Transport Research Laboratory

Driver Interaction With Temporary Traffic Management

by R Wood, M Palmer, L Walter and I Rillie

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Task 593(387)

FINAL PROJECT REPORT

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FINAL PROJECT REPORT RPN 1813

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By R Wood, M Palmer, L Walter and I Rillie (TRL)

Prepared for: Project Record: **Task 593(387)**

Driver Interaction With Temporary Traffic Management

Client: **Highways Agency, NetServ**

Paul Mitchell

This Draft Report has been prepared for Highways Agency.

The views expressed are those of the author(s) and not necessarily those of Highways Agency.

	Name	Date Approved
Project Manager	Paul Walton	29/06/11
Technical Referee	Iain Rillie	29/06/11

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Executive summary

Road worker safety is a key area of network operations that is of great importance to the Highways Agency. Road worker activity during road works carries a high risk of injury due to the exposure to 'live' traffic, particularly during short-term works at night. Contractors have suggested that the number of signs used in a closure could be reduced to lessen risk exposure when deploying or removing the signs.

Although reducing the number of signs used for temporary traffic management (TTM) would lower risk exposure for operatives, there would also be a reduction in the information available to vehicles approaching the road works. The Highways Agency has a duty to consider risk to both the road-worker and the travelling public when considering any change in current policy or practices.

Previous work (Baguley, 1996) identified that there was scope to reduce the number of signs and simplify TTM. This project aims to provide the Agency with a data-led case for any recommended changes, based on objective measurements of driver behaviour from a driving simulator study and an on-road trial of simplified TTM layouts shown via the simulator study to reduce risk without compromising safety.

The first phase of the work engaged with stakeholders to develop simplified alternative TTM designs that could be used in place of the current Chapter 8 relaxation layouts. Engaging with key stakeholders at this time ensured that suggested changes would be practicable and would facilitate involvement of supply chain partners in any trial of the layout on the network, since it was important that these new designs were operationally valid alternatives to the current Chapter 8 TTM layout.

The first two layouts for the simulator study were developed with direct involvement from stakeholders during the workshop. The third was developed subsequently by TRL using information gained from within the workshop. Each layout reduced the number of signs on approach to the road works, while still informing drivers about the road configuration ahead and the required behaviour. The first layout removed a small number of signs from the standard configuration; the second layout removed more signs whereby the third layout used a minimal signage configuration. The three designs moved progressively away from the standard Chapter 8 layout, permitting investigation as to the safe minimal signage level.

The simulator trial showed that driver behaviour was relatively consistent across the four TTM configurations under test; statistical results indicated that for each of the modified layouts, behaviour did not differ significantly from that observed in the relaxed DZB6 control configuration.

- All drivers present in the lane to be closed (lane 3) on approach to the road works had merged into lane 2 at least 200 metres before the cone taper, suggesting that in all layouts drivers understood the TTM measures and what they had to do in response
- Drivers reduced speed when in a road works environment
- Few drivers looked directly at TTM signs, regardless of the TTM configuration used

The simulator results indicate drivers behaved in a safe and consistent manner in the four different TTM configurations presented, with no significant changes in any safety critical behaviour on the approach to road works.

For reasons of practicality and based on stakeholder feedback an on-road trial to test the use of Layout 1 (omission of 600 yard warning signs and Detail 'A') was recommended. Traffic management contractors considered this to be a relatively simple approach that could be implemented quickly without changes to signing authorisations.

Following discussions with DfT and contractors, it was further proposed that omission of the 200 yard warning signs should also be trialled, subject to the satisfactory conclusion of the initial on-road trials of Layout 1.

As the final stage of the project , an on-road trial was undertaken. Two trial layouts (1A and 1B) were evaluated. Layout 1A omitted the Detail 'A' from the hard shoulder and both 600 yard advance warning signs. Layout 1B simplified the Layout 1A further by omitting the 200 yard advance warning signs. These two layouts were trialled successively and compared with the current layout defined in Chapter 8.

Utilising video recording of passing traffic, evidence of any changes in driver merging behaviour was gathered. Analysis of this data for over 120,000 vehicles within two HA areas (Area 4 & Area 10) showed that:

- There was no evidence to suggest that there is a difference in the lane movement of vehicles under the different experimental conditions.
- Similarly, contractors did not report any vehicles entering the hard shoulder after 'Detail A's were removed.
- Both contractors involved in the trials expressed satisfaction with the 1B simplified layout, stating they were content to continue using the layout.

Using the Measurement of Injury Risk (MIRI) index, Layout 1A has the potential to provide a reduction in risk exposure of 14% for closures of this type and reduce carriageway crossings by 35%. Layout 1B, where the 200 yard, 600 yard and Detail 'A' signing is removed, has the potential to provide a reduction in risk exposure of 22% for closures of this type and reduce carriageway crossings by 52%

It is therefore possible that by using the signing Layout 1B as trialled that the Highways Agency can achieve a substantial reduction in carriageway crossings and road worker exposure to risk of injury.

1 Introduction

Road worker safety is a key area of network operations that is of great importance to the Highways Agency. Road worker activity during road works carries a high risk of injury due to the exposure to 'live' traffic, particularly during short-term works at night. Contractors have suggested that the number of signs used in a closure could be reduced to lessen risk exposure when deploying or removing the signs.

Although reducing the number of signs used for temporary traffic management (TTM) would lower risk exposure for operatives, there would also be a reduction in the information available to vehicles approaching the road works. The Highways Agency has a duty to consider risk to both the road-worker and the travelling public when considering any change in current policy or practices.

Previous work (Baguley, 1996) identified that there was scope to reduce the number of signs and simplify TTM. This project aims to provide the Agency with a data-led case for any recommended changes, based on objective measurements of driver behaviour from a driving simulator study and an on-road trial of simplified TTM layouts shown via the simulator study to reduce risk without compromising safety.

1.1 Structure of the project

The whole task consisted of three phases:

Phase 1: Stakeholder engagement

- Sub-task 1: Review of previous research and consultancy;
- Sub-task 2: Stakeholder workshops and test layout design;

Phase 2: Driving simulator trials

- Sub-task 3: Simulator study of three simplified TTM layouts

Phase 3: Limited area roll-out

- Sub-task 4: Network trial of simplified layouts;
- Sub-task 5: Analysis and reporting

This report presents the summary results from the first two phases of the trial (with the exception of the literature review which is contained in a separate report) and the detailed analysis of the results from Phase 3 together with recommendations.

1.2 Delivery Matrix

This Task aimed to provide the Agency with a data-led case for any recommended changes, obtained by objectively measuring driver reaction to current and simplified sign layouts and carrying out a controlled network trial of a simplified temporary traffic management sign layout. The following objectives were defined for the project:

- Measure driver visual behaviour and car control and hence establish driver reactions to the simplification of current temporary traffic management signage
- Carry out a trial of the best alternative TTM layout identified in the simulator study
- Monitor the trial and report the key findings regarding road worker risk and driver reaction

These objectives are delivered in the following sections within this report:

Requirement:	Objective is met by:	Within:
Sub-task 1: Review of previous research and consultancy		
- Review the previous work carried out in this area	Previous work reviewed, in particular sign size, shape, colour, symbol design, message type and relevance to road works sign simplification.	Previous review report from Sub-task 1
Sub-task 2: Stakeholder workshops and test layout/methodology design		
- Run a maximum of two stakeholder workshops at TRL's premises	A single stakeholder workshop was held, split into four sessions.	Section 2 and previous report from Sub-tasks 2 & 3
- Produce three potential test layouts from the stakeholder workshops to guide the simulator study	Suitable layouts were designed for the simulator trial. Further development of one layout was undertaken prior to the trial. Guidance from the stakeholders was used when designing the on-road trial	Sections 3 and 4 and previous report from Sub-tasks 2 & 3
Sub-Task 3: Simulator studies		
- Current 'relaxation' closure will act as control; up to three experimental conditions will be trialled	Extensive simulator trial of three trials conditions. Participants interviewed to gain additional information	Section 4 and previous report from Sub-tasks 2 & 3
- Examine drivers' behaviour in response to modification of the TTM layout	Data obtained during the trial of vehicle speed and position, merging behaviour and eye movement analysed	Section 4 and previous report from Sub-tasks 2 & 3
Sub-Task 3: Network trial of one simplified layout		
- Facilitate a network trial of one of the simplified layouts	On-road trial conducted in two HA regions, utilising simulator layout 1 (Layout 1A) and a modified version with omission of 600 yard signs (Layout 1B)	Section 5

2 Phase 1: Stakeholder Workshop

As part of Phase 1 of the project, a stakeholder workshop was held to obtain views on simplifying the layout for signing the approach to a short term temporary lane closure on a dual carriageway road and how best this could be achieved. By engaging with key stakeholders at this time it ensured that the suggested changes would be practicable and would facilitate involvement of supply chain partners in any trial of the layout on the network.

Attendees invited to the workshop were selected to represent a diverse range of opinion in relation to TTM. Representatives were invited from:

- Supply chain partners
- Road user organisations
- Highways Agency (HA) Chapter 8 team

Attendees were split into three groups to discuss the ideas and themes. Each group contained at least one supply chain partner, one member of the Highways Agency team and one member of TRL staff to facilitate discussion. After these sessions, the groups reconvened to decide on the layouts that would be put forward for testing in a driving simulator trial.

2.1 Discussions upon current Chapter 8 layout (DZB6)

The single lane closure (as shown in Figure 1) is that most widely used on the network. For relaxation lane closures, imposing and enforcing mandatory speed limits is currently impractical (though work is ongoing to develop average speed enforcement equipment suitable for use in these situations). Until it is possible to enforce speed limits at such works, this type of temporary traffic management carries the greatest risk for road workers due to the speeds at which traffic passes the works site.

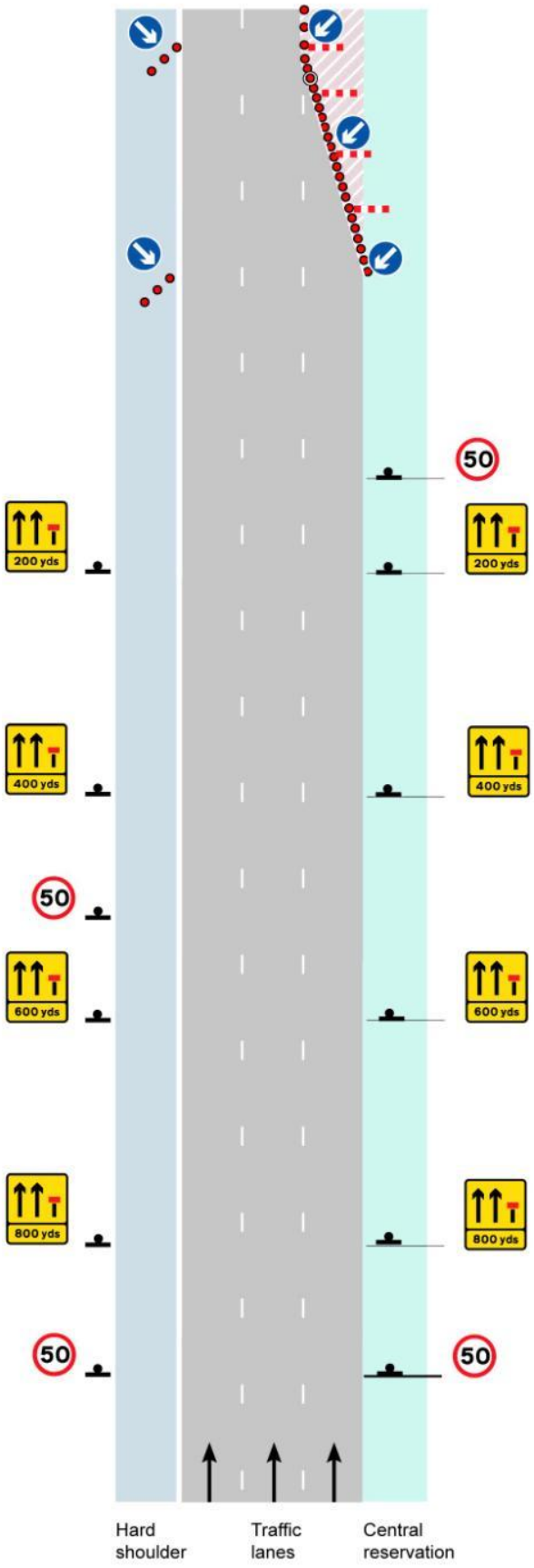

Figure 1: Layout for the lane change zone for a single lane closure on a dual carriageway road for which the national speed limit applies (Diagram DZB6)

The workshop was undertaken as four sessions, each with a specific theme. A glossary of terms used in the workshop is contained in Appendix A.

2.1.1 Session 1: Ideal driver behaviour

Stakeholders stated that ensuring drivers complied with all speed limits (either temporary or permanent), would immediately improve safety through road works. Stakeholders then indicated that on approach to road works, drivers should:

- See the signs
- Understand the signs
- Obey them at the appropriate time.

It was felt that under the current conditions drivers do not obey the signs for a variety of reasons. Drivers may fail to see, fail to understand, or simply choose not to comply with the traffic management warning equipment used to mark out the closed lane.

There was discussion over the point upstream of the lane closure at which drivers should move out of the lane to be closed. Stakeholders agreed that a driver in the lane to be closed should start planning their lane change manoeuvre no later than the 800 yard 'wicket board' sign. The manoeuvre should start between the 600 yards and 400 yards signs (within the current layout – see Figure 1), and that all drivers should be out of the closed lane by the 200 yard 'wicket board'.

Discussions highlighted that timely presentation of appropriate information is an important feature of TTM. An example identified by stakeholders as to where there may be a shortcoming in the signs used currently was the existing 'wicket board' signs which indicate a lane closure but fail to provide the driver with an instruction what to do and when. Stakeholders felt that an alternative that would give an appropriate order was the 'hooked arrow' sign, although this type of sign is intended to warn of a permanent lane loss (as shown in Figure 2) rather than a temporary lane closure.

Figure 2: 'Hooked arrow' signs warning of lane loss on a dual-carriageway

The issue of speed and compliance with posted limits was a key discussion topic. It was generally felt that the lack of enforcement in relaxed works resulted in excessive speed and that this was often a contributory factor in accidents, however data has subsequently suggested that the use of mandatory speed limits is the most effective method of achieving speed reductions and further (less substantial) reductions are observed with the addition of an enforcement system (Wood, Sexton and Rillie, 2010). Where advisory speed limits are in place the stakeholders felt that only when the speed limit is reduced to 40mph is there a noticeable reduction in speed. Subsequent research

has shown that with a 50mph advisory speed limit alone, mean vehicle speed actually increased by 0.97mph when compared to no advisory speed limit being shown (Wood et al, 2010).

2.1.2 Session 2: Critique of current Chapter 8 principles

Stakeholders felt that the current Chapter 8 design does not address all the needs of the road user or the road worker.

There can be a conflict between the respective requirements of traffic management operatives and motorists. Manual handling of signs was the greatest concern expressed by stakeholders; particularly members of the group who work in the traffic management industry. Moving large signs across the carriageway can be a cumbersome and awkward task resulting in the operatives responsible being further exposed to live traffic. An operative moving a large sign may also be obscured from the view of motorists and therefore may not register as a significant hazard. Such signs also present a danger to motorists if dropped, or fall into the carriageway at any point during operations. A review of sign sizes conducted in relation to concerns raised by the industry concluded that in certain cases sign sizes could be reduced (Clark et al, 2011).

2.1.3 Session 3: Ideas for change

Of the changes discussed, stakeholders agreed that the most promising option was to remove signs with the aim of simplifying the message given to drivers and a secondary benefit of reducing the exposure of traffic management operatives to live traffic when implementing the lane closure.

2.1.4 Session 4: Effects of any change to Chapter 8 principles

Discussions highlighted the difficulties and financial cost of implementing changes to the layout on a national scale but did not identify any perceived risk from late merging. There was a concern that, were any changes to be introduced gradually, there would be the potential for a driver to experience inconsistency of traffic management layout in a single journey, possibly leading to confusion. Any changes implemented could also require an information campaign to ensure motorists were aware of the new scheme and any such campaign would have its own associated costs. It was decided that this project would focus on reducing the number of signs and improving the clarity of the message given to drivers.

2.1.5 Outcomes from the workshop

Three ideas to be tested were developed from the workshop: a minor change, a moderate change and a large change from the current Chapter 8 layout (DZB6) for the approach to a lane closure on a three lane, dual carriageway road. The changes simplify the layout but still give the driver all the important information required to negotiate the approach to the road works safely. Changes applied consist of a reduction in the number of signs on the approach, simplification of the message given to drivers and adjustment to the distances at which some of these signs are placed.

3 Layouts developed for simulator evaluation

The final output from the stakeholder workshops was a series of proposed layouts for simulator evaluation. The proposed 'control' layout was the current Chapter 8 (DZB6) layout which was then used as a template for adjustments to the advance warning signing. Maintaining a familiar overall layout of TTM was considered to be of benefit as drivers would be more likely to accept changes that are based on an existing layout.

3.1 Proposed layout change 1: Minor change

Within this proposed layout (shown in Figure 3) the Detail 'A' (one sign and three cones) has been removed from the hard shoulder. Under normal circumstances traffic should not use the hard shoulder and removing the Detail 'A' improves access to vehicles that have broken down and for emergency vehicles attempting to respond to any incident. The taper layout is as per Diagram DZB3 for a relaxation taper. The 600 yard 'wicket board' sign has also been removed on both sides of the carriageway.

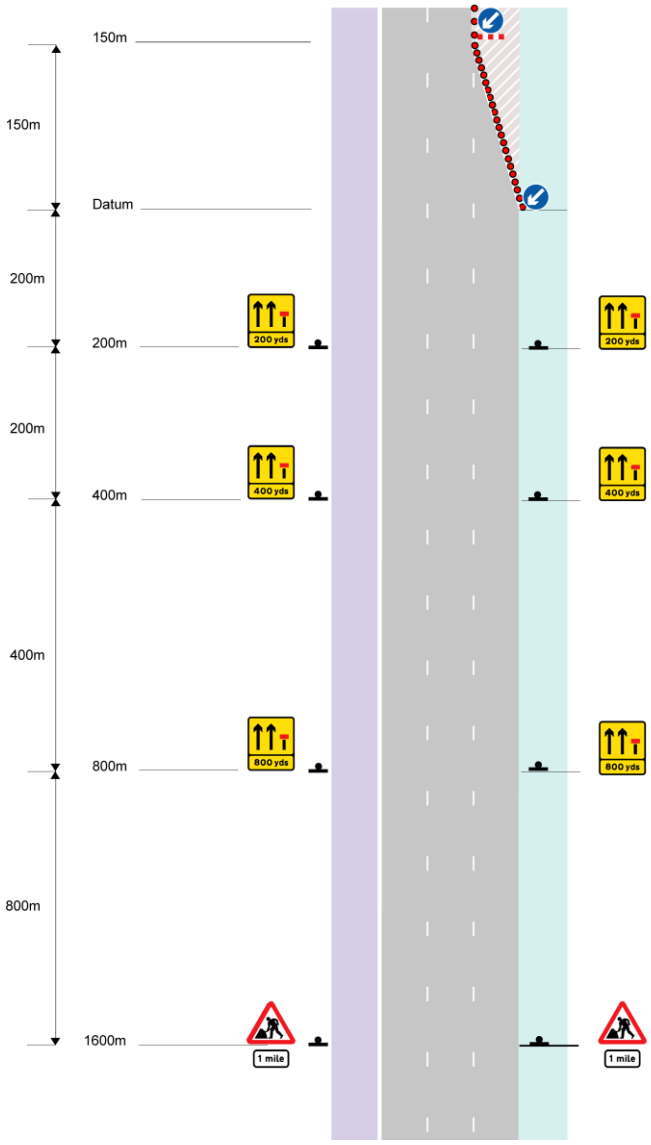

Figure 3: Proposed closure layout 1 – Simple sign reduction

3.2 Proposed layout change 2: Moderate change

For the moderate change shown in Figure 4, the changes in and around the taper remain the same. The 800 yard 'wicket board' sign is removed, replaced by a 'road works' (Diagram 7001) triangular warning sign. The 1 mile supplementary plate underneath it is also removed. The 600 yard and 400 yard 'wicket board' signs were replaced with 'hooked arrow' signs. The distance information on these signs was removed completely; however at the 400 yard position the distance information replaced with a bottom panel containing the advisory message 'Now'.

Replacing the 'wicket board' signs with 'hooked arrow signs is a move towards harmonisation with permanent road signs (Figure 2). It may also provides the driver with a clearer message of what they have to do unlike a standard 'wicket board' sign that shows that the lane ahead is closed, but gives the driver no instruction.

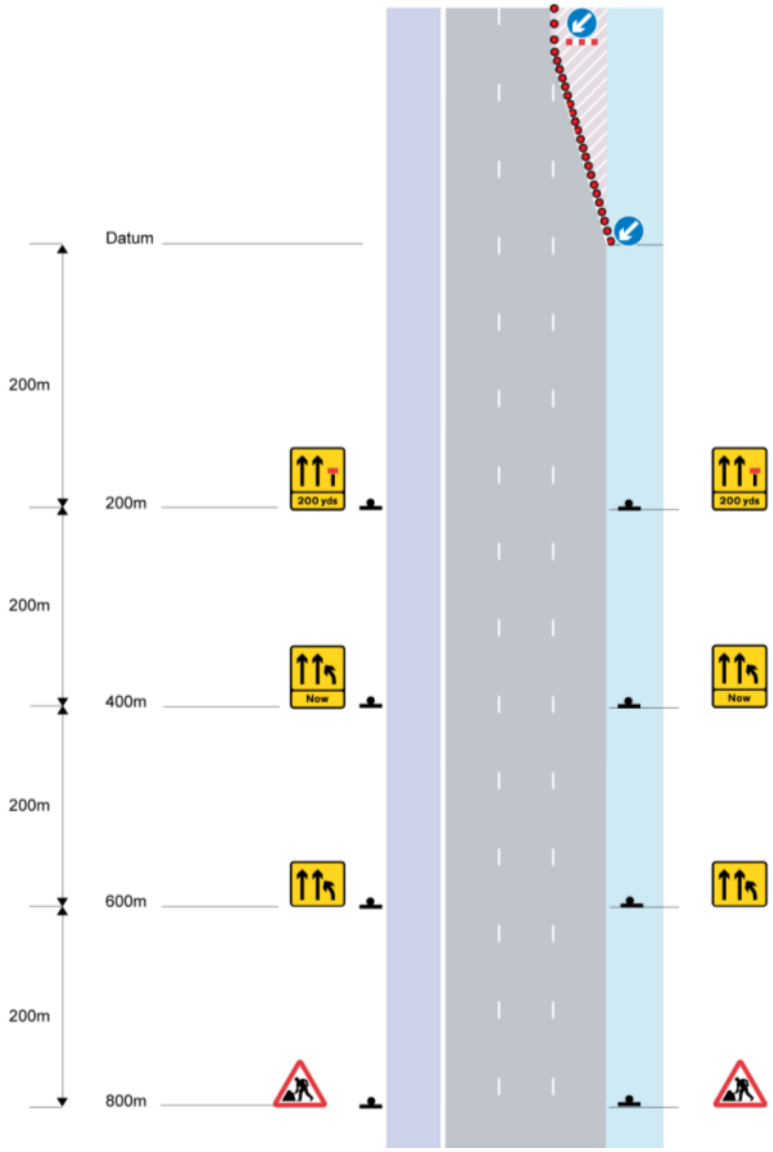

Figure 4: Proposed closure layout 2 – Use of 'hooked arrow' signs

3.3 Proposed layout change 3: Large change

The most radical change to minimal signage (Figure 5) did not come out of the workshop directly but was developed by TRL using a number of concepts from the literature and the workshop. The changes within this layout build on the use of a 'hooked arrow' sign and removal of signage. Only one 'Keep left/right' arrow sign and lane closure sign is used in the taper; this is located approximately in the middle of the taper (subject to clearance/road space availability). This change in position brings the sign into the driver's direct sightline, which research suggests (Wilkie and Wann, 2002) will increase the chances that a driver will detect the sign from a greater distance.

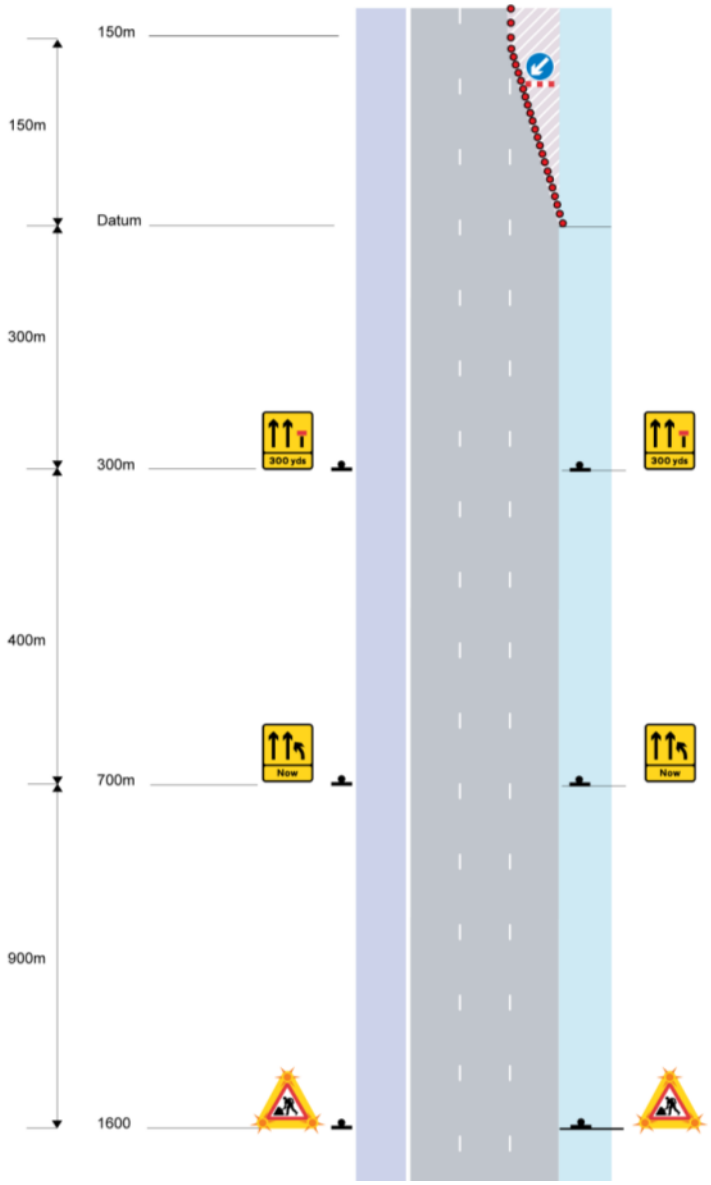

Figure 5: Proposed closure layout 3 – Minimal signage

Based on research into conspicuity, there is a change to the men at work warning triangle, which gives the driver their first indication they are travelling into a road works area. The distance plate has been removed and synchronous amber flashing lights attached to the corners of the sign face. The intention is that the lighting would aid the conspicuity of the sign, communicating the triangular 'hazard' shape to approaching drivers and thus ensuring that drivers would not pass the sign without looking at it. The

removal of the supplementary distance plate is intended to cause the driver to seek information on how far away from the road works they are, looking past the signs to the road works, taper and lateral cones. This may focus a driver's attention on the traffic conditions and may lead to drivers merging earlier. The distances have been altered slightly, moving the 200 yard 'wicket board' sign to 300 yards and moving the 600 yard 'wicket board' sign to 700 yards. It is anticipated that giving information earlier to drivers would encourage earlier decisions to change lane in some drivers who follow the advance merge sign.

4 Phase 2: Simulator Trial

The use of a driving simulator allowed the research team to develop a driving scenario that provided a safe, realistic and consistent environment in which to assess driver behaviour when travelling through the different TTM configurations developed for the study.

Figure 6: TRL Driving Simulator

During the simulator trial, computer systems logged data from the driven vehicle 20 times a second throughout each trial drive. The recorded data was separated into vehicle control measures and visual behaviour measures. Vehicle control measures include information on the speed of the vehicle driven by the participant, when and how drivers change lane, the way in which a driver brakes and the movement of the vehicle within the lane or related to other vehicles in the simulation.

The measures of visual behaviour enabled an assessment of the duration and frequency with which participants looked at the signs present when driving through the road works and their distance from each sign when they chose to look at it. These measures help to identify the information the participants used to make decisions when approaching the road works and to determine what information tended to be ignored.

4.1 Modified TTM layouts

Four TTM configurations (the three experimental layouts described in Section 3 plus the standard Chapter 8 layout as a control) were created in the simulator and each participant drove through all four configurations. A screen shot of the simulated road works is shown in Figure 7

Figure 7: Screenshot of simulated roadworks

4.1.1 Overview of results from simulator trial

The results of the simulator trial showed that driver behaviour was relatively consistent across the four TTM configurations under test; statistical results indicated that for each of the modified layouts, behaviour did not differ significantly from that observed in the standard Chapter 8 configuration. Specifically:

- Drivers maintained a similar following times to the vehicle in front regardless of whether they were in a road works section or not
- All drivers present in the lane to be closed (lane 3) on approach to the road works had merged into lane 2 at least 200 metres before the cone taper, suggesting that in all layouts drivers understood the TTM measures and what they had to do in response
- Drivers reduced speed when in a roadwork environment

The result of this study differs from the findings of previous work in this area which indicated that omission of the 600 yard signing caused drivers to remain in the closed lane longer than for the standard Chapter 8 layout. However, this study developed a more robust methodology and examined a number of areas that the previous work was unable to consider (due to technological advancement in the TRL simulator).

When examining drivers' visual behaviour, it is clear that:

- Few drivers looked directly at TTM signs, regardless of the TTM configuration used
- Glance durations were typically short (less than 0.5s)

The post-trial questionnaire results suggest that participants had a subjective preference for Layout 1. There was a tendency to report that the number of signs in Layout 1 was appropriate and it was easy to understand the information presented. However:

- The results of the post-trial questionnaire suggested that drivers are not fully aware of the number of signs in a temporary closure
- The results also suggest that drivers are unable to distinguish differences in TTM configuration while travelling through the works area
- Some drivers commented on the lack of a speed limit sign, expecting a 50mph limit to be applied (and enforced).
- No consensus emerged when participants were asked which if any of the road works they encountered had "too many signs"
- Participants asked to rate the clarity of the four TTM configurations indicated that Layout 1 was significantly clearer than all other layouts (including the control)

- An interesting finding, apparent in the simulator and questionnaire data, was the tendency for drivers to travel at a slower speed through road works

4.1.2 Recommendations from the simulator study

The results of this simulator research indicated that drivers behaved in a safe and consistent manner in the four different TTM configurations presented. There were no significant changes in any safety critical behaviour on the approach to road works in any of the alternate designs compared to the control (Chapter 8) layout. This suggested that any of the three alternate TTM designs could safely be used on the network.

As a result, an on-road trial to test the use of Layout 1 was recommended. This layout involved omission of two features from the standard configuration: 600 yard 'wickets' and 'Detail A'. Traffic management contractors regard these changes as relatively superficial and that they could be covered by the current risk assessment procedures with no requirement for new equipment or signs

Following discussions with contractors, it was recommended that the next sign to be examined for omission should be the 200 yard 'wicket'. Removing these would be a further step to reducing the number of signs in a closure, which if deemed safe would help further reduce the risk to road workers

5 Phase 3: On-Road Trial

Following on from the simulator trial, an on-road trial was undertaken. This evaluated the difference in road user behaviour and traffic count per lane for an offside lane closure on a three-lane motorway with hard shoulder between the control layout (Chapter 8) and experimental conditions.

The simulator trial recommended that Layout 1 (as shown in Section 3.1) should be used. This involved:

- Removal of both 600 yard 'wicket' signs
- Removal of 'Detail A'

Traffic management contractors considered these changes to be relatively superficial and that they could be covered by the current risk assessment procedures, thus delivering the on-road trial would be relatively straightforward.

During discussions with DfT to gain approval for the trial it was suggested that omission of the 200 yard "wicket" sign should be considered. Following examination of the data from the simulator study and in particular the glance duration data it was suggested that this layout should also be trialled. For the on-road trial this further reduced layout (where the 600 yard, 200 yard and Detail 'A' signing was omitted) was referred to as trial layout '1B', with the trial layout as evaluated in the simulator known as Layout 1A.

It was made clear from the outset of the trial that this layout would only be trialled if layout '1A' was deemed a success. The three layouts are shown in Figure 8:

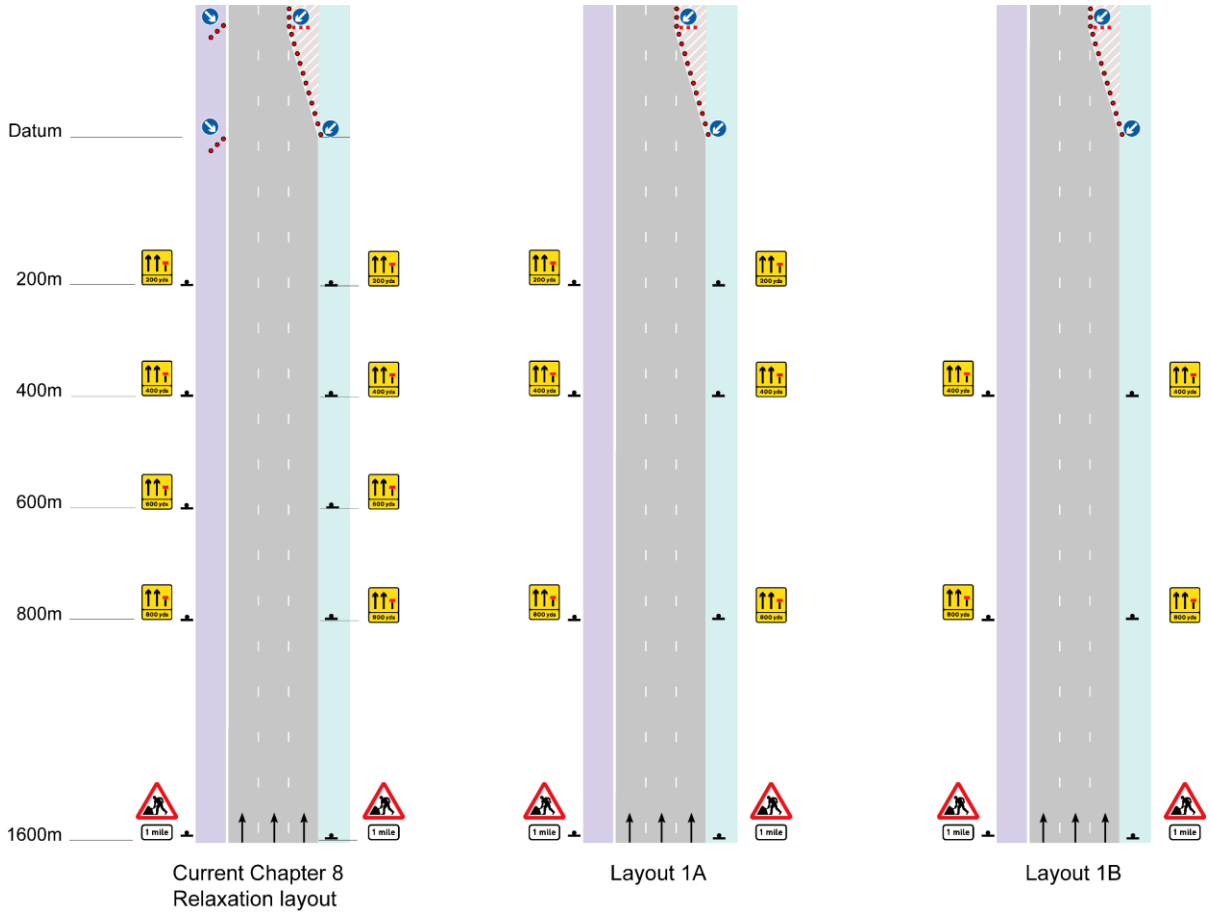

Figure 8: Control and simplified layouts used during on-road trial

5.1 Trial delivery

The trial was carried out in two Highways Agency Areas. Within Area 10, the trial was carried out by AOne+, the incumbent MAC, as part of their routine maintenance operations. Within Area 4, the trial was carried out as part of the drainage survey work being undertaken for Balfour Beatty Mott MacDonald.

The approach to the trial was the same in each of the Areas in which data were collected. For each layout, irrespective of type, temporary sign mounting frames were deployed in each location (800, 600, 400 and 200 yards) as would be normal for the standard Chapter 8 layout. Where Layout 1A and 1B signing was required, this was achieved by ensuring that the 'wicket' sign faces were not displayed to oncoming drivers. Typically this was achieved by folding down split-faced signs therefore displaying the grey rear of the sign (as shown in Figure 9 below) and by placing 'Detail A' components covered in a safe position off the hard shoulder.

Figure 9: Example of horizontal split-faced 'wicket' sign being folded down

This approach allowed full Chapter 8 signing to be reinstated if deemed necessary by the contractor. Contractors were briefed to end the trial and deploy full Chapter 8 'relaxation' signing (i.e. the control layout) if there were any safety concerns; this did not happen during any trial condition.

The trial was undertaken in phases, with video recording of traffic behaviour to provide the data for the trial (further detail of this is given within Section 5.2). Data for the Chapter 8 relaxation offside lane closure on a three lane motorway (the control layout) was collected first, followed by the data for Layout 1A.

Once the data for Layout 1A was received, this was analysed to determine whether there was any observable difference in driver behaviour between the experimental and control layouts. The decision to move onto Layout 1B was not taken until initial analysis had

deemed this first stage had been completed successfully without incident and all stakeholders involved confirmed it was safe to continue with the second layout.

5.2 Traffic Flow Camera Systems

Camera systems were designed and manufactured by TRL to gather video recordings to allow traffic flow, lane occupancy and driver behaviour to be determined and analysed. These systems allowed for data to be collected on lit and unlit carriageways. From the 200 yard sign position it is possible to track a vehicle's position to the start point of the taper.

Figure 10: Camera system attached to TTM sign 'A'-frame

Analysis of both lane occupancy and traffic behaviour was made possible by installing these camera systems upon the advance 'wicket' sign frames at 800, 600, 400 and 200 yards. The sign frames remained in place (albeit, depending on the trial condition, with the sign face not displayed) for the 600 and 200 yard signs, which ensured recordings could be undertaken at all four sign locations during all three conditions.

Data collection was undertaken for the two trial areas (Area 4, South East and Area 10, North West and continued until sufficient data had been obtained for each of the three trial conditions. This duration was dependant on the number of appropriate road works being undertaken and traffic flows. Works used to collect data included planned maintenance, such as drainage surveys, and responsive maintenance such as central barrier repairs resulting from damage sustained during collisions.

Limitations were placed on the suitability of works locations, such that work sites needed to be:

- On three-lane carriageways with a hard shoulder
- Not in close proximity to junctions, which could affect driver merging behaviour
- During overnight works

Also, works would be subject to all limitations and restrictions imposed by Contractors, Chapter 8 or the Highways Agency including for example maximum traffic flow.

Cameras were positioned on the 'downstream' side of nearside sign frames to obtain a view of vehicles travelling away from the camera. Typical camera images are shown in Figure 11.

Figure 11: Typical camera views (left image from 200 yard sign, with taper and sequential lamps visible)

The HA's contractors carried out deployment and retrieval of the camera systems during trials and undertook daily maintenance. Times, locations and weather conditions of camera deployments were logged. Video was recorded onto solid-state Micro-SD memory cards, which were returned to TRL for analysis.

5.3 Results of On-Road Trial

The trial analysed multiple lane three road works sites for durations of between 1 and 6 hours, with lane usage and behaviour recorded for more than 120,000 vehicles. Table 1, shows the sizes of samples analysed for each of the trial conditions.

Table 1: Number of vehicles in each trial condition

Trial condition	Vehicle count
Control	41,992
1A	34,414
1B	45,635

Due to the constraints associated with collecting data from operational roadwork sites, variance in flow and trial duration (and thus total number of vehicles counted for each trial condition) was recorded. However, the greatest number of vehicles counted occurred for the most significant layout change (Trial 1B).

5.3.1 Statistical analysis method

As a number of variances occurring from the trial were identified, a 'repeated measures ANOVA' statistical model was used to identify the effect of alternative road works signing options on lane change behaviour. Specific attention was paid to the behaviour of occupants of the (later closed) third lane.

To define this, analysis of three different factors was undertaken: lane used (L1-L3), sign/measurement position (800-200) and condition type (Control, 1A and 1B). The

'repeated measures ANOVA' detects statistically significant differences within each factor, e.g. whether there is a difference in the number of vehicles in each lane, and within interactions, e.g. whether the change in the number of vehicles in each lane varies by experiment. In order to identify whether changes to road works signing as demonstrated in trials 1A and 1B affected lane change behaviour, consideration was given to the interaction between the three factors; lane used, sign/measurement point and experiment type (trial condition).

5.3.2 Results

The results of the model showed that all of the main factors were statistically significant, but only some of the interactions between factors (shown as $x \times y$ in the text below) were statistically significant. The analysis of each factor and interactions are identified below:

Sign/measurement point: significant ($p<0.05$)
There is a significant difference in the overall number of vehicles at each sign point. This was not unexpected as although most of the vehicles are counted passing each sign point there was some difficulties in starting each count at exactly the right time during operational deployment of the trial therefore resulting in some variance.

Lane: significant ($p<0.05$)
There is a significant difference in the overall number of vehicles in each lane. This is again as expected with usage of a carriageway regardless of whether road works are present or not.

Experiment: significant ($p<0.05$)
There is a significant difference in the overall number of vehicles in each experiment (see Table 1) for the reasons previously identified.

Sign point × experiment: not significant ($p>0.10$)
There is no significant difference in the number of vehicles at each sign point across the different experiments. That is, if the number of vehicles reduced from the 800yds to 200yds in the control group then a similar pattern was observed in the two experimental groups.

Sign point × lane: significant ($p<0.05$)
Differences in the number of vehicles at each sign point vary by lane. As expected, at each sign point there was an overall difference in the distribution of vehicles by lane. In this case there was a reduction in the overall number of vehicles in lane 3 by the 200yrd point.

Experiment × lane: significant ($p<0.10$)
The distribution of vehicles across the lanes differs by experiment. This is mainly due to the differences in traffic flows – a lower flow will generally lead to a higher proportion of the flow occupying the inside and middle lanes.

For the interactions:

Sign point × experiment × lane: not significant ($p>0.10$)
Considering the interaction of the factors and interactions identified above which are mostly a factor of the study design, the interaction between sign/measurement point, experiment and lane was not significant.

That is, the pattern of vehicles moving lanes did not differ significantly between the three different experiments.

Figure 12 shows that the proportion of vehicles which were occupying lane 1 at each sign point is higher at the control sites than the two experimental sites. This is due to there being a generally lower flow rate at the control sites and therefore less of a requirement for drivers to use lanes 2 and 3.

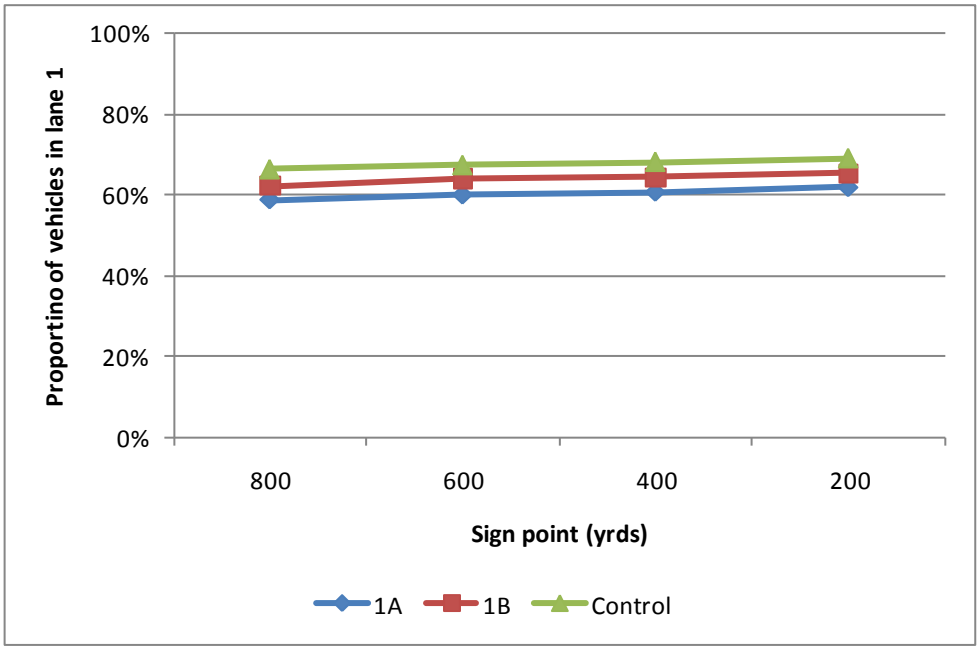

Figure 12: Proportion of vehicles in lane 1

Figure 13 shows the proportion of vehicles occupying lane 2, this shows that the proportion of vehicles occupying lane 2 at control sites is lower than for either experimental site, again due to the lower flow rates recorded.

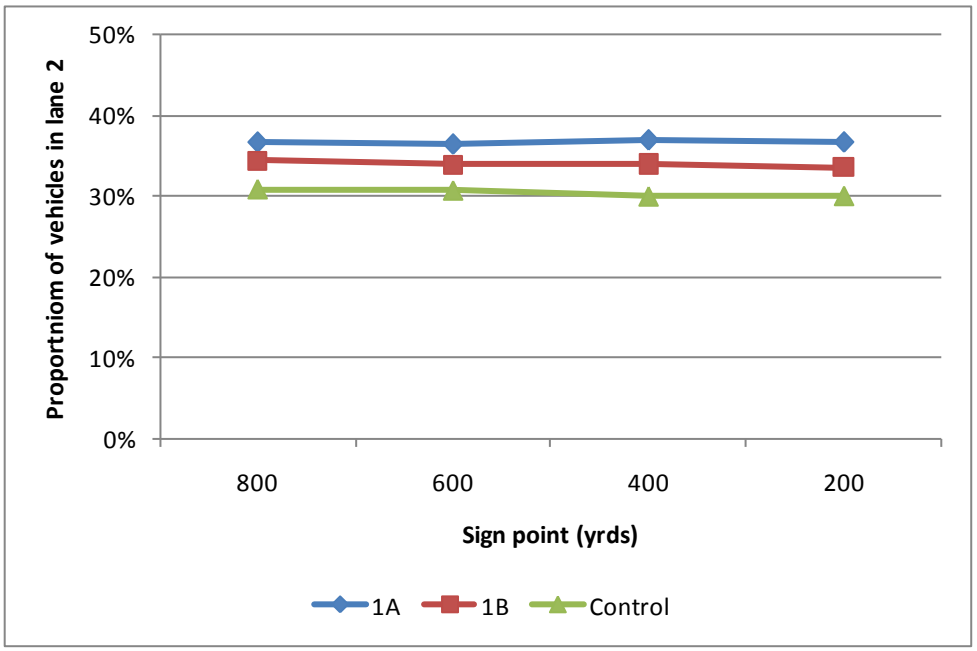

Figure 13: Proportion of vehicles in lane 2

Figure 14 shows that the proportion of vehicles in lane 3 (the closed lane) decreased to approximately the same proportion (~1%) despite the differences in proportions of vehicles in lane 3 at the 800 yard sign. During both experimental conditions a higher lane 3 occupancy was recorded than for the control at the 800 yard sign/measurement point; it is interesting to note that at this point there had been no change in the signing layout between the two experimental conditions and the control.

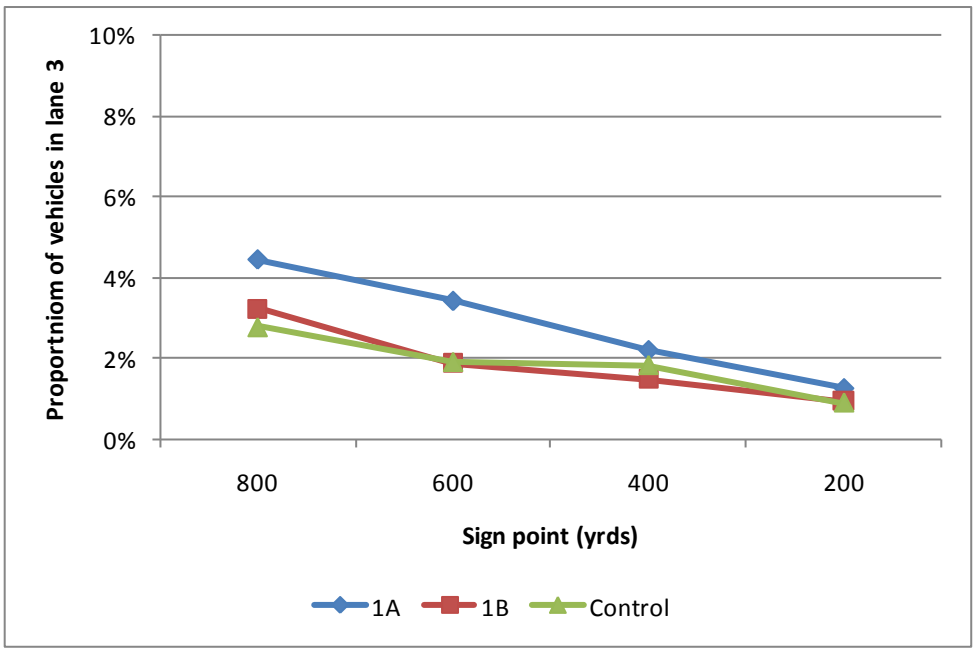

Figure 14: Proportion of vehicles in lane 3

5.4 Results summary

The modelling procedure shows that once differences in vehicle counts (caused by the experimental design) are controlled there is no statistical evidence to suggest there is any difference in the lane movement of vehicles in the different experimental conditions.

It is very difficult to state absolutely that there is no difference between experimental conditions and so that they are the same. The nature of statistical testing is that it cannot prove absolutely that something is the same; it can only show that it is highly probable that it is not different. Ensuring that such statistical testing is based on an adequate sample size is critical to ensuring the findings of the test are robust. In this trial it can be shown that there is an adequate sample size as the results of analysing a sub-set of the data results in an equally consistent outcome, indicating the sample size was sufficient to provide a robust result.

Assuming that the sites that were surveyed during the trial were representative of sites in general, which it is believed that they were (as sites were chosen at random in relation to required works), then there is substantial evidence to suggest that there is no difference in the distribution of vehicles moving out of lane 3 in the three experimental conditions.

In addition both Managing Agent Contractors (MACs) involved with the trial have reported that they are pleased with both experimental trial conditions and would like to see the widespread usage of such techniques in the near future.

5.4.1 Effect of changes upon the MIRi Index

The effect of the two road works layouts (1A and 1B) trialled on road worker safety and risk exposure can be quantified by using the Minimisation of Injury Risk (MIRI) Index (Fowler et al, 2011). The MIRi Index has been developed from an in-depth understanding of the work processes involved with deploying TTM and applies to the deployment and retrieval of TTM associated with relaxation closures (excluding the longitudinal coning), which accident and incident data suggests is the highest risk activity undertaken by road workers. The MIRi Index has been supplemented with a carriageway crossing value based on an aggregated value of carriageway crossings and although not a precise value, it allows quantification of reductions in carriageway crossings that can be achieved by changes in working practices and road work layouts.

For the purposes of calculating the effect of utilisation of Layouts 1A and 1B using the MIRI Index a number of assumptions have been made which include:

- 3 lane carriageway only
- offside (Lane 3) closure
- TM Installation using a TM vehicle and separate Impact Protection Vehicle (IPV)
- Signs secured using sandbags
- Taper installation conducted by IPV following TM vehicle into closure

The MIRI values for an unchanged DZB6 layout and the trialled 1A and 1B versions are identified in Table 2.

Table 2: MIRI Index calculations for trialled Layouts 1A and 1B

	Current practice		Layout 1A		Layout 1B	
Activity	**MIRi Index**	**CC value**	**MIRi Index**	**CC value**	**MIRi Index**	**CC value**
Advance signing	66433	40	57733	32	49033	24
Detail 'A'	15849	19	0	0	0	0
Taper installation	46936	0	46936	0	46936	0
Taper removal	35686	0	35686	0	35686	0
Advance signing	66433	40	57733	32	49033	24
Total MIRi Index / CC value	231337	99	198088	64	189672	48
Reduction in value	-	-	-14%	-35%	-22%	-52%

By utilising Layout 1A a reduction of 14% can be achieved in MIRi Index with a reduction of 35% in carriageway crossings. However, using Layout 1B will reduce the MIRi Index value by 22% and achieve a carriageway crossing reduction of 52%.

6 Conclusions & Recommendations

- The on-road trials were based on layouts developed from workshops involving key stakeholders and subsequently trials in the TRL driving simulator.
- Within the on-road trials, driver behaviour and lane occupancy of over 120,000 vehicles were assessed within two HA areas (Area 4 & Area 10) for one control (Chapter 8) and two trial conditions (Layouts 1A & 1B).
- Detailed analysis of the lane occupancy proportion was undertaken for varying flow levels, areas and both lit and unlit motorway sections.
- The on-road trials of the two simplified TTM layouts (for lane 3 closures) showed that that there was no evidence to suggest that there is a difference in driver response to the traffic management layouts in the different experimental conditions.
- Similarly, contractors did not report any vehicles entering the hard shoulder after 'Detail A's were removed.
- Both contractors involved in the trials expressed satisfaction with the 1B simplified layout, stating they were content to continue using the layout.
- Using the Measurement of Injury Risk (MIRI) index, layout 1A has the potential to provide a reduction in risk exposure of 14% for closures of this type and reduce carriageway crossings by 35%
- Using the Measurement of Injury Risk (MIRI) index, layout 1B has the potential to provide a reduction in risk exposure of 22% for closures of this type and reduce carriageway crossings by 52%
- It is therefore possible that by using signing layout trialled in 1B that the Highways Agency can achieve a substantial reduction in carriageway crossings and road worker exposure to risk of injury.

Recommendation

The results and feedback from the MACs involved in operating the trial suggest that there is no difference in road user behaviour between the current Chapter 8 layout and the Layout 1B (simplified) layout. Assuming that the trial sites used were representative of the wider network, it is therefore recommended that Layout 1B should be considered for adoption as an alternative to the currently permitted relaxed layout in Chapter 8, with the two layouts considered as equivalent.

The proposed simplified relaxed layout should only be applied to relaxed works where traffic flows are light (less than 1200 veh/hour/lane open); for reasons of consistency the same signing approach should be considered for all lane closures irrespective of carriageway width and lane closed (as per the approach taken in Chapter 8) to deliver consistency of message for road users approaching a lane closure.

Although this trial has been conducted in varying conditions (road geometry, topography, lighting and flow rates) it should remain the responsibility of the MAC and its Traffic Management teams to ensure that all factors are considered when deploying signing for short term overnight road works as it is expected that this signing may not be suitable for all applications, although the trial sites were indicative of a wide variety of works sites across England. Use of Layout 1B should therefore remain subject to appropriate risk assessment by the service provider as the decision on selection of appropriate traffic management measures should remain with the Service Provider.

The recommendations from this research should be linked to other initiatives that seek to improve road worker safety, in order to ensure harmonisation of objectives and ensure that the outcome of this trial does not adversely affect that of any other (and vice-versa).

Acknowledgements

The work described in this report was carried out in the Road Safety Group of the Transport Research Laboratory. The authors are grateful to A-One+ and Balfour Beatty Mott MacDonald for their full involvement and support of the on-road trial, the additional support of Colas, ATM Traffic Solutions and many other individuals who facilitated data collection and Iain Rillie who carried out the technical review and auditing of this report.

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Appendix A Glossary of workshop terms

For the avoidance of confusion between common terms used to describe items used within TTM, definitions were agreed as shown in Table 3.

Table 3: Glossary of terms used in the Stakeholder Workshop

Sign	TSRGD Diagram number	Meaning according to TSRGD	Term used in this report
	610	Vehicular traffic passing the sign must keep to the left of the sign where the arrow is pointed downwards to the left or to the right of the sign where the arrow is pointed downwards to the right.	Keep left/right arrow sign
	7105	Position of barrier to mark length of road closed to traffic or to guide traffic past an obstruction	Lane closed sign
	7001	Road works or temporary obstruction of the carriageway ahead	Road works warning sign
	7202 (variant)	Right hand lane of a three lane dual carriageway closed to traffic ahead	'Wicket board' sign
	7208	Distance ahead at which conditions indicated by sign shown above start to apply	Supplementary distance plate
	872.1 (proposed variant)[1]	The number of traffic lanes ahead on a dual carriageway or a one-way street reduces from three to two. Traffic in the right hand lane must move into the lane on the immediate left	'Hooked arrow' sign

[1] Sign 872.1 is currently only permitted with either a white, blue or green background

A keep left arrow with three cones placed at a 45° angle upstream of the sign is referred to in Chapter 8 as 'Detail A' (see Figure 15).

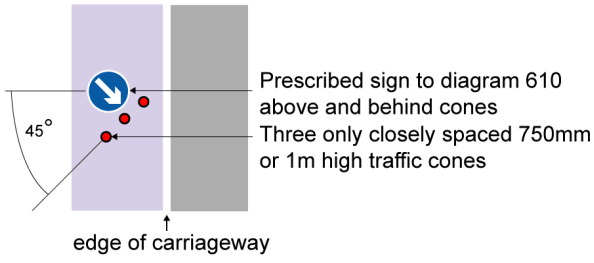

Figure 15: 'Detail A' layout

Appendix B – Analysis of Trial Data: factors

Interactions between factors are shown as $x \times y$ in the text below.

Sign point significant (p<0.05)

There is a significant difference in the overall number of vehicles at each sign point. Although most of the vehicles are counted passing each sign point there was some difficulties in starting each count at exactly the right time during operational deployment of the trial.

Table 4: Number of vehicles at each sign point

Sign point	Vehicle count
200	31,208
400	30,565
600	30,564
800	29,704

Lane significant (p<0.05)

There is a significant difference in the overall number of vehicles in each lane.

Table 5: Number of vehicles in each lane

Lane	Vehicle count
Lane1	78,511
Lane2	40,927
Lane3	2,603

Experiment significant (p<0.05)

There is a significant difference in the overall number of vehicles in each experiment.

Table 6: Number of vehicles in each trial condition

Experiment	Vehicle count
Control	41,992
1A	34,414
1B	45,635

Sign point × experiment not significant (p>0.10)

Differences in the number of vehicles at each sign point are the same across the different experiments. That is, if the number of vehicles reduces from the 800yrds to 200yrds in the control group then a similar pattern was observed in the two experimental groups.

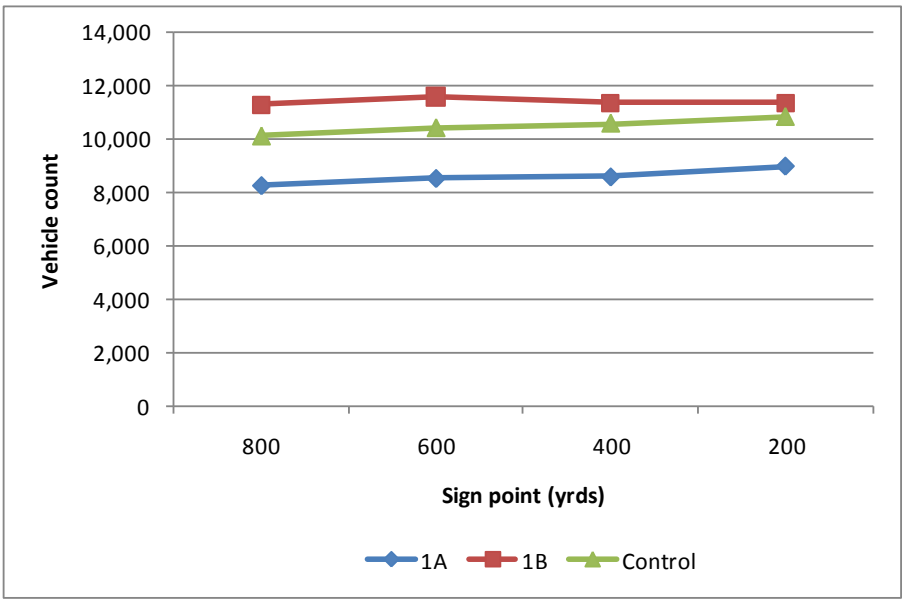

Figure 16: Number of vehicles at each sign point in each experiment

Sign point × lane significant (p<0.05)

Differences in the number of vehicles at each sign point vary by lane. That is, as expected, at each sign point there is an overall difference in the distribution of vehicles by lane. In this case there is a reduction in the overall number of vehicles in lane 3 by the 200yrd point.

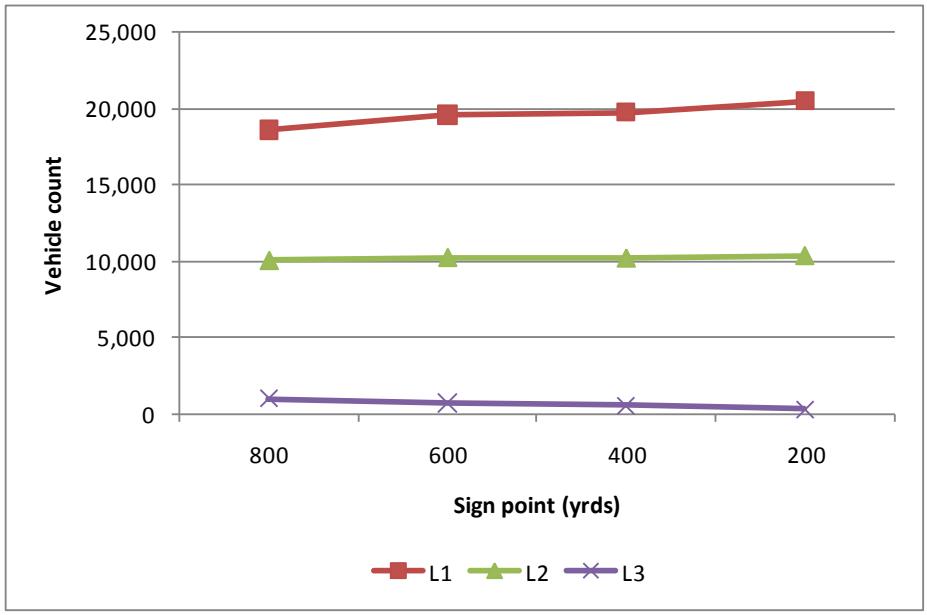

Figure 17: Number of vehicles at each sign point in each lane

Experiment × lane significant (p<0.10)

The distribution of vehicles across the lanes differs by experiment. This is mainly due to the differences in traffic flows – a lower flow will generally lead to a higher proportion of the flow occupying the inside and middle lanes.

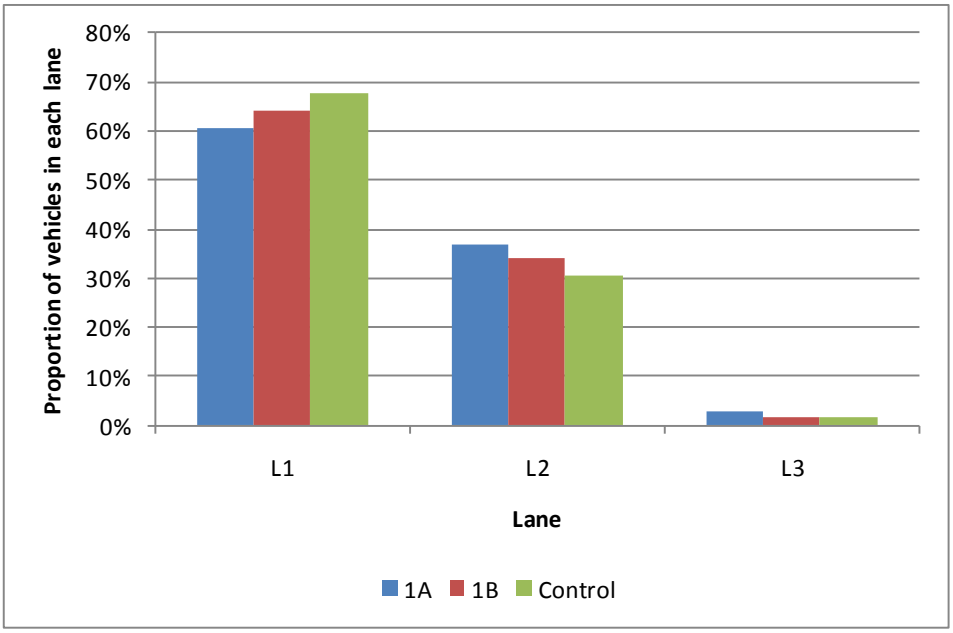

Figure 18: Number of vehicles in each lane in each experiment