judged from figure 1(bottom), in which the sign on the extreme right is produced by the main projector whereas all the other signs are produced by the high-resolution projector.

3 The study

3.1 Structure

To determine whether the simulator could be used reliably for evaluating traffic calming measures, three locations were chosen where traffic calming had been installed and the changes in speed measured in 'before-and-after' studies. These locations were then reproduced in the simulator. For each location, at least two versions were needed; one with the traffic calming features, and one without. Members of the public were asked to drive through these on the simulator, and the speed at which each driver drove through each version of each location was measured. If the average speed at the 'calmed' version of the location was lower than the average speed at the 'uncalmed' version, in a way that corresponded to the speed reduction at the real version of the same location, it would suggest the simulator trial was successfully evaluating the features.

Whereas urban 20 mph zones often incorporate deflections, speed reducing measures that have been tried in villages are usually of the signing/marking type. Full details of measures used in villages in the village speed reduction study (VISP) are given by Wheeler, Taylor & Barker (1994). For simplicity, the present study concentrated on measures used at village entrances. The simulated versions of the villages were connected with sections of rural road. A subject, therefore, would see their task as one long drive through the country, on which a number of villages were encountered.

One of the villages chosen had a number of traffic calming features at a single location. Several versions of this site were produced that contained some, but not all, of the features used at the real site. It was hoped that measuring speeds at each version would indicate which of the individual features was most effective. Versions were also produced in which one village had the traffic calming features that had, in reality, been installed at a different village, to see if the effect of the feature was different at different locations.

To help in the planning of any future trials, certain technical issues were addressed. One of these was whether it was necessary to use the high-resolution projector in the simulator (by presenting some villages both with, and without using the high-resolution projector); another was whether driver speeds were affected by the order in which villages were presented in the test routes.

3.2 The simulated villages

3.2.1 Selection of 'real' villages

The three villages selected for reproduction in the simulator were Craven Arms (Shropshire), Hermitage (Berkshire) and South Warnborough (Hampshire).

Craven Arms is on the A49 Trunk road south of Shrewsbury. It was selected since a large number of features had been installed at both entrances (and also within the village), and large speed reductions had resulted. It therefore represented a successful site. It also provided an opportunity for trying out several different versions of the same site, including versions that contained some but not all of the measures installed at the real site. Further details of these individual features are given below in section 3.2.2.2, whilst a full description of the real Craven Arms scheme is given by Wheeler, Godfrey, Lawrence and Phillips (1996). Only the southern approach was replicated in the trial (figures 1 and 2).

The ability to reject unsuccessful measures is clearly important. Consequently one of the less successful measures from the VISP trial was tested in the simulator. A 'significant marking' that had had little effect was required, as this would be a more stringent test than using a 'minor marking' that had had little effect. Hermitage in Berkshire satisfied these criteria. Full details of this village are given in Wheeler et al (1994); in outline, the measures, at one end of the village, consisted of emphasising the speed limit signs by adding village nameplates, and adding a red surface to the roadway over an area 5m by 40m (see figure 3).

The third site, South Warnborough in Hampshire, was selected because the speed reductions actually observed there were unexpectedly large and it would be interesting to see if similar results were obtained on the simulator. It has been suggested that the speed data at this site are misleading. This is possible, given that speeds can vary without any obvious explanation. The measures, at one end of the village, consisted of prominent signing at the start of the 40 mph zone (figure 4); then after a distance, PINCH POINT AHEAD signs; then after a further distance, road narrows/REDUCE SPEED NOW signs, and finally the pinch point situated 350m after the entrance (figure 5). Although this pinch point only involves a narrowing of 0.52m, the approach to it has a series of marker posts, which because of the alignment of the road are directly ahead of an approaching driver. It has been suggested that the marker posts, rather than the pinch point, are the cause of the speed reduction; extremely large speed reductions were recorded at night when the marker posts would be particularly prominent. Therefore a version of this village

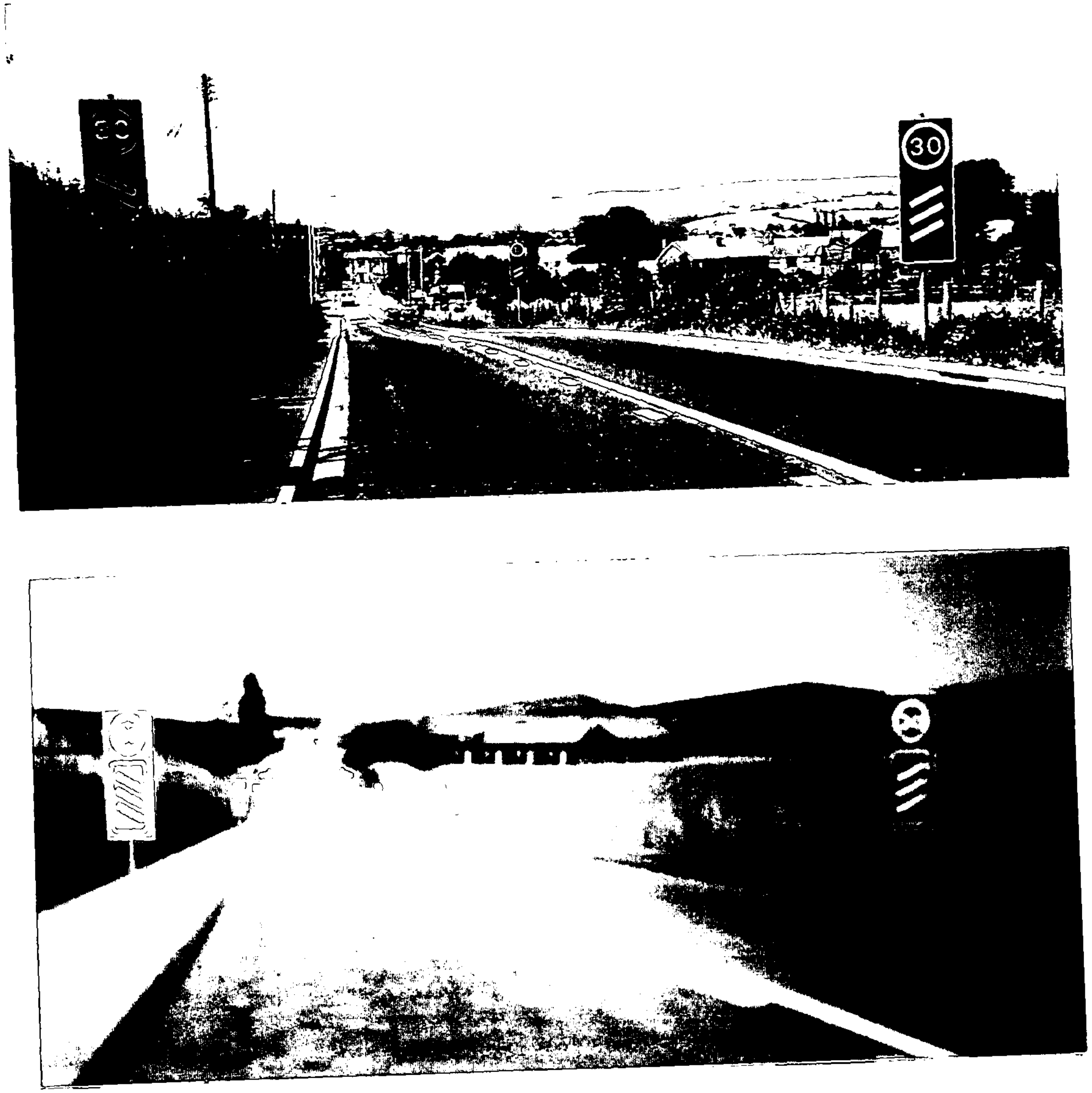

Figure 1 The approach to Craven Arms: real (top) and simulated (bottom)

Figure 2 The gateway to Craven Arms: real (top) and simulated (bottom)

Figure 3a The entrance to Hermitage: the real site. 'After' speed measurements commenced two days after this picture was taken

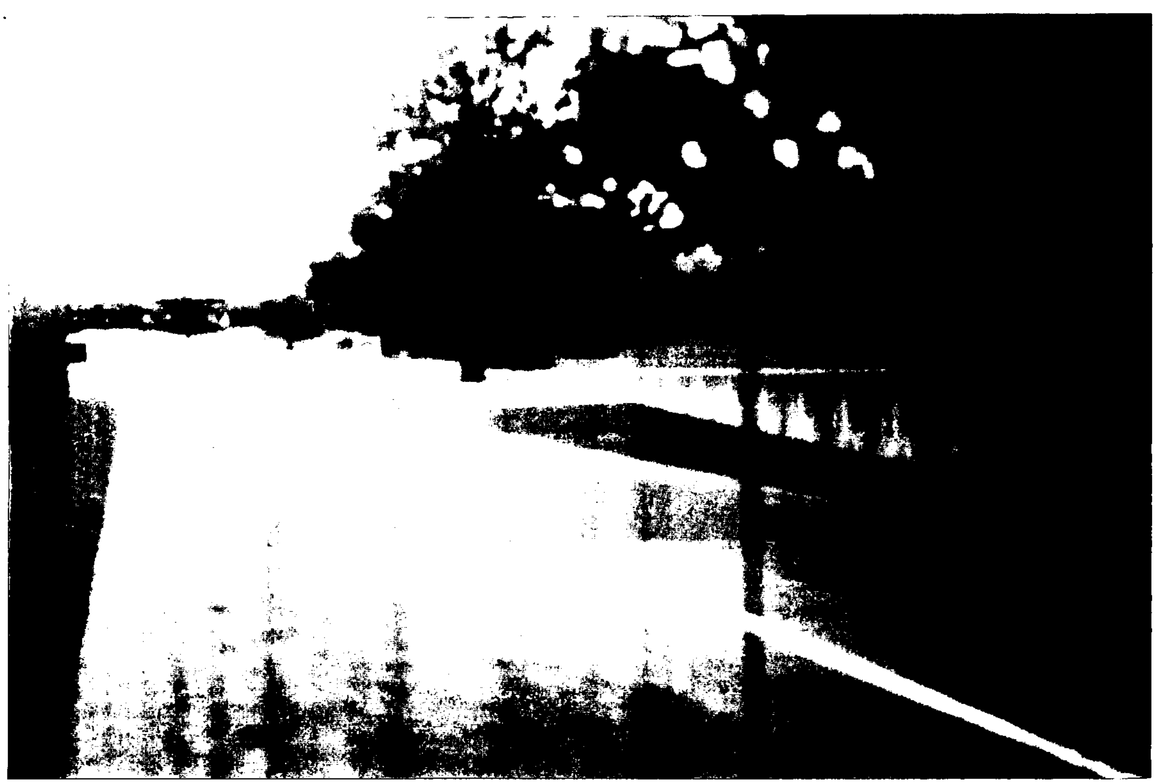

Figure 3b The entrance to Hermitage: the simulated site

Figure 4 The entrance to South Warnborough: real (right) and simulated (bottom)

Figure 5 The South Warnborough pinch point: real (right) and simulated (bottom)

without marker posts was included in the trial, as well as a version that included all the measures. Full details of the real South Warnborough scheme are also given in Wheeler et al (1994).

3.2.2 Generation of the simulated villages

3.2.2.1 The villages themselves

Whilst the simulations could not represent the real situation down to the last detail, it was expected that all the major features could be incorporated, with the exception of oncoming traffic.

Intuitively, it is possible that a driver's behaviour is influenced by the surrounding scenery. At Craven Arms, plenty of buildings are visible on the approach - well before the speed restricted zone is reached, it should be obvious drivers are about to enter a built-up area. This effect is particularly strong because of a whitewashed building that, due to the road alignment, is immediately ahead of drivers as they enter the village. A similar building was included in the simulated version (figs 1 and 2).

At Hermitage, distant buildings are visible before the gateway is reached, but a hedge hides the nearest buildings until a driver passes the gateway (fig 3). It was noted earlier that the measures at Hermitage were not particularly successful. One explanation offered for this was that the road goes over a small hill as it approaches the village. Although this hill is extremely low (one or two metres), the brow conceals the red surface until the driver is quite near. Accordingly, this hill was included in the simulated village.

At South Warnborough, there are several buildings immediately after passing the '40' sign, but then there is a lengthy tree-lined stretch before the pinch point and the next buildings are reached. Possibly, this lack of buildings encourages drivers not to take the speed limit seriously.

The simulated villages were designed to reproduce the impressions described above. Figures 1-5 enable the real and simulated villages to be compared. A short video has been produced, containing drive-through videos of the real and the simulated villages.

Since the study would focus on speeds at which drivers *approached and entered* the village, rather than the speeds *within* the village, most of the effort was applied to modelling the approach. Little attention was given to buildings that were only visible after passing the gateway. Subjects in the trial would only drive through the village in one direction, so there was no point in reproducing buildings that were only visible to drivers going in the 'other' direction.

The model villages were prepared using following materials: a drive-through video, a map of 1:2500 scale or similar (showing individual buildings), and still photographs. No site visits were made. Any buildings that were at all prominent on the drive-through video were identified on the map, emphasised, and annotated with the number of storeys and any other information (eg 'whitewashed'). Similarly, the locations of prominent trees, bushes, hedges and walls were marked, and annotated with their estimated height. Table 2 indicates the level of detail

Table 2 Number of buildings, trees and bushes specified on an individual basis

	Number of buildings	*Number of trees and bushes*
Craven Arms	6	5
Hermitage	9	12
South Warnborough	7	5

Note: each village contained additional buildings that were not specified on an individual basis

required for each village. To keep the test drive realistic, it was felt that after passing speed limit or village entrance signs, the driver should pass through a village of some kind. However (as already noted), it was not felt necessary for the interior of each village to be an accurate reproduction of the real village. Therefore the computer modeller was instructed to fill the rest of the village with buildings, the exact details of which were unimportant.

At South Warnborough, there are rumble areas on the approach to the village. These were omitted as it was thought the simulator would not be able to reproduce them. It should be noted that these rumble areas were not part of the traffic calming measures under investigation - they were present both before and after the village was calmed.

3.2.2.2 The individual measures at Craven Arms

The model of Craven Arms representing the 'before' situation had only 40 mph signs. Four more 'intermediate' models of Craven Arms were created which had some, but not all, of the features actually used at Craven Arms. These four models were as follows:

(1) "30": the 40 mph signs were replaced by 30 mph signs.

(2) "Red surface & roundels - RD": at the gateway, 12m of the road surface was coloured red, and on this was marked a '30' roundel (1.475m in width). A similar, though smaller, feature was constructed 60m inside the village, and two strips of red surfacing 0.3m wide were applied along the centre of the road. Ordinary 30 mph signs were also used.

(3) "Dragon's teeth - DT": a double series of white triangles were marked on the road just before the gateway. The triangles got larger the nearer they were to the gateway, in an attempt to create the impression of a narrowing. Ordinary 30 mph signs were also used.

(4) "Countdown signs - CD": these were similar to the countdown signs used at the approach to motorway exits, but with '30' added above the diagonal bars; they were white on a green background. The signs were placed 50m, 100m and 150m before the gateway on both sides of the road. Ordinary 30 mph signs were also used at the gateway itself, and below these were name signs marked "CRAVEN ARMS Gateway to the Marches".

The "fully calmed" version of Craven Arms, like the real Craven Arms, combined all these features (figs 1 and 2).

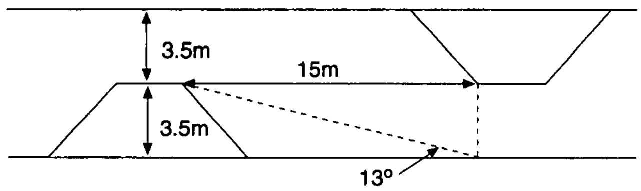

Figure 6 Dimensions of simulated chicane

3.2.2.3 Chicanes and humps

Chicanes and humps were also modelled. In this case it was not felt necessary to model a particular site, since the extensive experience with these measures on public roads enables their effects to be predicted.

Chicanes: a series of three chicanes were installed in a version of Craven Arms. So that speeds *at the entrance* to the village would be unaffected by the chicanes, they were sited well beyond the entrance (350m).

In the simulator, each chicane consisted of a build-out on the right-hand side of the road, followed by a similar build-out on the left (fig 6). A blue arrow sign on a pole was sited on each build-out, and the left-hand build-out also had a sign indicating priority over oncoming vehicles. Each build-out took up half the width of road (which was 7m wide), and the stagger length was 15m. This gave a 'path angle' of 13 degrees. This path angle is within the range of values found for chicanes on the public roads.

Based on measurements on the public roads, one would expect a chicane with a path angle of 13 degrees to give average speeds of 21 mph; measurements on the TRL test track suggest a slightly higher speed of 24 mph. In the relevant village on the simulator, the posted speed limit was 40 mph, so a clear reduction in speeds was anticipated.

Humps: a series of three humps was installed in a version of Hermitage; again these were sited well beyond the village entrance.

Each of the humps used was flat-topped and 75mm high. The 'plateau' was 4m long and the approach ramps had a gradient of 1 in 12. The distance between humps was about 80-90m. Webster and Layfield (1996) give speeds observed for real life humps of these dimensions. Predictive equations based on these speeds indicate an expected speed of 21 mph *between* the humps in the present trial. The posted speed limit of the relevant simulated village was 30 mph.

3.3 The test routes

Each subject drove a test route consisting of a rural road with 20 villages on it. The villages were at intervals of about 3km; each was about 600m long. The roads between the villages contained many shallow bends, but they contained no sharp bends, junctions, or anything else which would force the driver to slow down drastically.

It was thought that the speed at which a driver entered a village might depend not merely on the traffic calming used, but also on whether the driver had been in the simulator for some time, what the driver encountered in the previous village, etc. The latter were potential sources of inaccuracy, but could be guarded against by careful planning. The order of the villages in the test routes were therefore set out to minimise any such effects. Possible 'order' effects included:

- Settling-down effects - drivers might go slowly at first, until they got used to the set-up.
- Long term speed drift - it was doubted if drivers would consistently maintain exactly the same speed, especially over a long time period. Their speed might drift up or down a little.
- Previous village effects - a driver forced to slow down severely in one village might drive through the next one with unusual care. This seemed most likely to happen with measures that slowed the driver severely (humps and chicanes), but might occur for other measures.
- Unusual cautiousness when driving through a village for the first time.

Unfortunately, it was not known how large each of these effects were, or how important it was to guard against them. One aim of this study was to quantify these effects, to help the design of future studies. But in planning this study a judgement had to be made of which effects were most likely to be serious. Appendix A gives the test routes actually used, which were based on the following principles.

When comparing the speeds at which drivers entered two villages, the effect of long term speed drift would be minimised if the villages were close together in the test routes. So, in most cases, after driving through an uncalmed version of a village the very next one would be the calmed version of the same village. These pairs of villages are referred to as 'validation pairs'. For the same reason, the six different versions of Craven Arms were placed as close together as possible, as an unbroken sequence of six villages.

It was expected (after examining Riemersma et al, 1990) that the settling-down effects would be too severe for the first few villages to produce useful data. Accordingly it was decided that the first four villages in each route would be identical, so the size of the settling-down effects would be obvious. It was thought *possible* that the settling-down might take more than four villages. Accordingly the alternative versions of Craven Arms were sited at villages 6 to 11 in each test route, as these were of intermediate priority. The validation against real sites was of the highest priority, so most of the validation pairs were sited at villages 12 to 17, where there was no chance of them being distorted by settling-down effects.

Humps or chicanes only occurred within the very last village on each test route, so they could not have any distorting effects on subsequent villages.

These last villages also had gateways from 'other' villages because it is possible that a given measure has different effects at different sites. Two simulated villages were created to investigate this; (a) Craven Arms village with the traffic calming measures from Hermitage; (b) Hermitage village with the traffic calming measures from Craven Arms ('fully calmed' version).

The order in which the different validation pairs occurred, and the order in which the versions of Craven Arms occurred, was varied between test routes.

3.4 Test procedure

Four test routes were used, the details of which are given in Appendix A. 16 subjects took part in the trial. Each route was driven by four subjects; one older man (40-50 years old), one older woman, one younger man (20-30 year old), and one younger woman. All the subjects had previous experience of the TRL driving simulator.

Each subject first drove a practice session of about 10 minutes. This involved driving behind another car along a straight stretch of simulated motorway; subjects were told to maintain a fixed distance between them and the car ahead, whose speed increased until it was going at 60 mph. The main trial followed after a short break.

Subjects were told "You should drive as you would normally", and that the trial would involve driving along about 40 miles of rural road.

The car operated with a manual gearbox.

During the trial, the following were recorded every tenth of a second:

- location (using x and y co-ordinates)
- speed
- time
- steering angle
- accelerator position
- brake pressure
- gear.

Continuous video recordings were also made, showing the view of the road ahead, the subject's face, and the speedometer.

After their drive, each subject was interviewed to establish the subjective impact of the measures and the realism achieved in the simulator. They were first asked to mention any things they noticed that were intended to encourage drivers to slow down. Then they were shown photographs of several features and asked more questions about each. Finally, they were asked about the realism of the car handling and the surrounding scenery.

4 Results

4.1 Validation: speeds at real and simulated sites

4.1.1 Signing and marking measures

Table 3 shows for the real and simulated situations: the mean speeds at village entrances, both with ('after') and without ('before') measures; the change brought about by the traffic calming; and the standard deviations (σ) (for simulated villages only).

In all three villages, a speed reduction occurred in the simulator with the presence of traffic calming measures. The speed changes at Craven Arms were the same (-8.5 mph) in the simulator as in real life. The speed changes at Hermitage were greater when simulated (-3.4 mph) than in real life (-0.7 mph). The speed changes at South Warnborough were similar when simulated (-3 to -4 mph) to those in real life (-3 to -7 mph).

The absolute level of speeds recorded in the simulator were somewhat lower than those at real sites. Thus, although the speed changes at Craven Arms were the same in the simulator as in real life, in *percentage* terms the drop in the simulator is a little larger than that at the real village.

An alternative method of measurement used was to measure speed at the entrance *relative to the speed at which the driver approached the village.* (That is, the statistic measured was speed-on-approach minus speed-at-entrance). 'Approach speeds' were measured 350m before the entrance, where the traffic calming measures would not be visible. Results are given in Table 4. Compared with the results in Table 3, the simulated figure for Hermitage is closer to the real one, indicating that some of the difference between the simulated and real speed changes at Hermitage (in Table 3) may be due to differences in before and after approach speeds. (For the real Craven Arms and South Warnborough, real life measurements are not available).

4.1.2 Physical measures

4.1.2.1 Chicanes

Although the main emphasis of the trial was on signing and marking measures, one design of chicane was included to enable some assessment to be made, as described in section 3.2.2.3. Half of the subjects encountered them, as a series of three chicanes.

As previously mentioned, based on measurements on the public roads one would expect a chicane of the design used to give average minimum speeds of 21 mph; measurements on the TRL test track suggested a slightly higher speed of 24 mph.

Figure 7 shows the path taken by each subject through the chicanes, and their speeds have been plotted directly underneath. Mostly the subjects took very similar paths so, with a few exceptions, it is not possible to distinguish the individual paths on the graph. It has not been determined whether any subject clipped the edge of the build-outs, but generally the paths taken appear to be sensible.

Examining the graph of speeds, the braking prior to the first chicane is very obvious. There is quite a variation in speed through the first chicane, but considerably less by the time the second chicane is reached. The ranges of speeds are approximately as follows:

- First chicane: 7 - 33 mph
- Second chicane: 10 - 22 mph
- Third chicane: 7 - 22 mph

For the second and third chicanes, it is evident that the average speeds are somewhat below the 21 mph expected in real life.

The only unusual behaviour was provided by a subject who, beyond the second chicane, collided with the left-hand kerb and subsequently came to a complete stop. (Curiously, this is the subject who encountered no serious problems negotiating the first chicane at more than 30 mph!). This is likely to be due to the relatively slow response of the simulator. When the steering wheel is turned, there is a slight delay before the simulator responds; the lack of an immediate response may induce the driver to turn the

Table 3 Average speeds at village entrances (mph)

	Before	*After*	*Change* (After-Before)*
CRAVEN ARMS			
Real	41.6	33.1	-8.5
Simulated	36.3 (σ=3.1)	27.8 (σ=4.0)	-8.5 ± 0.9 (σ=3.5)
HERMITAGE			
Real	40.7	40.0	-0.7
Simulated	35.2 (σ=4.6)	31.8 (σ=5.2)	-3.4 ± 0.9 (σ=3.5)
SOUTH WARNBOROUGH			
Entrance:			
Real	47	42	-5
Simulated	39.7	35.4	-4.3 ± 1.6 (σ=6.2)
'Site 2'†			
Real	44	41	-3
Simulated	37.2	33.8	-3.4 ± 0.9 (σ=3.7)
Pinch point			
Real	45	38	-7
Simulated	35.6	31.6	-3.9 ± 0.9 (σ=3.7)

Table A2, Appendix A, specifies which test-route villages were used in the calculations.
* Throughout this report, figures after a ± sign are 'standard errors'; a figure has to be at least twice its standard error to be statistically significant.
† 'Site 2' was approximately midway between the entrance and the pinch point.

Table 4 Speed at entrance (mph), relative to the speed at which the driver approached the village

		*Change**
CRAVEN ARMS		
	Simulated	-8.9 (σ=6.1)
HERMITAGE		
	Real	-2.2
	Simulated	-3.2 (σ=3.8)
SOUTH WARNBOROUGH		
Entrance		
	Simulated	-1.6
'Site 2'		
	Simulated	-0.8
Pinch point		
	Simulated	-1.3

*'Change' is here defined as $(s_{ea}-s_{eb}) - (s_{aa}-s_{ab})$
where
s_{ea} = speed entering the village, with calming features
s_{eb} = speed entering the village, without calming features
s_{aa} = speed approaching the village, with calming features
s_{ab} = speed approaching the village, without calming features

steering wheel further, ultimately causing a sharper swerve than intended. As stated in section 2, this is only noticeable when negotiating sharp bends, and would not have affected the rest of the trial.

4.1.2.2 Humps

Eight subjects had humps on their route rather than chicanes. The set-up consisted of a series of three humps.

The mean speed of these eight subjects was calculated. It reached a maximum of 24 mph between the first and second humps, and 23 mph between the second and third humps. (The minimum mean speeds were 22, 19 and 18 mph). Before the humps were reached, the mean speeds were 30 mph, both 200m before and 100m before.

The simulator speeds between humps are therefore close to those expected in the real environment - 2-3 mph greater than the predicted speed (based on public road experience) of 21 mph (section 3.2.2.3). Since some real hump schemes have speeds 3 mph greater than predicted (see Webster and Layfield, 1996), this small discrepancy is not serious.

4.2 Effect of individual measures

One aim of this programme is to investigate the effectiveness of alternative traffic calming measures. Accordingly the present study examined separately each of the different features used at Craven Arms. This was done mainly to gain experience rather than to provide immediately useful information since, with the small number of subjects used, it was doubtful if this study could discriminate between features, except where the difference was large.

4.2.1 Craven Arms - mean speeds

In each test route, the sixth to eleventh villages encountered were versions of Craven Arms, consisting of the four 'intermediate' versions described in section 3.2.2.2, plus the uncalmed '40 mph' version and the 'fully calmed' version. The exact sequence varied between different test routes. Table 5 shows the mean (simulator) speed at each of these villages, measured just inside the gateway. Using these figures, the mean speeds at each version can be compared.

Table 5 makes it clear which measures produced the lowest speeds. It does not, however, provide the best method for deciding whether the differences between any two measures are statistically significant; for this an alternative method of comparison was used, the results of which are given in Table 6. Consider, for example, the comparison of 30 mph signs with roundels. In the alternative method of calculation, the speed at which a driver drove through 'Roundels' was subtracted from the

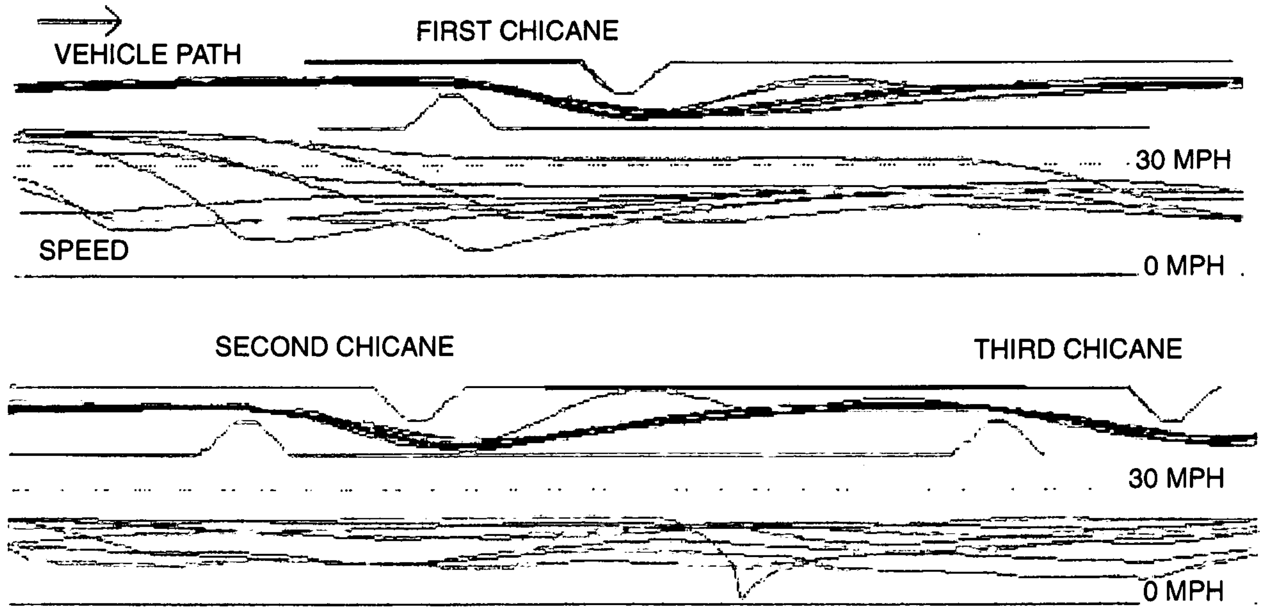

Figure 7 Behaviour at chicanes. The paths by each subject have been plotted in blue. The speeds taken by each subject have been plotted in red (the speeds at the first chicane are plotted underneath the diagram of the first chicane, etc.)

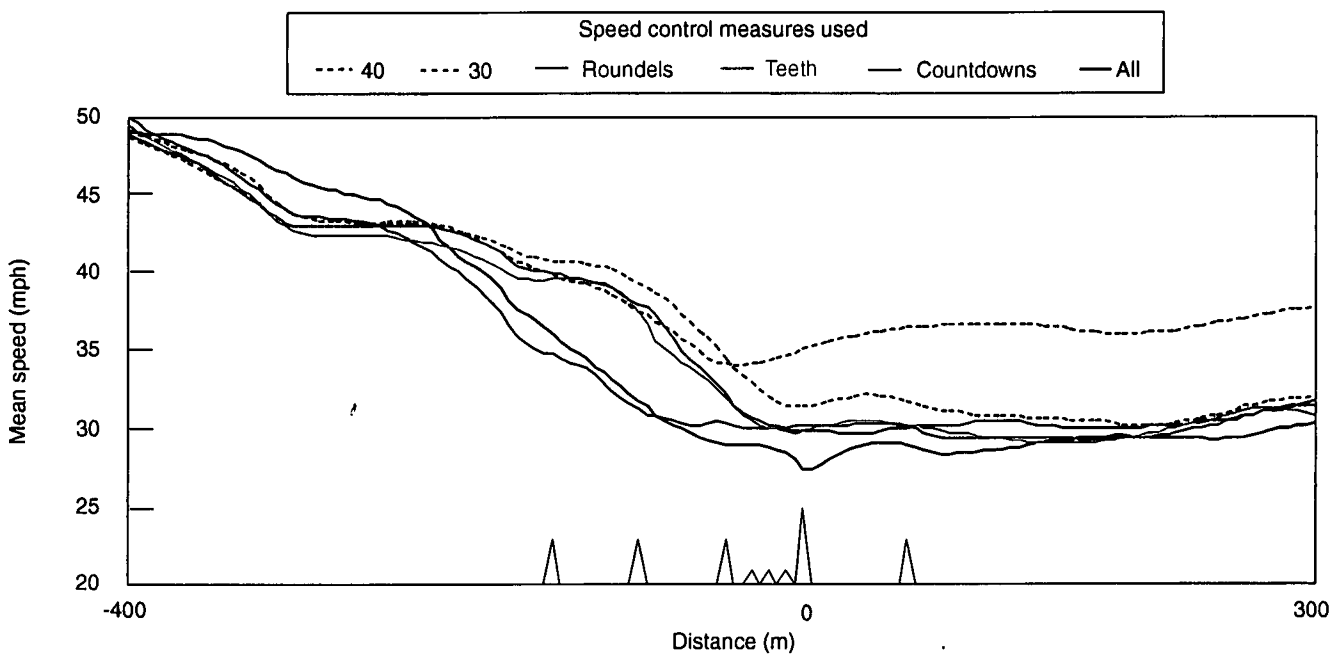

Figure 8 Speeds entering Cravens Arms

Table 5 Speeds (mph) at various versions of Craven Arms (in simulator)

	Mean speed	*Standard deviation (σ)*	*Standard error of mean*
40 (Uncalmed)	35.6	2.8	0.7
30 (30 mph signs)	31.7	6.0	1.5
RD (Roundels)	30.1	4.1	1.1
DT (Dragon's teeth)	30.1	3.5	0.9
CD (Countdown signs)	29.9	2.8	0.7
Full (All measures)	27.7	4.6	1.2

These calculations do not take into account any versions of Craven Arms beyond villages 6-11, so when compared with Table 3, there are slight differences in the speeds for the uncalmed and fully calmed Craven Arms.

Table 6 Differences between speeds recorded at various simulated versions of Craven Arms (in mph), and the corresponding standard errors

	40	*30*	*RD*	*DT*	*CD*
40*					
30*	**3.9** ± 1.4				
RD*	**5.5** ± 1.2	1.6 ± 1.1			
DT*	**5.5** ± 0.7	1.6 ± 1.2	0.0 ± 1.1		
CD*	**5.8** ± 1.0	1.8 ± 1.3	0.3 ± 1.0	0.3 ± 1.0	
FULL*	**7.9** ± 1.0	**4.0** ± 1.6	2.4 ± 1.4	2.4 ± 1.4	2.2 ± 1.2

Differences that are statistically significant at the 5% level are in **bold**.
*See Table 5 for definitions.

speed at which the *same driver* drove through '30 mph signs'. This statistic was then averaged over all drivers, and the standard deviation and standard error computed. The difference was 1.6 ± 1.1 mph; therefore, since the difference was not much bigger than the standard error, it was not statistically significant. Table 6 gives comparisons of this kind for all the Craven Arms measures.

This is a more cumbersome calculation than simply comparing the mean speeds, but it does have the advantage that it sometimes results in smaller standard errors. The complications are worth tolerating since the other method of reducing the statistical error (increasing the number of drivers) is expensive. The reason the errors can be reduced is as follows: if a driver who goes faster than average through '30 mph signs' also goes faster than average through 'Roundels', then the *difference* between his two speeds may be similar to those for other drivers, even though his actual speeds are larger. Thus, the differences between speeds could vary less than the speeds themselves.

The results in Table 6 show that the 40 mph (uncalmed) version was significantly 'faster' than all the other versions, and the 30 mph signs version is significantly 'faster' than the fully calmed (all measures) version; but the other differences are non-significant. Unfortunately, the relative effects of the 'one-feature sites' (RD, DT and CD) are particularly inconclusive; each could have a true effect anywhere between 'useless' and 'as effective as the fully calmed site'. The results suggest that a reduction of 4 mph in mean speed was obtained simply by reducing the speed limit from 40 mph to 30 mph; a further 4 mph reduction was only obtained with the 'All measures' version.

How do these speed reductions compare with reductions obtained from similar measures on public roads? In 20 villages in Suffolk, reduction of the speed limit from 40 mph to 30 mph has been accompanied by an overall reduction of the 85th percentile speed of 4.2 mph (Jeanes, 1996). The agreement with the simulator results is surprisingly close, given that the simulator results are effectively based on a single village, and that in Suffolk the change varied from 0 to 10 mph for individual villages. Note that the simulator figure refers to the speed at the village entrance, which may not be the location used in the Suffolk speed measurements.

Barker and Helliar-Symons (1997) describe trials of countdown signs and roundels. They found that 40 mph roundels produced a significant reduction in mean speed (about 3.5 mph), but that 30 mph roundels and countdown signs did not produce a significant change. It is of course possible that the latter measures did reduce speed but that, as in the simulator, the reductions were too small to be statistically significant. Thus there is no clear discrepancy between the simulator and road trials data.

4.2.2 Craven Arms - speed profiles

Figure 8 shows, for the different versions of the Craven Arms gateway, how the mean speed drops over the 400m approaching the gateway, and how it continues for a further 300m. The large 'spike' indicates the position of the gateway; the medium spikes indicate the three locations of the countdown signs (on one side of the gateway), and the location of the second roundel (on the other); the small spikes indicate the location of the dragon's teeth.

The clearest distinction between the speed profiles is between the sites with countdown signs on the approach and those without; encouragingly, at the former, speeds on the *approach* to the gateway are lower than those achieved by other measures, although *at* the gateway there is little difference.

With one exception, once the drivers had gone 200m into the village there was little difference in speed between any of the sites. This accords with experience on public roads during the VISP project - Wheeler et al (1994) state that "even where speeds have been much reduced at the gateway, this reduction is not maintained over any appreciable distance" (unless additional calming measures are used in the village itself). The exception is the site with the '40' sign. Perhaps, because the subjects knew they were being watched, they observed the 30 mph speed limit more scrupulously than they would usually.

4.2.3 Craven Arms - subjects' opinions of the measures

The results of the interviews with the subjects, to establish the subjective impact of the measures and the realism achieved, are shown in Table 7. The overall impression given is that the dragon's teeth were the least memorable of the three Craven Arms measures, and seen as the least effective. Yet the speed measurements in the simulator did not show any difference between the teeth and the roundels.

Residents of the real Craven Arms village held similar opinions; only 43% of residents thought the tooth markings were useful, compared with 66/68% for the other two measures (Wheeler et al, 1996).

The vast majority of subjects rated the realism of these traffic calming measures as 'Good' or 'Adequate'.

Table 7 Reaction of sixteen subjects to individual measures at Craven Arms

Number of subjects who:	*Roundels on a red surface*	*Dragon's teeth*	*Countdown signs*
Mentioned the measure without assistance	8	4	10
Said they had seen the measure, when shown a photograph	15	12	15
Said it affected their speed:			
Not at all	0	3	1
Slowed them slightly	6	6	4
Slowed them considerably	9	3	9
Different effect on different occasions	0	0	1
Said they had seen it on public roads:	8	1	3
Rated its realism as:			
Good	10	6	6
Adequate	4	4	5
Poor	1	0	2

Table 8 Speed reductions (simulator) at South Warnborough (mph), including the 'partially calmed' version

	Speed at calmed site minus speed at partially calmed site
Entrance	1.5 ± 2.1
'Site 2'	1.9 ± 1.2
Pinch point	0.8 ± 1.4

Only subjects on test routes A and C included (see Appendix A)

4.2.4 South Warnborough - marker posts

As mentioned in section 3.2.1, a 'partially calmed' version of South Warnborough was tried which included all the traffic calming measures, except the marker posts on the approach to the pinch point. This modification was only expected to affect speeds at the pinch point, not at the two earlier measuring points. As Table 8 shows, the speed at the pinch point for the partially calmed site was only 0.8 mph different from the speed at the calmed site.

This suggests that the marker posts made little difference to the speed at the pinch point.

4.3 Effect of the order of villages in the test route

In section 3.3 it was explained that the speed through a village might not depend merely on the nature of the village and on the traffic calming measures used, but also on the position of the village within the test route. This could interfere with the accuracy of simulator studies unless precautions were taken. Examples of such effects were given in section 3.3. The current study was designed to reveal serious effects of this kind.

Since these investigations were only indirectly related to traffic calming, and since most of them did not reveal any effect, the details are relegated to Appendix B. However, one result was sufficiently interesting to be worth describing here. A summary of this result is given in the next paragraph, and full details are given in section B.2, *Sensitivity to traffic calming when driving through a village several times.*

Some of the subjects drove through a number of different versions of Craven Arms and immediately afterwards encountered an uncalmed version of Craven Arms, followed by a version with all the traffic calming measures. In this case, the speed entering the calmed village was only 5 mph less than when entering the uncalmed version. In other circumstances, the speed entering the calmed villages was 10 mph less than when entering the uncalmed villages; these were all cases where the uncalmed Craven Arms was preceded by a different village (either Hermitage or South Warnborough). This suggests that, when drivers pass through a particular village a number of times in succession, they become less sensitive to traffic calming features. This is clearly undesirable in a study that is intended to detect the effects of traffic calming. There is therefore a case for avoiding this in future experiments - on each test route, the villages should change repeatedly.

The phenomenon just described has to be allowed for in some of the analyses, and so is referred to in some of the following sections.

Other effects such as settling-down or long term speed drift were not statistically significant. However, it is still possible that small distorting effects (of around 2 mph) could have gone undetected. It is therefore desirable to take precautions against these, but only where these precautions do not interfere with other aspects of the experiment.

4.4 Effect of the same measures at different sites

This section describes the results from the inclusion of the Craven Arms measures in Hermitage, and the Hermitage measures at Craven Arms. The last village of each test route consisted of one of these sites, half the subjects driving through one and half through the other. The results for the two different sets of subjects are given in separate tables (9 and 10).

In some ways the two locations are similar; both villages are approached on a left-hand bend, with a hedge on the left and fields on the right, followed by a straight downhill stretch just before the gateway. However, at Craven Arms the built-up area is visible earlier. Another difference is that at Hermitage, the brow of the hill tends to conceal the feature installed there; when the same feature was installed on the simulated Craven Arms, the hill did not conceal it but instead provided a grandstand view. It was thought that this might make the measure more effective.

Table 9 shows that the Craven Arms measures had almost as much effect when located at Hermitage as they did at Craven Arms (in fact, the difference is not statistically significant). They were also much more effective than the original Hermitage measures. In Table 10 it can be seen that the Hermitage measures, when located at Craven Arms, were no more effective than when located at Hermitage (the difference is not statistically significant).

This gives the impression that, as might be expected, the measure used has more effect than the location. Whilst no significant 'location effect' has been detected, it is clear that a 'location effect' of 2 or 3 mph could easily go undetected with the small sample used here.

Table 9 Change in mean speed on entrance to village with measures, compared to without measures (mph)

Measures used	*Village used*	*Change in mean speed*
Craven Arms measures	at Craven Arms	-9.0 ± 1.0
Craven Arms measures	at Hermitage	-7.3 ± 1.2
Hermitage measures	at Hermitage	-3.0 ± 1.0

Only subjects on test routes B and D included (see Appendix A)

Table 10 Change in mean speed on entrance to village with measures, compared to without measures (mph)

Measures used	*Village used*	*Change in mean speed*
Craven Arms measures	at Craven Arms	-8.4 ± 1.5
Hermitage measures	at Craven Arms	-2.1 ± 1.0
Hermitage measures	at Hermitage	-3.9 ± 1.5

Only subjects on test routes A and C included (see Appendix A)

4.5 Effect of not using the high-resolution projector

As noted in section 2, a 'high-resolution' projector was used in addition to the main simulator projectors. An attempt was made to establish if this was necessary, by seeing if the subjects drove differently when the 'high-resolution' projector was not used. Unfortunately, the results were also influenced by an 'order-of-village' effect which made it difficult to interpret the results, so no definite conclusion was reached.

4.6 Subjects' opinions on simulator realism

As noted in section 3.2.2.1, the simulations could not replicate every detail of the real world, but were intended to reproduce the important features. The subjects were interviewed to ascertain how realistic they thought the simulations were.

4.6.1 Car handling

When asked about the handling of the car, many subjects remarked that it was good or adequate. Two subjects criticised the gearbox. Two said it was heavy to drive or that they were not used to a large car. Three remarked about the slow response. Two said the steering had been improved (all the subjects had driven the simulator before) but others still criticised the steering.

4.6.2 Scenery

Drivers were asked how realistic they found the villages and the scenery; 6 rated it as "Good", 7 as "Adequate" and 2 as "Poor". The only specific criticism was that there was no livestock in the fields.

5 Summary and discussion

5.1 Signing and marking measures

At the three villages, it was found that when signing and marking measures were present, speeds differed from those obtained when they were not present. These differences are summarised in Table 11.

At the broadest level, all the simulated signing-and-marking measures produced a reduction in speed, like the real ones.

At a more detailed level, it is important that the simulator can do more than merely predict if a speed reduction will occur; it must be able to distinguish between schemes that give a large reduction and schemes that give a small one. Craven Arms and Hermitage were included principally to test this, and the simulator does correctly indicate that the Craven Arms measures are much more effective than the Hermitage measures.

At the most detailed level, the simulator correctly indicates that the South Warnborough measures have an intermediate effect (between the other two), although the difference between South Warnborough and Hermitage is very small compared with the observed public road figures. However, the public road figures may contain a certain amount of error. At control sites on the public roads, speeds typically vary by about 2 mph without any obvious cause

Table 11 Comparison of speeds on public roads and in the simulator

	Public road	*Simulator*
Signing and marking measures: Speed changes (mph)		
Full traffic calming at Craven Arms	-8.5	-8.5
Traffic calming at Hermitage	-0.7	-3.4
Traffic calming at South Warnborough		
- at the entrance	-5	-4.3
- at 'Site 2'	-3	-3.4
- at the pinch point	-7	-3.9
Physical measures: Absolute speeds (mph)		
At a chicane (with a 13 degree 'path angle')	21	About 15
Between 75mm high humps	21	24

(and occasionally much more). (Examples can be found in Barker & Helliar-Symons, 1997, and in tables 4 & 5 of Wheeler et al, 1994). This degree of uncertainty in the public road figures *might* be responsible for all the differences between the public road and simulated figures. Thus it is almost impossible to demonstrate whether or not the simulator is accurate at the finest level of detail.

The speed reductions at the real South Warnborough pinch point have generally been regarded as surprisingly large. This site was chosen for the simulator trial to indicate what would happen when there was a discrepancy between what was expected on an 'engineering judgement' basis, and what was indicated by speed measurements. The results from the simulator seem to support engineering judgement.

Overall, these results are satisfactory; the real and simulated changes agree about as well as could be hoped for, given the expected accuracy of the public road data.

The 'speed profiles' (figure 8) cannot be compared *quantitatively* with public road data, but *qualitatively* they are similar in two respects. First, they indicate the countdown signs affect speeds earlier than the other measures, as common sense would suggest. Second, they suggest that the effect of the measures does not persist for more than 200m, which is consistent with the conclusions of the VISP project.

Thus the reaction of drivers broadly mirrors that observed on the road. This indicates that subjects can learn the handling characteristics of the simulator sufficiently well (since the agreement with public road results would not have been obtained if the handling was too difficult).

Together, the results discussed here indicate that the key questions posed at the start of the study and given in the Introduction are satisfactorily answered.

5.2 Physical measures

As noted in section 2, the hydraulics of the TRL driving simulator are unable to reproduce the full range of forces associated with chicanes and humps. Nevertheless, as indicated in Table 11, the speeds recorded at humps were close to those expected; and the behaviour at chicanes was broadly realistic, although the speeds were somewhat lower than would be expected from observations on the public road.

The author has tried driving through the simulator chicanes at over 30 mph and, subjectively, found it to be unpleasant; but this was because of the frantic rate at which the steering wheel had to be turned, not because of the unpleasant centrifugal forces which would have occurred in real life. If simulated chicanes deliver their 'punishment' by a different method from real chicanes, it may be doubted whether variations in layout would produce the same effects in both cases. The drivers' behaviour may have been influenced by force of habit (all eight subjects had driven through chicanes on the public roads), which would produce a realistic response when driving through an ordinary chicane, but might not produce a realistic response when driving through an unusual chicane. This could be addressed by testing some different designs in the simulator, and seeing whether they produced variations in behaviour similar to those in real life.

The simulator hydraulics, as presently set up, do not give a sufficiently unpleasant jolt when driving over humps at speed. Even more so than with the chicanes, one suspects that drivers were governed by habit, and that they would not have behaved differently if confronted with steeper ramps, etc.

On the other hand, the results show that a typical design of chicane and a standard design of hump can be successfully simulated. So it should be possible to investigate whether, for instance, standard humps can be made more effective by adding special markings, etc.

Therefore the simulator could be used for the study of ordinary deflections, but the study of innovative deflections must be subject to the reservations given above.

5.3 Realism of the graphics

When asked about the realism of the villages and scenery, 6 subjects rated it as "Good" and 7 as "Adequate". When asked about the realism of the individual traffic calming measures at Craven Arms, the response was broadly similar. These subjective views support the conclusion (from the objective measurements made in the study) that the realism of the simulator graphics is satisfactory for the purpose of investigating the effectiveness of traffic calming measures.

The need for an additional high-resolution projected image was investigated. Unfortunately, no clear conclusion emerged as there was more than one way of interpreting the evidence obtained. The need for this enhancement is thus still mainly a matter of judgement; subjectively, the extra readability appears to be a substantial improvement.

5.4 Trial design

Speeds can be affected by the order in which villages are placed in the test route. Making drivers go through the same village repeatedly appears to reduce their sensitivity to traffic calming measures, but this can be avoided by frequently changing the villages in the test route. It is desirable to produce several test routes, with features presented to subjects in different orders, to minimise the effects of 'order'. There are no serious problems in comparing villages that are a long way from each other on the test routes.

With the number of subjects used (16), it was not possible to detect small speed changes (such as a 2 mph difference), but this could be remedied by using more subjects.

All the subjects in the present validation trial were experienced at driving the simulator, so it is desirable to use similarly experienced drivers in any future trials.

5.5 The relative merits of road trials and simulator trials

Whilst it is not practical to validate every detail of the simulator, the above results show that the simulator has in practice given realistic results in a number of different circumstances. It is therefore likely that most results from it will be realistic, providing it is used judiciously.

The desirability for future simulator trials depends not only on the reliability of such trials, but also on whether the simulator offers advantages over other methods of assessment - ie road trials, and engineering judgement. Observations of speeds in public trials are subject to a certain degree of uncertainty (maybe of the order of 2 mph), although this can be reduced if the same measure is trialled at a number of different sites. In practice, different measures are installed at different sites, which may affect comparability; in many respects, the simulator can come closer to an 'ideal' controlled experiment. Thus there are pros and cons of each approach.

Where no one method of monitoring can provide conclusive results, it is desirable to compare evidence from different methods. Simulator trials could clearly be helpful in this respect. They could be used to sift out ineffective measures before they are tried on the public roads, and also be useful in providing measurements, such as speed profiles, that are not obtained from conventional road trials.

6 Acknowledgements

The author thanks the team at the TRL Driving Simulator for running the trial; Reality Visuals for reproducing the villages; and Roger Layfield, Iwan Parry, Marie Taylor and Allan Wheeler for advice.

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Appendix A: The test routes

A.1 The test routes

The following is the sequence of villages for each of the four test routes. The mean speed observed in the simulator at the gateway of each village is given (in mph).

Table A1 The test routes

Village	*Route A*	*Route B*	*Route C*	*Route D*
1	Hermitage (uncalmed) 33.75	South Warn. (uncalmed) 32.00	Hermitage (calmed) 34.50	South Warn. (calmed) 30.00
2	Hermitage (uncalmed) 34.00	South Warn. (uncalmed) 34.25	Hermitage (calmed) 38.75	South Warn. (calmed) 30.50
3	Hermitage (uncalmed) 32.50	South Warn. (uncalmed) 36.25	Hermitage (calmed) 39.50	South Warn. (uncalmed) 33.25
4	Hermitage (uncalmed) 31.00	South Warn. (uncalmed) 36.75	Hermitage (calmed) 36.75	South Warn. (uncalmed) 33.75
5	South Warn. (partially calmed) 30.75	South Warn. (partially calmed) 30.75	South Warn. (partially calmed) 32.00	South Warn. (partially calmed) 32.00
6	Craven Arms (uncalmed) 37.00	Craven Arms (uncalmed) 35.00	Craven Arms (partially calmed #1) 35.00	Craven Arms (partially calmed #4) 29.00
7	Craven Arms (fully calmed) 25.00	Craven Arms (fully calmed) 26.00	Craven Arms (partially calmed #2) 33.25	Craven Arms (partially calmed #3) 28.50
8	Craven Arms (partially calmed #1) 30.25	Craven Arms (partially calmed #4) 29.00	Craven Arms (partially calmed #3) 29.75	Craven Arms (partially calmed #2) 27.75
9	Craven Arms (partially calmed #2) 29.00	Craven Arms (partially calmed #3) 31.50	Craven Arms (partially calmed #4) 32.75	Craven Arms (partially calmed #1) 30.25
10	Craven Arms (partially calmed #3) 30.75	Craven Arms (partially calmed #2) 30.50	Craven Arms (uncalmed) 36.25	Craven Arms (uncalmed) 34.25
11	Craven Arms (partially calmed #4) 28.75	Craven Arms (partially calmed #1) 31.25	Craven Arms (fully calmed) 31.50	Craven Arms (fully calmed) 28.25
12	Hermitage (uncalmed) 33.00	South Warn. (uncalmed) 36.50	South Warn (uncalmed) 37.25	Hermitage (uncalmed) 35.50
13	Hermitage (calmed) 29.25	South Warn. (calmed) 31.25	South Warn (calmed) 35.50	Hermitage (calmed) 33.25
14	South Warn. (uncalmed) 35.75	Hermitage (uncalmed) 33.00	Hermitage (uncalmed) 39.25	South Warn. (uncalmed) 35.75
15	South Warn. (calmed) 28.50	Hermitage (calmed) 29.25	Hermitage (calmed) 35.25	South Warn. (calmed) 32.00

Table A1 The test routes (continued)

Village	*Route A*	*Route B*	*Route C*	*Route D*
16	South Warn. (calmed) 31.25	South Warn. (calmed) 33.25	Craven Arms (uncalmed) 39.00	Craven Arms (uncalmed) 36.25
17	South Warn. (uncalmed) 34.25	South Warn. (uncalmed) 35.50	Craven Arms (calmed) 28.50	Craven Arms (calmed) 27.25
18	South Warn. (uncalmed, with low resolution) 31.50	South Warn. (uncalmed, with low resolution) 35.25	Craven Arms (uncalmed, with low resolution) 36.25	Craven Arms (uncalmed, with low resolution) 32.00
19	South Warn. (calmed, with low resolution) 30.50	South Warn. (calmed, with low resolution) 31.75	Craven Arms (calmed, with low resolution) 29.50	Craven Arms (calmed, with low resolution) 29.00
20	Craven Arms — with Hermitage marks, and chicanes 34.25	Hermitage — with Craven Arms marks, and humps 25.75	Craven Arms — with Hermitage marks, and chicanes 34.75	Hermitage — with Craven Arms marks, and humps 28.25

Notes:
1 The partially calmed versions of Craven Arms are described in section 3.2.2.2.
2 The speeds at South Warnborough are measured about 50m before the pinch point; the speeds for the other two villages are measured about 15m after the village entrance.

A.2 The villages used in each analysis

The following tables show, for the analyses described in the main text, precisely which villages were used. Generally, the methods involved comparing the speed of drivers at one location with the speed of the *same drivers* at a different location. This was because comparisons between different drivers would have been subject to an additional source of error, caused by the fact that no two drivers are identical.

In these tables, 'A6' means 'village 6 in route A'; and 'A6/A7' means 'the speeds in village A6 were compared with the speeds in village A7'.

Table A2 Test route villages used when calculating the speed changes brought about by signing and marking measures (section 4.1.1, tables 3 & 4)

Craven Arms	A6/A7,B6/B7,C10/C11,C16/C17,D10/D11,D16/D17
Hermitage	A12/A13,B14/B15,C14/C15,D12/D13
South Warnborough	A14/A15,B12/B13,C12/C13,D14/D15

Table A3 Test route villages used when examining the 'partially calmed' version of South Warnborough (section 4.2.4, table 8)

A5/A14/A15, C5/C12/C13

Table A4 Test route villages used when examining the effect of Craven Arms measures at Hermitage (section 4.4, table 9)

Measures used	*Village used*	*Test route villages*
Craven Arms measures	at Craven Arms	B6/B7,D16/D17
Craven Arms measures	at Hermitage	B14/B20,D12/D20
Hermitage measures	at Hermitage	B14/B15,D12/D13

Table A4 shows that, for the purposes of section 4.4, the villages D10/D11 were ignored when estimating the effect of Craven Arms measures at Craven Arms. This is because D10/D11 were part of a block in which each driver had to go through Craven Arms six times in succession and, as explained in section 4.3, this seems to have altered driver behaviour. As the villages being investigated in section 4.4 (B20 & D20) do not form part of such a block, D10/D11 is not an appropriate comparison.

A similar comment applies to table A5. Village C20 is preceded by other versions of Craven Arms, and is therefore compared with C10 & C11 as these are also preceded by various versions of Craven Arms. Village A20, on the other hand, is not immediately preceded by Craven Arms and therefore village A6 forms a suitable comparison.

Table A5 Test route villages used when examining the effect of Hermitage measures at Craven Arms (section 4.4, table 10).

Measures used	*Village used*	*Test route villages*
Craven Arms measures	at Craven Arms	A6/A7,C10/C11
Hermitage measures	at Craven Arms	A6/A20,C10/C20
Hermitage measures	at Hermitage	A12/A13,C14/C15

Appendix B: The effect of the order of the villages in the test routes

B.1 Introduction

The speed at which a subject drives through the village might be affected, not just by the traffic calming features, but also by the position of the village on the test route. As the latter could distort the results, it is desirable to design each study in a way that eliminates such distorting effects. But this is difficult unless something is known about them.

For instance, if it is possible that the character of a village affects the behaviour of drivers, why not eliminate such effects by having just one village repeated throughout the entire test route? But would such a boring, unrealistic arrangement itself distort the behaviour of drivers? One can imagine many *possible* 'order' effects, and guarding against them all may be impossible. So it is useful to know which effect causes most problems in practice. This section attempts to quantify several possible 'order' effects:

- Unusual cautiousness when driving through a village for the first time.
- Where the same village (Craven Arms) appeared repeatedly, the average speed might change within that block of villages.
- Settling-down effects - drivers might go slowly until they got used to the set-up.
- Long-term speed drift - it was doubted that drivers would consistently maintain the same speed over a long time period. Their speed might drift up or down a little.
- Does a 'after/before' test (where a traffic-calmed village is followed by an uncalmed version of the same village) give the same results as a 'before/after' test (where the two villages are the other way round)?
- Previous village effects - a driver forced to slow severely in one village might drive through the next with unusual care.

B.2 Sensitivity to traffic calming when driving through a village several times

Someone entering a village for the first time might drive cautiously. If an 'uncalmed' village was met first and the 'calmed' village met second (as was usual in this study), this would reduce the apparent effect of the calming. Table B1 should show any such effects.

There is an effect but not of the type expected. For Craven Arms, the difference in speed is relatively small for those who have just driven through Craven Arms four times already (5.4 mph). Perhaps, driving through Craven Arms repeatedly, their speed soon became a matter of habit, and so traffic calming measures had less effect. These drivers then went through four 'other' villages (Hermitage & South Warnborough). Then they once more drove through Craven Arms, uncalmed and calmed, this time recording an average difference of 9.8 mph; this suggests that the 'other' villages dispelled the effect of habit. For comparison, the speed reduction at the real Craven Arms was 8.5 mph.

The experiment in the Daimler-Benz simulator provides only partial corroboration of these effects (Riemersma et al, 1990, their Table III). The response to traffic calming measures was indeed greatest when driving through the simulated Weiteveen for the first time. However, since that study involved driving through a single village repeatedly, one might expect most of the speed reductions in that study to be 'dulled by habit' and therefore too small; in fact they were large compared with the real life Weiteveen.

It is unclear which is most realistic, the 'first-time' response or the 'habit-dulled' response. Intuitively, the 'first-time' response seems more likely to be realistic, since in a real journey, each village is different from the last. However, the 'first-time' response has the advantage that it is larger and so more likely to be statistically significant. This suggests that a future study should not measure the 'habit-dulled' response, but instead concentrate on the 'first-time' response (and the 'not been through recently' response, which seems to be similar).

In summary, on each test route, the villages should change frequently so that subjects would not drive through the same village many times in succession.

B.3 'Settling-down' during the early part of the drive

Drivers might go slowly for a few minutes until they got used to the simulator. Therefore the plan for this study was that, for each subject, the first four villages would be identical, so any 'settling-down' effects would be obvious. (This was not done for route D, which was therefore excluded from the settling-down analysis).

A simple linear model was fitted to data from the first four villages which, taken literally, indicated that subjects drove through each village 0.5 mph faster than the previous village.

Table B1 Difference between speeds entering an uncalmed version of a village, and entering the calmed version of the same village which follows immediately afterwards; broken down by whether that village has been entered before

	Difference in speeds (mph)	*Number of subjects*	*Villages*
Craven Arms:			
if not been through before	-10.5 ± 1.1	8	A6/7,B6/7
if been through but not recently	-9.8 ± 0.8	8	C16/17,D16/17
if been through just before	-5.4 ± 1.1	8	C10/11,D10/11
Hermitage:			
if not been through before	-3.0 ± 1.0	8	B14/15,D12/13
if been through but not recently	-3.9 ± 1.5	8	A12/13,C14/15

South Warnborough is not included as all examples would be in the 'been through but not recently' category

But this effect was nowhere near statistically significant. Nor were significant effects revealed by more complicated models (where the effect did not have to be linear).

To sum up, no evidence of settling-down effects was found.

The first four villages of route C (calmed Hermitage) were entered at a higher speed than those of route A (uncalmed Hermitage). It seems the individuals driving on route C tended to be faster than those on other routes; measurements from villages 6-11 also suggested that route C drivers were about 3 mph faster (on average) than the others. Given the size of the statistical errors, it is a little surprising that the difference was so large. It does emphasise the desirability of basing comparisons on the *same individuals* driving through different measures, rather than testing each measure with a different group of drivers.

B.4 Long term speed drift

Perhaps drivers go at a slightly different speed during, say, the second half of a drive, compared with the first half. This is not a matter of getting used to the simulator initially, but rather that the driver's speed might just drift up by a few mph after a while, possibly without any conscious decision to do so. Clearly any general tendency for speed to drift upwards (say) during the test drive, even if only by a few mph, could create difficulties comparing two villages that are a long way apart.

A different problem would be created if half the drivers drifted upwards and half drifted downwards. The *average* speed might not drift, but there would be an additional source of statistical error, making the study less sensitive.

To examine this, the following villages were compared: A1 with A12 (both uncalmed Hermitage, and neither having Hermitage as the previous village); D2 with D15 (both calmed South Warnborough, both having South Warnborough as the previous village); and similarly B1 with B12; and similarly C2 with C15. Thus each comparison involved two identical villages that had 10 or 12 villages separating them. For each subject, the speed through the gateway of the earlier village was subtracted from the speed through the gateway of the later, and the resulting figure called the *long term drift.*

An estimate of *short term drift* was also made by comparing A3 with A4, B3 with B4, C3 with C4, and D3 with D4 (in all cases, identical villages with identical traffic measures).

The average value of long term drift was only 0.4 ± 1.2 mph, the standard deviation being 4.8 mph. The average value of short term drift was -0.8 ± 0.7 mph, the standard deviation being 2.9 mph.

Thus no evidence was found that comparisons between distant villages would be much worse than comparisons between nearby villages. The standard deviations suggest there might be more noise in the distant comparison, but this may not be large enough to be serious; in tables 9 & 10, two of the estimates ('Craven Arms measures at Hermitage' and 'Hermitage measures at Craven Arms') will have been affected by long term drift, yet the errors of those estimates are not obviously worse than the others in the same tables.

In conclusion, long term drift is small or non-existent, and unlikely to cause major problems. It is not likely to be worth taking precautions against it if these precautions interfere with other aspects of the study. Precautions should be taken only where this *can* be done without causing such interference.

B.5 Change in mean speed whilst driving through a village several times

For villages 6-11, where subjects drove through Craven Arms six times in succession, the data were examined to see if there was any change in the average speed, such as a tendency to drive more quickly through the later villages. But statistical modelling of the data did not find any evidence for this, beyond the variation that was clearly due to the traffic calming measures.

This may appear to contradict the finding given earlier, that making someone drive through Craven Arms six times in succession dulled their response to traffic calming. However this dulled response could involve going slightly faster at traffic calming measures, and going less fast in their absence, with little effect on the *average* speed.

B.6 After/before

In this study, tests of traffic calming have mostly involved the uncalmed village coming immediately *before* the calmed village in the test route. However, in two cases the uncalmed village came *after*. Table B2 shows speed changes for these two methods.

Subjects on Route A drove through the 'uncalmed before calmed' South Warnborough villages and then *immediately* drove through the 'calmed before uncalmed' South

Table B2 Speed at South Warnborough (mph); difference between uncalmed and calmed villages

		Speed change		
		Route A	*Route B*	*Villages*
Entrance				
	Uncalmed before calmed	-11.8 ± 2.4	-1.3 ± 1.8	A14/15,B12/13
	Calmed before uncalmed	-1.0 ± 1.0	2.5 ± 1.5	A16/17,B16/17
'Site 2'				
	Uncalmed before calmed	-4.0 ± 3.3	-3.8 ± 1.7	A14/15,B12/13
	Calmed before uncalmed	-1.8 ± 0.9	-1.3 ± 1.1	A16/17,B16/17
Pinch point				
	Uncalmed before calmed	-7.3 ± 1.1	-4.5 ± 1.0	A14/15,B12/13
	Calmed before uncalmed	-4.3 ± 1.3	-3.3 ± 2.3	A16/17,B16/17

Only subjects on test routes A and B included

Warnboroughs. As noted in section B.2, one would expect this to make the drivers less sensitive to traffic calming anyway. Consequently, although the 'calmed before uncalmed' always gave feebler speed reduction figures, the reason is uncertain.

This problem does not apply to subjects on Route B, who drove through Hermitage immediately before arriving at the 'calmed before uncalmed' villages. For route B, the measures appeared less effective when judged by the 'calmed before uncalmed' method (indeed the signs at the entrance appear to have made drivers speed up), though the differences are not large compared with the errors. There is corroboration of this from the Daimler-Benz simulator (Riemersma et al, 1990), but only for subjects driving through the first and second villages in the test route, not for later villages.

It is therefore likely, but not certain, that the 'calmed before uncalmed' method produces smaller speed changes. It is not clear what implications this has, if any, for comparisons between alternative traffic calming measures.

B.7 Effect of the previous village

The character of the previous village might have an influence. This was examined, using villages 12-17 on the test routes (where the identity of the village kept changing on all test routes). For instance, at the entrance to Hermitage (uncalmed), did the speed differ depending on whether the preceding village was Craven Arms or South Warnborough? For this and similar comparisons, no statistically significant differences emerged. Nor was the effect of traffic calming signficantly altered by the identity of the village before.

B.8 Conclusions about the order of villages

The one positive implication is that, if drivers go through the same village a number of times in succession, they seem to become less sensitive to different traffic calming measures. It is unclear whether this results in speed measurements that are more accurate or that are less accurate. Clearly reduced sensitivity is undesirable (if there is no change in accuracy), since it makes it more difficult to discriminate between rival traffic calming measures. The reduction in sensitivity may be by a factor of two. There is therefore an advantage in ensuring drivers do not pass through the same village a large number of times in succession - on each test route, the villages should change frequently.

The test routes for the current trial do not conform to this, especially in regard to testing the partially calmed versions of Craven Arms. These were arranged as a single block of six successive Craven Arms villages, to reduce any distortion caused by 'long term speed drift'. It now appears that 'long term speed drift' is not very serious, probably adding only a small amount of noise, and unimportant compared to something that could reduce sensitivity by a factor of two.

The other 'order' effects that have been investigated have not been statistically significant. This may mean the effects did not exist, but it is possible that a small effect existed that could not be detected. Given the error estimates, a reasonable rule-of-thumb is that an effect that produced a distortion of 4 mph or more would have been detected (if it was sought), but a distorting effect of 2 mph could easily have gone undetected. A distortion of 2 mph could be quite undesirable in some circumstances, and therefore precautions should still be taken against possible effects of long term speed drift etc (eg, by reversing the order of villages for different drivers). Naturally these precautions should have a lower priority than precautions against 'habit-dulling'.

Appendix C: The sample size needed to distinguish between measures

Different drivers will pass the same traffic calming measure at different speeds. Because of this, the average speed in the simulator of a group of, say, 16 drivers, will be slightly different from the 'true average speed' (that is, the average speed which would be obtained if every driver in the country was put through the simulator). This difference is the *statistical error*, which will be discussed in this appendix; it can be reduced by increasing the number of drivers in the group.

Doubling the number of subjects should reduce the statistical error of speed differences by 30%. If the errors in Table 6 in the main report were reduced by 30%, then the differences between the fully-calmed site and the one-feature sites would all be significant; and the differences between the '30-only' site and the one-feature sites would be on the borderline of significance. This suggests that an increase in the number of subjects would have been useful in discriminating between different measures.

The standard errors of the speed differences in Table 6 typically had values of 1.2 mph. Thus, when comparing different traffic calming schemes, differences in speed of 2.4 mph would just be significant. Since the standard error is inversely proportional to the square root of the number of subjects, this can be used to estimate the number of subjects needed to detect a given difference (Table C.1).

It should be realised that this Table indicates when it is *probable* that a given difference will be detected (about 50% likely); to be almost certain that a given difference will be detected, a larger sample size would be necessary.

What reduction in speed can be expected from a 'typical' traffic calming measure? In the simulator results above, 'single-measure' sites at Craven Arms achieved a reduction of about 1.7 mph (but subject to a large amount of error); simulated Hermitage (effectively a single measure site) produced a reduction of 3.4 mph. The study by Barker and Helliar-Symons (1997) suggested 40 mph roundels produce

Table C.1 Number of subjects needed, for it to be probable that a given difference in speeds will be detected

Number of subjects	*Typical standard error*	*Difference in speeds that is just significant*
16	1.2 mph	2.4 mph
32	0.8 mph	1.7 mph
64	0.6 mph	1.2 mph
128	0.4 mph	0.8 mph

a reduction of 3.5 mph but did not detect any effect for 30 mph roundels and countdown signs. The VISP study (Wheeler, Taylor and Barker, 1994) found speed reductions less than 3 mph at a number of sites, though at others, reductions of up to 7 mph might be obtained at gateways, often using a combination of measures.

On the whole, it seems likely that a single signing/ marking measure will typically change speeds by no more than 3 mph. A minimum requirement for a simulator study would therefore be to detect 3 mph differences, so as to distinguish between an effective measure and a useless one. However, such a study would not be able to deal with any measures of intermediate value - a measure producing a 1 mph reduction could easily *appear* to be better than one producing a 2 mph reduction. Thus there would be advantages in detecting a 1.5 mph difference.

The statistical errors stated above only refer to the error in measuring the effect of the simulated traffic calming measure. When making predictions about what will happen in reality, the errors will actually be larger because there is an additional source of error, namely that the effect of the simulated traffic calming measure may not be exactly the same as the effect of the real traffic calming measure. Keeping the statistical error small will allow some leeway for this additional error.

Thus, it would be useful for future studies to use considerably more than the 16 subjects used in the present study.

ABSTRACT

The report describes a pilot study which investigated the potential for using the TRL driving simulator to assess the effectiveness of traffic calming measures. The entrances to three real villages have been reproduced on the simulator. All the villages had traffic calming measures, in the form of signs and markings. Sixteen members of the public drove through the simulated villages, both with and without the traffic calming present. The speeds they drove at were compared with observations of speeds made before and after the introduction of measures at the real villages. The result was that speeds and speed changes observed in the simulator were broadly comparable with those observed in real life. This suggests that the simulator could provide a useful means of assessing the effectiveness of traffic calming features involving signs and markings. Some chicanes and humps were also simulated and behaviour at these was also broadly comparable with that observed on the public roads. Aspects of trial design were investigated.

RELATED REPORTS

PR 85 *Speed reduction in 24 villages: details from the VISP study* by A Wheeler, M Taylor and J Barker. 1994 (price code L).

TRL186 *Traffic calming — road hump schemes using 75 mm high humps* by D C Webster and R E Layfield. 1996 (price code H).

TRL201 *Count-down signs and roundel markings* by J Barker and R D Helliar-Symons. 1997 (price code J).

TRL212 *Traffic calming on major roads: the A49 trunk road at Craven Arms, Shropshire* by A H Wheeler, P G Abbott, N S Godfrey, D J Lawrence and S M Phillips. 1996 (price code L).

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