



Creating the future of transport

# Highways Agency

Managed Motorways 2 Concept Development

Tasks 2, 3, 4 and 5

Key Findings  
Report

CPR1062

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## Executive Summary

The Highways Agency (HA) is considering a new application of the Managed Motorways toolkit, referred to as Managed Motorways 2 (MM2). The overall aim of Managed Motorways is to tackle congestion at particular locations on the network. The MM2 concept seeks to deliver schemes that will provide comparable benefits to those expected of current Managed Motorways schemes, but at a reduced cost and with shorter timescales for implementation.

It is proposed that MM2 will meet these objectives by using less technology infrastructure than is used on current schemes, and by fully utilising the hard shoulder as a running lane without provision of Emergency Refuge Areas (ERAs).

This document describes the key findings of four tasks undertaken by TRL in support of the development of the MM2 concept, which focus on investigating the provision of on-road driver information within a Managed Motorways environment. These tasks were **Task 2** (Gantry Spacing Simulator Study), **Task 3** (MM2 Sign Comprehension Study), **Tasks 4 and 5B** (MM2 Sign Obscuration Study) and **Task 5A** (MM2 Design Evaluation Simulation Study).

Methodology and approach has been included where necessary to provide explanation of results. Further description of methodology can be found in each **task's Study Plan** issued between October 2010 and January 2011.

In general, the findings described in this document suggest that the approaches being considered for communicating on-road driver information within an MM2 environment are feasible. However, consideration should be made to the findings of Tasks 2 to 5 when developing the design and operation of MM2 schemes.

More specifically, these tasks addressed three key questions relating to the design of on-road driver information provision in an MM2 environment. The conclusions related to each question are summarised below:

### **When should driver information be communicated?**

*i.e. spacing and frequency of driver information update points*

The findings suggested that there was a relationship between the spacing of information update points and the speed of individual drivers; in Task 2 **participants' mean speed and spot speed** under gantries were higher when gantries were spaced further apart. Participants exhibited a greater degree of "surfing" behaviour as gantry spacing increased.

This study used a light traffic scenario to investigate experimentally the influence of variable mandatory **speed limits on an individual driver's speed choice**. It should be recognised that in a heavy traffic situation an individual's speed characteristics would be more dependent on other traffic, and that overall traffic conditions could be considered as the culmination of those individual drivers' behaviours.

None of the findings indicated that increasing the spacing between information update points would adversely influence driver compliance with lane closure instruction.

### **How should driver information be communicated?**

*i.e. the type of sign or signal used and whether it is gantry-mounted or verge-mounted*

Through the use of visualisation and response monitoring software, a driving simulator trial and questionnaires it was determined that, in general, equivalent options for verge- and gantry-mounted information provision can be **comprehended equally well**. Within the driving simulator trial, participants' driving behaviour was comparable in response to either signing option.

The findings of the obscuration study suggested that, in general, there would be only a small proportion of traffic that would have a verge-mounted signal obscured by an HGV in peak hour conditions, especially when considering the required viewing time to process speed limit information indicated by Task 3 and the adjustments that drivers can make to be able to see the sign.

Whether or not this estimated extent of obscuration would have an impact on **when** driver information should be communicated, would depend on how much obscuration would be the acceptable given operational and enforceability considerations.

This study also determined that moving the lateral position of the sign towards the central reservation or increasing the height of the sign could reduce obscuration rates. However, the benefit in terms of reduced obscuration should be considered in light of the design implications of such a movement.

**What information should be communicated?**

*i.e. what information should be displayed at an update point at any given time and location*

The findings highlighted some pros and cons of different approaches to communicating lane closure information and the options for supplementary information. While some options were more familiar to drivers, others presented a greater association with enforcement and were less ambiguous in terms of the location of the closure.

The findings also indicated that presenting several information elements on a single verge-mounted sign had a minimal impact on driver comprehension. Participants' subjective responses suggested that the use of supplementary information when communicating speed limit and lane closure instructions may have a positive influence on driver behaviour.

These and other conclusions are discussed in more detail for each task individually, and recommendations made for further related areas of investigation.

# 1 Introduction

## 1.1 Background

The Highways Agency (HA) is considering a new application of the Managed Motorways toolkit, referred to as Managed Motorways 2 (MM2). The overall aim of Managed Motorways is to tackle congestion at particular locations on the network. The MM2 concept seeks to deliver schemes that will provide comparable benefits to those expected of current Managed Motorways schemes, but at a reduced cost and with shorter timescales for implementation.

It is proposed that MM2 will meet these objectives by using less technology infrastructure than is used on current schemes, and by fully utilising the hard shoulder as a running lane without provision of Emergency Refuge Areas (ERAs).

However, as a result of meeting its objectives an MM2 scheme should not compromise road user safety. As a minimum, on a section of motorway on which it is implemented, an MM2 scheme should not lead to an overall safety level lower than would be expected otherwise, given predicted year-on-year trends. Furthermore, schemes should not improve the safety of one group of road users at the expense of another.

Within Managed Motorways schemes, enhancing On-Road Driver Information is a key mechanism for managing traffic, mainly through influencing vehicle speeds, to promote a safe and compliant motorway environment. This is achieved both through provision of mandatory (and safety-critical) instructions during **congestion and incidents, as well as helping to improve drivers' awareness of prevailing or upcoming traffic conditions.**

It is therefore necessary that within MM2 concept development, consideration is given to how On-Road Driver Information can be provided cost-effectively whilst attaining the desired driver behaviour for the effective and safe operation of an MM2 scheme.

Currently, there is insufficient understanding of how different options of On-Road Driver Information influences driver behaviour within a Managed Motorways environment to provide reassurance of the safety of the MM2 concept. TRL is undertaking tasks for the HA that will build an evidence base to help provide this reassurance. This will enable the HA to make informed decisions about the MM2 scheme design to optimise safety, cost effectiveness and performance.

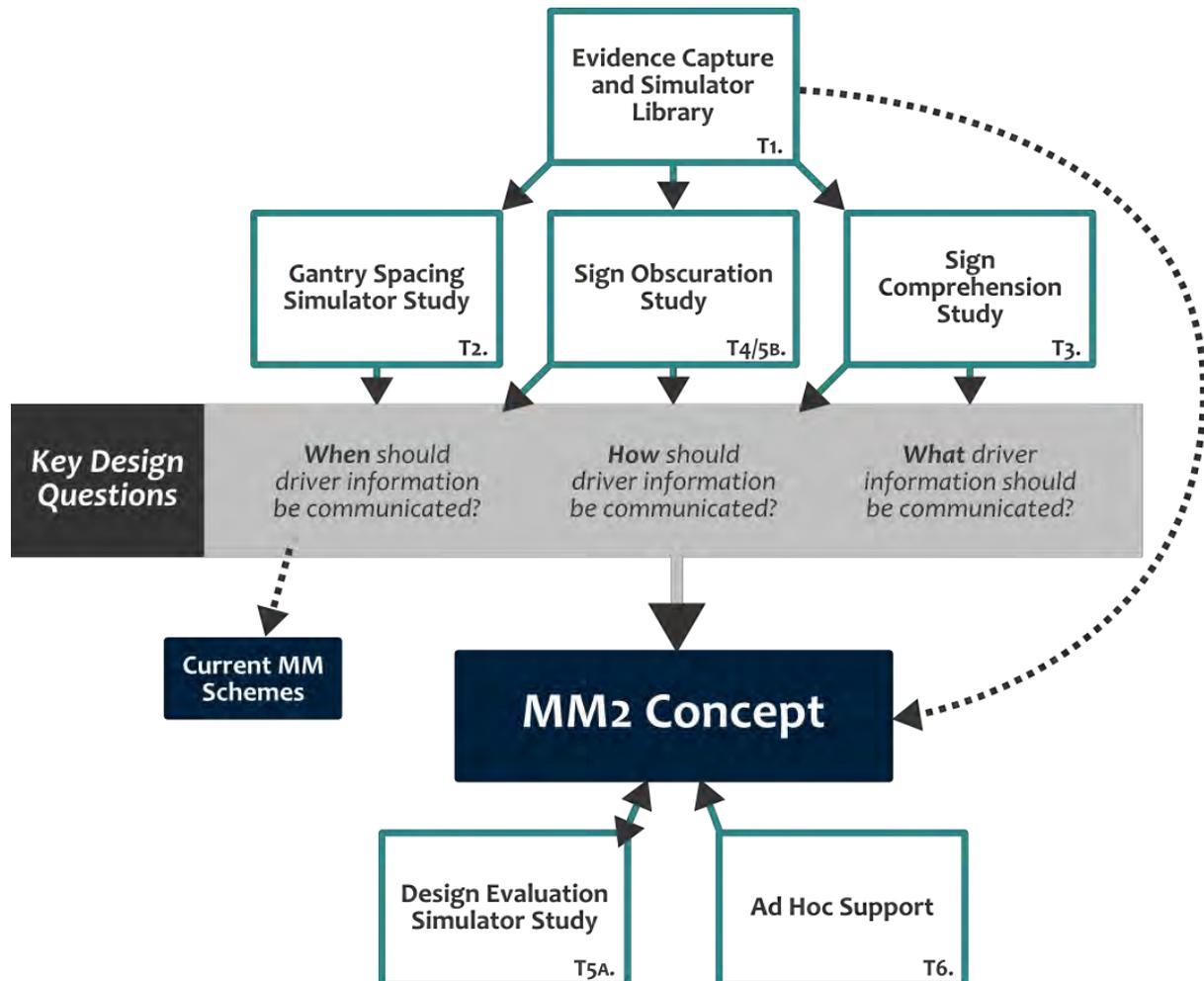
Further information on the background of this work **is provided in TRL's MM2 Interim Report** submitted to the HA in November 2010.

## 1.2 MM2 Concept Development Work Programme

TRL’s work programme to support MM2 concept development consists of six tasks. These tasks address the following three key questions relating to the design of On-Road Driver Information provision:

- > **When** should driver information be communicated?  
*i.e. spacing and frequency of driver information update points*
- > **How** should driver information be communicated?  
*i.e. the type of sign or signal used and whether it is gantry-mounted or verge-mounted*
- > **What** information should be communicated?  
*i.e. what information should be displayed at an update point at any given time and location*

Figure 1 illustrates how the individual tasks fit within the work programme.



**Figure 1: Overview of TRL’s Programme of Work**

**Task 1 MM2 Evidence Capture** involved the consolidation of existing evidence and TRL work relevant to MM2 Concept Development and was completed in October 2010.

**Task 2 Gantry Spacing Simulator Study** involved a driving simulator trial to investigate the effect that varying the spacing of driver information update points has on driver behaviour and compliance with variable mandatory speed limits and lane status instructions. This is to help answer the question (relevant to both MM2 and current Managed Motorways schemes) as to when driver information should be communicated.

**Task 3 MM2 Sign Comprehension Study** involved a trial using a PC-based software tool to investigate the speed and accuracy of driver comprehension of sign designs which could potentially be used within an MM2 environment. This study compared responses with the same information provided through gantry-mounted VMS and signals and a single verge-mounted VMS. The findings from this task will help determine both how and what driver information should be communicated within MM2 schemes.

**Tasks 4 and 5B MM2 Sign Obscuration Study** used a modelling approach to investigate and assess the impact of obscuration of signs and signals within an MM2 scheme, with particular focus on the difference between overhead gantry-mounted driver information provision and verge-mounted driver information provision. The findings from this task will help determine both how and when driver information should be communicated within MM2 schemes.

**Task 5A MM2 Design Evaluation Simulator Study** comprised of a driving simulator trial to investigate driver comprehension and behavioural response to on-road driver information provision via verge-mounted variable message signs on a stretch of motorway with 4 permanent running lanes and no hard shoulder. More specifically, the study compared driver responses to driver information displayed on gantry-mounted signs and signals versus verge-mounted MS4 signs only.

The focus within these tasks is the provision of safety-critical driver information, relating to speed limits and lane closures.

### 1.3 Document Purpose and Outline

The purpose of this document is to present the outputs of the research undertaken by TRL for **Task 2** (Gantry Spacing Simulator Study), **Task 3** (MM2 Sign Comprehension Study), **Tasks 4 and 5B** (MM2 Sign Obscuration Study) and **Task 5A** (MM2 Design Evaluation Simulation Study).

**Sections 2 to 5** of this report include the following details for each task:

- > Overview of task approach, objectives and methodology;
- > Key Findings; and
- > Discussion and Recommendations.

**Section 6** provides a conclusion to the document.

Within this document, blue text boxes have been used to highlight headline evidence statements and to provide summaries of the key findings in a particular section, where appropriate.

The accompanying briefing note to this document provides a high-level summary of the key findings from each task.

## 2 Task 2 Gantry Spacing Simulator Study

### 2.1 Background

Task 2 comprised a driving simulator trial to investigate the effect that varying gantry spacing has on driver behaviour and compliance with variable mandatory speed limits and lane status instruction.

It was agreed that the trial would use a Managed Motorways environment, based on the design of Interim Advice Note (IAN) 111 rather than that of a potential MM2 scheme, for the following reasons:

- > To address the current HA standard for motorway gantry signal spacing (set out in IAN 87/07) applicable to Managed Motorways schemes and to potentially produce cost savings for early schemes.
- > Ease of implementation – the visual environment can be quickly adapted from the existing library.
- > To ensure that the spacing of information provision is investigated in isolation, without introducing additional changes to the MM environment arising from MM2 design.

This study investigated whether a change in the spacing between information updates to that currently used within Managed Motorway schemes had an impact on driver behaviour and compliance in particular.

The evidence produced from this trial can be used to improve understanding of the implications of sign rationalisation for MM2 scheme design.

### 2.2 Task Objectives

The objectives of this task were to:

- > Improve understanding of the relationship between gantry spacing and driver behaviour and compliance with a) speed limits and b) lane status, within a Managed Motorway environment;
- > Propose the optimal gantry spacing for the safe and effective operation of Managed Motorway schemes; and
- > Inform decision-making regarding the distance between information updates within MM2 scheme design.

## 2.3 Methodology

This study involved a trial using TRL's driving simulator, as well as a questionnaire assessment of driver attitudes and perceptions of on-road driver information provision. Participants were separated into two experimental groups, focussing on either:

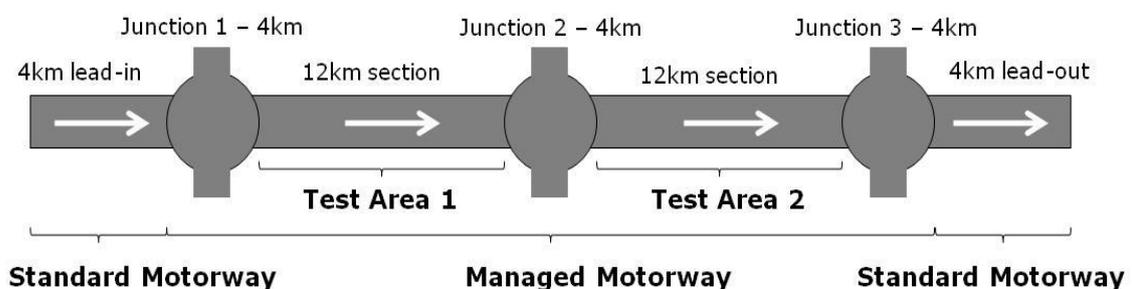
- > **Speed choice** - Compliance with Variable Mandatory Speed Limits (VMSL) of 60mph, 50mph and 40mph; or
- > **Lane choice** - Use of the hard shoulder (to be referred to as Lane Below Signal 1, LBS1) when in open and closed status.

For each of these experimental groups, six different gantry spacing layouts were investigated:

- > 500m > 800m > 1000m > 1500m > 2000m > 3000m

A full methodology for this study is recorded in the Task 2 Study Plan issued at the beginning of the task and agreed with the MM2 Programme Board. The following provides a brief summary:

- > Before completing any experimental drives, participants undertook an initial familiarisation drive to ensure that they were comfortable with both the driving simulator controls and simulated environment.
- > All participants undertook two drives in the simulator, lasting approximately 25 minutes. The route for each drive was identical apart from two test areas (see Figure 2) in which the space between gantries was one of the six layouts listed above. Through the completion of the two drives, each participant experienced four of the six gantry spacings, with all participants driving through a section with 1000m and 1500m gantry spacing. The order in which participants encountered the test areas with one of the six gantry spacing layout was varied.



**Figure 2: Gantry spacing driving simulator test route schematic**

- > The Managed Motorways scheme began at Junction 1 and participants passed through five VMSL gantries before reaching Test Area 1.
- > Participants in the Speed Choice group were asked to 'drive as if they were late for an important meeting' in order to motivate them to make good progress and maximise the likelihood of participants' willingness to exceed the speed limit.
- > Participants in the group focussing on hard shoulder usage were asked to 'use the hard shoulder at all times as long as it is open to traffic' to help ensure that they did not remain in LBS 2 – 4 irrespective of the hard shoulder status.
- > Other traffic along the routes was programmed to be light with some non-compliant vehicles. The presence of other traffic was important to create a realistic driving environment. However, the traffic was kept light so as to minimise its influence on participants' speed or lane choice.
- > Enforcement of speed limits was implied through the provision of enforcement signing and secondary speed check markings as provided in existing Managed Motorway schemes. These were present at all gantries.
- > The questionnaire was completed following the second drive and required participants to comment on their awareness and perception of driver information provision within that drive only. Participants were also asked about their understanding of information communicated via gantry-mounted signals and signs, and enforcement indicators.

The analysis focused on the Areas of Measurement outlined in the following two sections of this report. These sections describe the Key Findings relating to both Speed Choice and Lane Choice participant groups.

#### **Note on intervisibility between gantries**

The signal gantry intervisibility requirement is defined in IAN 87/07, the background to which is based on the understanding that ***"always having an indicator in view or knowing that one will shortly come into view, discourages drivers from increasing speed after passing one gantry and braking before the next; the "surfing" effect."***

Naturally, the extent to which signal gantry intervisibility was achieved in the gantry spacing layouts studied within this trial varies. At the 500m and 800m spacings, there was intervisibility of gantries for all but two or three locations, where a gantry was obscured by a pair of low over-bridges.

At 1000m spacing, there were several more locations where intervisibility was not achieved due to over-bridges and the geometry of the road. For gantry spacings greater than this, the gantries were rarely intervisible.

It should be noted, however, that for gantry spacings over 500m, when an unobstructed sight line was available, the visible gantries in the simulated environment may not have been prominent enough to be noticed by a participant who was not actively seeking it out. The distance at which the gantry **begins to 'stand out' of the visible scene** would have varied between participants and locations. A general range for the distance at which the gantry was distinct from the background features was between 600m and 700m.

A selection of screenshots from the driving simulator routes for different gantry spacings are included in Appendix A. These are for information only as due to the resolution of the image, it is not possible to accurately illustrate the extent to which the scene is visible within the driving simulator itself.

#### *Note on participant sample size*

Initially 96 participants were recruited to take part in this trial, 48 in each experimental group.

Due to an error in the automated extraction of data relating to a substantial **number of participants' drives in the Speed Choice group**, the data for these participants had to be disregarded and an additional 30 participants were required to complete the trial. Because of this, while the number of participants driving each gantry spacing layout was the same, the total number of participants in the Speed Choice group was less than in the Lane Choice group. This should be specifically noted in relation to the questionnaire analysis where data from the two groups are combined in places.

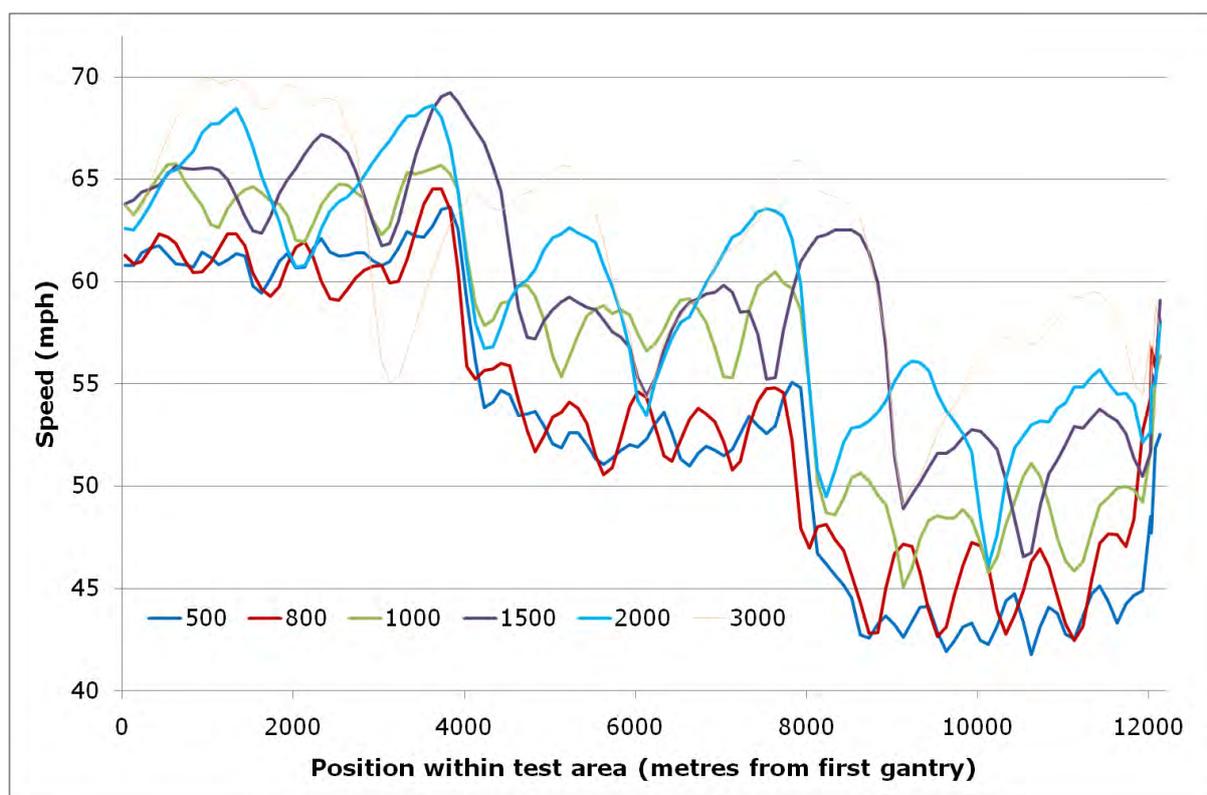
## 2.4 Key Findings

### 2.4.1 Driving Behaviour - Speed Choice Group

#### 2.4.1.1 Assessment measures

The driving simulator takes a measurement of the vehicle’s speed every 0.05 seconds. This data was used to investigate participants’ **speed choice**, how chosen speeds relate to the speed limit presented on overhead AMI signals, and if compliance with these speed limits is affected by the frequency of gantries.

Figure 3 illustrates the speed profiles generated by the data from the start to the end of each test area. Data has been averaged over every 100m.



**Figure 3: Test area speed profiles for each gantry spacing layout averaged across all participants**

From this overview, different characteristics of the speed data can be observed. Some of these characteristics can be attributed to geometric features of the road.

While these features must be taken into account, this study compares speed choice between gantry spacing layouts; road geometry is identical between routes and it is expected that participants will be affected in a similar way by these aspects of the environment.

The assessment measures listed below were used to determine whether any **relationship can be seen between differences in characteristics of drivers' speed choice and the gantry spacing layout in which they were driving.**

1. Mean speed
2. Spot speed passing under gantries
3. Time spent travelling at speeds higher than the displayed speed limit (i.e. compliance)
4. **Variability in speed, particularly in relation to gantries (i.e. "surfing")**

**Factors relating to individuals' speed choice are numerous and complex. Some effort has been made within the experimental design to account for these features. For example, it was arranged for the age group and gender of participants to be distributed amongst drives. Also, the order in which different gantry spacing layouts are driven has been varied, to account for learning effects.**

**Furthermore, due to the observed variation in participants' driving behaviour, statistical tests were carried out to assess the extent to which this variation can be attributed to the spacing between gantries. These tests are described below in relation to each assessment measure.**

In each test area participants were subject to three different speed limits.

Table 1 indicates the order in which the speed limits were displayed and the number of gantries displaying the speed limit under each gantry spacing layout. The final 60mph gantry marks the end of the test area and the gantries in the junction sections between test areas were all displaying 60mph.

**Table 1: Speed limits displayed within the test areas and the number of gantries displaying each speed limit**

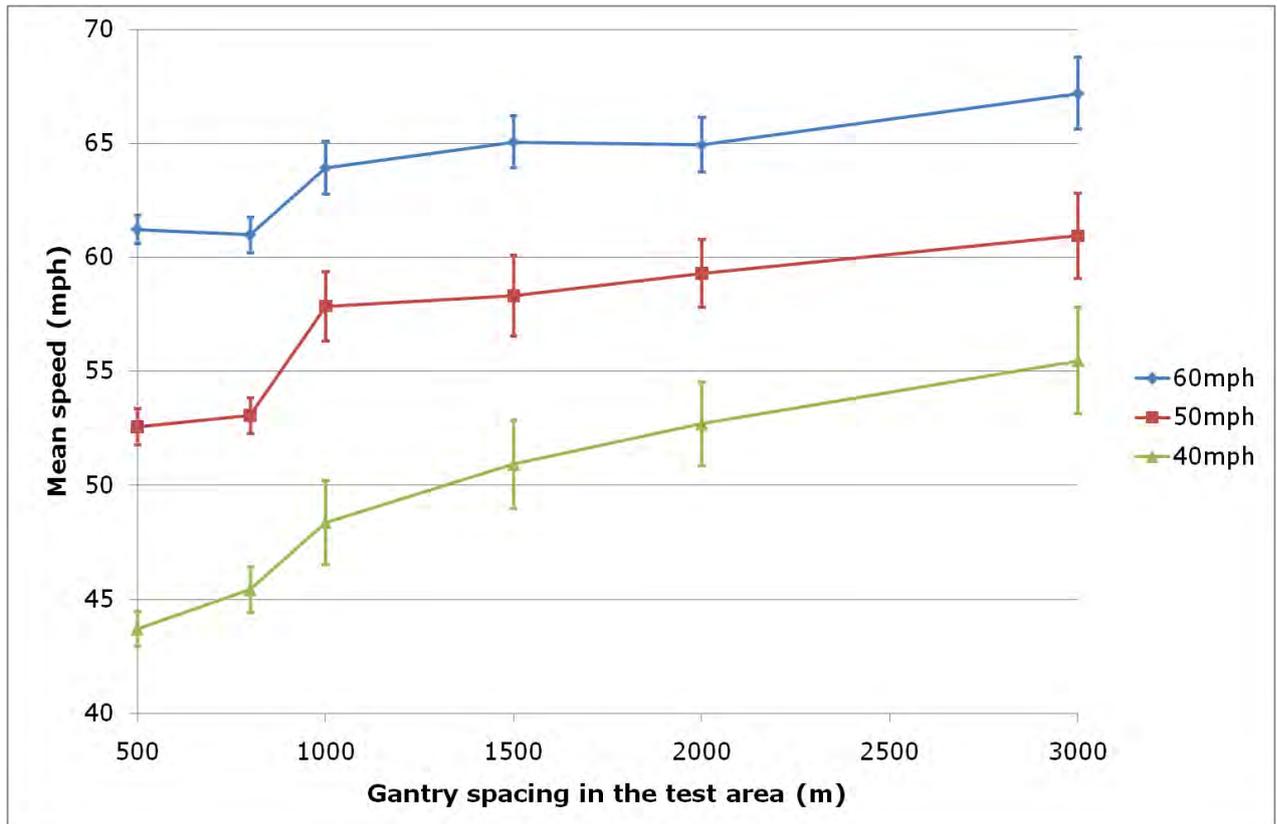
				
<b>500m</b> spacing	8	8	8	1
<b>800m</b> spacing	5	5	5	1
<b>1000m</b> spacing	4	4	4	1
<b>1500m</b> spacing	3	3	2	1
<b>2000m</b> spacing	2	2	2	1
<b>3000m</b> spacing	1	2	1	1

The following sections describe the key findings of the Speed Choice group, addressing each of the assessment measures.

#### 2.4.1.2 Findings

##### Assessment Measure 1: Mean speed

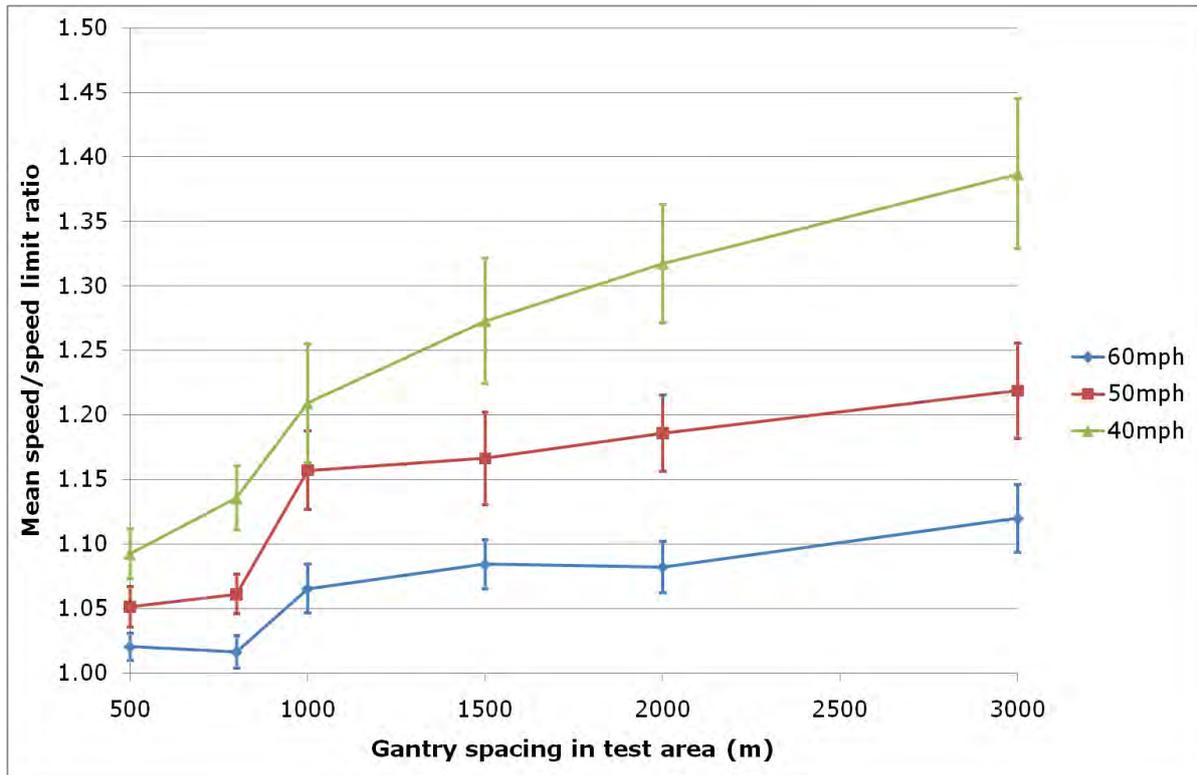
Figure 4 (below) shows for each gantry spacing layout the mean speed separated for the three speed limits that applied within the drives. On initial inspection it can be seen that mean speeds for all gantry spacing layouts were higher than the displayed speed limit, and generally increased with increasing gantry spacing.



**Figure 4: Mean speed as a function of gantry spacing layout for each speed limit ( $\pm$ SEM)**

As would be expected, mean speeds were inherently higher if the speed limit displayed was higher. To enable a statistical comparison of these results across the three speed limits, the raw speed data (mph) were transformed to ratios by dividing each value by the particular speed limit that applied in the associated section within the test area.

Figure 5 shows the mean speed/speed limit ratio for each gantry spacing and for each of the three speed limit sections in the test area. A ratio of 1.1, for example, indicates a speed of 10% above the displayed speed limit. The same data, but expressed as the percentage above the speed limit, is shown in Appendix B (Table 33).



**Figure 5: Mean speed/speed limit ratio as a function of gantry spacing layout for each speed limit ( $\pm$ SEM)**

Two further types of analysis were carried out to determine the statistical significance<sup>1</sup> of these results, i.e. whether or not any differences in mean speed can be assigned to the difference in gantry spacings in the test areas rather than randomness or variability between participants.

To assess whether or not gantry spacing had a significant effect on mean speed in general, a 6\*3 between-subjects Analysis of Variance (ANOVA) was performed. The first between-subject factor was gantry spacing, which had 6 levels; one for each of the gantry spacing layouts used in the test areas (500, 800, 1000, 1500, 2000, 3000m). The second between-subject factor was displayed speed limit, which had 3 levels (40, 50, 60mph).

Results showed a significant main effect of speed limit ( $F(2,396)=45.6, p<.001$ )<sup>2</sup> A significant main effect was also observed for gantry spacing ( $F(5,396)=16.4, p<.001$ ) There was no significant interaction between the factor speed limit and gantry spacing ( $F(10,396)=1.493, p=.139$ ).

<sup>1</sup> For efficiency of communication, if not explicitly stated, all references to the findings in this report being *significant* will be referring to *statistical* significance.

<sup>2</sup> Statistical significance is assigned in both tests to any comparison with a p-value at the 10% level or less.

The ANOVA test tells us that the mean speed/speed limit ratio differed significantly for the different speed limit sections as well as for the different gantry spacings i.e. in general, gantry spacing had a significant effect on mean speed.

Also of interest are the pairs of gantry spacings, between which, the mean speed/speed limit ratio differed significantly. To test this, each gantry spacing was compared with all the others by performing pairwise post-hoc comparisons (**Tukey's HSD test**) for all speed limits. The comparisons are detailed in Appendix B (Table 34) and summarised below.

The mean speed/speed limit ratio for the 1500m spacing was significantly higher than the shortest spacings (500m and 800m) in most cases. The increase in mean speed between 800m and 1500m was between 4.1mph to 5.5mph depending on the speed limit.

There were significant differences in mean speed/speed limit ratio between the shortest spacings (500m and 800m) and the longest spacings (2000m and 3000m) for all speed limits. In terms of mean speed this difference is in the range of 3.7 to 11.8mph (depending on the speed limit and spacings being compared).

Under the 50mph speed limit, the mean speed/speed limit ratio was significantly higher in the 1000m spacing than the 500m spacing. The relevant difference in mean speed is 4.8mph.

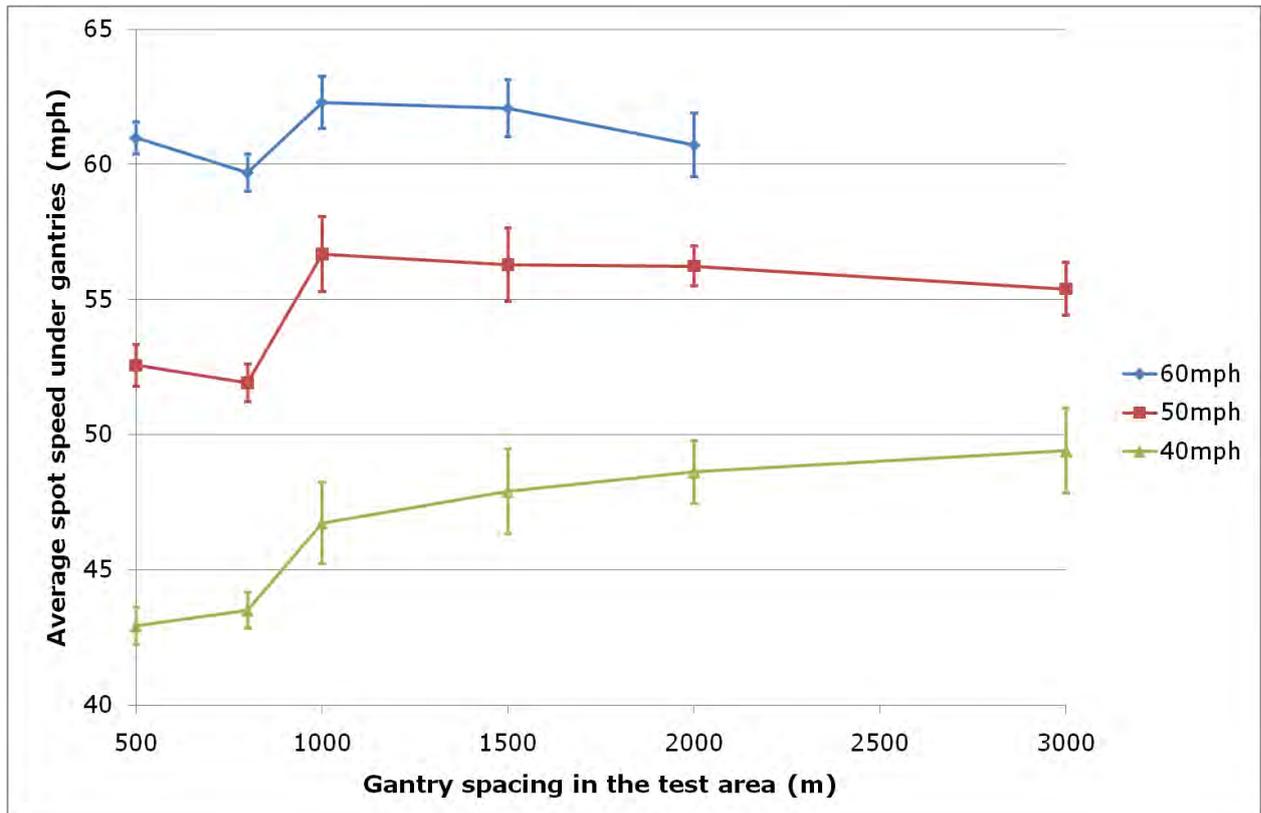
Overall, there were much fewer statistically significant differences under the 60mph limit than at the lower limits.

### **Assessment Measure 2: Spot speed**

Spot, or instantaneous, speed refers to an individual speed measurement data point taken at a particular point on a route. This assessment measures seeks to investigate spot speeds at the point at which participants pass under a VMSL gantry.

Figure 6 shows the average spot speed of participants when passing under a gantry for all six gantry spacings in each of the three speed limit sections. The speed recorded at the first 60mph gantry was removed from this analysis as this speed will not have been affected by the gantry spacing layout of the downstream test area. There is no data point for the initial set of 60mph gantries on the 3000m spacing layout as there was only one 60mph limit displayed in the first 60mph section for this spacing.

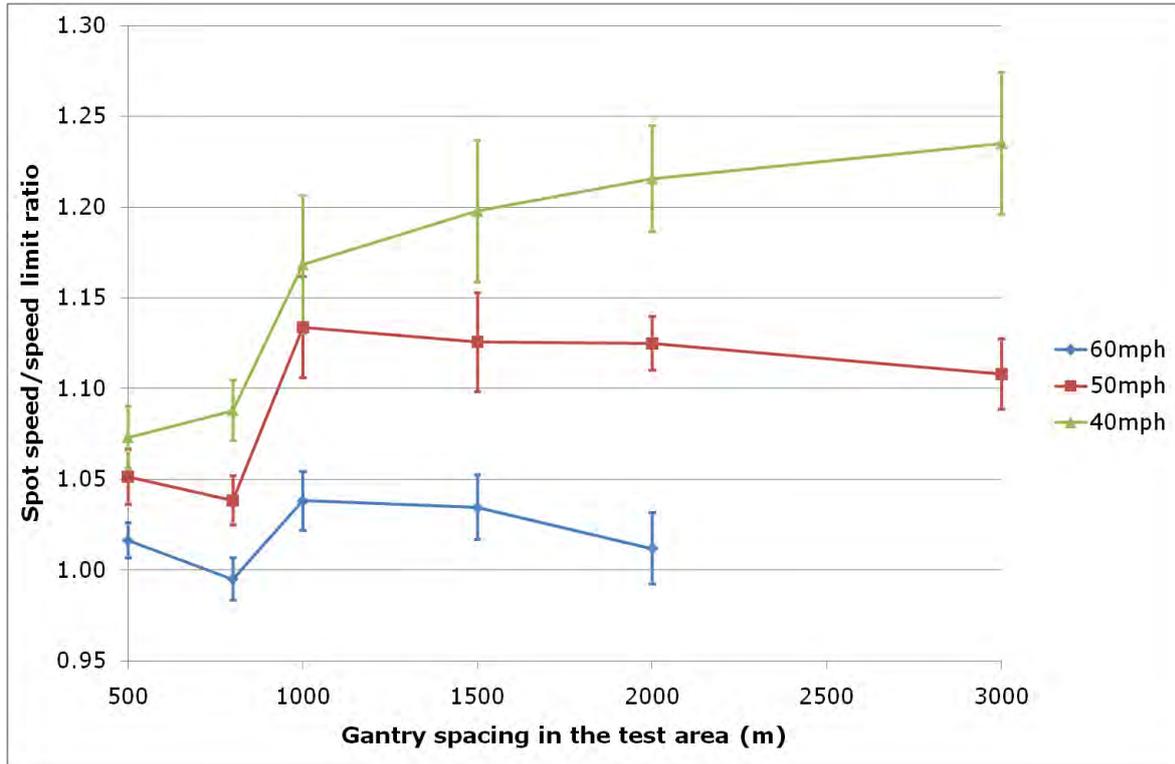
Similarly to mean speed, the average spot speeds under gantries were greater than the displayed limit, with the exception of the spot speeds under 60mph gantries in the 800m gantry spacing layout. Figure 6 also shows that the spot speeds under gantries at the two shortest spacings were markedly lower than at the 1000m spacing. The trend for longer gantry spacings is less distinct, showing a gradual decrease at 60 and 50mph but a slight increase at 40mph.



**Figure 6: Spot speed under gantries as a function of gantry spacing layout for each speed limit ( $\pm$ SEM)**

As with mean speeds, spot speeds were inherently higher if the speed limit displayed was higher. To enable a statistical comparison of the spot speed, results across the three speed limits were transformed to ratios in a similar way.

Figure 7 shows the ratio between the spot speed and speed limit and more clearly shows the differential effect on spot speed for the 40mph section.



**Figure 7: Spot speed/speed limit ratio as a function of gantry spacing layout for each speed limit (±SEM)**

As for the mean speed assessment measure, statistical analysis was carried out to determine the statistical significance of these results.

Performing the ANOVA test on the spot speed/speed limit ratio data, results indicated a significant main effect of both speed limit ( $F_{(2,375)}=43.471, p<.001$ ) and gantry spacing ( $F_{(5,375)}=8.598, p<.001$ ). The interaction effect was found to approach significance ( $F_{(9,375)}=1.845, p=.058$ ).

The ANOVA test tells us that the spot speed/speed limit ratio differed significantly for the different speed limit sections as well as for the different gantry spacings, i.e. in general, gantry spacing had a significant effect on spot speed under gantries.

The above interaction effect is due to the continued increase in spot speeds with increased gantry spacing at 40mph only. It can be understood in light of **observed "surfing" between gantries, where participants drive at or close to the speed limit when passing under gantries but drive at higher speeds between consecutive gantries** (see Assessment Measure 4). At longer gantry spacings participants reached higher maximum speeds and would presumably find it more difficult to reduce speed back down to 40mph when passing under a gantry.

Tukey's HSD test was also carried out to determine for which pairs of gantry spacings the difference in spot speed/speed limit ratio differed significantly, for each displayed speed limit. The comparisons are detail in Appendix B (Table 35) and summarised below.

All significant differences in spot speed/speed limit ratios at 50 and 40mph were between the two shortest spacings and spacings from 1000m to 3000m. For the difference between 500m and 3000m this relates to an increase in spot speed of 6.5mph for the 40mph section.

Also worth noting are differences between the spot speed/speed limit ratios at the two shortest spacings and the middle (1000m and 1500m) spacings; at 50mph all spot speed/speed limit ratios at the middle spacings were higher than the shorter spacings at either a significant or approaching significant level. This relates to a difference in spot speeds of between 3.7 and 4.8mph depending on the comparison.

Average spot speed was observed to be lower at the 800m spacing than the 500m spacing at 50mph and 60mph by 0.7mph and 1.3mph respectively. This difference was not statistically significant.

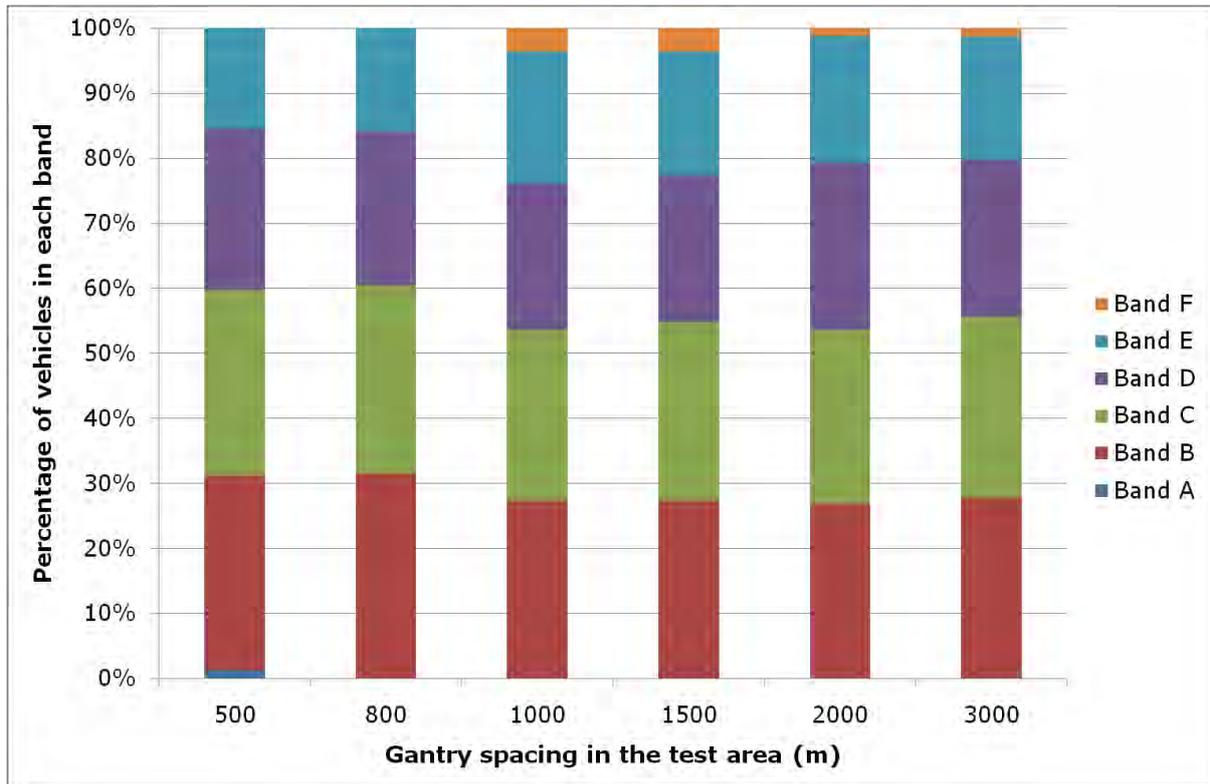
At 60mph there were no statistically significant differences in the spot speed/speed limit ratios between any of the gantry spacings.

***Assessment Measure 3: Time spent travelling at speeds higher than the displayed speed limit (i.e. compliance)***

To investigate compliance with the displayed speed limit, the time spent by each participant over the speed limit was analysed. Before looking at the averages across participants the spread of the sample was investigated. Each of the test areas driven by each participant was split into five different bands (see Table 2) representing increasing levels of non-compliance with the displayed speed limit. Figure 8 represents the percentage of test area drives in each band for each gantry spacing layout.

**Table 2: Bands for assessing the proportion of time spent exceeding the speed limit**

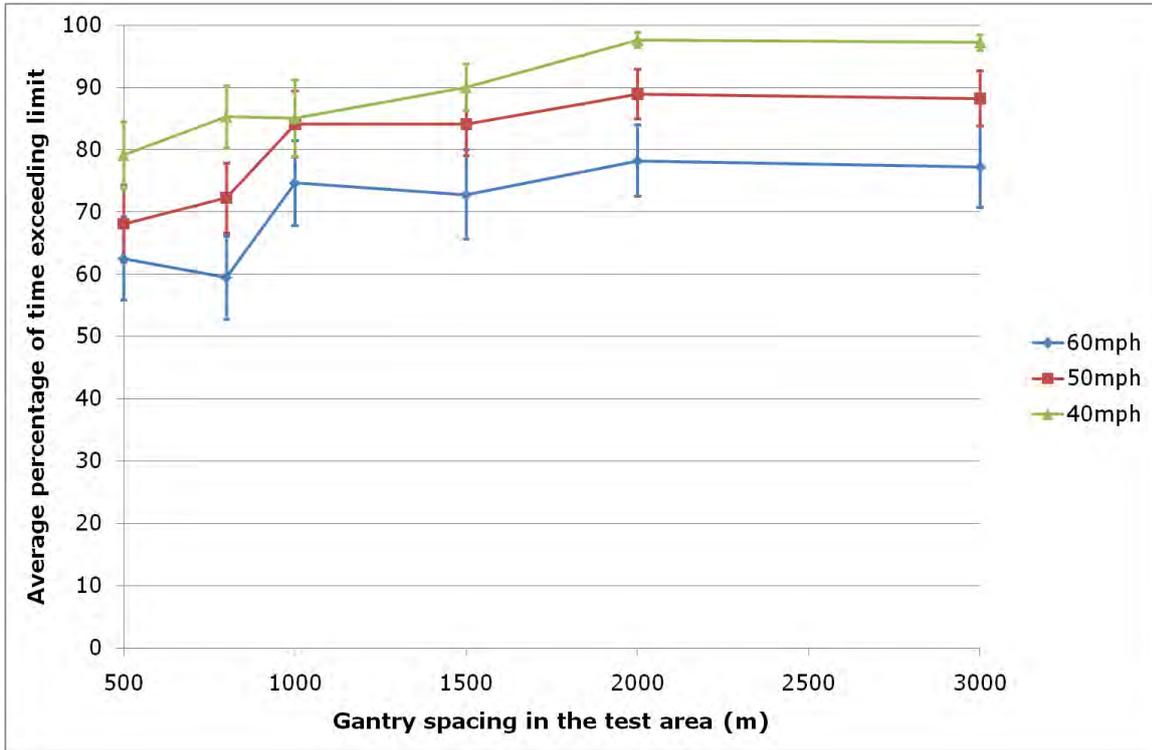
<b>Band</b>	<b>Percentage of time spent exceeding the speed limit in a test area</b>
F	Between 99 and 100%
E	Between 75 and 99%
D	Between 50 and 75%
C	Between 25 and 50%
B	Between 0 and 25%
A	0%



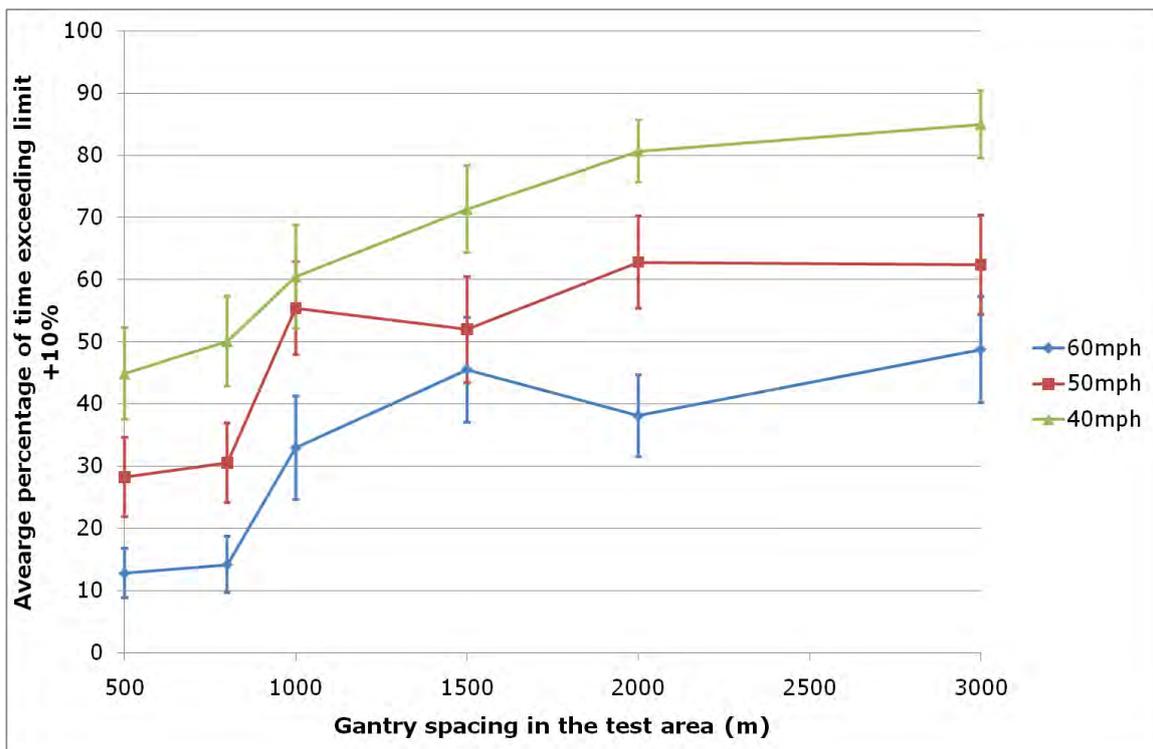
**Figure 8: Percentage of test area drives in each band for measuring percentage of time spent exceeding the displayed speed limit in a test area**

It can be seen from Figure 8 that the proportion of participants’ drives in each compliance group is fairly consistent across all gantry spacings. Only one participant in one test area (with 500m spacing) did not exceed the displayed speed limit at any point.

Figure 9 and Figure 10 represent the average percentage of participants’ time spent travelling above the displayed speed limit and the speed limit plus 10% (i.e. 44mph, 55mph and 66mph) within the test areas under each gantry spacing layout. With a few exceptions, both the time above the speed limit and the time above the speed limit plus 10% increases with gantry spacing but remains largely constant after 2000m.



**Figure 9: Average percentage of time spent travelling at speeds above the displayed speed limit as a function of gantry spacing layout for each speed limit ( $\pm$ SEM)**



**Figure 10: Average percentage of time spent travelling at speeds above the displayed speed limit plus 10% as a function of gantry spacing layout for each limit ( $\pm$ SEM)**

Statistical tests were carried out on the data relating to the percentage of time above the speed limit plus 10% only. Results from the ANOVA test indicated a significant main effect of both speed limit ( $F(2,396)=33.507$ ,  $p<.001$ ) and gantry spacing ( $F(5,375)=14.242$ ,  $p<.001$ ). There was no interaction effect ( $F(10,375)=.390$ ,  $p=.951$ ).

The ANOVA test tells us that the percentage of time spent at speeds greater than the speed limit plus 10% differed significantly for the different speed limit sections as well as for the different gantry spacings, i.e. in general, gantry spacing had a significant effect on the level of compliance of participants.

**Tukey's HSD test was also carried out to determine for which pairs of gantry spacings the difference in time spent over the speed limit plus 10% differed significantly, for each displayed speed limit. The comparisons are detail in Appendix B (Table 36) and summarised below.**

As observed in Figure 10, the time spent above the speed limit plus 10% generally increases with gantry spacing. The two exceptions were for the 1500m spacing at 50mph and the 2000m spacing at 60mph. However, neither of these decreases were found to be statistically significant.

The difference between the shortest spacings (500m and 800m) and the longest spacings (2000m and 3000m) is either significant or approaching significance for all speed limits. This relates to an increase in percentage time above the speed limit plus 10% of between 23.9% and 40%.

Notably, at 60mph the average percentage of time spent at speeds higher than 66mph is significantly higher at 1500m spacing than both the 500m and 800m spacings (32.7% higher and 31.3% higher respectively).

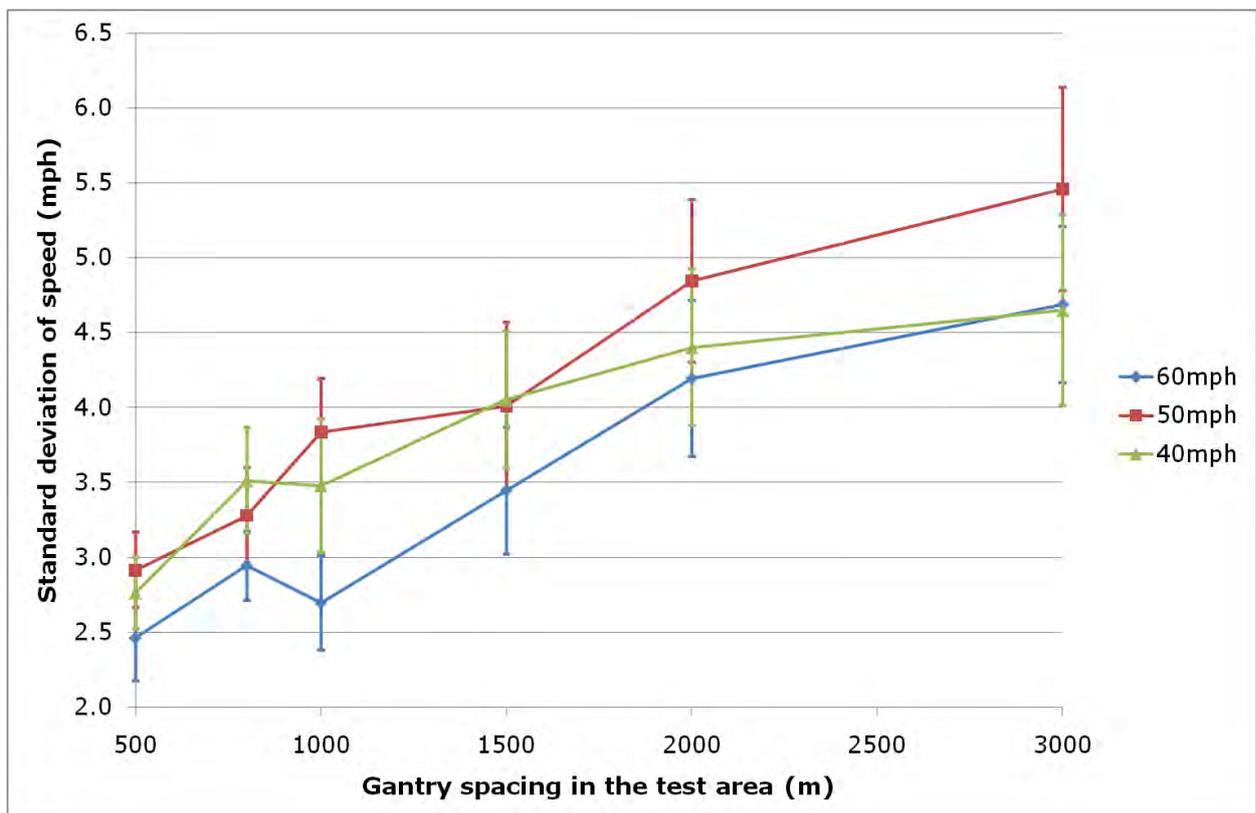
#### ***Assessment Measure 4: Variability in speed, particularly in relation to gantries (i.e. "surfing")***

Gantries used for displaying VMSL can be equipped with speed enforcement cameras and at each gantry location there are outward indicators that spot speed enforcement is possible. This is mainly in the form of enforcement camera **signs and horizontal road markings used for measuring drivers' speed**. Whilst cameras are not present on all gantries within a scheme, drivers would generally not be aware of which ones are equipped in this way. As a result of this threat of enforcement, many drivers exhibit a driver behaviour which will be referred to **here as "surfing"**. **Surfing is when drivers reduce their speed to below the speed limit (or below a perceived speed limit enforcement threshold) to pass under a gantry before speeding up to speeds higher than the speed limit then slowing down again to pass under the next gantry.**

VMSL gantries used within this simulator trial have been equipped with the same indicators of enforcement as would be actually used, and despite there being no means of enforcement in the simulated environment, many participants exhibited surfing behaviour similar to that which can be observed in actual schemes. This behaviour can be seen to some extent in the speed profiles displayed in Figure 3. To quantify and compare how surfing may differ between gantry spacing layouts two measures have been analysed:

- > Standard deviation of speed; and
- > The difference between speed under a gantry and the maximum speed between that and the following gantry.

Figure 11 shows the standard deviation of speed for each gantry spacing and speed limit. The standard deviation has been used a measure of variation in participants' speed choice. **The increase in the standard deviation with increasing gantry spacing observed in Figure 11 indicates that the variation in driving speed increased with increasing gantry spacing.**



**Figure 11: Standard Deviation of speed (mph) as a function of gantry spacing (m) for each speed limit ( $\pm$ SEM)**

As for previous assessment measures, an ANOVA test was performed. Results indicated a significant main effect of both speed limit ( $F_{(3,396)}=14.94$ ,  $p=.035$ ) and gantry spacing ( $F_{(5,396)}=47.05$ ,  $p<.001$ ). Again, no significant interaction effect was observed ( $F_{(10,396)}=1.181$ ,  $p=.988$ ).

The ANOVA test tells us that standard deviation differed significantly for the different speed limit sections as well as for the different gantry spacings, i.e. in **general, gantry spacing had a significant effect on the variation in participants' speed.**

**Tukey's HSD test** was also performed to test whether the standard deviation of speed differed for the different gantry spacings. The p-values for each pairwise comparison for all three speed limit sections are provided in Appendix B (Table 37) and summarised below.

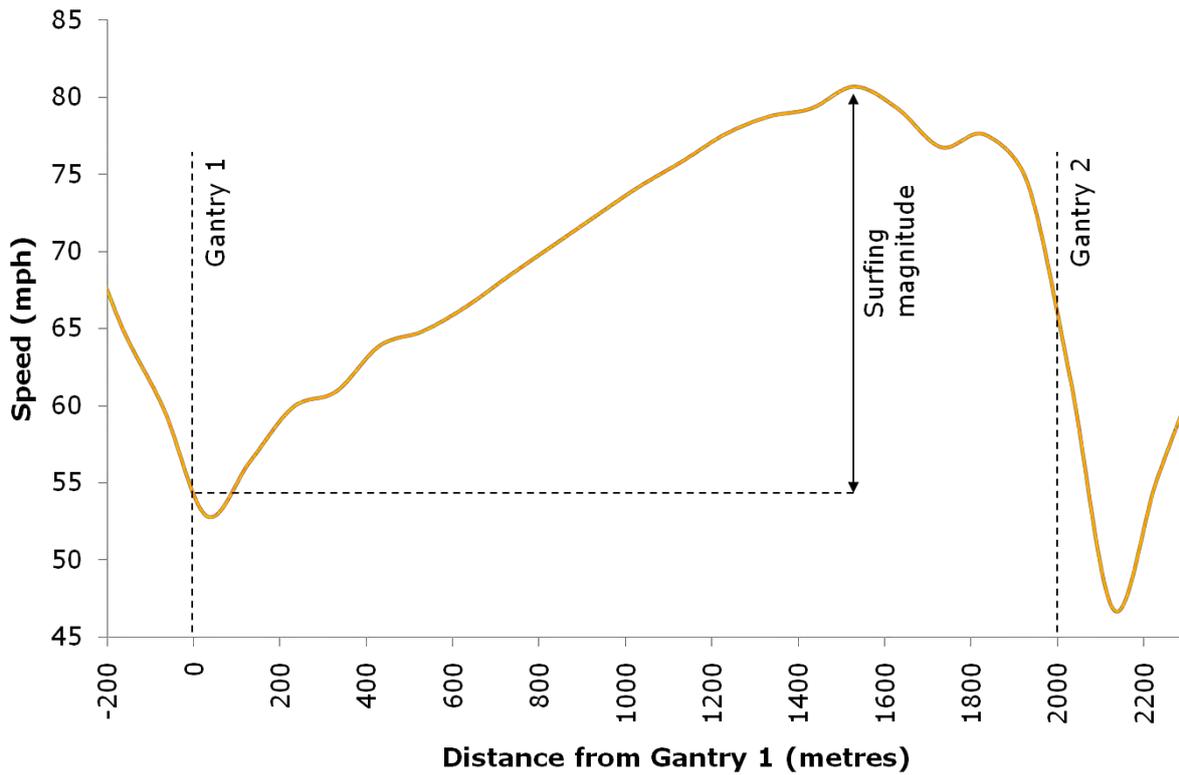
The only significant difference in standard deviation in the 40mph section was between the shortest and longest spacings; the standard deviation for the 3000m spacing was 1.9mph greater than the 500m spacing.

For 50mph and 60mph sections, 2000m and 3000m both had significantly greater standard deviations than 500m (between 1.7 and 2.5mph greater), and 3000m had a significantly higher standard deviation than 800m.

3000m spacing also had a significantly higher standard deviation (2mph) than 1000m spacing in the 60mph section.

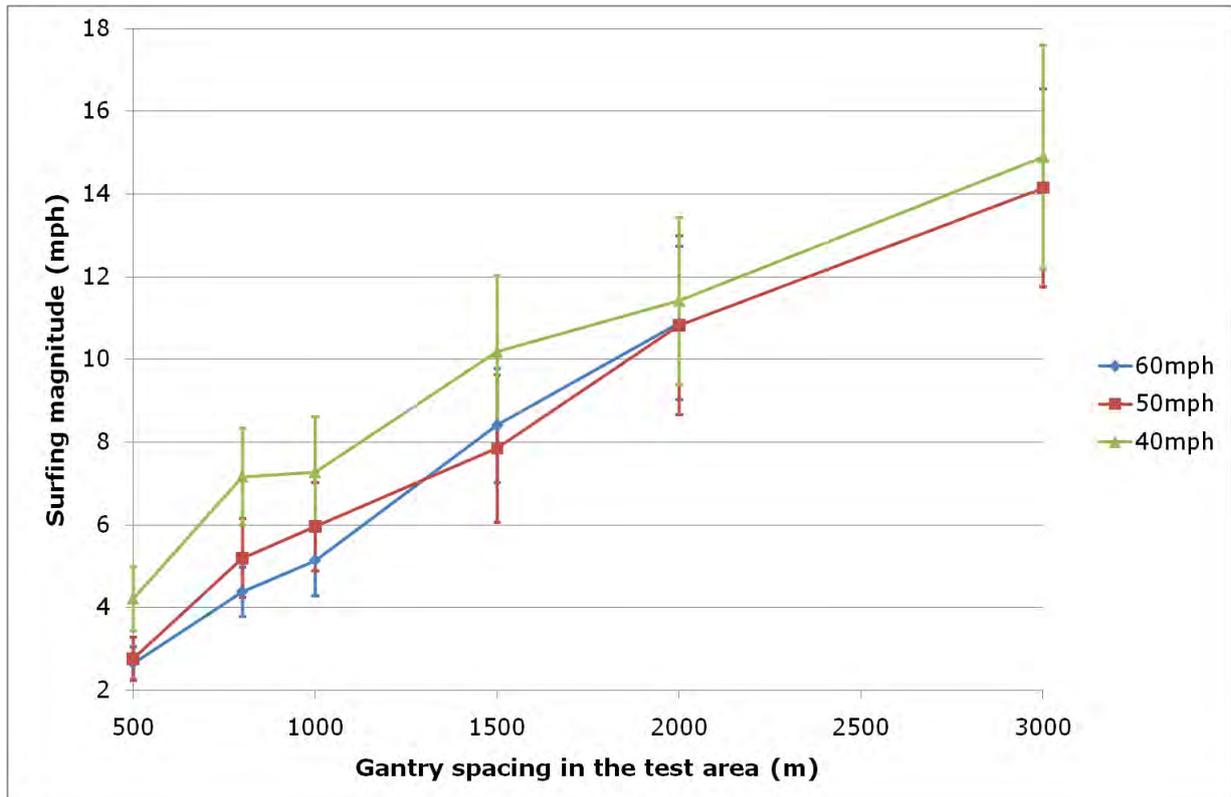
There were no significant differences between the shorter spacings (500m and 800m) and the middle spacings (1000m and 1500m) for all speed limits.

While the standard deviation of speed is an appropriate measure for **investigating variation in participants' speed, it does not specifically identify** differences in speed choice in relation to individual gantries. Another measure **was used to assess the extent of participants' surfing behaviour by** looking at the **difference between a participant's speed under a gantry and the maximum speed reached after that gantry but before reaching the next one** (see Figure 12). This looks at the height of the peaks in the speed profiles (Figure 3) caused by surfing, and for ease of reference will be referred to as the ***surfing magnitude***.



**Figure 12: Example of an individual participant's speed profile between two gantries, with surfing magnitude indicated**

Figure 13 shows the average surfing magnitude between consecutive gantries for each gantry spacing layout and speed limit section. As shown in Figure 13, surfing occurred in all gantry spacings, but tended to be more pronounced with increased gantry spacings.



**Figure 13: Surfing magnitude (mph) as a function of gantry spacing (m) for each speed limit ( $\pm$ SEM)**

A similar ANOVA test to those used for the other assessment measures indicated no significant main effect of speed limit ( $F_{(2,375)}=1.996, p=.137$ ) and indicated that the magnitude of surfing did not differ between the speed limit sections. A significant main effect was however found for gantry spacing ( $F_{(5,375)}=17.056, p<.001$ ) with larger spacings leading to a larger magnitude of surfing. No significant interaction effect was observed ( $F_{(9,375)}=0.107, p=1.000$ ).

The ANOVA test tells us that surfing magnitude differed significantly for the different gantry spacings (although not for different speed limit sections), i.e. in general, gantry spacing had a significant effect on the extent to which participants exhibited surfing behaviour.

For each speed limit, **Tukey’s HSD tests** were performed to test whether the magnitude of surfing differed for the different gantry spacings. The p-values for each pairwise comparison for all three speed limit sections are provided in Appendix B (Table 38) and summarised below.

Surfing magnitude was found to be significantly greater with 3000m spacing than all spacings lower than 2000m spacing in either the 40 or 50mph sections (between 6.3 to 11.4mph difference depending on the comparison), and the 2000m spacing was significantly greater than the 500m spacing (7.2mph and 8.1mph for 40mph and 50mph sections respectively). No other statistically significant relationships were found for these speed limit sections.

In the 60mph section, 2000m was found to have a significantly greater surfing magnitude than all the spacings less than 1500m (as much as 8.2mph greater compared with 500m), and the 1500m spacing was found to have significantly greater surfing magnitude than the two shortest spacings (4.0mph and 5.8mph greater for 800m and 500m respectively).

## **2.4.2 Driving Behaviour - Lane Choice Group**

### **2.4.2.1 Assessment Measures**

The driving simulator records the lateral position of the vehicle relative to the carriageway every 0.05 seconds. This data was used to investigate if and when participants moved in and out of the hard shoulder (i.e. LBS1), how these movements relate to the lane status instruction presented on overhead signals, and if compliance with these instructions is effected by the frequency of gantries.

The assessment measures listed below aim to determine whether any **relationship can be seen between differences in characteristics of drivers' utilisation of LBS1 and the gantry spacing layout in which they were driving:**

1. The number of participants moving into LBS1 while it is closed to traffic; and
2. The location at which participants move out of LBS1 relative to the instruction presented to them (i.e. a Lane Divert Right Arrow or Red X).

The following sections describe the key findings of the Lane Choice group, addressing each of the assessment measures.

### **2.4.2.2 Findings**

#### ***Assessment Measure 1: The number of participants moving into LBS1 while it is closed to traffic***

Of the 48 participants in the Lane Choice group, only two moved into LBS1 whilst it was closed as a running lane (equal to 4.17% of the sample).

Table 3 describes these movements and some driver characteristics of the two participants.

**Table 3: Participants moving into LBS1 whilst it is closed as a running lane**

<b>Participant No.</b>	P11	P36
<b>Drive</b>	1st	1st
<b>Test Area</b>	1	2
<b>Gantry Spacing</b>	2000m	1000m
<b>Distance travelled in LBS1 before returning to LBS2</b>	496m	446m
<b>Number of "Red X" gantries passed under</b>	0	1
<b>Drives on a section of motorway with mandatory variable speed limits...</b>	Occasionally	Often
<b>Considers Red X compliance to be...</b>	Mandatory	Mandatory
<b>Age</b>	53	31
<b>Estimated Annual Mileage</b>	10,000	50,000
<b>Years driving</b>	35	13
<b>Sex</b>	Male	Male

The occurrences of participants entering LBS1 whilst it was closed to traffic were too few to attribute any differences to the effects of gantry spacing.

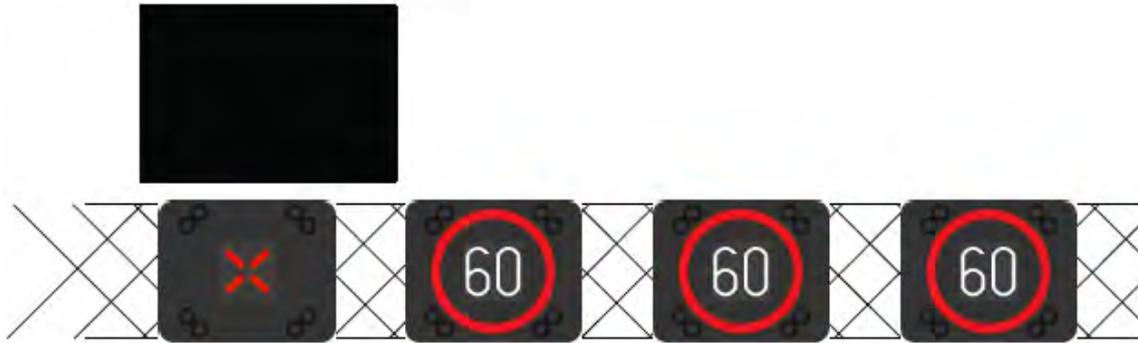
*Assessment Measure 2: The location at which participants move out of LBS1 relative to the instruction presented to them (i.e. a Lane Divert Right Arrow or Red X)*

In each experimental section LBS1 is initially open as a running lane. At a point approximately midway along section, participants reach a gantry instructing them to move out of LBS1 (Figure 14).



**Figure 14: The "LDR Gantry"**

The subsequent gantry (Figure 15) indicates that the LBS1 is now closed to traffic unless for emergency access.

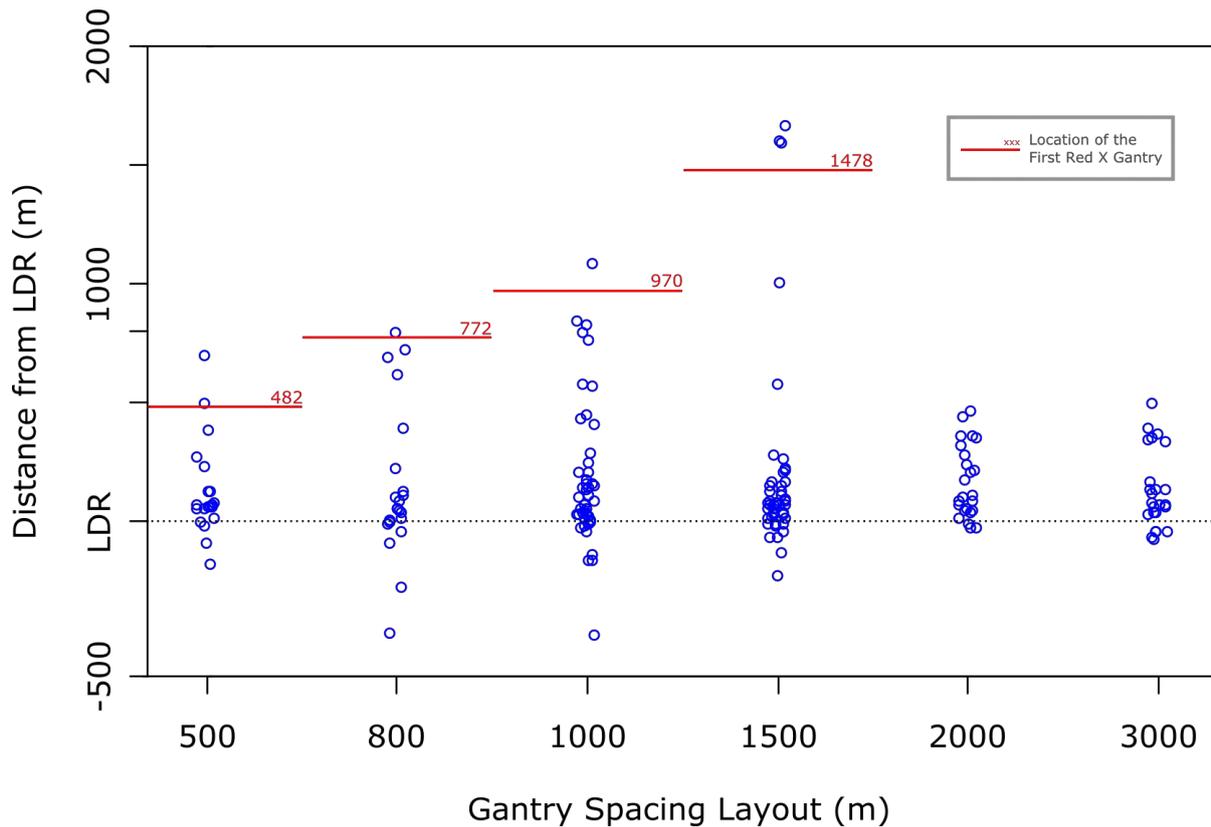


**Figure 15: The "First Red X Gantry"**

The actual location of these gantries varies between gantry spacing layouts.

Figure 16 indicates the location of participants departure from LBS1, relative to the LDR Gantry, for each gantry spacing. The vast majority of participants, for all experimental sections, were in LBS1 as they approached this gantry due to **the instruction given at the start of each drive to 'use the hard shoulder at all times as long as it is open to traffic'**. Any traffic which had already moved out of the hard shoulder before 500m before the LDR gantry is not included in this graph. Note that the sample size for the 1000m and 1500m gantry spacings is twice as large as the rest.

The horizontal red lines indicate where the First Red X Gantry was situated relative to the LDR Gantry.



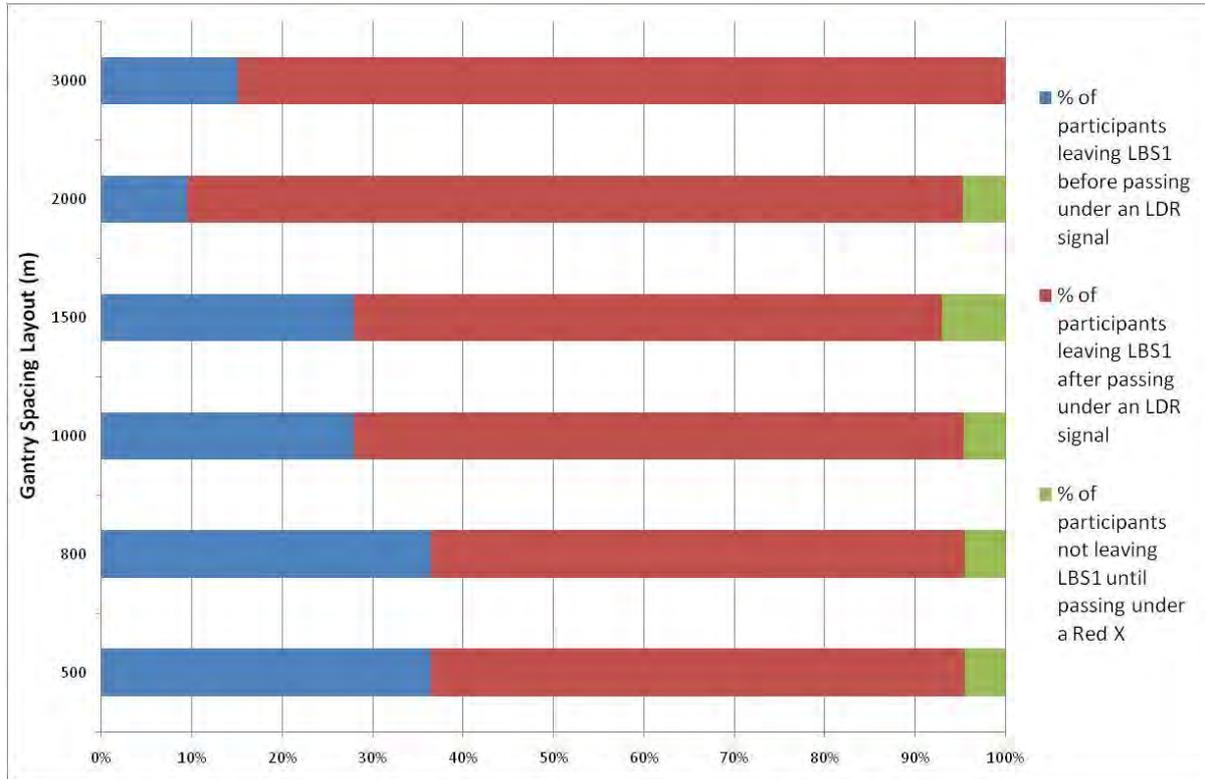
**Figure 16: Location of LBS1 departure relative, in metres, to the LDR Gantry for each gantry spacing**

Table 4 contains the average and standard deviation of the points represented in Figure 16.

**Table 4: Average departure from LBS1 relative to LDR Gantry, with standard deviation, in metres**

	500m	800m	1000m	1500m	2000m	3000m
<b>Mean departure distance following the LDR Gantry (m)</b>	123.38	139.45	182.84	197.12	161.26	126.99
<b>Standard Deviation of departure distance (m)</b>	203.89	317.45	307.90	425.36	152.91	163.27

Figure 17 indicates the percentage of vehicles departing from LBS1 before passing under the LDR Gantry, after passing under the LDR Gantry and after passing under the First Red X Gantry, for each gantry spacing.



**Figure 17: Percentage of vehicles departing from LBS1 before passing under the LDR Gantry, after passing under the LDR Gantry and after passing under the First Red X Gantry for each gantry spacing**

These results suggest that the spacing of gantries may have affected the immediacy with which participants responded to instruction. At lower gantry spacings participants were more likely to leave LBS1 before reaching the LDR signal.

However, at 2000m and 3000m spacings all participants left LBS1 within approximately 500m after the LDR signal. At lower gantry spacings the spread was much greater, with some participants waiting until after the Red X signal before leaving LBS1.

In total there were 6 participants who waited until passing under the First Red X Gantry before leaving LBS1.

Table 5 describes these movements and some driver characteristics of the participants.

**Table 5: Participants waiting until passing under the First Red X Gantry before leaving LBS1**

<b>Participant No.</b>	P18	P23	P22	P6	P36	P40
<b>Drive</b>	2nd	1st	1st	1st	1st	1st
<b>Test Area</b>	1	1	1	2	1	1
<b>Gantry Spacing</b>	500m	800m	1000m	1500m	1500m	1500m
<b>Number of "Red X" gantries passed under</b>	1	1	1	1	1	1
<b>Distance travelled following First Red X Gantry</b>	199m	4m	82m	162m	95m	88m
<b>Drives on a section of motorway with mandatory variable speed limits...</b>	Occasionally	Very rarely	Occasionally	Occasionally	Often	Never
<b>Considers Red X compliance to be...*</b>	Mandatory	Compulsory	Mandatory	Compulsory	Mandatory	Mandatory
<b>Age</b>	39	37	54	28	31	56
<b>Estimated Annual Mileage</b>	16,000	10,000	10,000	20,000	50,000	3,500
<b>Years driving</b>	22	20	34	11	13	34
<b>Sex</b>	Female	Male	Female	Female	Male	Male

\*Mandatory is defined in the questionnaire as *"illegal not to do so"*. Compulsory is defined as *"not illegal, but could constitute driving without due care and attention"*.

### Average speed within the Lane Choice group

This part of the trial was not specifically studying the speed that participants chose to drive. They were instructed to use the hard shoulder as often is possible and would have been restricted in speed choice by the surrounding simulated traffic. Also, the displayed speed limit was kept constant at 60mph. However, speed data was recorded and assessed for any difference between routes assignable to the spacing between gantries.

There was no evidence of a relationship between average speed and gantry spacings for participants in the Lane Choice group. Average speeds across all spacings were below the displayed limit and ranged between 51 – 53mph.

### 2.4.3 Questionnaire

#### 2.4.3.1 Overview

All participants of both Speed Choice and Lane Choice groups completed a questionnaire following their second drive. The purpose of the questionnaire was to **provide further information surrounding results obtained from participants' drive data** (e.g. as in Table 5) as well as to investigate any variation in self-reported experience of drives between the different gantry layouts.

Participants were asked a series of questions regarding:

- > Previous experience of VMSL environments;
- > Comprehension of the information displayed on VMSL gantries;
- > Confidence in the speed limit or status of hard shoulder (depending on which experimental group they were in);
- > Perceived suitability of frequency of information updates; and
- > Awareness of enforcement measures throughout the simulator drives.

Where appropriate, some of these questions related specifically to the individual **participants' simulator drives and therefore were analysed** to determine any effect of gantry spacing.

The Key Findings from the Task 2 questionnaire are detailed below.

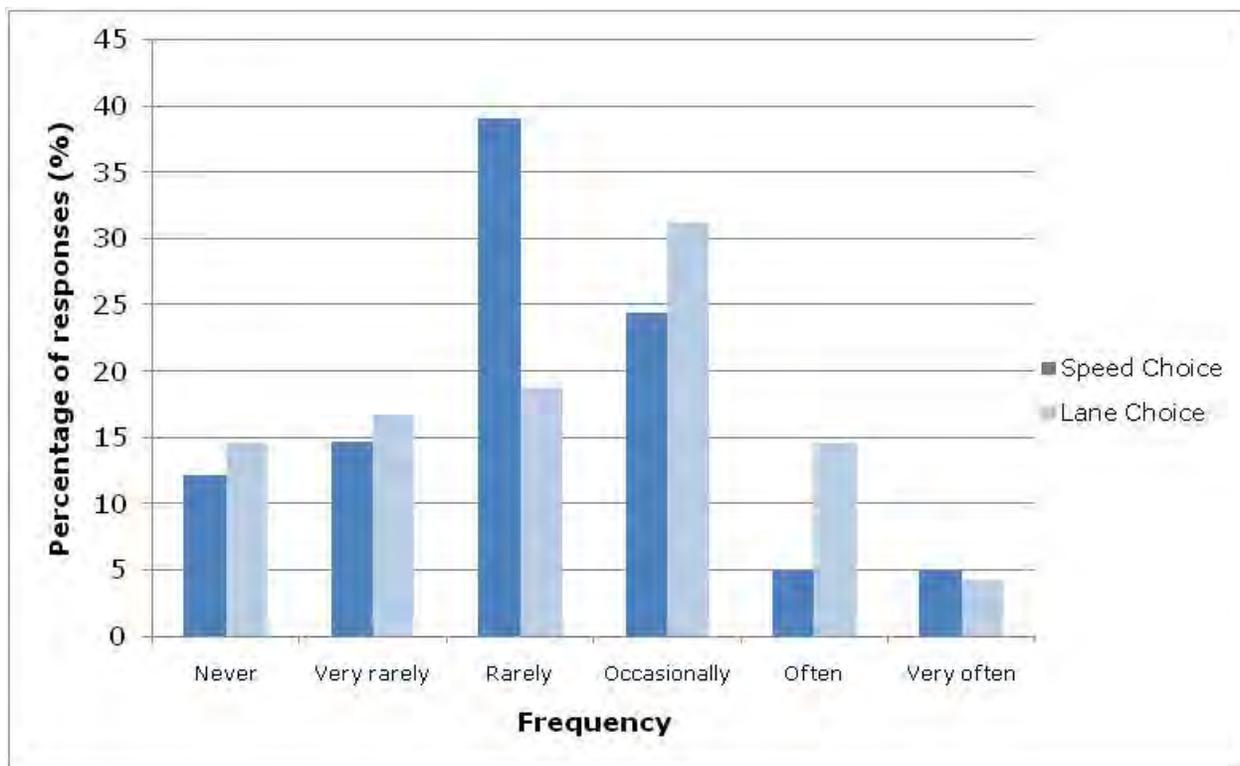
#### 2.4.3.2 Findings

##### Previous experience of VMSL environments

Participants were asked specifically how often they had driven (not as a passenger) on a section of motorway equipped with variable speed limits (e.g. M25 / M42) in the last 12 months. An example image of a gantry from the M42 scheme was presented in the questionnaire. The categories used were:

<b>Never</b>	
<b>Very Rarely</b>	Once or twice only
<b>Rarely</b>	About once every few months
<b>Occasionally</b>	At least once a month
<b>Often</b>	Once a week or more
<b>Very Often</b>	Daily, or almost daily

Figure 18 illustrates the level of experience that participants in the Speed Choice and Lane Choice group have of driving in VMSL environments within the last 12 months.



**Figure 18: Histogram of participants’ responses in relation to the frequency with which they have driven through VMSL schemes in the past 12 months**

From the results it can be seen that most participants have driven infrequently in VMSL schemes in the past year, with only 10% (Speed Choice group) and 19% (Lane Choice group) of participants having experienced them ‘often’ or ‘very often’.

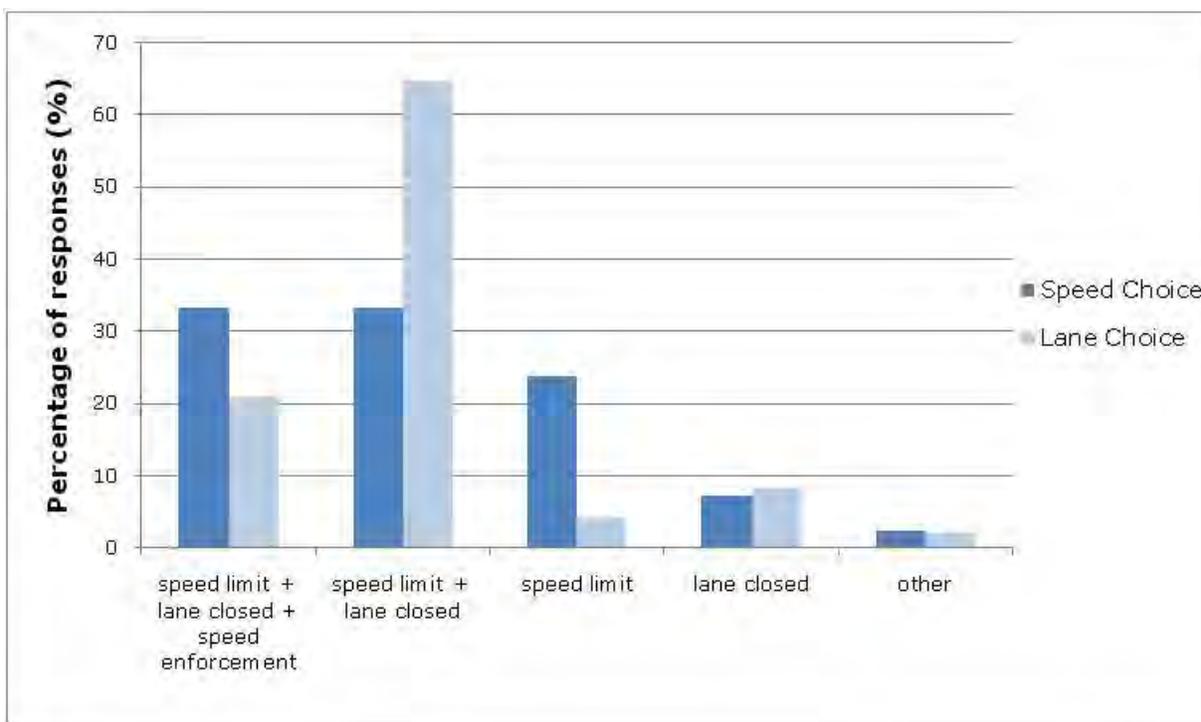
**Comprehension of driver information displayed on VMSL gantries**

Participants were initially asked to describe in their own words what information they thought was being communicated by the overhead gantry illustrated in Figure 19. They were then asked to report how they thought that they or other drivers would change their behaviour in response to the presence of the gantry and whether compliance with the speed limit or lane closure instruction was mandatory or otherwise.



**Figure 19: Image presented in the questionnaire of overhead gantry displaying information on a lane closure and speed limits, as well as an enforcement camera sign**

Figure 20 presents responses from participants for both the Speed Choice and Lane Choice group, categorised in relation to the three informational components displayed on the gantry (i.e. lane closure, speed limit and speed enforcement camera sign).



**Figure 20: Histogram of participants' responses in relation to their description of the information components communicated on a VMSL gantry**

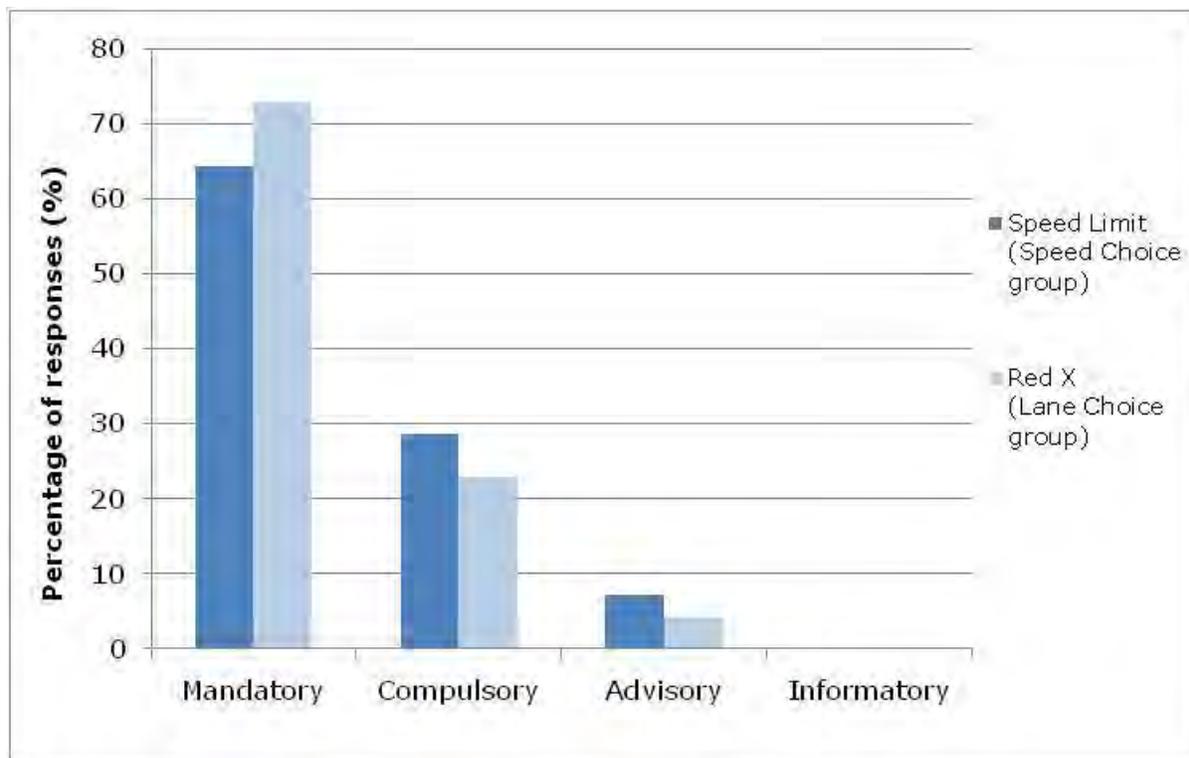
As illustrated in Figure 20, the results indicated that there was a high level of comprehension of the information being communicated by the gantry, although participants did not always describe all the individual information components and in particular the majority did not mention the presence of the speed enforcement camera sign. Participants in the Lane Choice group were more likely to identify both the speed limit and lane closure information, whereas participants in the Speed Choice group were more likely to identify the speed limit only.

In terms of self-reported response, participants demonstrated a good understanding of the correct behavioural change after seeing the speed limit and lane closure instructions. These responses were highly correlated with their understanding of what information the gantry was communicating. A reasonable proportion of all participants (29%) reported that they thought there would be some level of non-compliance by other drivers, although no participants indicated that they themselves might behave in a non-compliant manner.

Participants were also asked to choose one of the following options to describe the speed limit (Speed Choice group) or Red X (Lane Choice group) instruction:

<b>Mandatory</b>	Illegal not to do so
<b>Compulsory</b>	Not illegal, but could constitute driving without due care and attention
<b>Advisory</b>	Not illegal, but strongly advised by the authorities
<b>Informatory</b>	No legal consequences for ignoring

Figure 21 below illustrates the percentage of participants who interpreted the instructions as mandatory or otherwise.



**Figure 21: Histogram of participants' responses in relation to their perception of the speed limit or lane closure (i.e. Red X) instructions as mandatory or otherwise**

The results indicated that the majority of participants believed the information on speed limits and lane closure information (i.e. Red X) displayed on the gantry to be a mandatory instruction. No participants in either the Speed Choice or Lane Choice group thought that the instruction was just for providing information. These results correlate well with the findings of the Task 3 questionnaire (see Section 3.5.2.2), which also asked participants to indicate whether they believed the speed limit aspect with a red ring to be mandatory or otherwise.

**Confidence in the speed limit or status of the hard shoulder and perceived suitability of frequency of information updates**

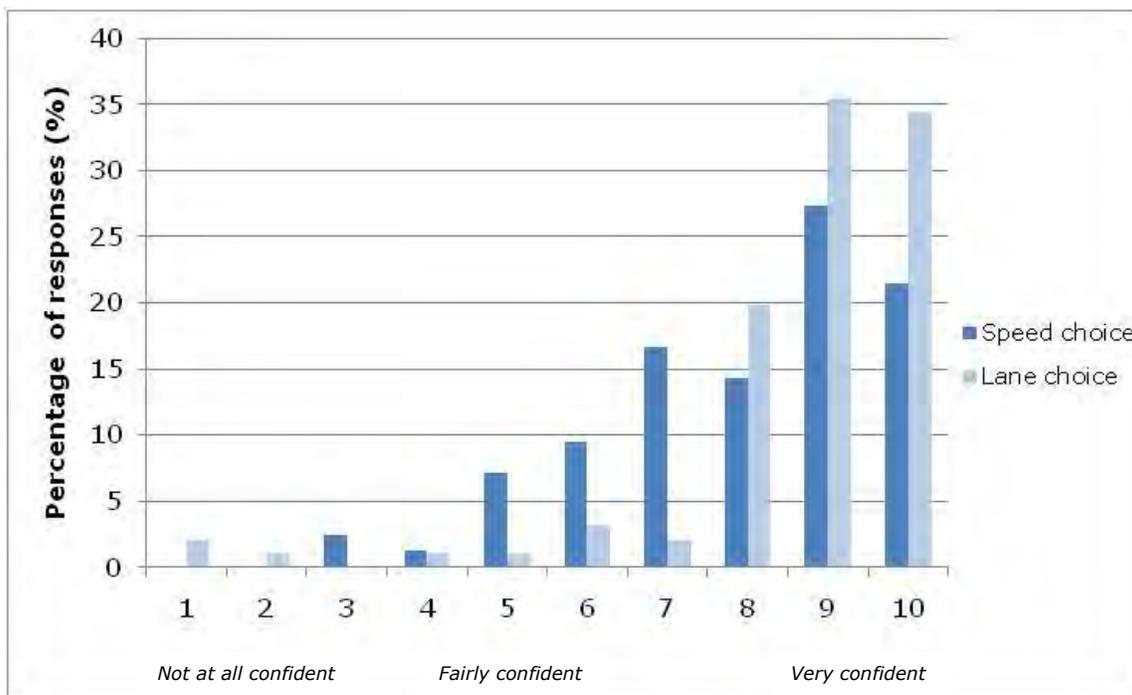
After completion of the two simulator drives, participants were asked specific questions about the two test areas within their second (and final) drive. This meant that participant responses could be attributed to their experience of driving in a specific gantry spacing layouts. The test areas were clearly indicated to participants diagrammatically within the questionnaire.

Depending on which group they were in, participants were asked about their confidence in either the status of the hard shoulder or the speed limit, as well as their perception of the frequency with which information was displayed on the gantries. An example of the questions and scales used is illustrated in Figure 22 below.

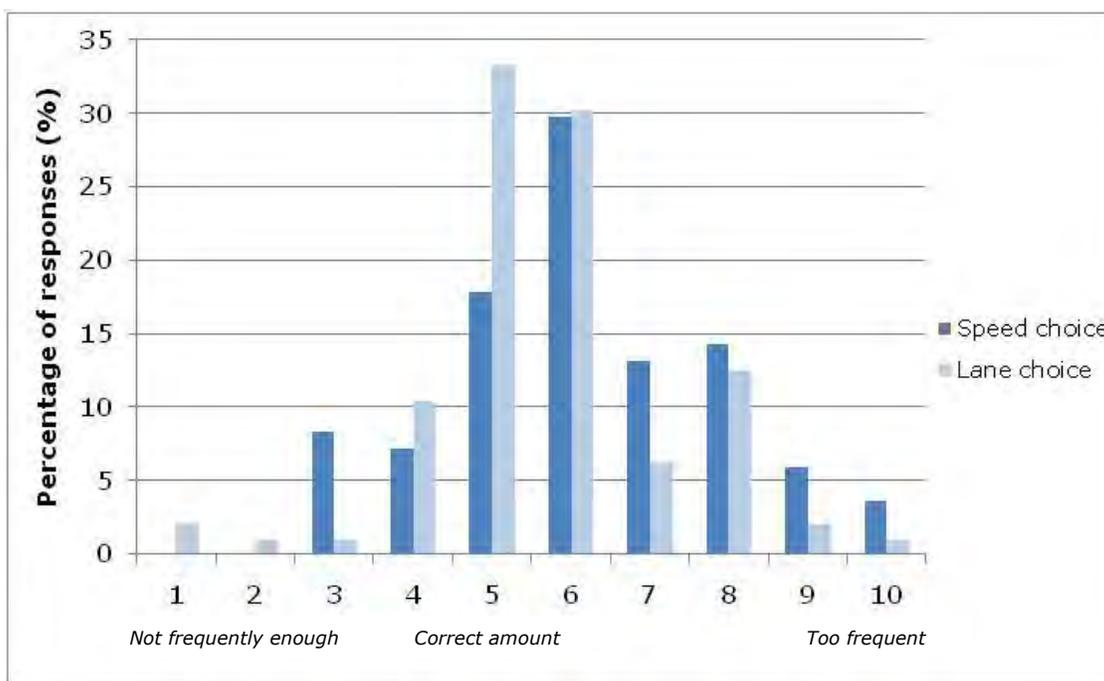
<p><b>Lane Choice:</b> How confident were you of the status of the hard shoulder (whether it was open or closed as a running lane) throughout the [first / second] half of the drive?</p> <p><b>Speed Choice:</b> How confident were you of the speed limit throughout the [first / second] half of the drive?</p> <p><i>(Please circle the number that you feel is most appropriate)</i></p>									
<i>Not at all Confident</i>			<i>Fairly Confident</i>				<i>Very Confident</i>		
1	2	3	4	5	6	7	8	9	10
<p>Did you feel the information displayed on the overhead gantries was provided frequently enough?</p> <p><i>(Please circle the number that you feel is most appropriate)</i></p>									
<i>Not frequently enough</i>			<i>Correct amount</i>				<i>Too frequent</i>		
1	2	3	4	5	6	7	8	9	10

**Figure 22: Questions asked in relation to each test area within the participants’ second drive**

Figure 23 and Figure 24 below illustrate the percentage distribution of responses by Speed Choice and Lane Choice participants for the confidence rating and frequency rating respectively.



**Figure 23: Histogram of participants' confidence ratings regarding their awareness of speed limit / Hard Shoulder status**



**Figure 24: Histogram of participants' ratings regarding their perception of the frequency of information provision**

Table 6 and Table 7 present the mean response for each gantry spacing layout referred to for each of the questions.

**Table 6: Mean responses of participants' confidence in their awareness of the hard shoulder status or speed limit as displayed on gantries within the test areas for different gantry spacing layouts**

	Gantry spacing layout of test area referred to					
	500m	800m	1000m	1500m	2000m	3000m
<b>Speed Choice Group - Confidence in awareness of hard shoulder status</b>	8.00	8.33	8.28	7.58	8.22	8.17
(1 = not confident, 10 = very confident)						
<b>Lane Choice Group - Confidence in awareness of speed limit</b>	9.33	9.25	8.17	8.54	8.67	8.75
(1 = not confident, 10 = very confident)						

**Table 7: Mean responses of participants' perception of the frequency of information provision within the test areas for different gantry spacing layouts**

	Gantry spacing layout of test area referred to					
	500m	800m	1000m	1500m	2000m	3000m
<b>Speed Choice Group - Perception of frequency of information provision</b>	6.33	6.42	6.56	6.17	5.89	5.92
(1 = not frequently enough, 10 = too frequently)						
<b>Lane Choice Group - Perception of frequency of information provision</b>	6.00	5.00	5.88	5.46	5.50	6.42
(1 = not frequently enough, 10 = too frequently)						

As can be seen in Figure 23 and Table 6, participants reported a high degree of confidence in their awareness of either the speed limit or the status of the hard shoulder for all gantry spacing layouts. For most gantry spacings, the mean confidence ratings for the Lane Choice group were slightly higher than those for the Speed Choice group.

A One-Way ANOVA test was performed on the Lane Choice and Speed Choice data sets to determine if the differences in the mean values for confidence between the six gantry spacings were statistically significant.

For both the Lane Choice and Speed Choice group, there was no difference in the confidence ratings between gantry spacing layouts (Speed Choice:  $F(5,78) = .75$ ,  $p = .62$ ; Lane Choice  $F(5,90) = 1.02$ ,  $p = .41$ ).

As illustrated in Figure 24 and Table 7, ratings of frequency of information were mainly clustered around the centre point of the scale (5.5), indicating that participants generally found the frequency of the information displayed to be about the “correct amount”.

The data for participant rating of frequency of information was also analysed using a One-Way ANOVA for differences in ratings depending on gantry spacing layout.

For both the Lane Choice and Speed Choice group, the difference in means for each spacing was not found to be statistically significant (Speed Choice:  $F(5,78) = .48$ ,  $p = .79$ ; Lane Choice:  $F(5,90) = .57$ ,  $p = .73$ ).

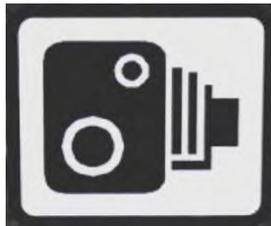
Therefore, it is inferred that participants did not differ in their ratings of their confidence in their awareness of the instructions being communicated to them, and they felt the frequency of information displayed was appropriate in all gantry spacing layouts.

### Awareness of enforcement indicators throughout the simulator drives

Participants were asked about visual indications of enforcement measures presented at each gantry on all drives with reference to the two images (Figure 25 and Figure 26) below.



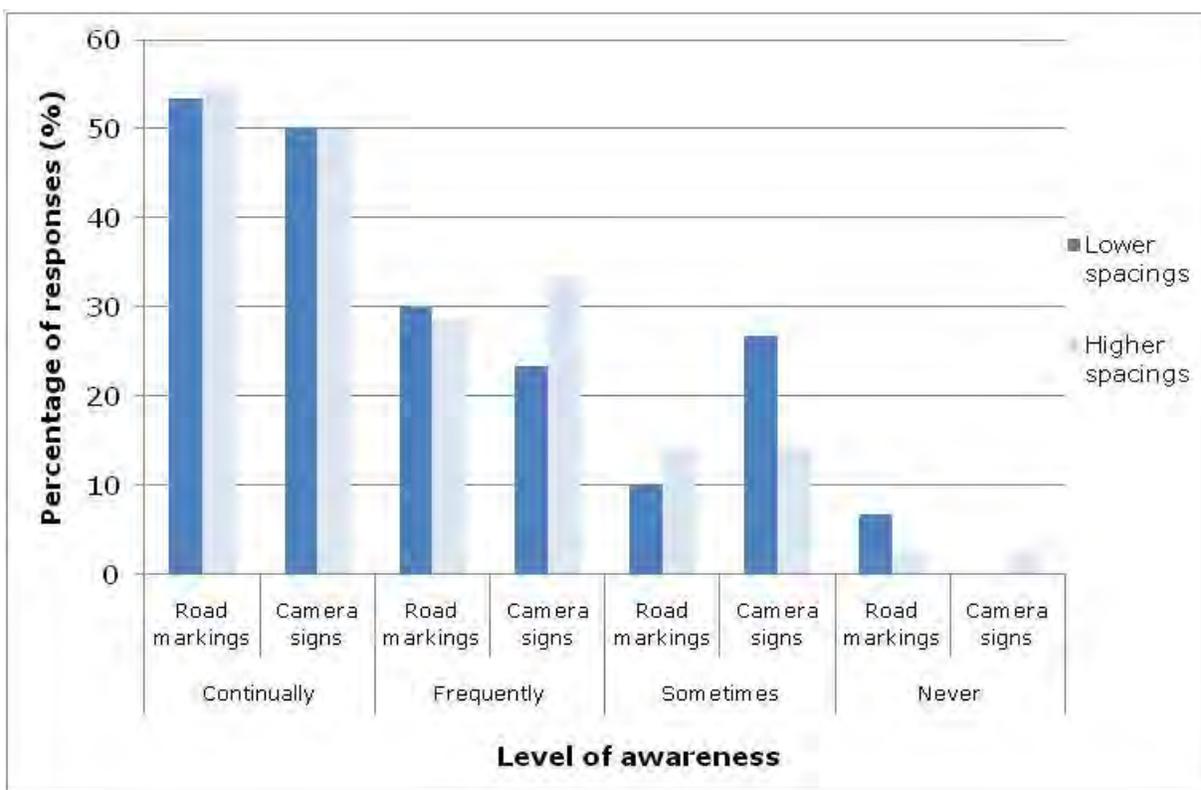
**Figure 25: Enforcement markings used within the simulated environment**



**Figure 26: Enforcement camera sign located on each gantry**

Participants were asked *'how aware were you of the presence of these markings / signs whilst driving the routes?'*

Figure 27 illustrates participants' responses to the questions relating to enforcement road markings and enforcement camera signs respectively. These questions did not relate to one specific drive or test area, however those participants that drove a combination of the 500, 800, 1000 or 1500m spacings (referred to as the 'lower spacings') were compared with those participants that drove a combination of the 1000, 1500, 2000 or 3000m spacings (referred to as the 'higher spacings'). The graph below does not include data from all participants that undertook the trial, as some drove a combination of the 500, 800, 2000 and 3000m spacings, and it should also be noted that there was a slightly larger sample size for the higher spacings than for the lower spacings.



**Figure 27: Histogram of participants' responses in relation to their awareness of enforcement road markings and enforcement camera signs within the simulator route**

Awareness of enforcement signs and road markings was high and did not differ significantly between participants who drove routes with lower spacings and those who drove routes with higher spacings. Only a few participants reported never being aware of the speed enforcement markings or speed camera signs. Further analysis indicated that the majority of participants in both the Speed Choice and Lane Choice group were either continually or frequently aware of the two enforcement indicators.

Participants were also asked to describe what they thought each enforcement indicator meant.

Participants in both the Speed Choice and Lane Choice group demonstrated a good understanding of both types of enforcement indicator.

Almost all participants (97%) correctly interpreted the meaning of the enforcement camera sign. Whilst the majority of participants also correctly interpreted the enforcement markings to relate to speed enforcement calculations (72%) there were a number of other responses that did not capture the exact meaning of the markings, **although were highly relevant (e.g. 'mark your speed' and 'variable speed limit in operation')**. **There were also more unclear responses**, i.e. responses which could not be categorised, in relation to the enforcement markings (7 responses) than the enforcement camera sign (3 responses).

The fact that participants demonstrated both a strong understanding and awareness of the presence of enforcement indicators suggests that they perceived the environment within which they were driving to be one where speed limits would be enforced and as such may have adjusted their driving as they would in the real world.

## 2.5 Discussion and Recommendations

Task 2 has investigated the effect of varying the spacing of signal gantries on driver behaviour, in terms of speed and lane choice. The key findings are summarised and discussed below.

### *The effects of different gantry spacings on speed choice*

On the Active Traffic Management Pilot on the M42, gantries are spaced nominally 500m apart. Current guidance<sup>3</sup> states that inter-junction gantries should have a desired spacing of 800m. This study has shown no statistically significant effects **between participants' driving behaviour for the 500 and 800m spacings.**

However, it has been observed that increasing the spacing of gantries beyond **800m has had an effect on participants' driving behaviour. The longest spacings** (2000 and 3000m) have shown significant differences than the shortest spacings (500 and 800m) against all of the assessment measures.

There were no significant differences between the 500m and 800m spacings for any of the speed assessment measures.

The differences in participant driver behaviour between the spacings of 1000m and 1500m and the shortest spacings (500m and 800m) were less pronounced and not always statistically significant.

- > For several assessment measures there was a noticeable increase in speed between the shortest spacings and the 1000m spacing. However, differences were only statistically significant at 50mph and all but one were between the 500m and 1000m spacings.
- > There were more significant differences found relating to the 1500m spacings. Notably, for 40mph and 50mph speed limits, mean speed was approximately 5mph higher and spot speeds under gantries were approximately 4mph higher with gantries spaced at 1500m than with gantries spaced at 500m or 800m.
- > Furthermore, at 60mph speed limits, the average percentage of time spent at speeds above 66mph was approximately 30% higher and surfing magnitude was approximately 5mph higher for the 1500m spacing than the 500m and 800m spacings.

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<sup>3</sup> Interim Advice Note 87/07 clause 4.3.

### *The role of surrounding traffic*

The simulated traffic used within this trial was purposefully light so as not to have too great an influence on participants' speed and lane choice. The driving characteristics of the participants in the Speed Choice group are likely to be typical of drivers "driving as if late for an important meeting" and unhindered by other traffic. In reality, much of the use of VMSL would be at higher traffic flows and the surrounding traffic would have a greater effect on individual drivers' behaviour. Also, not all drivers within a population of traffic will be motivated to driver faster than they may normally. Mean speed of a sample of traffic, for example, is likely to be lower than the mean speed of the participants in this study for this reason. It is recommended that to fully understand the implications of increased gantry spacing, more consideration is given to the effect of surrounding traffic on individual driver compliance.

### *Variation with displayed speed limit*

In general, the effects of longer gantry spacing were much more pronounced when the speed limit was 40mph. 40mph is the most restrictive speed limit that would be automatically displayed in a Managed Motorways scheme and, therefore, differences between the required speed and participants desired speed are likely to be greatest. With longer gantry spacings, participants would have had more time to reach and maintain their desired speed between gantries. Hence, both the range in which participants had to vary their speed choice and the distance in which they would have to do it becomes greater as the speed limit decreases and the spacing between gantries increases.

At dense levels of traffic the impact of this change in behaviour is likely to be reduced, as discussed above. However, there may be safety implications for poor compliance with the 40mph speed limit when less traffic is present. The 40mph speed limit is used in response to slow moving vehicles. This may be, for example, to protect the back of a queue following a collision. Poor compliance may increase the risk of a secondary incident. In practice, however, this would be in part mitigated by supplementary text messages or pictograms (not used within this trial) which would give drivers more of a reason to reduce their speed. Section 3.5.2.3 looks further at the importance drivers place on this supplementary information.

Consideration also should be given to the role of additional fixed signs which serve to inform and / or remind drivers about the fact that they are driving within a **special scheme. 'Gateway' signing, for example, may have a conditioning effect on drivers' speed choice by highlighting that they** are in an environment where variable mandatory speed limits are in operation and prompting drivers to be aware of the information that is displayed. Further investigation should be undertaken to **determine the effect of 'gateway' and other fixed signing to** improving; this may provide a relatively simple and inexpensive option to counteract the effects of longer gantry spacings.

#### *The effect of gantry spacing on compliance with Red X*

There were too few occurrences of participants entering LBS1 whilst closed to traffic to attribute any differences in compliance with Red X to the effects of gantry spacing.

#### *Immediacy of response to lane closure instruction*

The results of the Lane Choice group suggested that the spacing of gantries may have affected the immediacy with which participants responded to instruction regarding lane closures. At lower gantry spacings participants were more likely to leave LBS1 before reaching the LDR signal. However, at 2000m and 3000m spacings all participants left LBS1 within approximately 500m after the LDR signal. At lower gantry spacings the spread was much greater, with some participants waiting until after the Red X signal before leaving LBS1. A possible reason for this is that with information updates further apart drivers place more importance on the information that *is* presented them, i.e. increased exposure to VMSL gantries reduces the emphasis and urgency of instruction on a single gantry. With the LDR signal it may be the case that at shorter gantry spacings participants were anticipating the subsequent Red X so waited until that was visible before moving out of LBS1, while at longer spacings participants acted on the LDR signal alone.

#### *Impact on operational flexibility*

The other more general safety implication of longer gantry spacing, not directly addressed in this study, is the reduced operational flexibility that comes with having gantries further apart. For the queue protection function provided by the VMSL greater gantry spacing means greater potential distance between the reduced speed limit and the queue or incident that it is trying to protect. Not only is this an issue because of surfing (i.e. the further a surfing driver is from a gantry the higher their speed will be) but it also means that the amount of traffic already having passed under the gantry before the speed limit or lane closure instruction is set (and hence given no warning by the VMSL system) will be greater.

### Real-world applicability

This study was a comparative study designed to compare differences in gantry spacing layouts with a simulated driving environment. While the significant relationships between gantry spacing layouts can be used to inform decision making regarding future Managed Motorways and MM2 design, absolute results cannot be necessarily translated in to real-world scenarios without some thought. For example, as discussed in the paragraph above, participants in the Speed Choice group were given particular instruction to get them to drive faster than perhaps they normally would and, therefore, could be considered as representative of the fastest portion of a sample of traffic rather a sample as whole. It is recommended that some consideration be given to the correlation of the Speed Choice results in this study to actual traffic data. This will also provide a means of validating the trial and, if necessary, translating the absolute numbers analysed within this study to directly applicable results.

Results suggest, however, that the driving behaviour exhibited by the trial participants was very much like what would be expected in a real-world scenario. Despite the absence of any real enforcement, many of the Speed Choice participants chose to surf between gantries, slowing to pass under gantries as if concerned about being caught violating the displayed speed limit. This behaviour, along with the high awareness of enforcement measures that participants reported through the questionnaire, suggests unsurprisingly that the perception of enforcement is a key factor in influencing driver behaviour within a Managed Motorways environment. It is recommended that further study is undertaken to investigate the relationship between driver perception of enforcement and **compliance. For example, looking at how spot speed at gantries varies if they aren't equipped with enforcement signs and road markings.**

## 3 Task 3 MM2 Sign Comprehension Study

### 3.1 Background

The driving task requires accurate processing of information with timely responses to produce safe driving behaviour. There are constraints on the time available for a driver to see, interpret and act upon information provided whilst travelling. It is vital that a message displayed on a sign can be easily comprehended within a short space of time and thus minimise the need for drivers to inspect a sign for extended periods of time (i.e. minimise the 'eyes-off-the-road' time).

Sign comprehension and sign use are associated with three stages: legibility, recognition, and interpretation<sup>4</sup>. Legibility refers to the relationship between the driver, the sign, and the environment and is essential for the initial perception of the sign. Key parameters associated with legibility include luminance, uniformity, contrast, and size. Recognition refers to whether the driver can readily distinguish the sign, especially in the context of other signs and stimuli. For example: How well do the parts of this sign relate to one another? Does the construction of the sign support accurate recognition? Is it easily confused with other signs?

Finally, interpretation reflects the relationships among the driver, the sign, and the referent or message associated with the sign. Key parameters are whether the driver comprehends the meaning, intent, or purpose of the sign.

One of the key design features being considered as part of the MM2 concept is the provision of on-road driver information via verge-mounted signing only, which differs from the current standards for Managed Motorway schemes which require the use of gantry-mounted Advanced Motorway Indicator (AMI) signals and variable message signs (VMS).

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<sup>4</sup> Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2004). In-Vehicle Display Icons and Other Information Elements. Volume I: Guidelines (FHWA-RD-03-065). McLean, VA: FHWA (<http://www.tfrc.gov/safety/pubs/03065/index.htm>).

For MM2 schemes, the use of verge-mounted cantilever Motorway Signal Mark 4 (MS4) VMS, which have a fully programmable dual-colour display panel (see Figure 28 below), has been proposed.



**Figure 28: Illustration of a) gantry-mounted AMI signals and an MS4 and b) verge-mounted MS4**

This potential move to verge-mounted Managed Motorway signing raises several questions around comprehensibility: Will drivers comprehend the relevant information if displayed solely on an MS4? How best should lane specific information be displayed? What effect does supplementary information have on the comprehension of safety critical information?

To help answer these questions, TRL has been tasked with investigating driver comprehension and response to signing options which could potentially be used within an MM2 environment. This task (Task 3 MM2 Sign Comprehension Study) involves a trial using a PC-based Comprehension Test software tool and questionnaire.

### 3.2 Task Objectives

The primary objectives of Task 3 are therefore to:

- > **Evaluate drivers' sign comprehension** of potential designs for MS4 aspects and message configurations to be used in an MM2 scenario; and
- > Compare the effectiveness of the potential designs for verge-mounted information provision with equivalent options for gantry-mounted information provision; and
- > To propose verge-mounted MS4 message configurations and sequences for use within the MM2 environment, which could be further evaluated within **TRL's driving simulator.**

### 3.3 Methodology

A full description of the methodologies used are recorded in the Task 3 MM2 Sign Comprehension Study Plan, which was produced and agreed with the HA at the start of the task. This section provides an overview and additional details where relevant.

Task 3 will help determine if the MM2 concept for verge-mounted information provision can be developed further, by helping to answer the following question:

- > Can safety-critical information be communicated as effectively to drivers via a single verge-mounted MS4 as on a fully-equipped gantry with lane-specific AMI signals and an MS4?

Within the context of this task, safety critical information refers to a) speed limits, and b) lane closure instructions. When considering the use of verge-mounted MS4s to display this safety critical information, several issues should be taken into account.

Firstly, whereas the speed limit roundel is the approved aspect for displaying instructions regarding mandatory maximum speed limits on AMIs, it has not previously been used on an MS4. Furthermore, within existing Managed Motorway environments, the speed limit roundels are displayed above each individual lane. With regard to MM2 schemes, this raises the question if drivers understand the MS4 information to apply to *all* running lanes.

VMS have been used in the past to communicate lane specific closures, for example **there is a HA approved 'Wicket' Enhanced Motorway Indicator (EMI) aspect to communicate lane closures<sup>5</sup>**. However, this aspect may not be appropriate for communicating all of the required information in the event of a lane closure in an MM2 environment; for example, to inform drivers that a lane is closed to traffic immediately or to provide instruction to drivers to move out of a particular lane.

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<sup>5</sup> The 'Wicket' aspect (illustrated below) is detailed in the HA Specification 'MCE 2214 Motorway Signal Mark 4 (MS4) Requirements for Signal Equipment (Display and Communications Equipment)'.



Furthermore, the physical signing 'space' available to communicate safety-critical information to drivers is reduced in the proposed MM2 environment and therefore novel ways of presenting safety-critical information should be considered.

Therefore, as part of MM2 concept development it is necessary to develop and evaluate:

- > EMI aspects communicating lane closure information and instruction; and
- > MS4 message configuration when presenting speed limit and / or lane closure aspects.

Figure 29 on the next page provides an overview of the approach to the evaluation of designs for MM2 verge-mounted information provision, including the Task 3 Comprehension Test and questionnaire<sup>6</sup>. Task 3 will provide evidence of effective candidate designs and will guide decision-making on which designs should be taken forward for more detailed testing of actual driver response in future MM2 driving simulation studies.

**Sections 3.3.1** and **3.3.2** provide a summary of the methodologies used for the Task 3 Comprehension Tests.

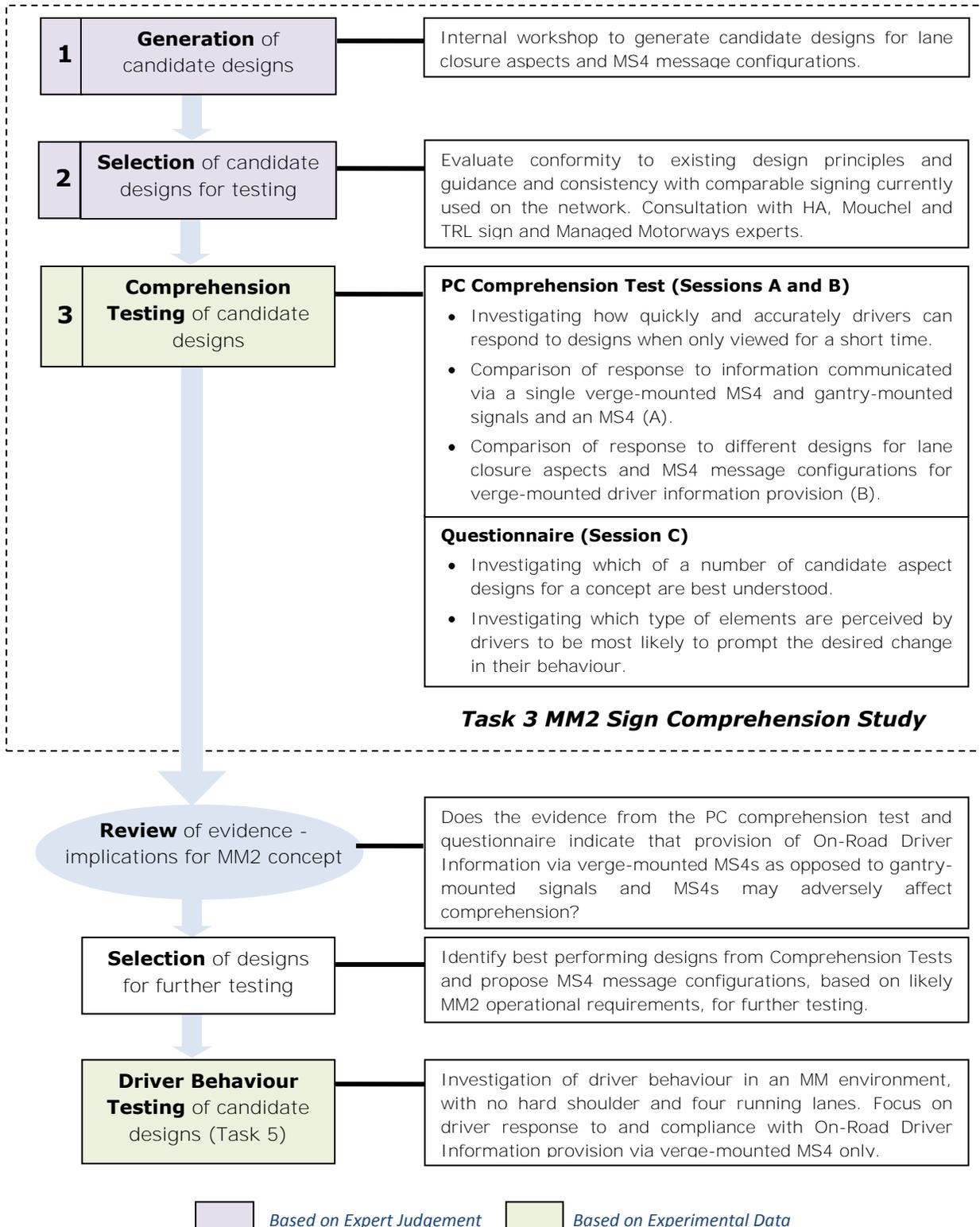
**Section 3.4** details the development of the candidate designs for the lane closure aspect and MS4 message configurations (stages 1 and 2 in Figure 29).

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<sup>6</sup> This methodology is aligned with international approaches to sign design evaluation and development, as discussed in the following publications:

Campbell, J.L., Richard, Brown, J.L, Lichty, M.G, Grahan, J., O'Laughlin, M. (2010). **Human Factors Guidelines for Road Systems**. NCHRP Report 600C. Washington, DC :NCHRP  
[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_600C.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600C.pdf)

Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2004). In-Vehicle Display Icons and Other Information Elements. Volume I: Guidelines (FHWA-RD-03-065). McLean, VA: FHWA  
<http://www.tfrc.gov/safety/pubs/03065/index.htm>.



**Figure 29: Development of MM2 MS4 On-Road Driver Information Provision**

### 3.3.1 PC Comprehension Test

The PC test utilised a software tool that measured the response time and accuracy of participants to visual stimuli containing images of Managed Motorways On-Road Driver Information. The trial consisted of two experimental sessions, each undertaken by 48 participants, which are described below.

- > **Session A**<sup>7</sup> - Comparison of response to **gantry-mounted versus verge-mounted** information provision, including investigation of the effect of supplementary information (e.g. pictograms and text). For each possible gantry-mounted signing configuration identified, one or more verge-mounted MS4 configurations were developed that communicated the same information, where appropriate, with differences in the design of the lane closure aspect or the size and positioning of the speed limit aspect. Images of the gantry- and verge-mounted configurations (19 in total) tested in this session are detailed in Appendix C.

Within the first part of this session, the test images were displayed statically (referred to as the static version). Within the second part of this session, the **same images were displayed with animated 'zoom' to simulate a dynamic motorway environment** (referred to as the dynamic version). The dynamic version enabled investigation of the impact on response when the participant is required to read and process the information whilst in 'simulated motion'.

- > **Session B** - Comparison of response to different **MS4 message configurations**, when presenting speed limit and lane closure aspects a) either separately or together, and b) with pictograms and/or text to provide supporting and reinforcing information. For consistency the Wicket aspect design was used on all designs communicating lane closure information as it is expected to be the most familiar to drivers. Images of the MS4 message configurations (20 in total) tested in this session are detailed in Appendix C.

Within Session B, the static version only was used.

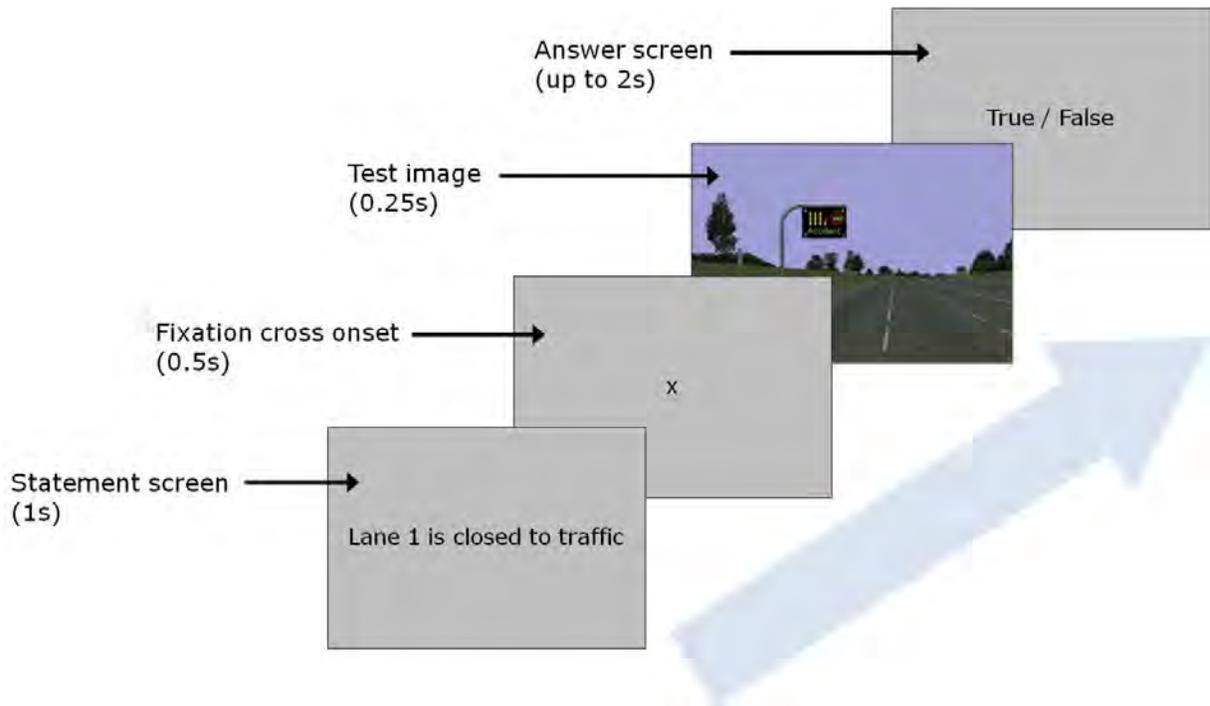
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<sup>7</sup> In this report, Sessions A and B are referred to in reversed order compared to in the Study Plan. This is solely to improve the readability of this report.

The following points provide a summary of the methodology for the static version:

- > The test images contained a verge-mounted MS4, or gantry-mounted signals and MS4, in the context of a motorway with four permanent running lanes and no hard shoulder.
- > Prior to starting the test, participants were shown an example of a test image with the lanes numbered 1 to 4 to familiarise them with the lane numbering.
- > The participants were then shown on a PC monitor the sequence of stimuli illustrated in Figure 30 and tasked to indicate a statement relating to an **image to be 'true' or 'false' as quickly as possible by means of a button press** (see Figure 31). The exposure time for the test images was varied between 0.25, 0.50 and 1 second. The response accuracy and time was recorded. Multiple images were tested in succession, with the static sessions lasting 20 minutes in total.
- > Each image was presented four times at the three exposure times (12 times in total) to account for learning effects. The order in which the images were displayed was randomised.
- > **Participants were asked about the displayed speed limit ('speed' statements), to indicate whether a lane was closed to traffic ('lane closed' statements) or to indicate if they were required to move out of a particular lane ('move out of lane' statements).** In addition, dummy images and statements were included, relating to supplementary text and pictograms in the images. The responses to these statements were not included in the analysis.

The methodology used for the *dynamic* version was the same as for the static presentation apart from the fact that the exposure time was 4 seconds (for all presentations), and participants were asked to register a true or false response as soon as possible after the image appeared on screen rather than waiting until prompted. The dynamic session lasted 10 minutes in total (96 image presentations).



**Figure 30: Order and duration of the stimuli used in the PC Comprehension Test – Static Version**



**Figure 31: Experimental setup for the PC Comprehension Test**

### 3.3.2 Questionnaire

A questionnaire was completed by all 96 participants following the PC task, regardless of which experimental session they participated in. The questionnaire consisted of three parts: i) Comprehension of aspect designs; ii) Influence-potential of MS4 message elements and iii) Perceptions of verge-mounted driver information provision.

#### Comprehension of aspect designs

##### *Lane closure aspects*

The first part of the questionnaire investigated how participants interpreted the information being communicated by different lane closure aspect designs.

The lane closure aspect designs that were tested are detailed in Section 3.4 (Figure 33) of this report, and incorporated designs communicating single and double lane closures. The order in which the aspect designs were presented to different participants was randomised and not all participants were presented with all aspect designs.

- > For each lane closure aspect design, an image of an aspect was presented to participants within the questionnaire. Participants were then asked to describe in their own words what the aspect was communicating.
- > For each aspect, the 'intended meaning' was defined in terms of the key informational elements being communicated. The key informational elements for all signs related to one or both of the following:
  - **Information** about lane status i.e. lane closed to traffic / not in use; and
  - **Instruction** about how the driver should behave i.e. move out of lane.

- > In order to enhance the interpretation of the answers provided by participants, their responses were analysed in line with established methods for the evaluation of signs<sup>8</sup>. Participant responses were categorised into groups and then scored on the criteria described in Table 8.

**Table 8: Criteria for the scoring of participants' responses**

Score	Criteria
1	Response matches intended meaning exactly
2	Response captures key informational elements of intended meaning, but misses one or two minor elements
3	Response captures some elements of intended meaning, but misses one or more key informational elements
4	Response does not match intended meaning but is somewhat relevant
5	Response is in no way relevant to the intended meaning
6	Subject indicates no understanding of the aspect
7	No response

- > The mean scores were calculated for each aspect design to provide a rating **of participants' comprehension based on the extent to which the perceived meaning matched the intended meaning.**
- > In reference to each aspect design, participants were also asked to:
  - Describe how they would change their driving in response to observing the aspect;
  - Indicate at what point they would change their driving behaviour; and
  - Indicate whether they thought the aspect was mandatory or otherwise.
- > **Where appropriate, participants' responses to these questions were also categorised for analysis.**

<sup>8</sup> See references:

ISO/DIS 9186. (1988). Procedures for the development and testing of public information symbols. Geneva, Switzerland: ISO.

Zwaga, H., and Easterby, R. S. (1984). Developing effective symbols for public information. In R. Easterby and H. Zwaga (Eds.), Information design: The design and evaluation of signs and printed material (pp. 277-297). New York: J. Wiley & Sons.

### *Other aspects*

The other aspects that were investigated are detailed below:

- > **Mandatory and advisory speed limit aspects** – questions focused on the perception of the speed limit instruction as mandatory or otherwise; and
- > **Broken down vehicle aspect** – questions focused on participant interpretation of the information being communicated and their likely response.

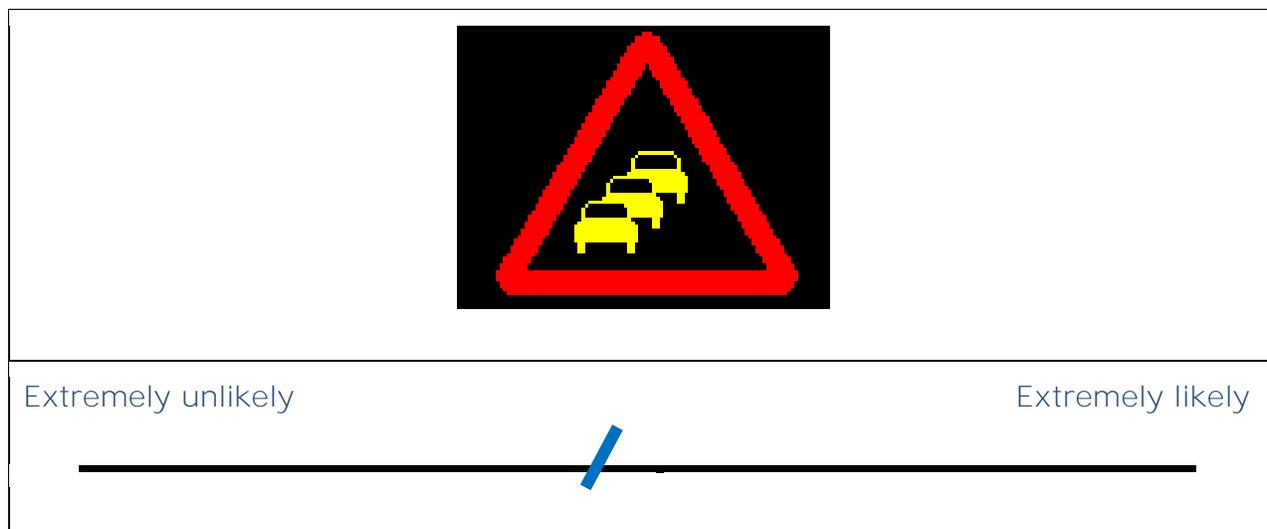
### *Influence-potential of MS4 message elements*

The second part of the questionnaire investigated **participants' perception** of the likely effect on their driving behaviour of different types of element that can be displayed on an MS4. The elements tested included mandatory and advisory speed limit aspects, lane closure aspects, warning pictograms and text.

- > Participants were given a description of a driving scenario:

*You are driving on a motorway with free flow traffic. Your current speed is slightly higher than the national speed limit (e.g. 72mph).*

- > Participants were then presented with an image of a sign incorporating a single element and asked to rate how likely they would be to reduce their driving speed after having observed the element. The scale selected was based on the visual analogue scale (VAS); participants were required to place **a mark on a continuous line which had "extremely unlikely" on one pole, and "extremely likely" on the other** (see Figure 32).
- > This was repeated for the different types of element, and with different information being presented e.g. speed limit aspects displaying 40mph, 50mph and 60mph, and warning pictograms for 'congestion', 'incident' and 'obstruction'.



**Figure 32: Question requiring participants to mark on a scale their likely behaviour in response to seeing the displayed element**

Analysis was then undertaken to determine which elements were perceived by participants to be most likely to change their driving behaviour. The position of each mark was measured and converted into a ratio, where 0 = extremely likely and 1 = extremely unlikely. Mean ratios were calculated for all test elements and compared.

***Perceptions of verge-mounted driver information provision***

Participants were asked to rate on a scale of 1 – 10 their perceptions of driver information provision via verge-mounted VMS in relation to safety and impact on driver behaviour. The mean scores were calculated and analysed.

### 3.4 Candidate Designs for Lane Closure Aspect and MS4 Message Configurations

The following paragraphs highlight the key considerations for the initial stages of this task when generating and selecting new designs for lane closure aspects and MS4 message configurations. The candidate designs that were selected for testing are also detailed.

#### 3.4.1 Lane Closure Aspect Design

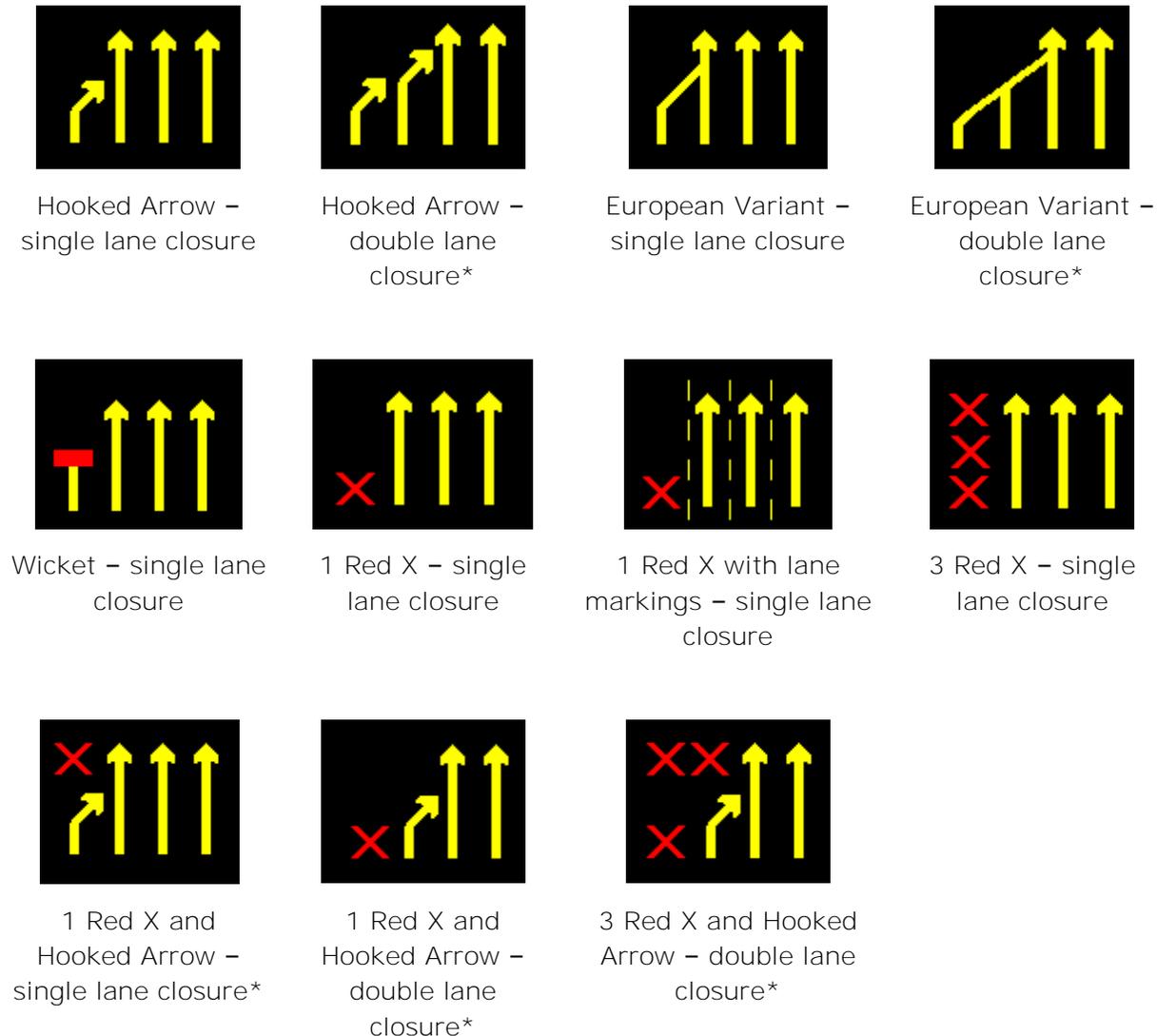
Currently, in the event of an incident or road works for example, gantry-mounted signals and VMS convey two types of lane closure information and / or instruction to drivers:

- > Lane Divert Right / Left (LDR/LDL) signal – instructing drivers to *move out of lane*; and
- > Red X signal – informing drivers that the *lane is closed to traffic*.

Therefore, to meet the operational functionality of current Managed Motorways schemes, lane closure aspects on a verge-mounted sign used in an MM2 scheme must also communicate both types of information. This could either be achieved via two different aspects presented on subsequent signs (mirroring the approach used to communicate lane closures via gantries) or communicating both types of information within the same aspect. The latter may be required for a two-lane closure for example, or if the spacing between information update points is increased within an MM2 environment and it is not operationally appropriate to display each piece of information separately.

Figure 33 below presents the candidate designs used in the PC Comprehension Test and / or questionnaire. The candidate designs were chosen on the basis that they were most consistent with existing approaches in communicating lane closure information and instructions on the road network and therefore should be more recognisable to drivers. For example, the designs incorporate arrows to communicate **running lanes** and the 'Wicket' or 'Red X' symbol to communicate a lane closure, consistent with existing aspects used on variable message signs and Red X gantry signalling respectively.

The use of a 'Hooked Arrow' to instruct drivers to move out of a lane is only currently used in fixed signing<sup>9</sup>, and another design for indicating a lane is closed ahead is based on a European design approved by the Vienna Convention on Road Signs and Signals (1968)<sup>10</sup>.



**Figure 33: Lane closure aspects (and descriptors) used in Task 3 Comprehension Tests**

*(Note: Designs that were only studied in the questionnaire are indicated with a \*)*

<sup>9</sup> Reference: Traffic Signs Regulations & General Directions, 2002, Diagram 872.1.

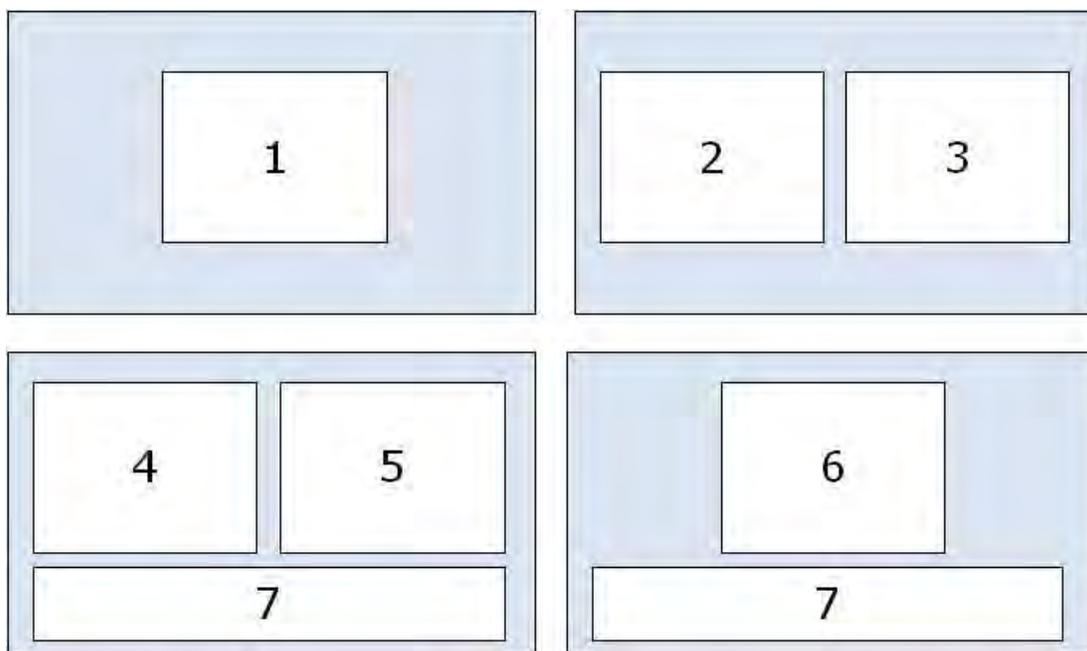
<sup>10</sup> Reference: Vienna Convention G12a.

### 3.4.2 MS4 Message Configurations

MS4 message configurations used in Session B of the PC task were developed by varying the number and arrangement of individual elements on the MS4. The elements used included speed limit and lane closure aspects, pictograms and text. It should be noted that MS4 message configurations were investigated in the PC Comprehension Test only.

The different MS4 message configurations were developed as follows:

- > All candidate designs contained a speed limit and / or lane closure aspect.
- > Figure 34 below illustrates the main areas of the MS4 that were used for the different message configurations. These areas were determined on the basis of the capabilities of the MS4 and the size of the elements, in line with HA specifications<sup>11</sup>.

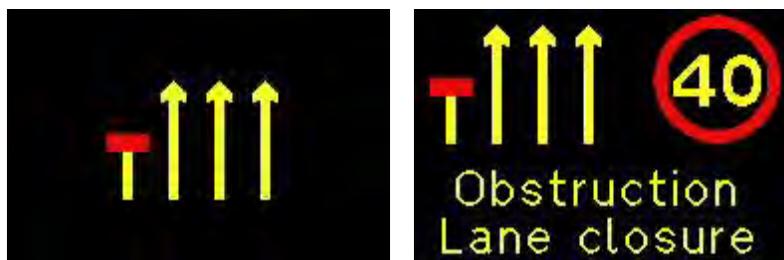


**Figure 34: Areas used within MS4 for different message configurations**

<sup>11</sup> Reference: MCE 2214B

- > Only text is displayed in the lower area (7), as it is single colour display (i.e. yellow only). Message configurations include one and two lines of text in this area<sup>12</sup>.
- > Areas 1 to 6 contain a speed limit aspect, lane closure aspect or pictogram. The speed limit aspect is always located to the right (area 3 or 5) if a lane closure aspect or pictogram is included as well. The lane closure aspect is also always located to the right if a speed limit aspect is not present and a pictogram is.

Configurations range in complexity from the simplest configuration where one speed limit or lane closure aspect is displayed, up to the most complex configuration where a speed limit aspect, lane closure aspect and two lines of text is displayed (see Figure 35 below). The full set of MS4 message configurations (17 in total) that were tested in Session 2 of the PC task is listed in Appendix C.



**Figure 35: Simplest and most complex MS4 message configurations assessed in Task 3 PC Comprehension Test**

<sup>12</sup> It should be noted that in order to fit two lines of text in the lower area (7) of the MS4 when also displaying a pictogram above, it is not possible to maintain the minimum spacing between the pictogram and adjacent text if there are ascending and descending letters. The required spacing between text lines was maintained for legibility.

## 3.5 Key Findings

### 3.5.1 PC Comprehension Test

#### 3.5.1.1 Assessment measures

The dependent variables in this test were accuracy and speed. Accuracy refers to **whether participants' response to the statements was correct**; speed refers to the time it took participants to choose the statement to be either true or false.

For both verge-mounted and gantry-mounted options, accuracy levels of participants' responses to speed limit and lane closure information were very high (>95%), even when presented at short exposure durations of 250 milliseconds.

This indicated that participants performed the task consistently without changing their tactics, for example, responding less accurately but faster (also known as the speed-accuracy trade off). From this it follows that speed, referred to as **response time**, can be confidently used as the primary assessment measure.

Statistical modelling and analysis was undertaken to determine whether the differences in response times between the images were statistically significant<sup>13</sup>.

The following sections present the main results from each experimental session.

#### 3.5.1.2 Findings

##### Session A – Verge-mounted versus Gantry-mounted Options

The first experimental session focussed on investigating differences between response times for images presenting speed limit and lane closure information either via a verge-mounted MS4 or gantry-mounted signals with an MS4.

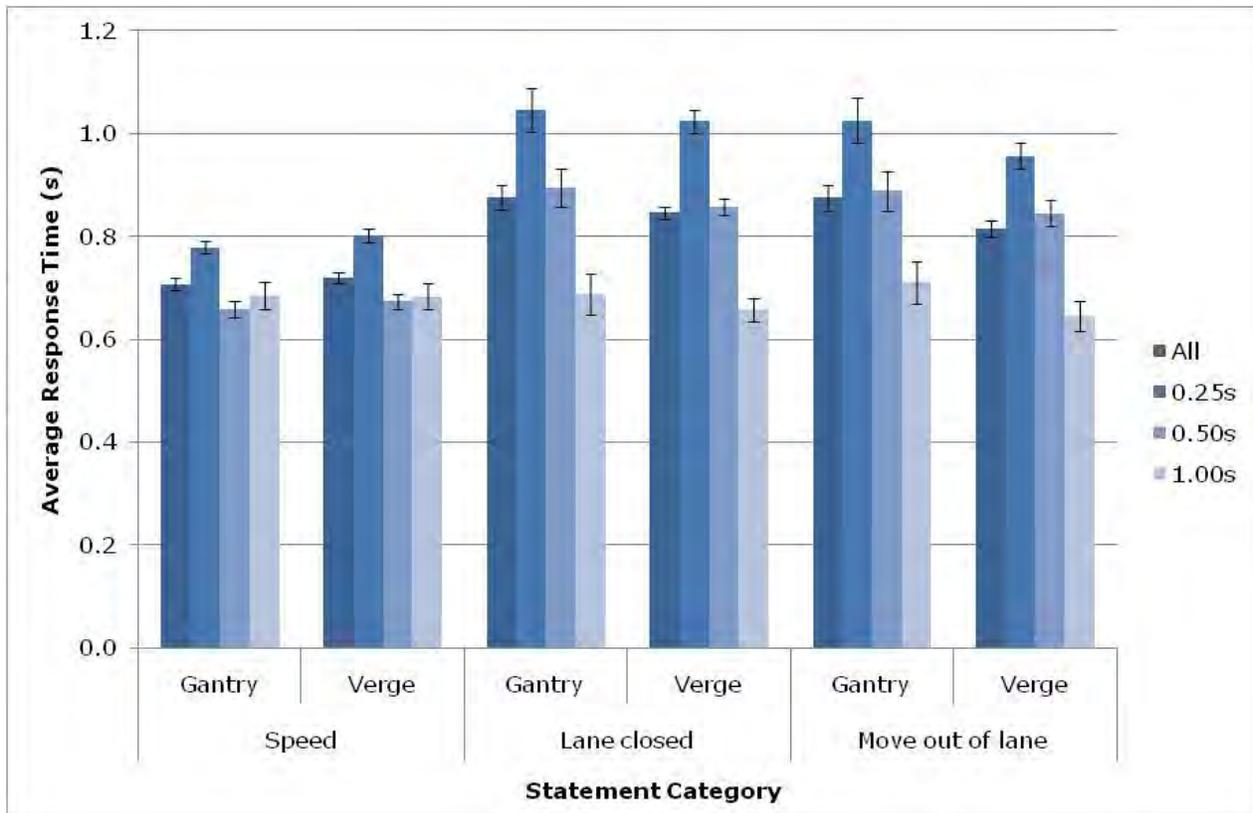
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<sup>13</sup> For efficiency of communication, if not explicitly stated, all references to the findings in this report being **significant** will be referring to **statistical** significance.

Statistical significance is assigned to any comparison with a p-value at the 10% level or less.

*Static version*

Figure 36 shows the mean (and Standard Error of the Mean, SEM) response times obtained in the static version of Session A for the verge-mounted and gantry-mounted options for each of the three statement categories, i.e. 'Speed', 'Lane closed', and 'Move out of lane'. The blue bar shows the grand mean calculated by combining the response times for each of the three exposure times used (0.25s, 0.50s and 1.00s).



**Figure 36: Average ( $\pm$ SEM) response times for the 'Speed', 'Lane closed', and 'Move out of lane' statements for each of the three exposure durations and collapsed across all exposure durations (All) for the verge-mounted and gantry-mounted options (Session A – Static version)**

The results from the static version (see Figure 36) show that the differences in response times between verge versus gantry-mounted options were found to be relatively small (<0.1s).

With the exception of the 'speed' statements, response times tended to be slightly shorter for the verge-mounted options.

Statistical analyses however indicated none of the differences in response time to be statistically significant ( $p > .05$ ).

The effect of sign type (verge versus gantry) on response time for the 'Speed' statements is less pronounced than for 'Lane closed' and 'Move out of lane' statements. This can possibly be explained by the fact that speed limit is displayed on each gantry AMI, whereas lane closure information is specific to the lane. Hence, visual search time required for lane closure information can be expected to be longer with the information presented on gantries. Within verge-mounted MS4s, all information is displayed in the same localised area.

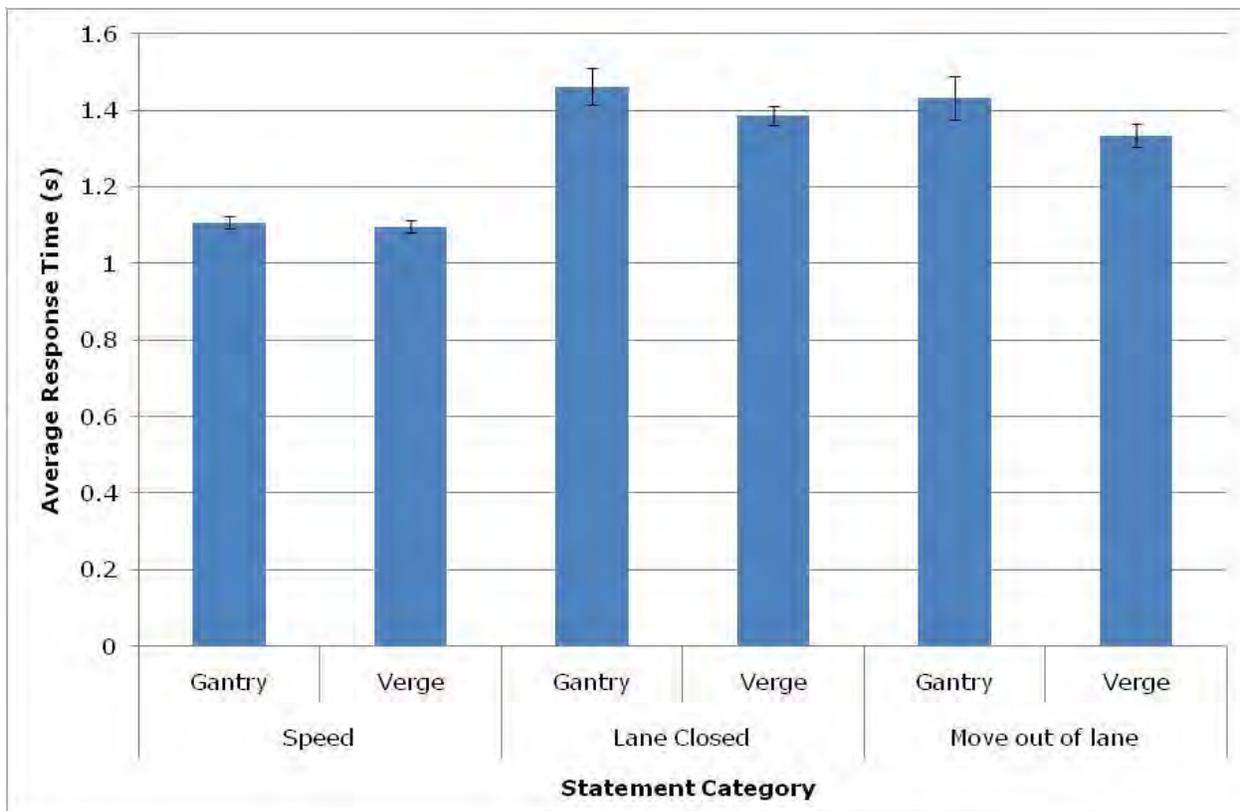
Figure 36 also shows the effect of exposure duration. The shortest exposure duration resulted in the slowest response time and the longest exposure duration resulted in the fastest response times for most categories. This suggests, unsurprisingly, that when participants had longer to extract the relevant information, they could be more certain of the correct response when prompted to indicate the correctness of the relevant statements.

Since accuracy levels were found to be high even in the 0.25s exposure duration condition, it was decided to focus the rest of the analysis on this dataset only. Given the high accuracy level, the 0.25s exposure duration condition provides the most critical test and is therefore the most sensitive performance condition.

As expected, for all options and statement categories, age had a significant effect whereby older participants responded significantly slower than younger participants ( $p < .05$ ). No significant gender effects were observed.

### ***Dynamic version***

Figure 37 shows the mean response times for the same verge and gantry-mounted options as in Figure 36, for each of the three statement categories obtained using the *dynamic* version.



**Figure 37: Average ( $\pm$ SEM) response times for the 'Speed', 'Lane closed', and 'Move out of lane' statements for the verge-mounted and gantry-mounted options (Session A – Dynamic version)**

The response times for the dynamic version show the same pattern as observed in the static version and tended to be shorter for the verge-mounted options, particularly in the 'Lane closed' and 'Move out of lane' statement categories.

Statistical analysis indicated a significant main effect of sign type (i.e. verge-mounted versus gantry-mounted) in the 'Lane closed' category ( $p=.051$ ). This means that verge-mounted options in the 'Lane closed' category were responded to significantly faster than the gantry-mounted options, with a difference in average response time of 0.08s.

The difference in response times between the verge-mounted and gantry-mounted options in the 'Move out of lane' category was significant at the 10% level ( $p=.081$ ). Therefore, verge-mounted options in the 'Move out of lane' category were responded to significantly faster than the gantry-mounted options, with a difference in average response time of 0.1s.

**There was no significant main effect of sign type in the 'Speed' statement category.**

Compared to the results obtained using the static version, it can be seen that in the dynamic version response times were approximately 0.2 to 0.4s higher. This difference in response times arises as a result of the methodology; the response time for the dynamic version is calculated from the point at which the image is first displayed on the screen and therefore incorporates the search and processing time required by the participant, whereas the static version measures the response time from the point at which the participant is prompted to respond and after they have seen the image. Furthermore, unlike the static version, the dynamic task was self-paced as opposed to system-paced. In other words, participants were allowed to view the scene until they were certain about the correct response required rather than being exposed to the scenes for fixed and limited time periods.

Again in line with the results of static version, a significant age effect observed with, on average, older participants responding slower ( $p < .05$ ). Unlike the static version, the dynamic version showed a significant effect of gender with female participants responding slower than male participants. In contrast to age (neuronal degeneration), there is no obvious reason for this.

In summary, the results for both the static and dynamic versions suggested that **participants' accuracy and speed of comprehension of information presented on a single verge-mounted MS4 was greater than or equal to the same information displayed on gantry-mounted signals and an MS4.**

In the dynamic version of the test, verge-mounted options were responded to significantly faster than gantry-mounted options for **'Lane closed' and 'Move out of lane' statements, with a difference in response times of 0.08s and 0.1s respectively.**

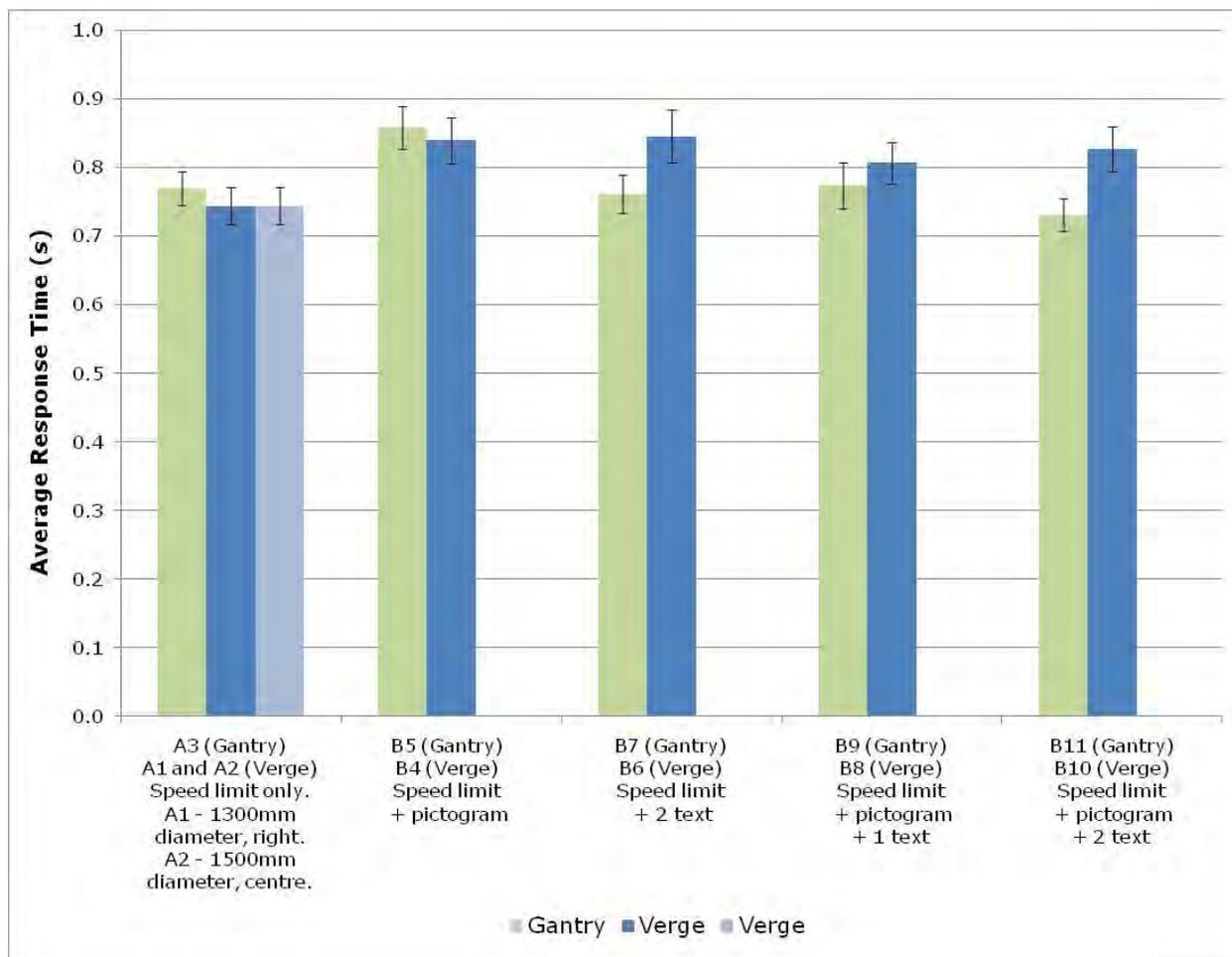
### **Session A – Individual Message Options**

Session A also investigated the effect of supplementary information (e.g. pictogram and text elements) on participant responses to both the gantry-mounted and verge-mounted signing options. Similarly, the impact of varying the size and position of speed limit aspects and different designs for lane closure aspects to be displayed on the verge-mounted MS4 was investigated.

Further analyses were therefore conducted to determine which individual verge-mounted and gantry-mounted options differed significantly with regard to response times.

*Static version*

Figure 38 shows the average response times to 'Speed' statements for all verge and gantry-mounted options individually (see Appendix C for images) as obtained via the static version and for an exposure duration of 0.25s.



**Figure 38: Average ( $\pm$ SEM) response time (s) for the verge and gantry-mounted options in the 'Speed' statement category (Session A – Static version, exposure duration = 0.25s)**

Figure 38 shows that with regard to the 'Speed' statements, some verge-mounted options tended to result in slightly longer response times compared to gantry-mounted options. However, post-hoc statistical tests did not indicate these differences to be statistically significant.

Post-hoc statistical tests indicated that the response time to sign **A2 (verge-mounted option)** was significantly faster compared to sign **B5 (gantry-mounted option)** (approaching significance at 5% level). The sign images are illustrated in Figure 44. The difference in average response time was 0.11s.



**A2 – Verge**

*Speed limit aspect (1500mm diameter)*

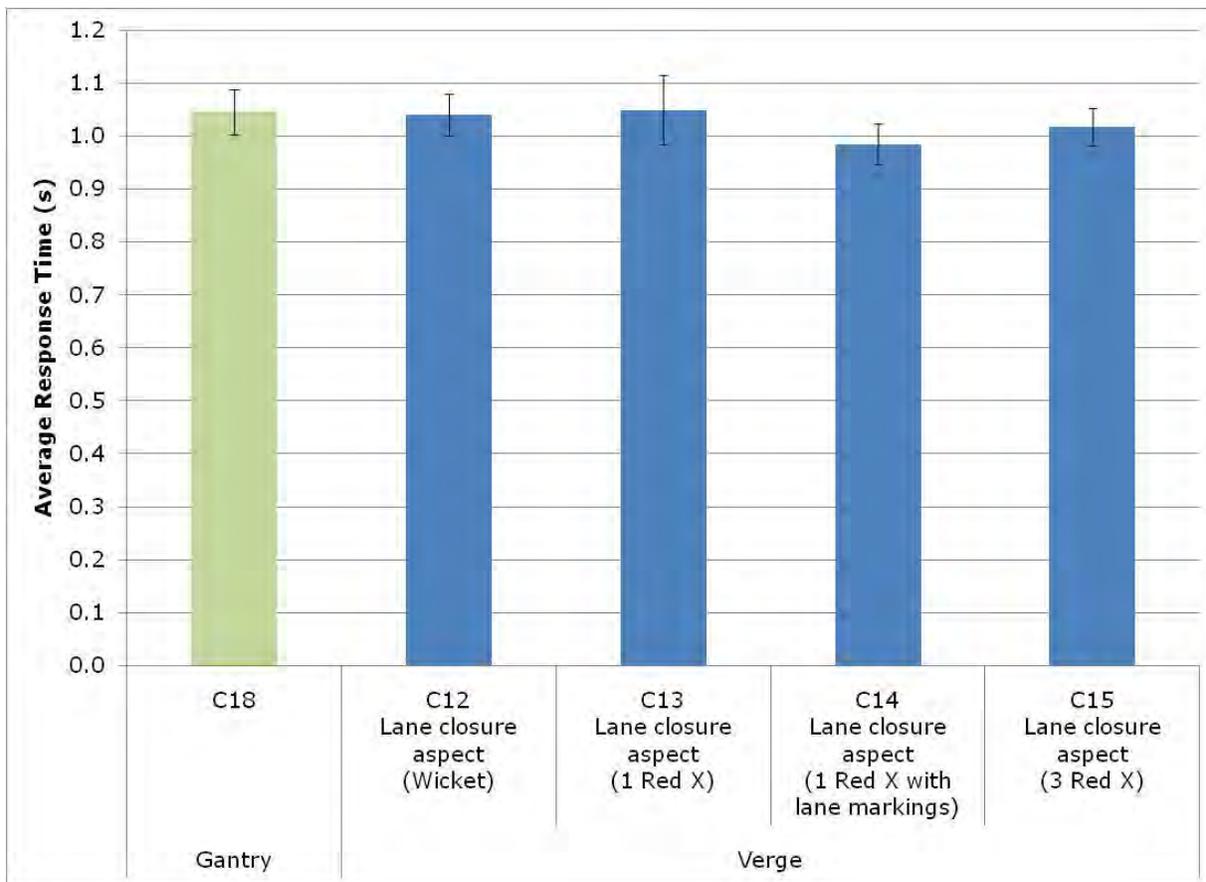


**B5 - Gantry**

*AMI speed limit aspect + pictogram*

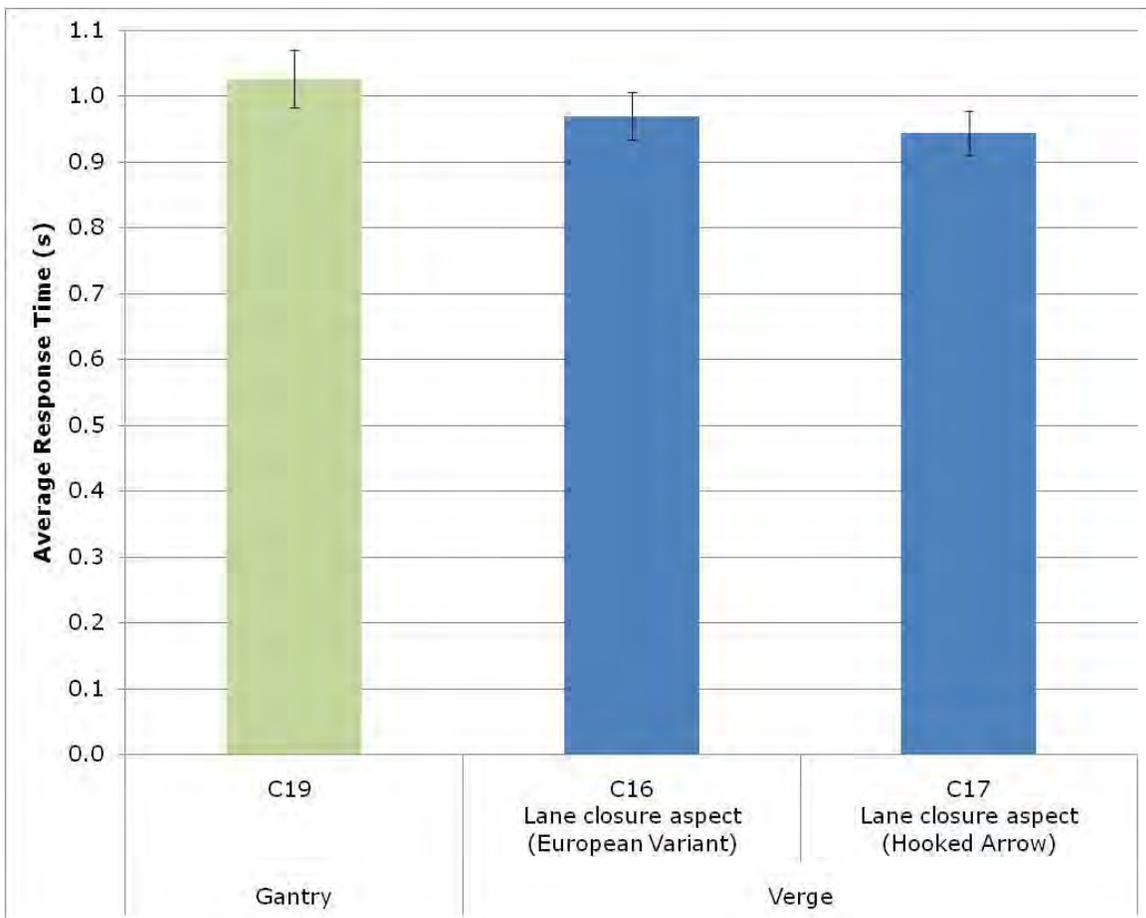
**Figure 39: Sign pairs with statistical differences in 'Speed' statement category: A2 had a significantly faster mean response time than B5 ( $p < .10$ ) (Session A – Static version)**

Figure 40 and Figure 41 show the response times for the 'Lane closed' statements and 'Move out of lane' statements respectively for all verge and gantry-mounted options individually (see Appendix C for images) as obtained via the static version and for an exposure duration of 0.25s.



**Figure 40: Average ( $\pm$ SEM) response time (s) for verge and gantry-mounted options in the 'Lane closed' statement category (Session A – Static version, exposure duration = 0.25s)**

As shown in Figure 40, information regarding lane closures appears to be equally well relayed via either verge or gantry-mounted options, with the different lane closure aspects appearing to be equally effective. No significant differences were observed between any of these signing options.



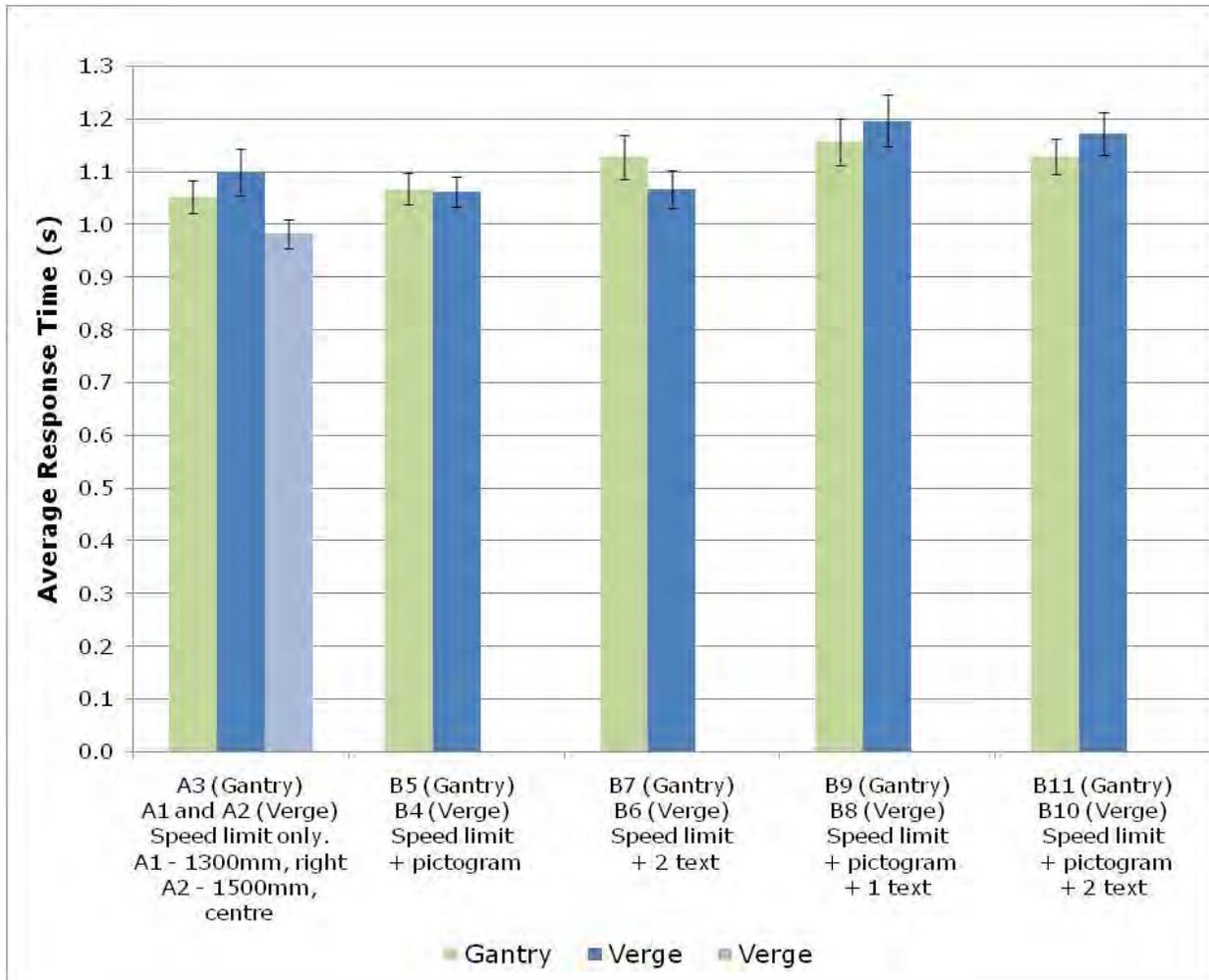
**Figure 41: Average ( $\pm$ SEM) response time (s) for verge and gantry-mounted options in the 'Move out of lane' statement category (Session A – Static version, exposure duration = 0.25s)**

Both of the individual verge-mounted options displaying different aspect designs (Hooked Arrow and European Variant) appeared to be more effective in providing instruction to 'Move out of lane' (Figure 41) than the gantry-mounted equivalent. No significant differences were observed between any of these signing options.

*Dynamic version*

For the dynamic version, a similar pattern emerged as that observed for the static version of the PC task.

Figure 42 shows the response times for the 'Speed' statement category for all verge and gantry-mounted options individually (see Appendix C for images) as obtained via the dynamic version.



**Figure 42: Average ( $\pm$ SEM) response time (s) for the verge and gantry-mounted options in the 'Speed' statement category (Session A – Dynamic version)**

Statistical analysis revealed a highly significant main effect of sign ( $p < .001$ ), meaning that, overall, the signing option displayed had a significant effect on response times.

Post-hoc statistical tests showed that at the 5% significance level ( $p < .05$ ), within the 'Speed' category the response time to sign **A2 (verge-mounted option)** was significantly faster than to the signs **B8, B9, B10, and B11 (both verge-mounted and gantry-mounted options)**. The sign images are illustrated in Figure 43. The difference in average response times ranged from around 0.15 – 0.21s.

A possible explanation for this finding is that sign A2 consisted of the large speed limit aspect centrally located within the verge-mounted MS4, not surrounded by any other information. Within the 'Speed' category, sign A2 therefore contained the least distractive elements and provided, in the context of signal-to-noise ratios, the largest signal. As such, a priori, sign A2 could have been expected to perform best.



**A2 - Verge**

*Speed limit aspect (1500mm diameter)*



**B8 - Verge**

*Speed limit aspect (1300mm diameter) + pictogram + text (1 line)*



**B9 - Gantry**

*AMI speed limit aspect + pictogram + text (1 line)*



**B10 - Verge**

*Speed limit aspect (1500mm diameter) + pictogram + text (2 lines)*



**B11 - Gantry**

*AMI speed limit aspect + pictogram + text (2 lines)*

**Figure 43: Sign pairs with statistical differences in 'Speed' statement category: A2 – significantly faster response times than B8, B9, B10 and B11 (Session A – Dynamic version)**

Post-hoc statistical tests also indicated that at the 10% level ( $p < .10$ ), the response time to sign **A3 (gantry-mounted option)** was significantly faster compared to sign **B10 (verge-mounted option)**, illustrated in Figure 44. The difference in average response time was 0.19s.

As before, these signs do not display equivalent information in terms of the number of informational elements; the gantry-mounted option does not include pictogram or text elements. It is possible, therefore, that the presence of the pictogram element in B10 had an effect on response time to the speed limit information by acting as a distracting element, when compared to A3. The effect of supplementary information on response time was further tested in Session B.



**A3 – Gantry**

*AMI speed limit aspect*



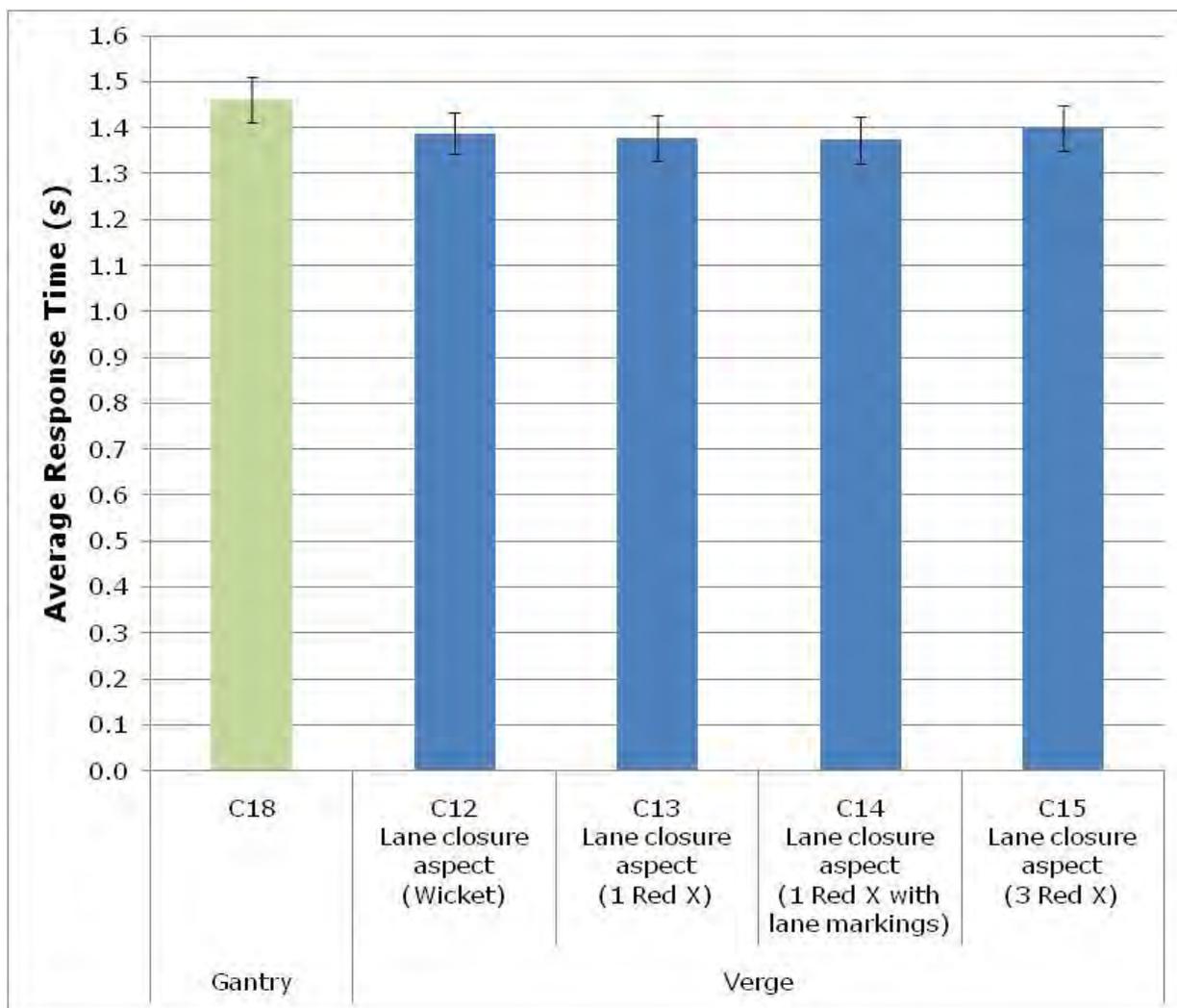
**B10 - Verge**

*Speed limit aspect (1300mm diameter) + pictogram + text (2 lines)*

**Figure 44: Sign pairs with statistical differences in 'Speed' statement category: A3 had a significantly faster mean response time than B10 ( $p < .10$ ) (Session A – Dynamic version)**

Other statistically significant differences between individual signing options in the dynamic version of Session A were found to be between two verge-mounted options or two gantry-mounted options only.

Figure 45 shows the response times for individual signing options in the 'Lane closed' category.



**Figure 45: Average ( $\pm$ SEM) response time (s) for the verge and gantry-mounted options in the 'Lane closed' statement category (Session A – Dynamic version)**

In general, the response times for all verge-mounted options are lower than the gantry-mounted equivalent.

Post-hoc statistical tests indicated that at the 10% level ( $p < .10$ ), the response time to **verge-mounted sign C14** was significantly faster compared to the equivalent **gantry-mounted sign option C18**, illustrated in Figure 46. The difference in average response time was 0.09s.



**C14 - Verge**

Speed limit aspect (1300mm diameter) + lane closure aspect (1 Red X with lane markings) + text (2 lines)

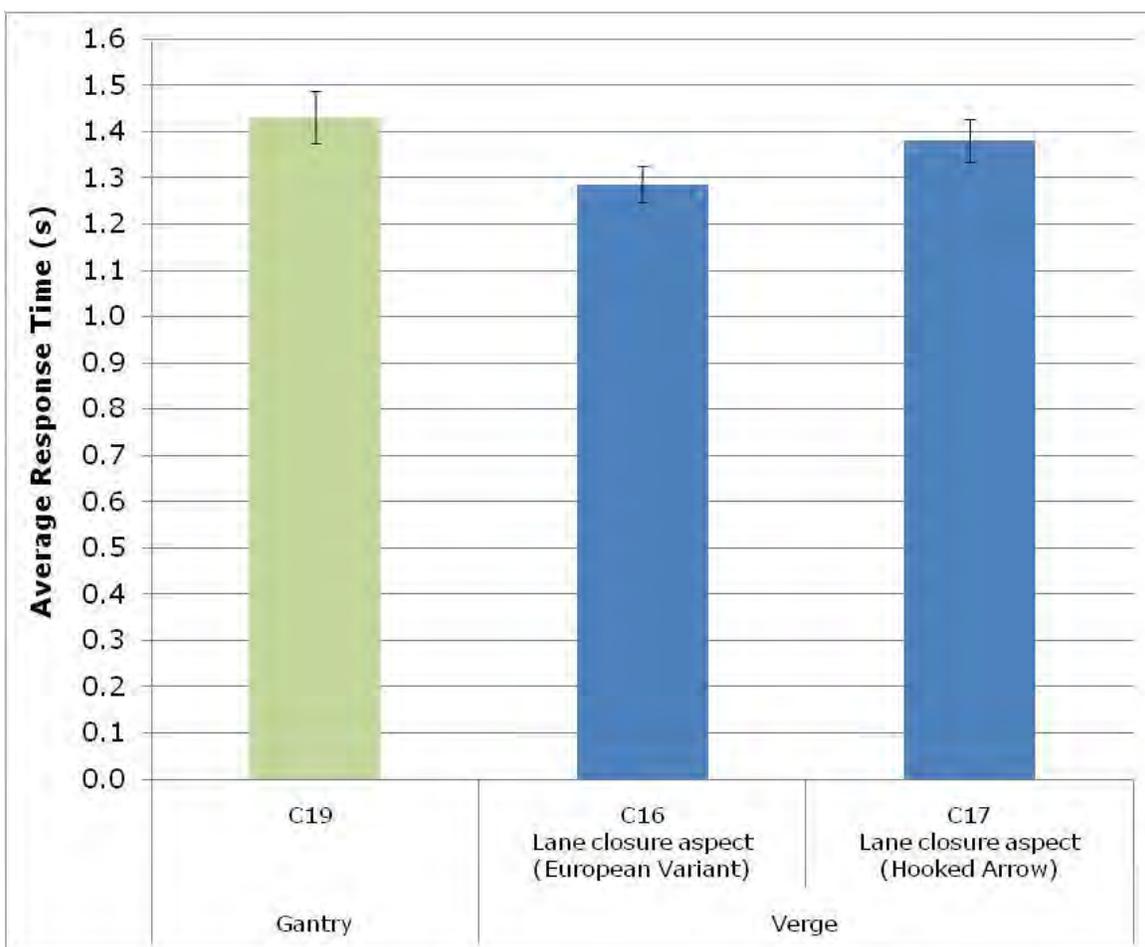


**C18 - Gantry**

AMI speed limit aspect + Red X signal + text (2 lines)

**Figure 46: Sign pairs with statistical differences in 'Lane Closed' statement category: C14 had a significantly faster mean response time than C18 ( $p < .10$ ) (Session A - Dynamic version)**

Finally, Figure 47 shows the response times for the 'Move out of lane' category.



**Figure 47: Average ( $\pm$ SEM) response time (s) for the verge and gantry-mounted options in the 'Move out of lane' statement category (Session A - Dynamic version)**

Statistical analysis revealed a significant main effect of sign ( $p < .05$ ) for the 'Move out of lane' statement category.

Post-hoc statistical tests indicated that at the 5% level ( $p < .05$ ), the response time to **verge-mounted sign C16** was significantly faster compared to the **equivalent gantry-mounted sign option C19**, illustrated in Figure 48. The difference in average response time was 0.14s.

This again suggests verge-mounted signing to be equal or better than gantry-mounted signing at instructing drivers to move out of a particular lane.



**C16 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (European variant) + text (2 lines)*



**C19 - Gantry**

*AMI speed limit aspect + LDR signal + text (2 lines)*

**Figure 48: Sign pairs with statistical differences in 'Move out of lane' statement category: C16 had a significantly faster mean response time than C19 (Session A – Dynamic version)**

For both the static and dynamic versions, there was no occasion where an individual gantry-mounted option was responded to significantly faster than an equivalent individual verge-mounted option for any of the statement categories. On the contrary, several verge-mounted options outperformed gantry-mounted options and indicate that driver information can be equally or better relayed via verge-mounted MS4 options than via gantry-mounted options.

There was no evidence to suggest that the addition of supplementary information adversely affected the response times to verge-mounted options compared with gantry-mounted options; there was only one occasion when a gantry-mounted option was responded to significantly faster than a verge-mounted option, where the verge option included an additional supplementary element. However, it does appear that the addition of supplementary information can affect response times for both verge-mounted and gantry-mounted options. This is explored further in Session B in relation to verge-mounted signing only.

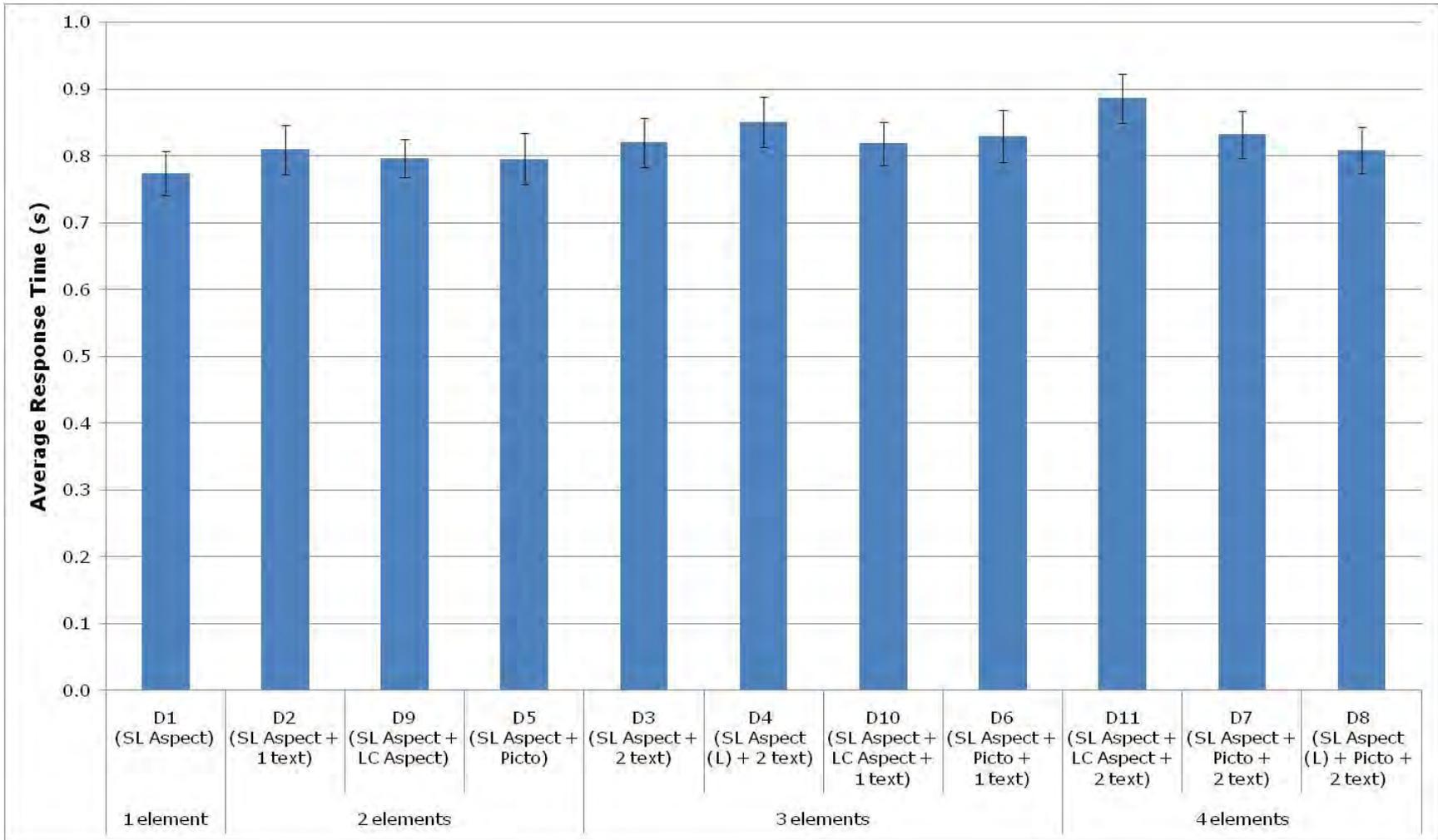
The verge-mounted option using a speed limit aspect of size 1500mm diameter and centred in the position of the MS4 was responded to significantly faster than both verge and gantry-mounted options which contained a 1300mm speed limit aspect with additional supplementary information (i.e. a pictogram and text element). The difference in average response times ranged from 0.11s to 0.21s.

The results also indicated that in general there was little difference in response times arising from variations in the design of the lane closure aspect on a verge-mounted MS4. The only significant results were found in the Dynamic version; the **'1 Red X with lane markings'** and **'European variant' lane closure aspects** had significantly faster response times to the equivalent gantry-mounted options (at 10 and 5% levels respectively); the difference in average response times were 0.09s and 0.14s.

### ***Session B – MS4 Message Configurations***

The second experimental session focused on investigating differences between response times for images presenting speed limit and lane closure information via a verge-mounted MS4, with different configurations of the MS4 message (see Appendix C). This session used the static version of the test only.

Figure 49 shows the average response times obtained for the verge-mounted MS4 message configurations for **the two 'Speed' and 'Lane closed' statement categories**, respectively.



**Figure 49: Average ( $\pm$ SEM) response time (s) for MS4 message configurations in the 'Speed' statement category (Session B – static version, exposure duration = 0.25s)**

[SL = Speed Limit, LC = Lane Closure, (S) = 1300mm diameter, (L) = 1500mm diameter]

*Note: Each line of text is considered as a separate element*

Figure 49 shows a very small increase in response times between D1 (displaying a speed limit aspect only) and the other message configurations displaying the speed limit aspect with additional elements.

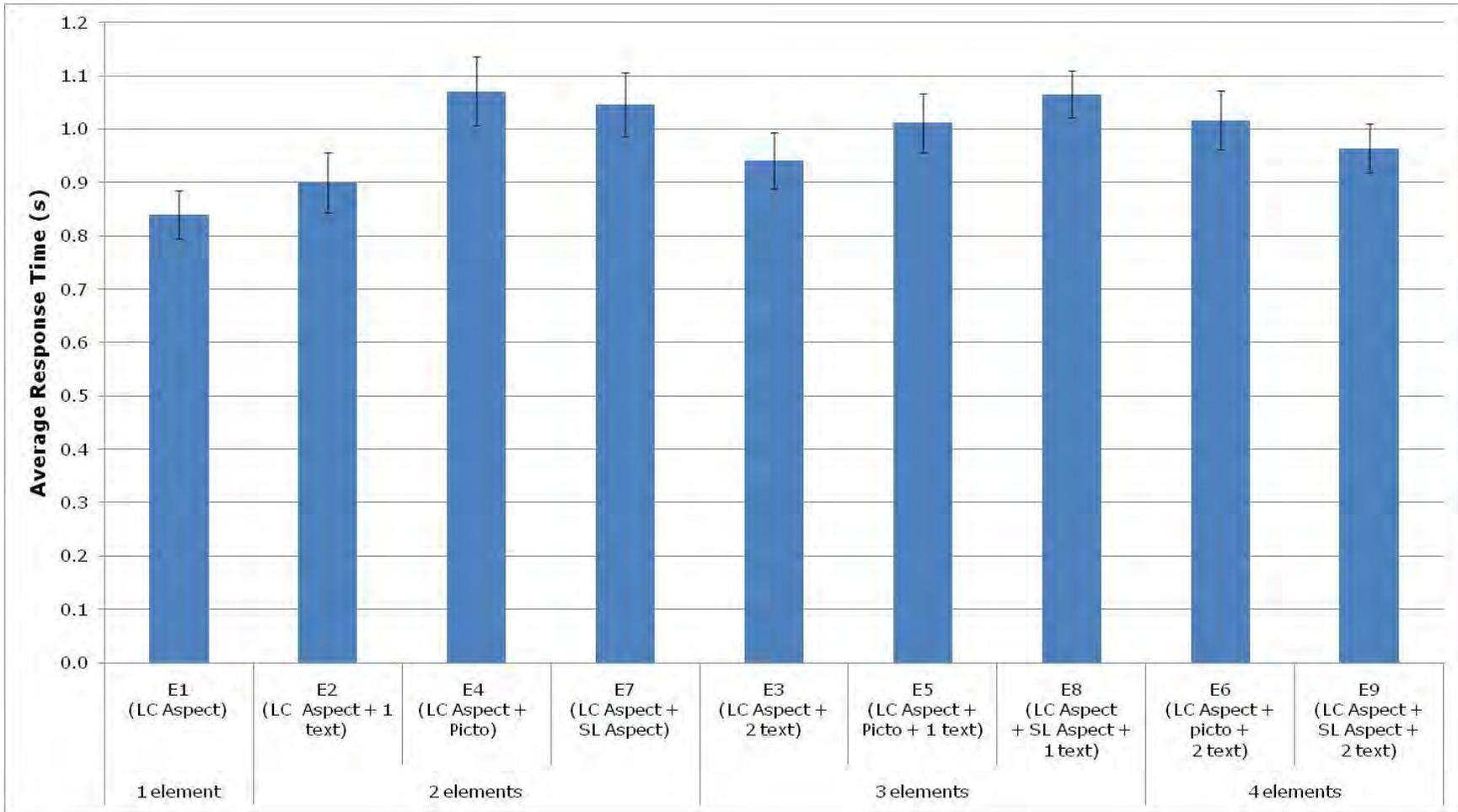
Statistical analysis however indicated that sign effect was not significant in the **'Speed' statement category, meaning that the differences in response times** between MS4 message configurations were not statistically significant.

This suggests that overall comprehension of speed limit instructions is not affected by being part of a complex message with additional information and may be explained by a pop-out effect<sup>14</sup> for the speed roundel. Pop out effects occur when a visual target has distinct features that separates it from its surroundings. For example, **a red X can be quickly found among any number of black X's and O's because the red X has a discriminative feature of colour and will "pop out"**. Similarly, the speed limit roundel is the only round aspect within both verge and gantry-mounted sign options.

Figure 50 below illustrates the response times for MS4 message configurations in the **'Lane closed'** statement category.

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<sup>14</sup> Reference: Treisman A, & Gelade G. (1980). A feature integration theory of attention. Cognitive Psychology Vol 12, pp. 97 – 136.



**Figure 50: Average ( $\pm$ SEM) response time (s) for MS4 message configurations in the 'Lane closed' statement category, grouped by the number of elements displayed on the message (Session B – Static version, exposure duration = 0.25s)**

[SL = Speed Limit, LC = Lane Closure, (S) = 1300mm diameter, (L) = 1500mm diameter]

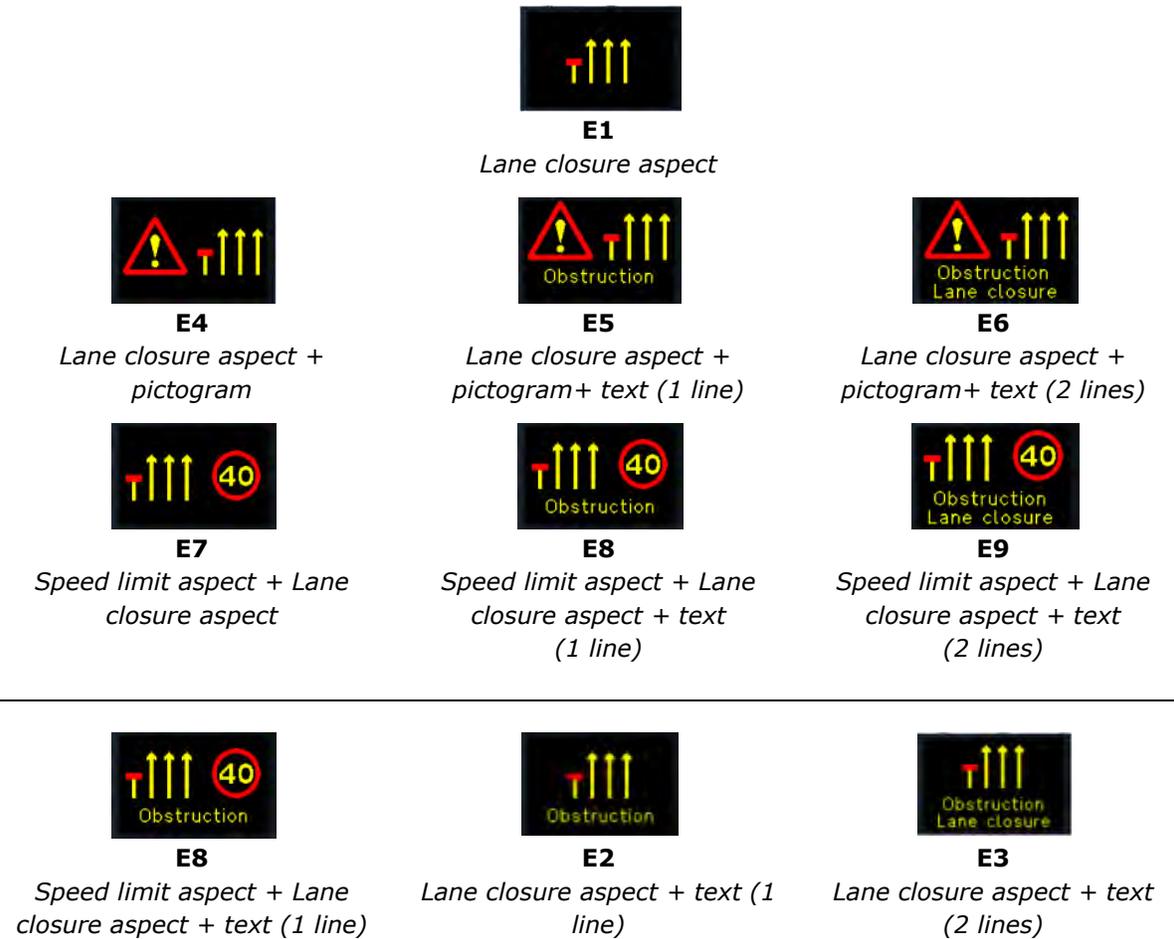
*Note: Each line of text is considered as a separate element*

Similarly to the response times to 'Speed' statements, an increase in response times to 'Lane closed' statements was observed as additional elements were added to the simplest configuration consisting of a single lane closure aspect (sign reference E1).

Post-hoc statistical tests indicated that sign effect was highly significant ( $p < 0.001$ ) for the 'Lane Closed' statements, i.e. the sign option displayed had a significant influence on participant response times. Comparisons determined that there were significant differences in response times between individual MS4 message configurations at the 5% and 10% level (see Figure 51):

- > **E1** (Lane closure aspect only) was responded to significantly *faster* than **E4, E5, E6, E7 and E8 ( $p < .05$ )** and **E9 ( $p < .10$ )**, all of which contained either a pictogram or lane closure aspect and / or one or two text elements. The difference in average response times ranged from 0.17s to 0.23s.
- > **E8** (Lane closure aspect + speed limit aspect + 1 line text) was responded to significantly *slower* than **E2** (lane closure aspect + 1 line text) ( $p < .05$ ) and **E3** (lane closure aspect + 2 lines text) ( $p < .10$ ). The difference in average response times was 0.16s and 0.12s respectively.

Similar to the explanation provided for the superior performance of the large speed limit aspect in the 'Speed' statement category, signs **E1, E2 and E3** contained the least distractive elements (i.e. lane closure aspect only or lane closure aspect with one or two text elements) and provided the largest signal in the context of signal-to-noise ratio.



**Figure 51: Sign pairs with statistical differences in 'Lane closed' statement category: E1 had significantly faster mean response times than E4, E5, E6, E7 and E8 ( $p < .05$ ) and E9 ( $p < .10$ ), E8 had significantly slower mean response times to E2 ( $p < .05$ ) and E3 ( $p < .10$ ) (Session A – Dynamic version)**

Generally, response times in the 'Lane closed' statement category were higher than for the 'Speed' category. The addition of supplementary elements also had a more significant effect on response times in the 'Lane closed' category, which suggests that participants found it harder to discern the lane closure aspect within an MS4 message when next to other elements. This could be because a lane closure aspect is more complex visually than a speed limit aspect and there may be more effects in terms of contour interaction (i.e. the interaction between the edges of elements within a message) which can affect processing time.

The mean response times recorded in Session B were similar to those recorded in Session A for both categories.

Overall, both Sessions A and B demonstrated that the speed limit and lane closure information displayed on a verge-mounted MS4 could be comprehended successfully even for the most complex configuration of MS4 message.

For speed limit instructions, it appeared that comprehension was equally good for all MS4 message configurations.

Response times were higher for the MS4 message configurations when lane closure as opposed to speed limit instruction was being communicated.

The results suggested that the addition of elements to an MS4 message containing a single speed limit or lane closure aspect may reduce performance in terms of sign comprehension. Significant differences in mean response times to lane closure information were noted between the simplest MS4 message configuration and more complex configurations including a second aspect, pictograms and / or text elements. The difference in average response times ranged from 0.17s to 0.23s.

The evidence does not suggest that there is a strong surplus effect beyond this level; performance did not significantly reduce when comparing the further addition of a pictogram and 1 or 2 lines of text. However, a significant increase in response **time was observed in the 'Lane closed' statement category between messages** containing just the lane closure aspect and one or two text elements, with a message including the speed limit aspect as well. The differences in average response times were 0.12s and 0.16s.

The results suggested that, due to the relatively high complexity, lane closure information was more likely to be affected by surrounding elements. Speed limit information, on the other hand, appeared to be more robust and less affected by additional information displayed within its proximity. In addition to the simplicity of the conveyed message, this can be explained by the pop-out effect that occurs for speed roundels.

## 3.5.2 Questionnaire

### 3.5.2.1 Areas of investigation

The following areas were investigated through the questionnaire:

#### > **Comprehension of aspect designs**

- Interpretation of aspect and the extent to which the intended meaning matches the perceived meaning;
- Perception of aspect as mandatory or otherwise; and
- Understanding of required driver behavioural response.

#### > **Influence-potential of MS4 message elements**

This part investigated which elements of a MS4 message, such as speed limit and lane closure aspects, pictograms and text, were perceived by participants to be most likely to influence their driving behaviour i.e. influence-potential.

#### > **Perceptions of verge-mounted driver information provision**

This part investigated participant perception of the effectiveness of verge-mounted driver information provision in terms of impact on safety and driver behaviour.

Participants were also provided the opportunity within the questionnaire to provide other general comments of relevance to this task.

### 3.5.2.2 Comprehension of aspect designs

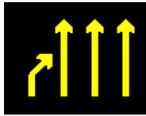
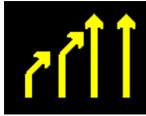
#### Lane closure aspects - interpretation

The responses for participants' interpretation of each lane closure aspect were categorised and coded on a scale of 1 to 7 according to the extent to which the perceived meaning matched the intended meaning (see Section 3.3.2 for detailed methodology). Table 9 details the ratings for each of the lane closure aspects investigated. Lower values indicate a closer match between the perceived and intended meaning.

**Table 9: Mean comprehension ratings for lane closure aspects**

[(S) and (D) refer to whether the aspect communicates a single or double lane closure]

Aspect	Intended Meaning – Key Informational Elements	Rating (Mean)
 <i>Wicket (S)</i>	Lane 1 closed	1.3
 <i>1 Red X (S)</i>	Lane 1 closed	1.3
 <i>1 Red X + lane markings (S)</i>	Lane 1 closed	1.5
 <i>3 Red X (S)</i>	Lane 1 closed	1.4
 <i>Hooked Arrow + Red X (S)</i>	Lane 1 closed + Move out of lane 1	1.7

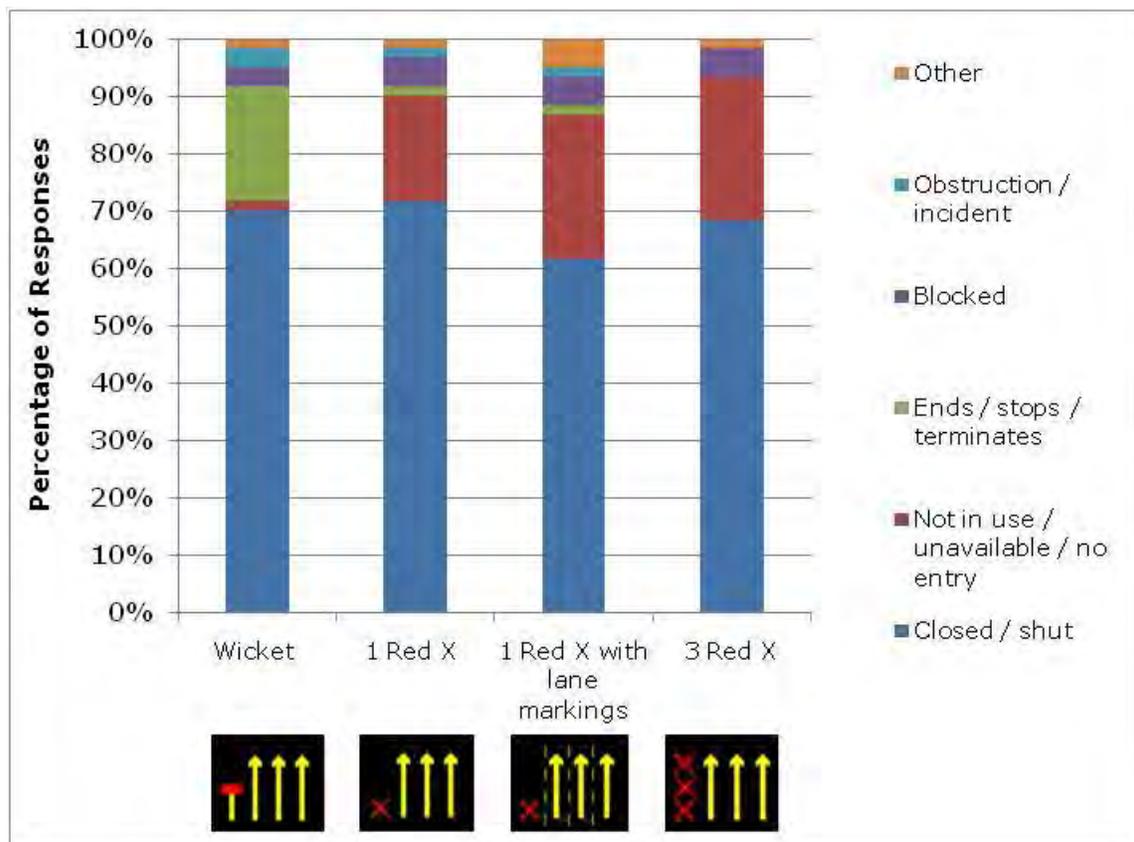
Aspect	Intended Meaning – Key Informational Elements	Rating (Mean)
 <i>Red X + Hooked Arrow (D)</i>	<b>Lane 1 closed + Move out of lane 2</b>	1.5
 <i>Hooked Arrow (S)</i>	<b>Move out of lane 1</b>	1.9
 <i>European Variant (S)</i>	<b>Move out of lane 1</b>	2.0
 <i>Hooked Arrow (D)</i>	<b>Move out of lanes 1 and 2</b>	2.4
 <i>European Variant (D)</i>	<b>Move out of lane 1 and 2</b>	2.5
 <i>3 Red X + Hooked Arrow (D)</i>	<b>Lane 1 and 2 closed + Move out of Lane 2</b>	2.0

The results indicated that participant comprehension of all lane closure aspects was strong. The majority of responses for each aspect scored in the top 2 categories on the scale, meaning that the key informational elements being communicated by the aspect were captured.

The following paragraphs investigate in further detail the interpretation, and consistency in interpretation, of the lane closure aspects grouped by the key informational element(s) being communicated.

*Detailed interpretation of 'Lane closed' aspects*

Figure 52 provides details of the proportion of responses that used a particular term to describe the status of LBS1 for each of the four aspect designs, whose intended meaning was 'Lane closed'.



**Figure 52: Terminology used by participants when describing 'Lane closed' aspects**

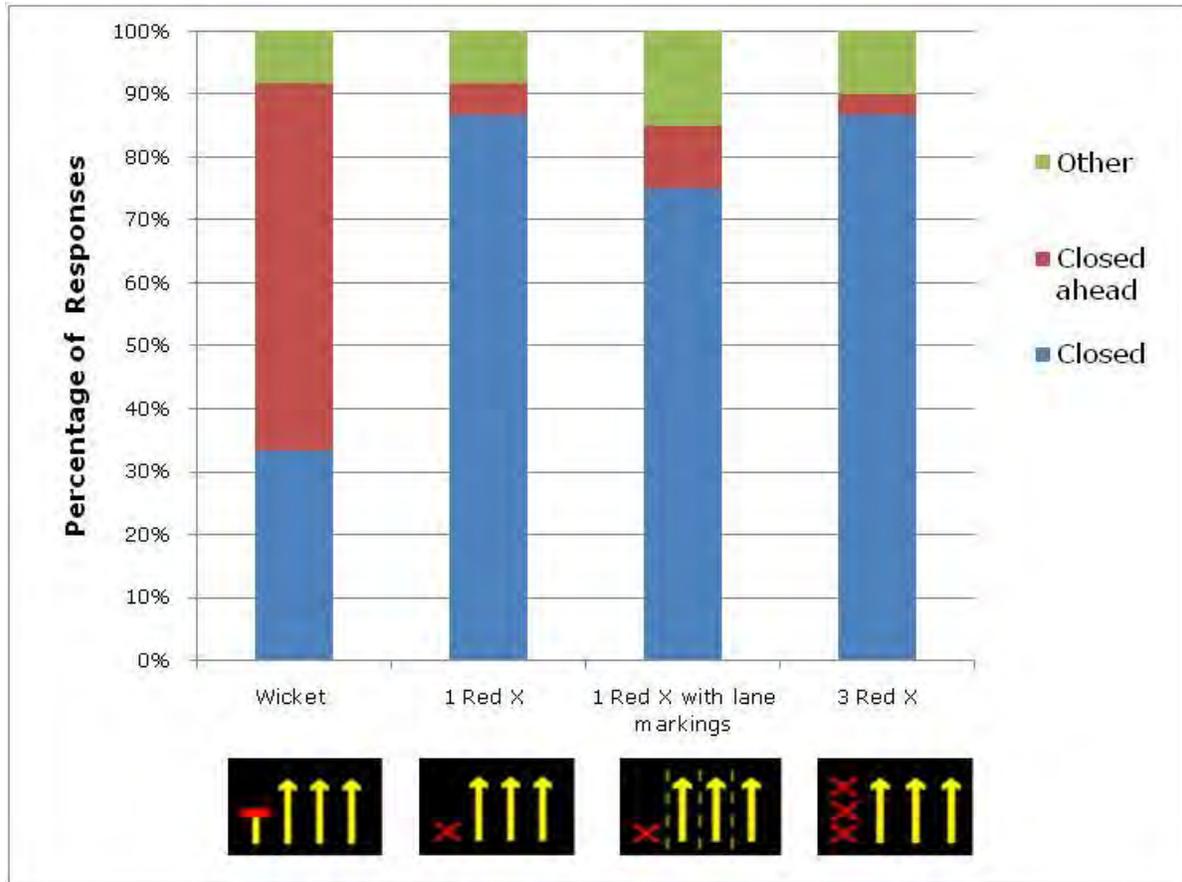
The results highlight that there are differences in the interpretation of the Wicket aspect compared to those designs incorporating a Red X.

As can be seen in Figure 53, for all aspect designs the majority of participants (>60%) **explicitly referred to the lane as 'closed'**. For those aspect designs incorporating a Red X, the next most frequently used term was that the lane was **'not in use / unavailable to traffic'**.

However, for the Wicket design, participants were more likely to refer to the lane as **'ending', 'stopping' or 'terminating'** (20%). One participant stated that the lane was a **'dead end'** and another that the lane **'ceases to exist'**. This suggests some ambiguity in participant interpretation of what to expect ahead.

More so than the single Red X aspect, participants interpreted the **'3 Red X'** aspect to mean that the lane was closed for a relatively greater distance, using phrases such as **'for some considerable distance', 'for the foreseeable future', and 'not reopening'**. Furthermore, participants viewed the aspect as communicating a stronger message that the lane should not be used, for example using phrases such as **'in no circumstances drive in', 'definitely not available', 'completely closed off' and 'seek to move urgently'**. No participants interpreted this design to mean that the lane **'ended' or similar**. One participant indicated that he did not know the meaning of this aspect.

Responses were also categorised, where appropriate, to assess the proportion of participants that interpreted each aspect as either communicating a lane closure **now**, i.e. in immediate effect, or **ahead**, i.e. some point downstream of the sign.

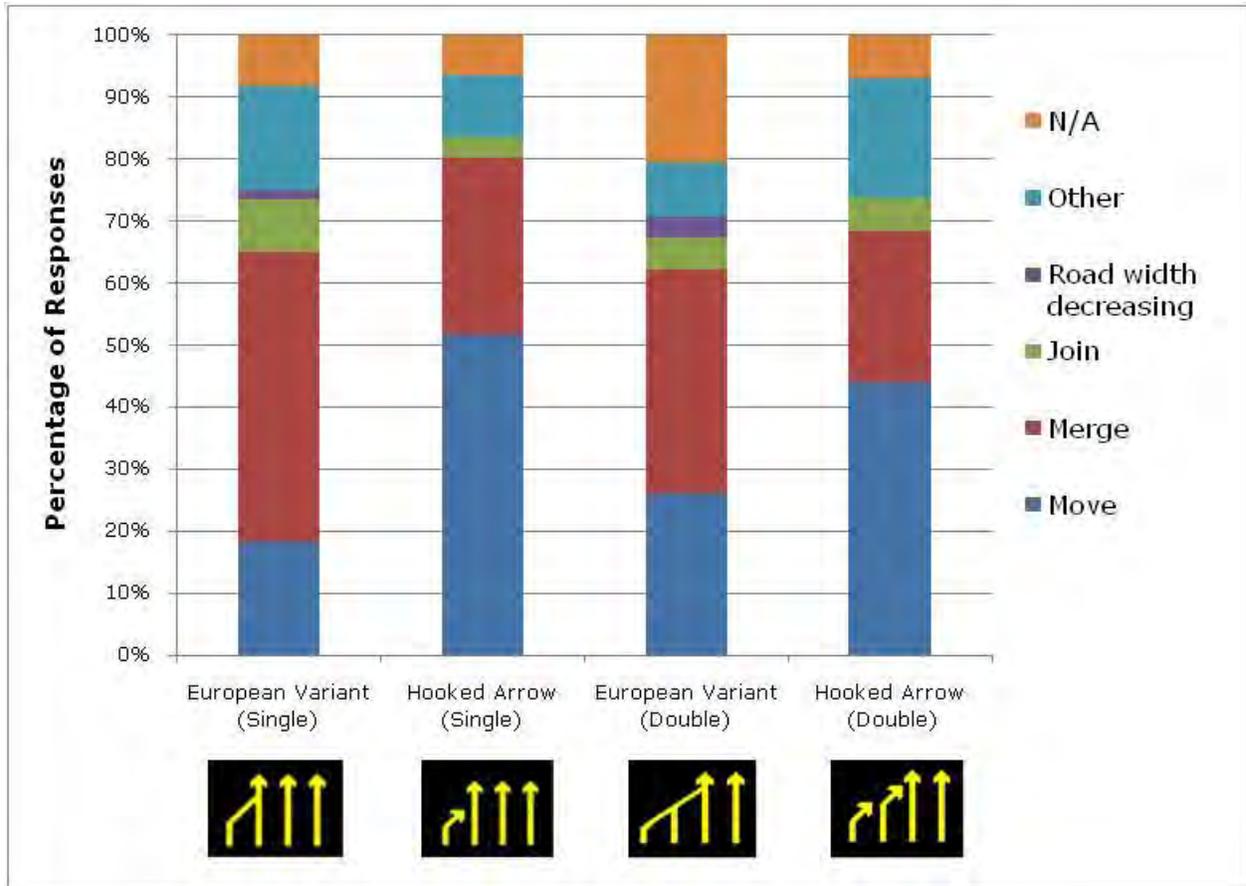


**Figure 53: Participant description of lane closure aspects in terms of 'closed' / 'closed ahead'**

The results highlight that participants were more likely to view the Wicket aspect as communicating a lane closure *ahead* than for designs with a Red X.

*Detailed interpretation of 'Move out of lane' aspects*

Figure 54 provides details of the terminology used by participants to describe the instruction being communicated for each of the four aspect designs that intended to communicate a 'move out of lane' instruction. The category 'not applicable' was used for incorrect and 'don't know' responses, as well as those responses that did not refer to the instruction directly (i.e. if the participant stated that there was a lane closure ahead only).



**Figure 54: Terminology used by participants when describing 'Move out of lane' aspects**

For all of the aspects in the figure above, there were a greater number of *'don't know'* responses and responses where the perceived meaning did not match the intended meaning than for aspects whose intended meaning was 'Lane closed'. For example, some participants referred to separate lanes of traffic joining the main carriageway or slip roads.

For the double lane closure aspects whose intended meaning was 'Move out of lane', most responses did not acknowledge the sequence with which drivers were to do so. This may have implications at an operational level if there is necessity to conduct a staged closure of two or more lanes.

The results suggested that there were differences in the interpretation of aspects containing the Hooked Arrow compared to the European Variant aspects.

The two aspects containing the Hooked Arrow were more likely to prompt responses that refer to the intended requirement for traffic or vehicles to *'move'* out of LBS1/2. The responses in relation to the European Variant aspects more frequently referred to the lanes as *'merging'*, and in some cases inferred or stated a physical change to the number of lanes or width of the road.

With regard to the European Variant of the double lane closure, one participant reported not to know what information was being communicated by the aspect.

Additional analysis was undertaken where responses were categorised in terms of whether the participant indicated an understanding of the lane as closed now or closed ahead.

For all four designs, a reasonable proportion of participants indicated that the aspects inform drivers of a lane closure *ahead*. This was most common in responses for the European Variant of the double lane closure.

#### *Detailed interpretation of 'Lane closed and move out of lane' aspects*

The remaining aspects contained a combination of Red X and Hooked Arrow symbols to display a single or double lane closure (see Figure 55 below).



**Figure 55: Aspects incorporating both Red X and Hooked Arrow symbols**

The intended meaning for these aspects combined both the 'lane closed' and 'move out of lane' informational elements. As a result, participants' perceived meaning rating was generally lower than for simpler aspects.

For the two designs where a Red X was displayed in the same lane as a Hooked Arrow, participants tended to be clearer in their description of when the lane closure would be in effect (i.e. *now* or *ahead*).

An analysis was undertaken to compare the single lane closure aspect with a Hooked Arrow and Red X, with the single lane closure aspect with a Hooked Arrow only. Results showed that the presence of the Red X meant that participants were more likely to reference both the status of the lane and the required movement as two distinct information elements (e.g. '*the lane is closed ahead and I am required to move out of the lane*'). Also, with the presence of the Red X, participants were less likely to misinterpret the aspect as referring a slip road or similar.

In summary, participants demonstrated a high level of understanding of lane closure aspects, particularly for those communicating single lane closures and containing a Red X or Wicket symbol.

The results indicated there was less consistency in interpretation of aspect designs intended to *instruct* drivers to move out of a particular lane in advance of a lane closure (e.g. European Variant or Hooked Arrow designs).

The Wicket aspect was more likely to be perceived as communicating a lane closure *ahead* than the aspect involving a Red X.

Comparing the Hooked Arrow and European Variant aspects, the Hooked Arrow aspects appeared to give clearer instruction of the need for traffic to move out of lane than the European Variant aspect. Participant interpretation of the latter was more likely to involve reference to some physical change to the road layout.

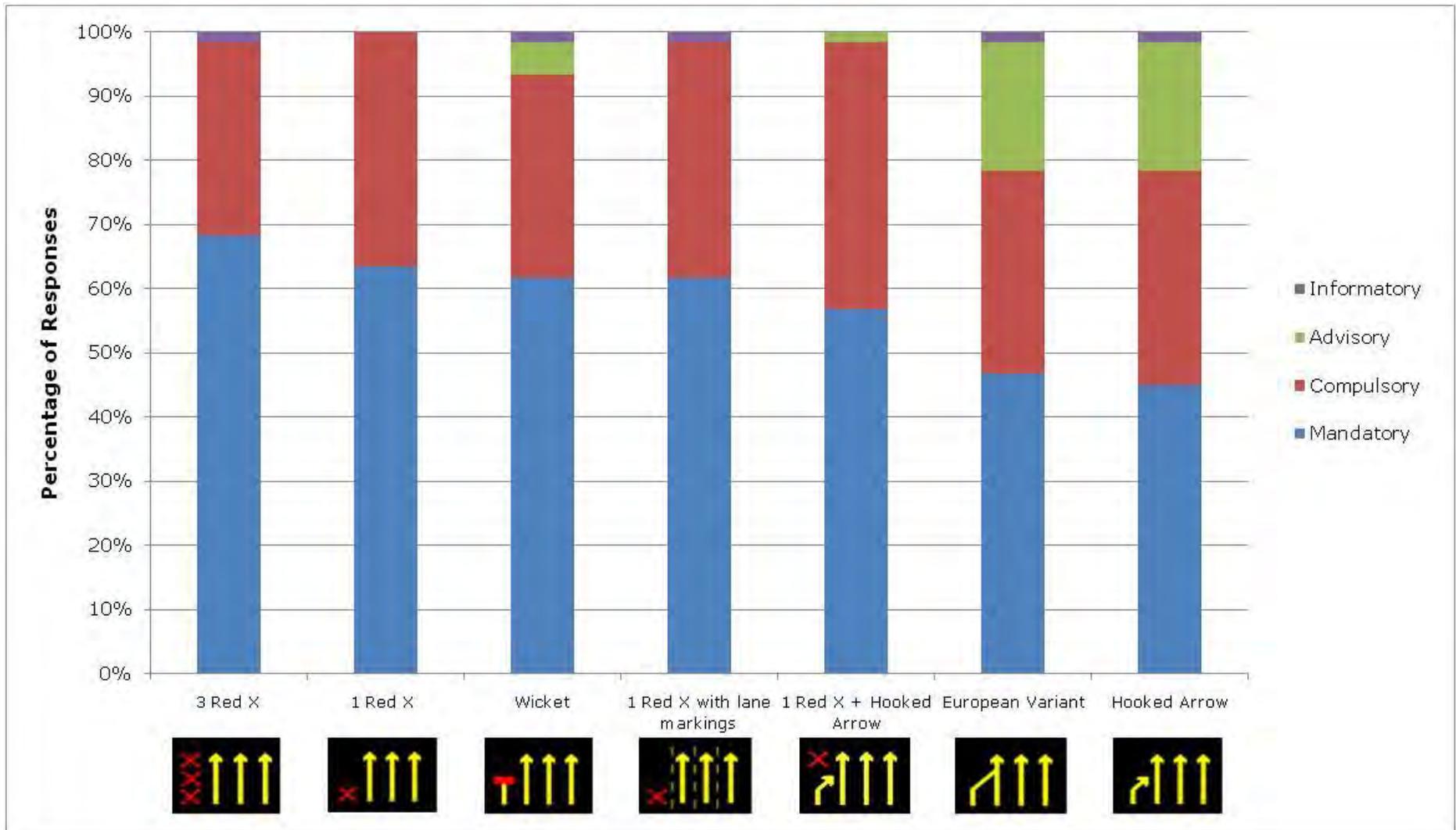
### Lane closure aspects - Perception of aspect as mandatory or otherwise

Drivers' perception of whether the information and / or instruction being communicated is mandatory is likely to affect the appropriateness and immediacy of their response. Participants were asked to choose one of the following categories in relation to each aspect:

<b>Mandatory</b>	Illegal not to do so
<b>Compulsory</b>	Not illegal, but could constitute driving without due care and attention
<b>Advisory</b>	Not illegal, but strongly advised by the authorities
<b>Informatory</b>	No legal consequences for ignoring

Of particular interest was whether the types of symbols incorporated within the aspect (e.g. Red X, Wicket, Hooked Arrow) influenced participant perceptions. This question was only asked in relation to aspects displaying single lane closures since those aspects displaying double lane closures incorporated the same types of symbol.

Figure 56 below presents the percentage of responses for each aspect, ranked in order of highest proportion of mandatory responses.



**Figure 56: Participant perception of the lane status aspects as a) mandatory, b) compulsory, c) advisory or d) informative**

For all lane closure aspect designs the majority of participants viewed the instruction as either mandatory or compulsory. This provides a positive indicator for driver compliance with lane closure instructions communicated through an aspect on a single VMS.

The results suggested that use of a Wicket or Red X aspect increased the likelihood **of participants' interpreting the instruction as mandatory.**

A few participants specifically requested the use of red for communicating a mandatory instruction when asked to comment in the questionnaire on driver information provision in general.

The Task 2 questionnaire (see section 2.4.3.2) also asked participants their perception of whether a Red X instruction on a gantry-mounted AMI signal was mandatory or otherwise. **For the 'Lane closed' aspects, between 62 and 68% of participants believed the lane closure aspect to be communicating a mandatory instruction (Task 3 section), compared with 73% of participants who believed that the Red X displayed on a gantry was mandatory (Task 2 section).**

#### *Lane closure aspects - Understanding of required driver behavioural response*

For each aspect design, the questionnaire asked participants to report how they believed they would change their driving if in LBS1 upon seeing the aspect (which communicates a LBS1 closure). Those aspects displaying a double lane closure repeated the same questions for both LBS1 and LBS2.

For all lane closure aspect designs, the large majority of participants (>84%) indicated that upon seeing the aspect they would prepare to change lanes and / or only drive in the open running lanes.

In some responses, participants explicitly stated that they would change lanes immediately, or as soon as it was safe to do so. Participants also suggested they would slow down, and for the single lane closure aspect designs incorporating a Red X or Wicket, a minority of participants indicated they would stop if unable to exit the lane in a safe manner.

For the Hooked Arrow and European Variant aspects, there were a greater number of responses indicating that apart from slowing down or driving with more caution they would not change their driving behaviour; this was correlated with participants that understood these aspects to be warning of merging traffic from a slip road or similar as opposed to a lane closure.

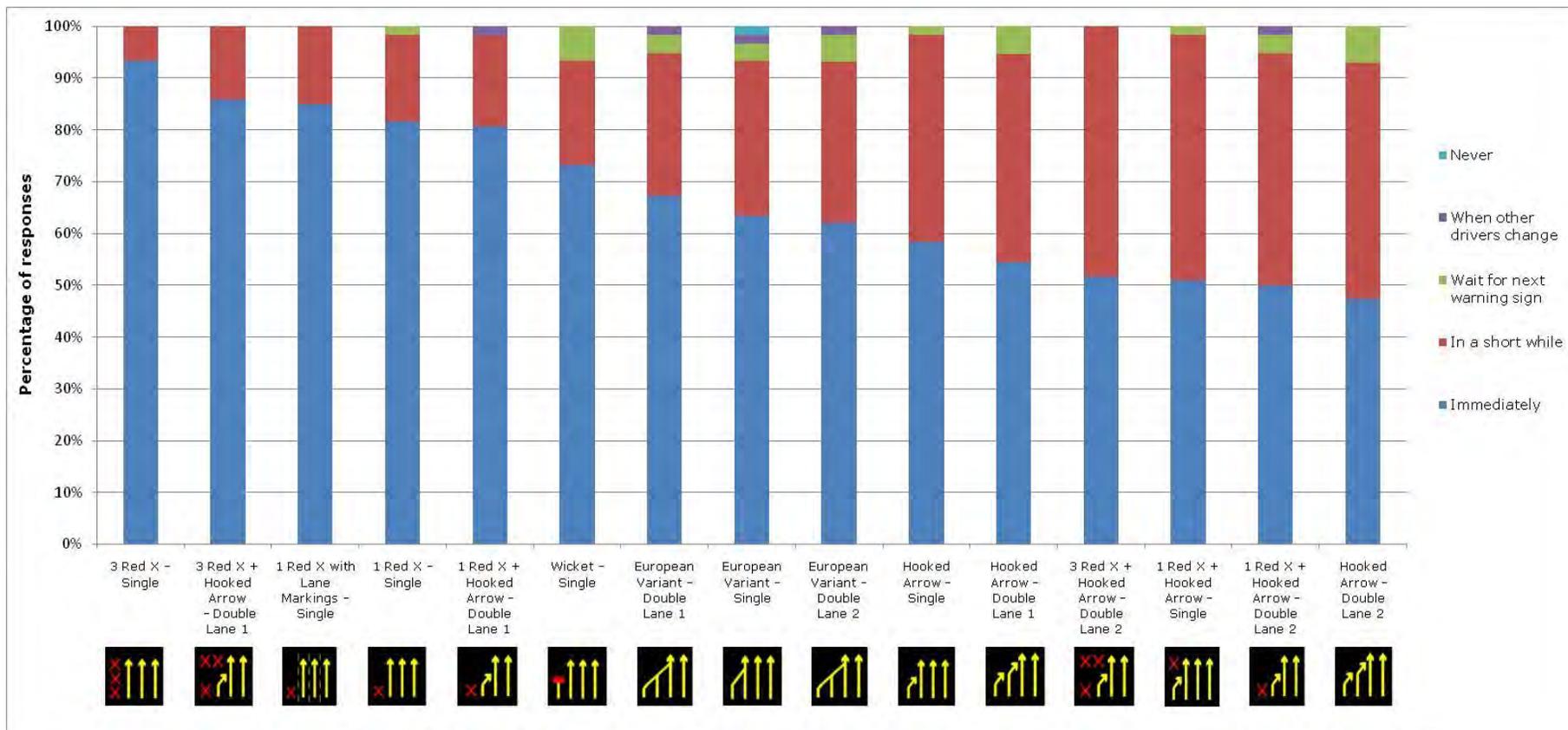
With regards to the European Variant aspect, the responses showed a greater tendency for participants to assume that the lane change would be initiated by a change in the layout of the lanes or road. For example, participants used phrases such *'automatically fed'* and *'channelled'*.

Figure 57 compares participant response regarding the immediacy with which they would be likely to change their driving behaviour after seeing the different aspect designs. The designs are ranked in order of the highest proportion of responses for **'immediately'**. **Aspects for which participants were asked how they respond in both LBS1 and LBS2 are ranked for each response separately.**

The results suggested that a Red X increases the likelihood that participants perceive a lane closure to be in immediate effect (i.e. from the location of the sign). Aspects more likely to be used in advance of a lane closure (e.g. Hooked Arrow and European Variant) had a greater variation in response.

The Wicket aspect and those displaying double lane closures had the highest **proportion of responses indicating the participant would *'await the next warning sign'***.

In the general comments section of the questionnaire, a few participants highlighted that it was not always clear from the lane closure information when, or how far ahead, the driver is required to respond and whether it is a temporary or permanent change. It was suggested that signing should include distance information.



**Figure 57: Participant perception of likelihood of a response a) immediately, b) in a short while, c) wait for the next warning sign, d) when other drivers change or e) never**

### Additional comments on lane closure aspects

At the end of the Task 3 questionnaire, participants were given the opportunity to provide general comments about the signs they had seen during the trial. A number of participants referred explicitly to the lane status elements displayed in the questionnaire. The points raised were:

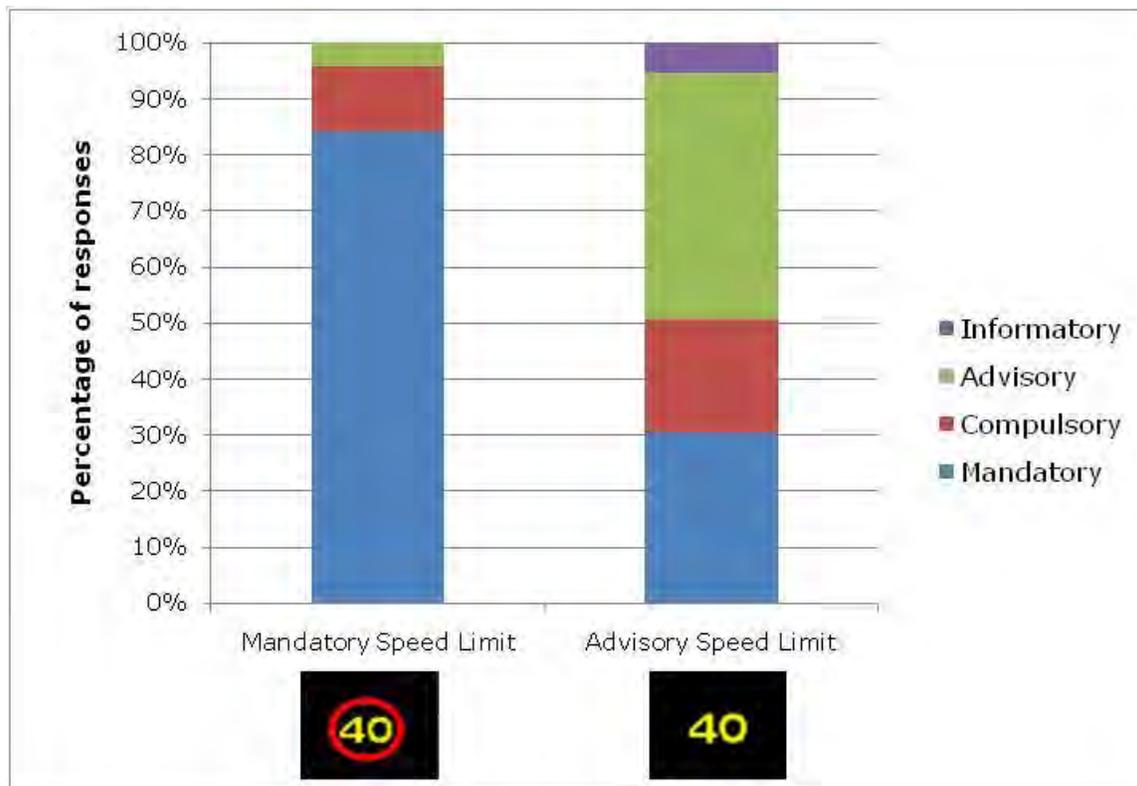
- > Some of the lane closure aspects are too detailed and contain unnecessary information (i.e. the designs with 3 Red X or with dotted lane markings). The designs should be kept simple and clear to ensure that they are instantly comprehensible and not distracting.
- > There should be a limit to the number of different types of information displayed on sign.
- > There should be consistency in use of aspect designs for communicating lane closures. The different variations can be confusing and raise questions such as; ***When does the change occur? Is it temporary or permanent?***
- > Red X provides clearer indication of lane closures than just use of yellow lines only.
- > Display of running lanes on signs is positive i.e. easier to read and understand.

Speed limit aspects - Perception of whether aspect is mandatory or otherwise

The questionnaire investigated participants' understanding of aspects displaying mandatory and advisory speed limits, where a red ring is displayed for a mandatory instruction and is absent for an advisory instruction. Participants were also asked what they thought the consequences of not complying would be if seen by the authorities.

Figure 58 below displays participant responses as to whether the instruction was mandatory or otherwise. The options for response were:

- Mandatory**      Illegal not to do so
- Compulsory**    Not illegal, but could constitute driving without due care and attention
- Advisory**        Not illegal, but strongly advised by the authorities
- Informatory**     No legal consequences for ignoring



**Figure 58: Participant perception of the speed limit aspects as a) mandatory, b) compulsory, c) advisory or d) informatory**

The majority of participants correctly interpreted the speed limit aspect with a red ring to be mandatory (84%) and understand there could be legal consequences for non-compliance (92%).

31% of participants believed the advisory speed limit aspect to be mandatory, and 44% of participants also thought there could be legal implications for non-compliance with the advisory speed limit.

A few participants suggested the mandatory speed limit aspect was only compulsory or advisory; this may be linked to the fact that it was displayed on a VMS sign and therefore has different colouration to speed limits displayed on fixed signing.

When asked to provide general comments about driver information provision, a number of participants raised concern that there is a lack of clarity between mandatory and advisory instructions, although it was commented that the questionnaire had helped to improve their understanding. It was also raised that the absence of the red ring is less likely to prompt driver response, and could be interpreted to mean that the sign is not working properly.

Whilst most participants correctly understood that the aspect incorporating a red ring communicates a mandatory speed limit instruction, participants were less consistent in their interpretation of the aspect displaying the advisory speed limit instruction. However, since participants tended to assume that it was mandatory or compulsory, this interpretation is not likely to have an adverse affect on driver behaviour.

These results correlate well with the findings of the Task 2 questionnaire (see Section 3.4.2.2), which also asked participants to indicate whether they believed the speed limit displayed on a gantry-mounted AMI signal was mandatory or otherwise. The image presented in the Task 3 section illustrated just the speed limit aspect, whereas the question in the Task 2 section referred to an image where the speed limits were displayed on a gantry. It was observed that a higher proportion of participants provided a correct response to the question presented in the Task 3 section than in the Task 2 section; 84% of participants believed the speed limit to be mandatory in the Task 3 section compared to an average of 69% of participants across both groups in the Task 2 section.

### Broken down vehicle aspect - Interpretation

Participants were presented with the aspect illustrated in Figure 59 and asked to write in their own words what information is being communicated. This symbol is based on a European design, where it would be displayed on VMS in animated form.



**Figure 59: European aspect design for warning of a broken down vehicle**

The majority of participants correctly understood that the aspect displays a broken down vehicle (86%), with many participants also indicating that the sign is providing warning or caution to drivers of what to expect ahead.

The remaining responses suggested the sign indicates the presence of stationary vehicle or traffic, or specifically referred to a vehicle fire or danger of the engine overheating. When asked to provide general comments about driver information provision in the questionnaire, one participant commented that this sign is *'too busy to interpret properly when driving'*.

### Broken down vehicle aspect - Understanding of required driver behavioural response

When asked how they might change their behaviour upon seeing this sign, the majority of drivers (72%) indicated they would slow down, and some would take additional secondary actions such as driving with caution or greater awareness.

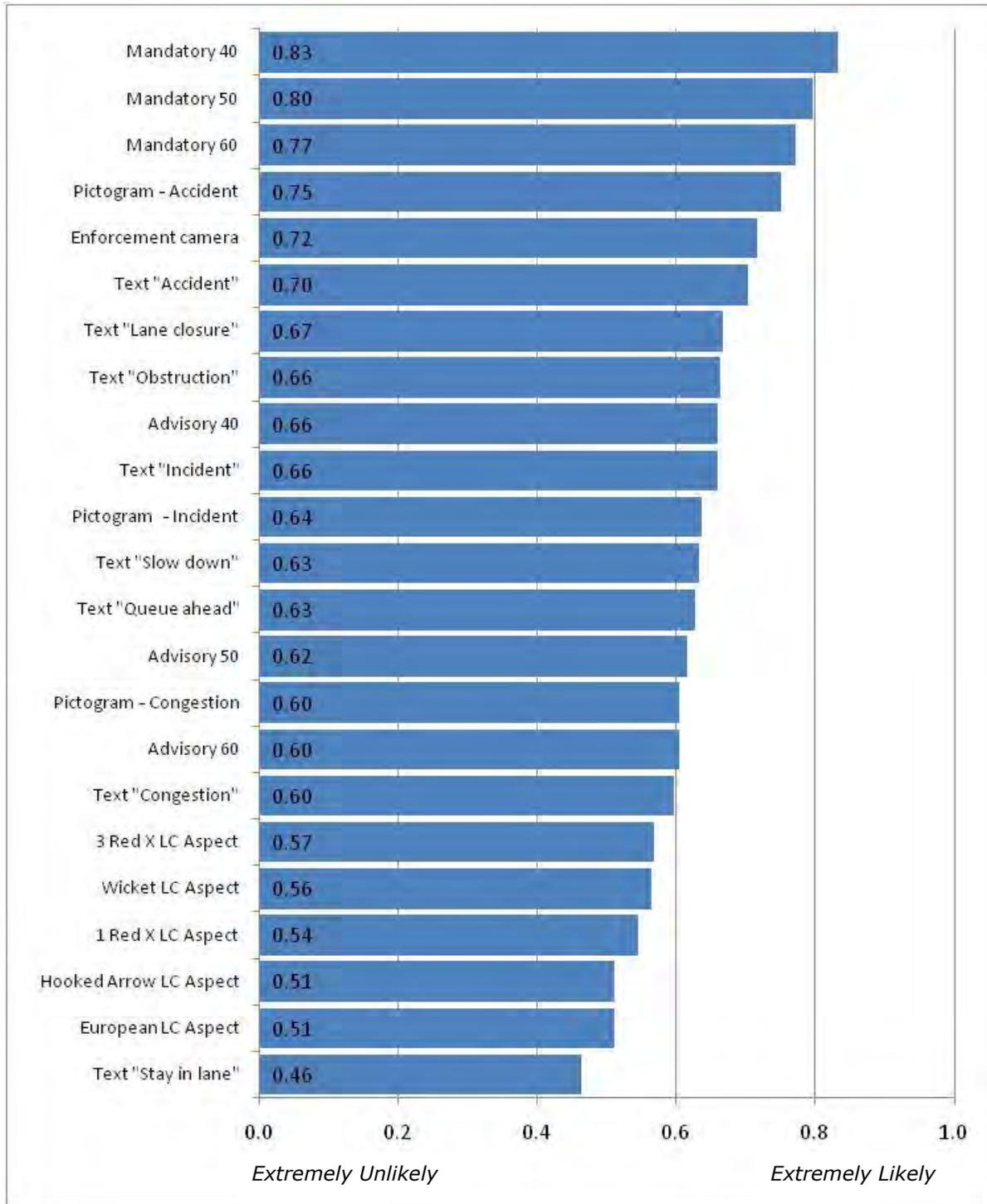
A few participants (5%) suggested they would make no change to their driving behaviour, particularly if the vehicle was not on a live running lane.

### 3.5.2.3 *Influence-potential of MS4 message elements*

This section of the questionnaire sought to investigate participant perceptions of different elements that could be displayed as part of a MS4 message, based on a rating of how likely they would be to reduce their driving speed upon observing the element. This gives a measure of the influence-potential of the message elements on driver behaviour. The types of element tested included speed limit and lane closure aspects, pictograms and text.

As detailed in Section 3.3.2, participants were required to mark their response for **each aspect on a continuous line which had 'extremely unlikely' at one pole and 'extremely likely' at the other**. The position of each mark was measured and converted into a ratio, where 0 = extremely likely and 1 = extremely unlikely.

**The participants' ratings for each test element were converted into a mean ratio, and then the elements were arranged in hierarchical order, as displayed in Figure 60. Those elements possessing the highest mean ratios are positioned at the top.**



**Figure 60: Mean ratios of perceived likelihood of MS4 message elements to influence speed choice**  
[LC = Lane Closure]

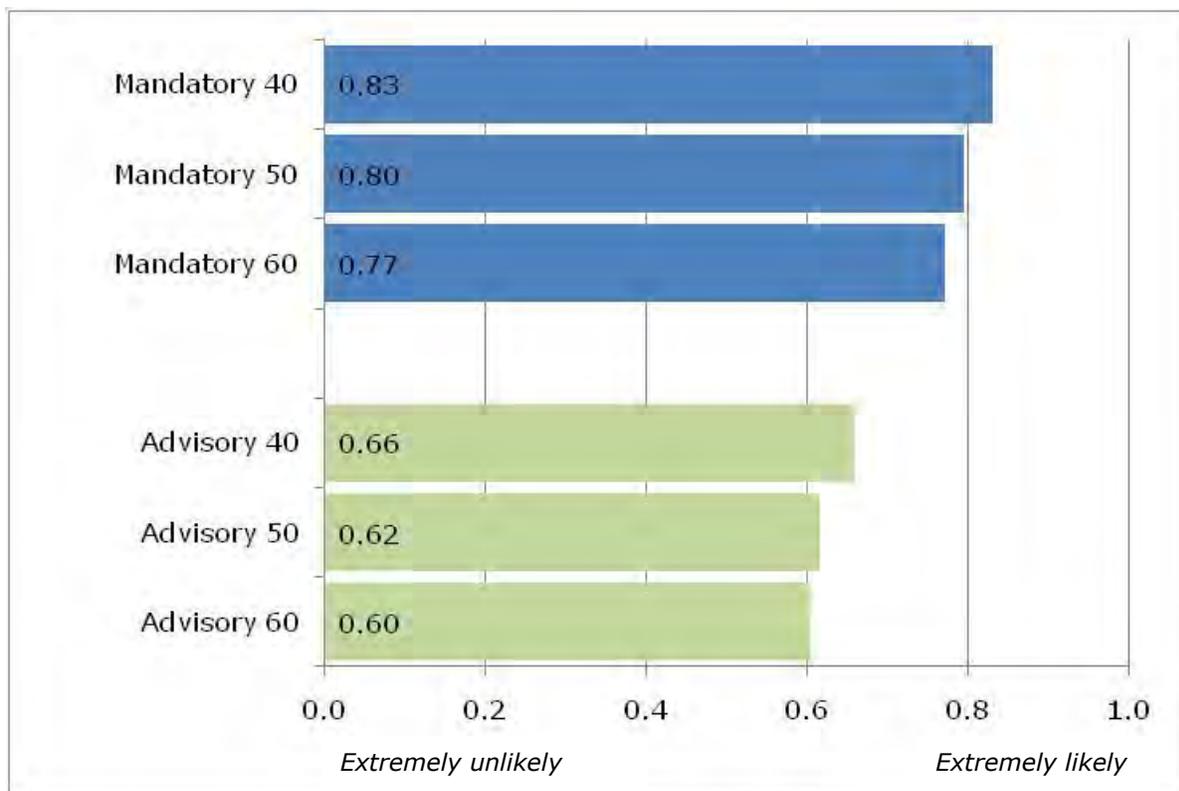
Figure 60 shows that the mean ratios for all elements bar one were more likely to lead to a reduction in their speed than not. The exception was the mean ratio for the text 'stay in lane' (M= 0.46).

The most effective elements for reducing participant speed were judged to be those aspects presenting a mandatory speed limit instruction.

Further investigation was then undertaken on the ratings for different types of element i.e. mandatory speed limit aspects, advisory speed limit aspects, lane closure aspects, warning pictograms and text.

***Mandatory and advisory speed limit aspects***

Participants were asked to rate three mandatory and three advisory speed limit aspects, displaying 40, 50 and 60mph. Figure 61 shows the scores for these six aspects.

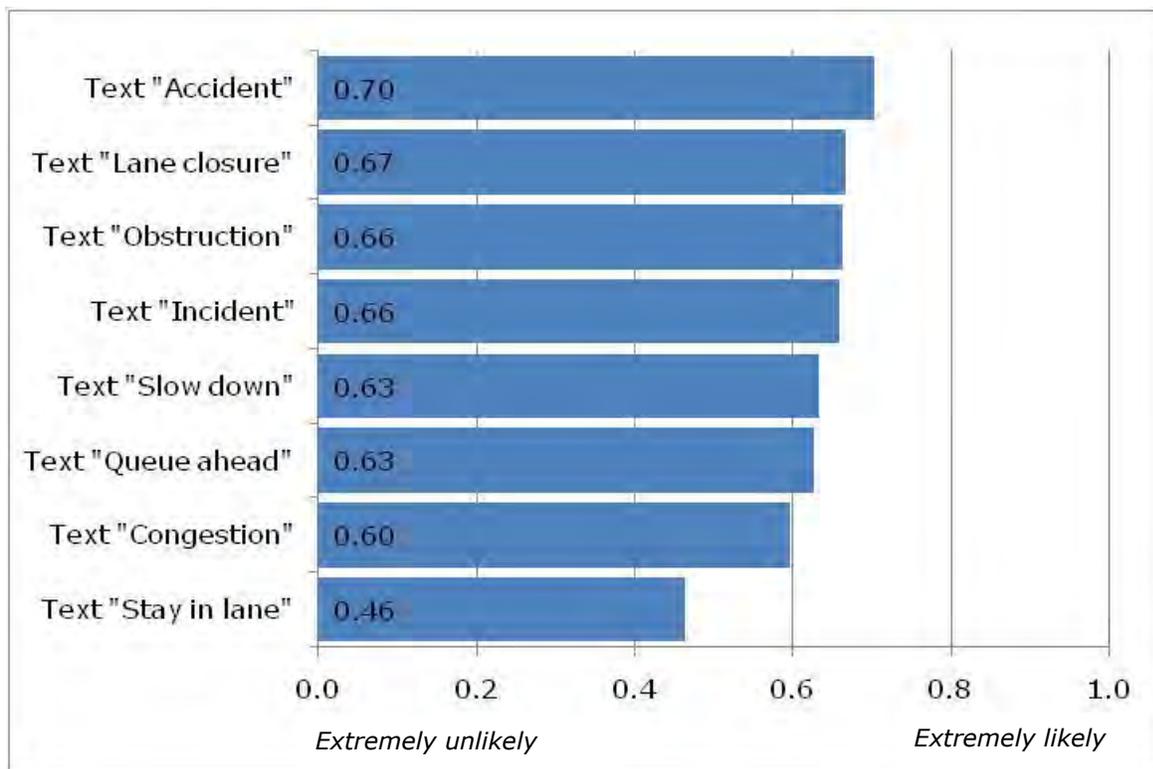


**Figure 61: Mean ratios of perceived likelihood of mandatory and advisory speed limit elements to influence speed choice**

The results show that all three mandatory aspects produced greater responses than the advisory aspects. For both mandatory and advisory aspects, there was a positive relationship between the value of speed limit and the degree of reduction in speed: the lower the speed limit, the greater the influence-potential.

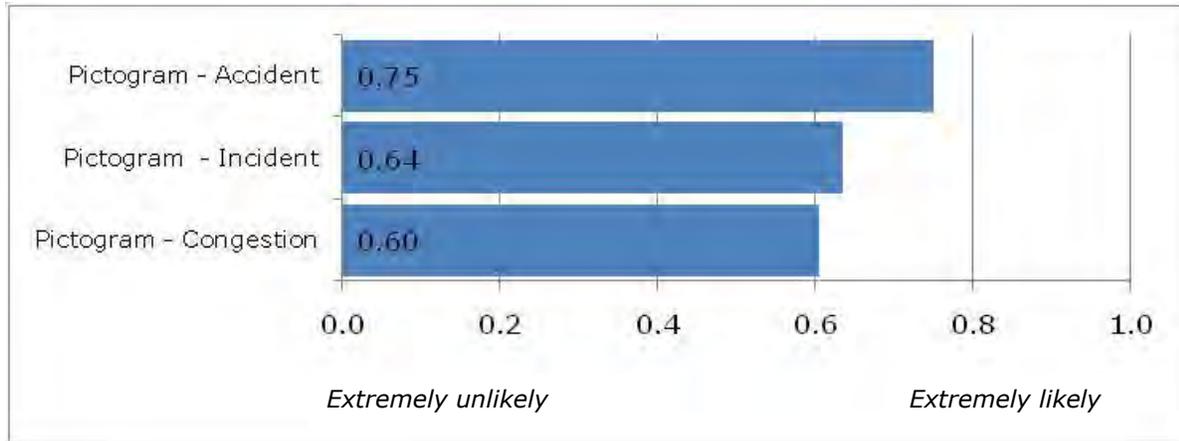
**Warning pictograms and text**

Mean ratios for only those elements with text and pictogram displays are presented in Figure 62 and Figure 63 below.



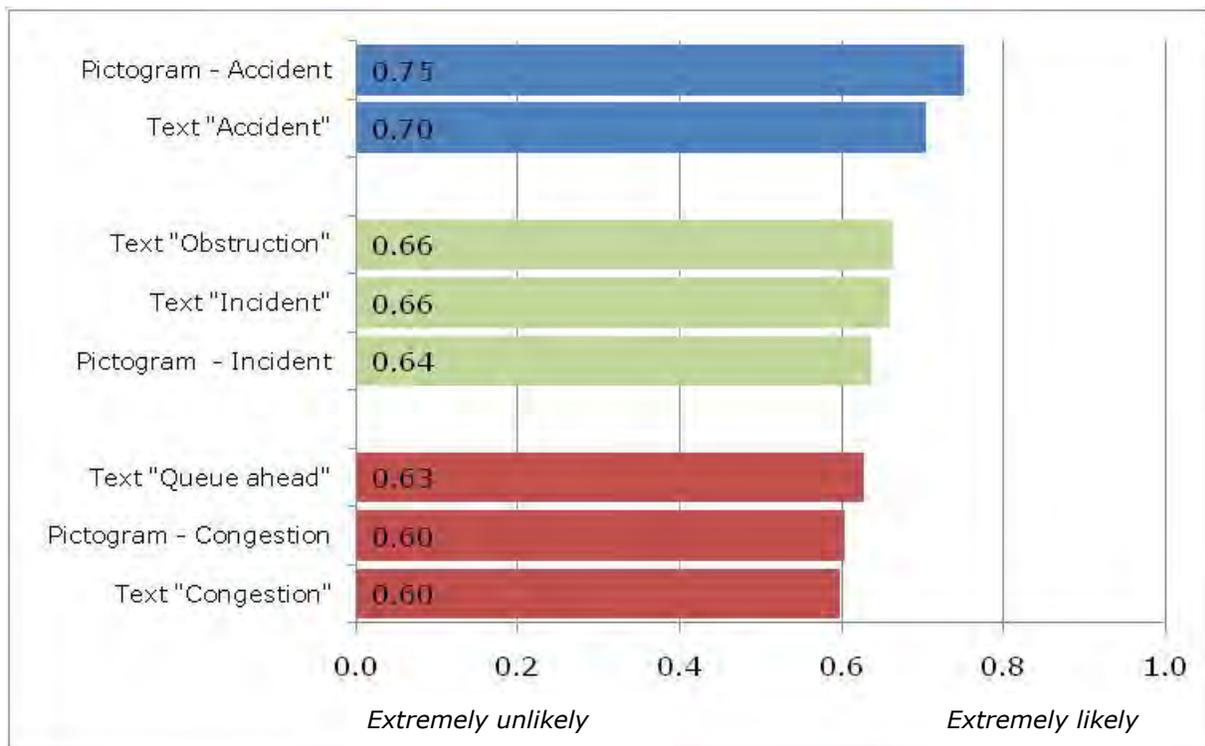
**Figure 62: Mean ratios of perceived likelihood of text elements to influence speed choice**

'Accident' and 'Lane closure' were rated as the most likely to cause a participant to reduce their speed with mean ratios of 0.70 and 0.67 respectively. 'Stay in lane' was the least likely to prompt this change (M = 0.46). This low score is understandable considering the text is not alerting a driver of a potential hazard ahead, only instructing them to not change lane.



**Figure 63: Mean ratios of perceived likelihood of pictogram elements to influence speed choice**

As shown in Figure 63, the 'Accident' pictogram produced the largest reduction in speed out of the three pictogram elements ( $M = 0.75$ ). This was substantially higher than either the 'Incident' ( $M = 0.64$ ) or the 'Congestion' ( $M = 0.60$ ) pictograms. Figure 64 illustrates the comparative ratings of related pictogram and textual elements.



**Figure 64: Comparative ratings of related pictogram and textual elements**

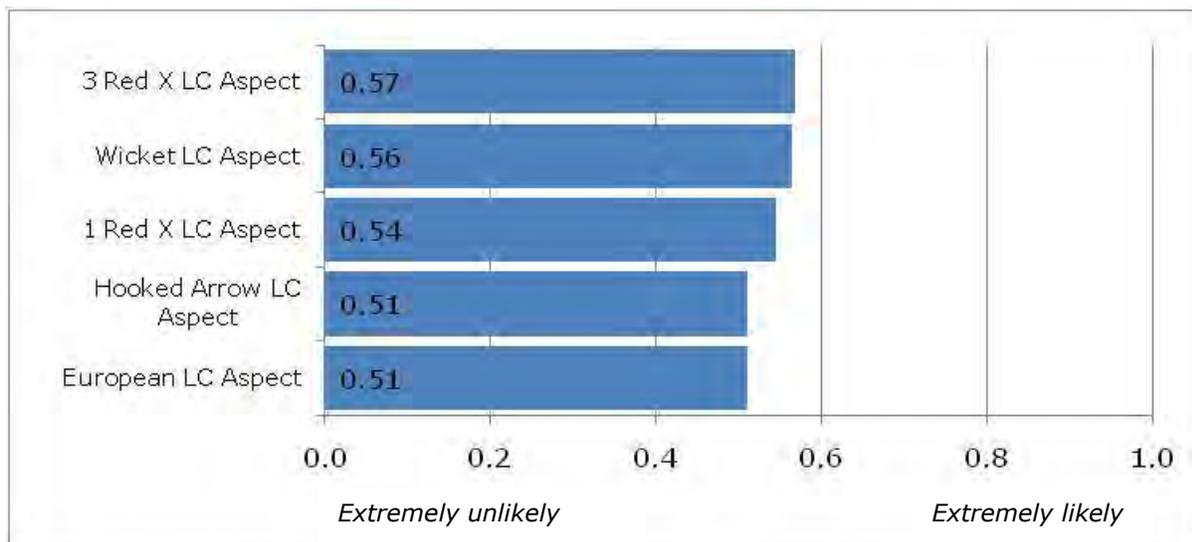
The results suggested a strong link between the pictogram and text elements, with a large degree of harmony in the ratings given to each set of related elements.

Following those, the obstruction and incident text elements were compared to the 'incident' pictogram. The mean ratings between three elements only differed by 0.02, suggesting little difference between the effectiveness of the elements.

Finally, the 'congestion' and 'queue ahead' elements were rated as producing the lowest levels of reduction in speed; little difference between the 'congestion' pictogram (M = 0.60), the 'queue ahead' text (M = 0.63) and the 'congestion' text (M = 0.60) was found.

**Lane closure aspects**

Mean ratios for only the lane closure aspects are presented in Figure 65.



**Figure 65: Mean ratios of perceived likelihood of lane closure aspects elements to influence speed choice**  
[LC = Lane Closure]

A comparison of the five aspects describing different lane closure information or instruction shows a clear difference between designs.

The '3 Red X' aspect for a single lane closure was judged likely to produce the greatest reduction in speed (M = .57), with the European Variant aspect for communicating a 'Move out of lane' instruction producing the least (M = .51).

A few participants indicated within the questionnaire that their likely response in terms of reducing speed would depend on which lane they were in, and therefore they may have provided a compromised response.

The results indicated that different types of MS4 elements have varying degrees of **'influence-potential' in terms of the perceived likelihood of influencing driver behaviour.**

Whilst a mandatory speed aspect is expected to have the greatest influence on driver speed choice, the findings suggest that the addition of supporting information may have a beneficial effect on driver behavioural response, particularly if the information relates to an accident ahead.

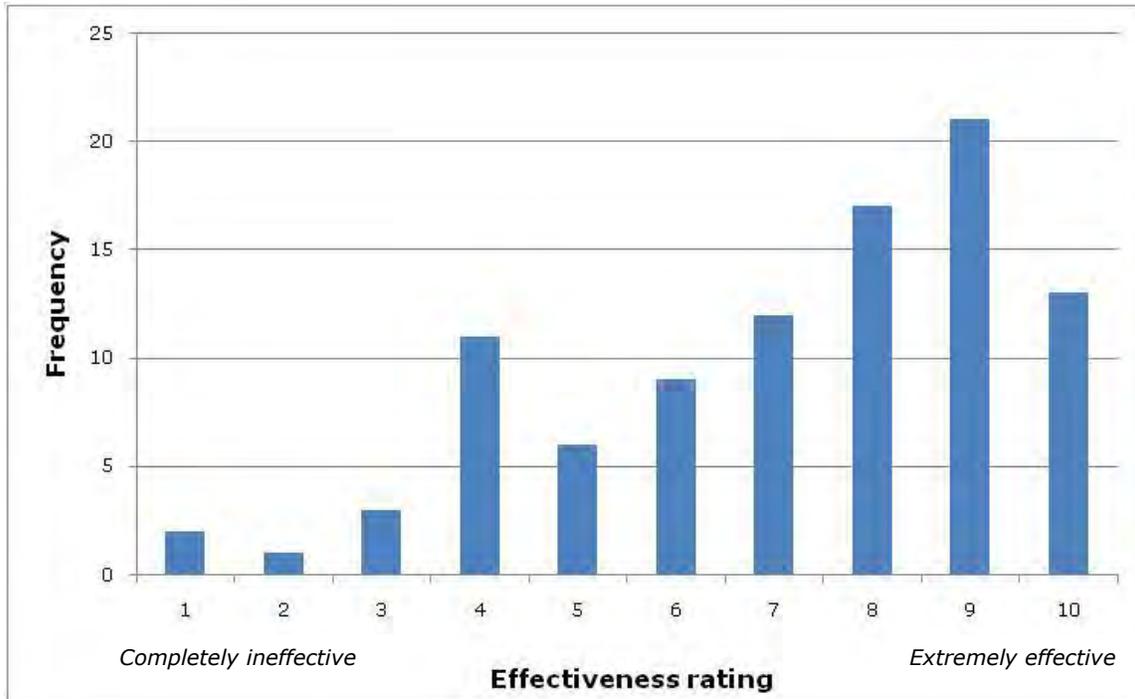
### 3.5.2.4 Public perception of On-Road Driver Information provision via VMS

One section of the questionnaire focused on **assessing participants' perceptions** of the use of VMS to convey information to drivers. Participants were shown an image of a verge-mounted MS4 (Figure 66) and asked to indicate on a scale of 1 to 10 how effective they think these signs are at a) closing lanes to traffic, b) increasing safety after an accident and c) improving driver behaviour.

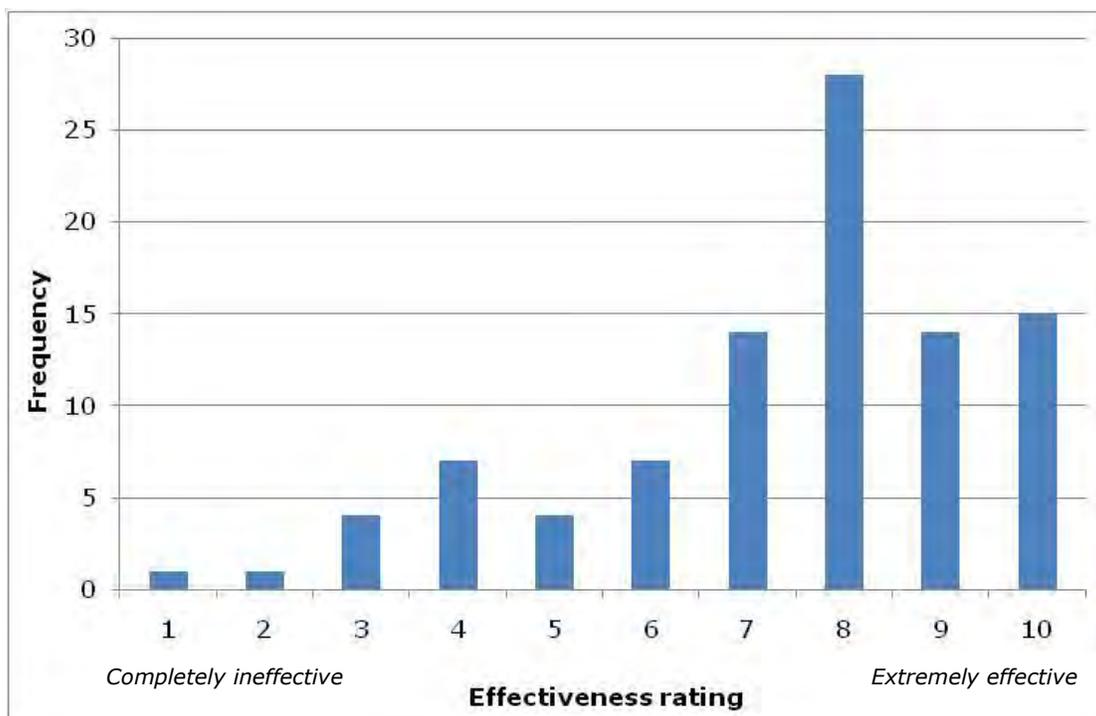


**Figure 66: Image of verge-mounted MS4 presented to participants in questionnaire**

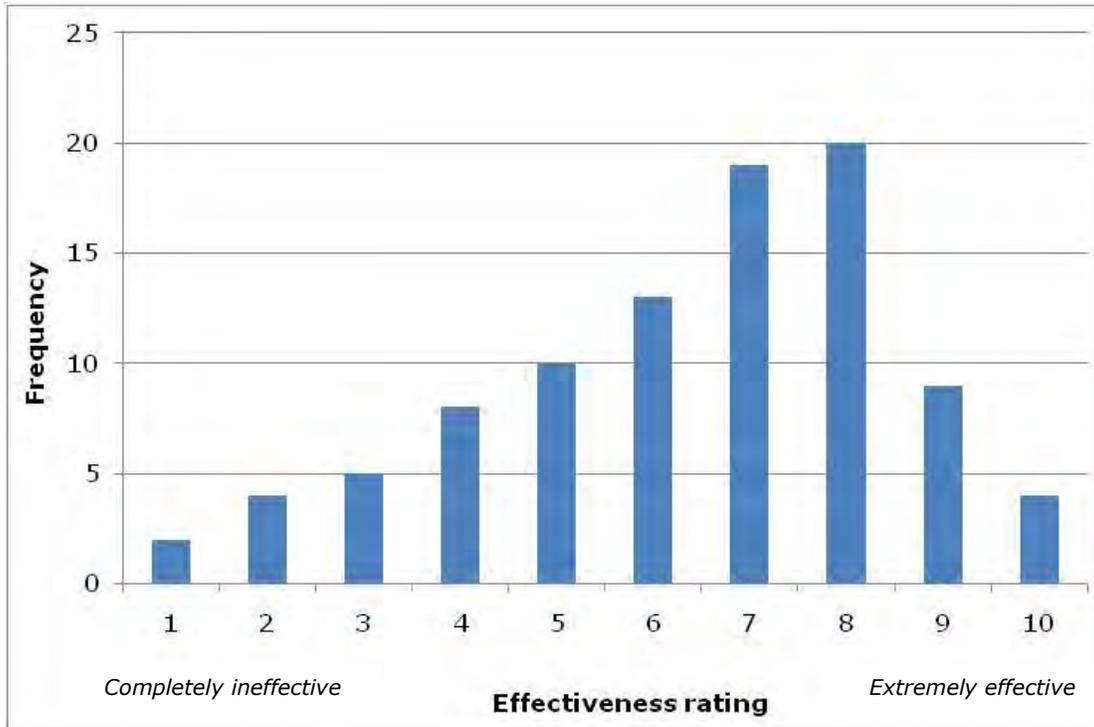
Figure 67, Figure 68 and Figure 69 below show the frequency of participant responses for each question.



**Figure 67: Frequency of participant responses when asked to indicate on a scale of 1 to 10, how effective they felt verge-mounted MS4s are at closing lanes to traffic**



**Figure 68: Frequency of participant responses when asked to indicate on a scale of 1 to 10, how effective they felt verge-mounted MS4s are at increasing safety following an accident**



**Figure 69: Frequency of participant responses when asked to indicate on a scale of 1 to 10, how effective they felt verge-mounted MS4s are at improving driver behaviour**

The mean average ratings for the three questions varied between 6.4 and 7.4. These results suggest participants have positive perceptions of the use and effectiveness of verge-mounted driver information provision via MS4s.

**3.5.2.5 Additional comments**

Within the questionnaire, all participants were given the opportunity to comment on the traffic sign designs that they had seen during the trial, as well as more general opinions on the provision of driver information on the motorway network.

Comments relating to specific sign designs presented within the questionnaire have been discussed within the appropriate section of this report. From the remaining comments, the points most frequently raised by participants are detailed in Table 10.

**Table 10: Additional comments raised by participants during the trial**

Theme	Comments
<b>Information on signs</b>	<ul style="list-style-type: none"> <li data-bbox="431 323 1435 422">&gt; Additional information should be provided when there are delays (e.g. time, distance, alternative routes) – <b>likely to reduce driver ‘stress’</b> and improve response.</li> <li data-bbox="431 436 1435 499">&gt; <b>Use of red colour to communicate ‘warning’ / mandatory instructions</b> – more likely to increase driver caution and awareness.</li> <li data-bbox="431 514 1435 577">&gt; When appropriate, VMS should be used to remind drivers to keep to the left hand lane except when overtaking.</li> <li data-bbox="431 592 1435 722">&gt; Inappropriate use of VMS to display warning information (e.g. for congestion or incident) when traffic is flowing freely has counter-productive effect – drivers believe the signing is inaccurate and ignore or respond based on their own judgement of the situation.</li> </ul>
<b>Level of provision</b>	<ul style="list-style-type: none"> <li data-bbox="431 749 1435 812">&gt; <b>Important not to cause ‘information overload’</b> by providing too many signs / too much information.</li> </ul>
<b>Obscuration / visibility</b>	<ul style="list-style-type: none"> <li data-bbox="431 848 1435 947">&gt; Roadside signs are not always visible due to obscuration by HGVs – one participant suggested that the same information should be provided above each lane on a gantry.</li> <li data-bbox="431 961 1435 1060">&gt; Overhead information provision is viewed as clearer in terms of which sign relates to which lane, but can lead to a lack of awareness of conditions in other lanes.</li> <li data-bbox="431 1075 1435 1121">&gt; Visibility of signs is important to ensure that drivers read the messages – need to be well-lit, use of flashing signs etc.</li> </ul>

A few participants commented positively on the current system for information provision, for example stating that it is ‘clear and effective’ and that overhead gantries are useful. However, it was raised by one participant that there needs to be greater awareness and / or enforcement of Red X mandatory instructions as there is currently non-compliance by drivers.

### 3.6 Discussion and Recommendations

The Key Findings of the Task 3 PC Comprehension Test suggest that comprehension of safety critical information presented on a single verge-mounted MS4 was found to be greater than or equal to the same information displayed on gantry-mounted signals and an MS4. More specifically, participants were able to process both speed limit and lane closure information with a very high level of accuracy if presented on a verge-mounted MS4 and with similar response times to when the same information is communicated on a gantry.

Some results suggested that participants found it easier to locate and process lane closure information for all lanes (i.e. not just the one they are positioned in) when displayed on a single verge-mounted sign as opposed to a gantry-mounted signal. This was most likely due to differences in visual search time required.

Within the PC Comprehension Test, only very small differences in response times were found between specific options for aspects displaying lane closure information, and the majority of differences in response time compared to equivalent gantry-mounted options were not found to be significant. However, the difference in comprehension of these aspects was investigated in detail through the participant questionnaire. A summary of the key findings is provided below.

- > A **Wicket** sign was found to have the highest rating for comprehension where intended meaning refers to 'lane closure'. However, participants consistently interpreted as indicating a lane closure further ahead as opposed to immediately. Wicket signs are currently used on the network in conjunction with distance information (e.g. 600yds); technically, these are incapable of communicating a lane now closed without any additional text to communicate this. Therefore, it is recommended that if this type of aspect is to be considered for use within MM2, further thought should be given to the role of supplementary text.
- > A **Red X** was found to communicate a need for a more immediate response to the information, and is also more likely to be perceived as mandatory. Aspects involving three consecutive Red Xs were found to communicate both of these particularly strongly. Currently, a LDR/LDL arrow is used on gantries in advance of a Red X to instruct drivers to move out of the lane before the closure is actually in place. MM2 would require some means of replicating this instruction on a verge-mounted sign to be used upstream of a Red X.

- > The two means considered of communicating such an instruction were the **Hooked Arrow** and **European Variant** aspects. A Hooked Arrow design was found to provide a clearer instruction to prompt drivers to change their driving behaviour. However, it is more likely to be perceived as advisory and more likely to result in a slower driver response. The European-variant design is sometimes interpreted to mean a physical change in the layout of the road / traffic lanes which might affect driver response.

Some designs were considered to be confusing, particularly those communicating a staged implementation (e.g. a Hooked Arrow followed by a Red X on the same aspect). This is especially pertinent to double lane closures, and given the possibility of greater spacing between information points with MM2 schemes, further thought should be given the best approach for implementing a lane closure in this way.

The questionnaire **also looked at the 'influence-potential' of different elements of MS4 messages** that could conceivably be used within an MM2 environment. As may have been expected, mandatory speed limits were most likely to make drivers reduce speed. The text and pictogram communicating an accident were the highest scoring supplementary information elements.

**Due to the overall reduction in sign 'space' that may be available in MM2 schemes** (i.e. MS4s rather than AMI and MS4s and at greater spacings) it is likely that a more selective approach will be required to determine the elements included in MS4 messages. It is recommended that these findings be used in support of these considerations.

Results from the PC Comprehension Test also suggested that the presence of additional information had an effect on the speed of comprehension of lane closure information (e.g. response times to statements regarding lane closures were longer if the lane closure aspect was displayed with other elements such as a pictogram and supplementary text). This was not a substantial effect; however, some consideration should be given to the benefits of supplementary information in terms of compliance to understand the trade-off with the effects on speed of comprehension. Interestingly, the number of additional elements (1 to 3) displayed did not make a significant difference.

The results of this task provided a positive indication that drivers will be able to comprehend speed limit and lane closure information communicated via a single verge-mounted MS4. Further investigation of actual driving behavioural responses was carried out in Task 5A to provide:

- > Reassurance that drivers understand which lanes that any information being communicated through verge-mounted MS4 applies to; and
- > Evidence of driver compliance and timeliness of response to lane closure information communicated using aspects incorporating either Red X or wicket symbols.

Several areas relating to sign comprehension may also be relevant to the MM2 concept but were outside the scope of this task. These include:

- > The comprehension of any text used on VMS not specifically related to the safety critical information be displayed (e.g. journey times or strategic diversions).
- > The comprehension of more than one piece of safety critical information at a time. The PC task involved statements about either the displayed speed or the lane(s) closed. It may be of interest to investigate response to statements involving both together, or the processing time required to comprehend a complete MS4 message.
- > The comprehension of fixed signs that could be used in an MM2 environment (e.g. gateway signs informing drivers of the start of a scheme).
- > Information recall could be measured by presenting a statement about the image *after* it has been shown rather than before.
- > The comprehension of sequences of signs and how the information presented on one sign may affect the comprehension of, and response to, the following sign.

## 4 Tasks 4 and 5B MM2 Obscuration Study

### 4.1 Background

Sign or signal obscuration can occur when a vehicle interrupts the line of sight from a driver of another vehicle to the sign or signal being viewed. The consequence of this may be that a driver passes a sign without being able to read it. This may cause a navigation problem for the driver if the sign provides route information or legal issues if required for traffic regulation enforcement; it may also present a safety issue if the sign is providing information regarding an approaching hazard or incident. Additionally, the driver may attempt to manoeuvre their vehicle to be able to view the sign which may in itself cause a hazard to traffic.

In the context of Managed Motorways, signals are used to display both mandatory variable speed limits and instruction on the availability of an individual lane. It is important to the safe and effective operation of Managed Motorways schemes that drivers are able to view the signal for an adequate length of time.

Currently within Managed Motorways schemes, signals are displayed on lane specific gantry mounted AMIs. For the MM2 concept it is proposed that gantry-mounted signals could be replaced by signals displayed on verge-mounted variable message signs; this clearly has the potential to have a considerable impact on obscuration. The aim of Task 4 is to investigate and assess this impact.

### 4.2 Task Objectives

**Obscuration was initially investigated in Task 4 of TRL's work programme. It was later determined that further investigation should be carried out under Task 5 Sub-task B.**

The objectives of Task 4 were:

- > To assess the obscuration of verge-mounted and overhead gantry-mounted information provision under different traffic characteristics;
- > To understand the impact of replacing overhead gantry-mounted information provision with verge-mounted information provision within an Managed Motorways environment in terms of obscuration;

- > To understand how changes to the positioning of verge-mounted signs could affect obscuration; and
- > To predict the impact of obscuration on driver compliance based on the **findings of Task 2, to be further evaluated in TRL's driving simulator.**

The objectives of Task 5 Sub-task B were:

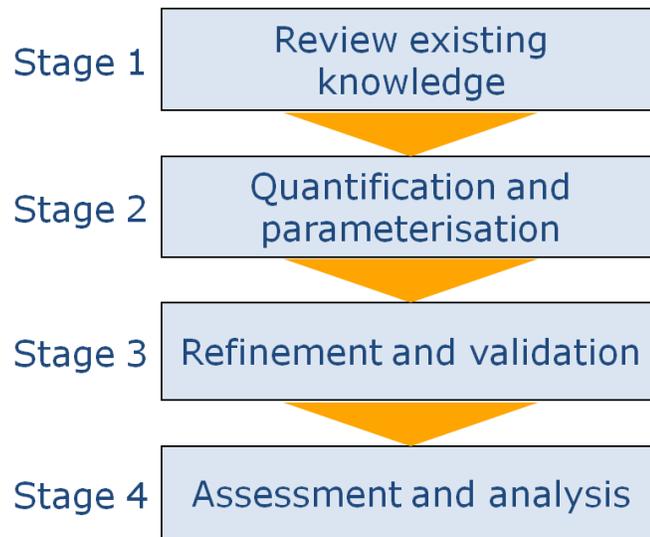
- > To confirm the optimum lateral position of the MS4 such that the maximum number of vehicles can view the signal;
- > To include obscuration with different distributions of HGV heights into the simulation model; and
- > To investigate the likelihood of obscuration of speed limit signals on two consecutive verge-mounted MS4s, including a comparison with obscuration of signals on a single gantry.
- > To investigate and assess the potential effect of lane-changing and individual speed variation on obscuration rates and individual obscuration;

## 4.3 Methodology

### 4.3.1 Overview

It was determined that given the size of the task, the above objectives should be achieved through the means of a desk-based modelling study rather than an on-road survey of any kind. A modelling approach also allows control of variables to investigate the effects that different variables have on obscuration.

At the beginning of the task, a full study plan was produced describing the methodology and approach to be taken. Figure 70 provides an overview of the 4-stage methodology which was described and subsequently agreed with the Highways Agency.



**Figure 70: Task 4 Methodology Overview**

For the sake of the findings detailed in this report it is necessary to provide further explanation of Stage 2.

### 4.3.2 *Quantification and Parameterisation*

There are many variables that will affect sign and signal obscuration and that needed to be considered in a model. These include, but are not limited to, the following areas:

- > Sign dimensions;
- > Sign location;
- > Signal legibility distances and angles;
- > Driver eye location and field of view;
- > Obscuring vehicle dimensions;
- > Traffic speed, flow and headways by lane;
- > Flow composition (proportions of vehicle types);
- > Number of lanes;
- > Road geometry, road curvature and topography;
- > Environmental conditions.

Each of these areas can be broken down into many more individual sub-variables and there is of course interdependence between them. For example, the legibility distance and angles will strongly depend on the geometry of the road on the approach to the sign and the existing weather conditions.

There is also a clear human factors element to any considerations around obscuration, which is the variability introduced by driver behaviour. The first level of complexity that this introduces is the element of driver choice in the time-dependent variables such as headway and speed. For example, drivers will have different following tolerances, different desired speeds, and different lane-changing tendencies.

There is also another level of complexity to the driver behaviour aspect concerning the driver interaction with the sign and the scheme. This would include consideration of questions such as: Does the driver want to see the sign? Do they speed up or slow down in accordance with this desire? Do they understand the scheme? Do they move within their vehicle to view the sign? How far are they willing to turn their line of sight from the road ahead? Does the driver actively wish to avoid seeing the sign? Do they turn their head? Modelling all these factors fully and accurately would be an extremely complicated task.<sup>15</sup>

Assessing obscuration for a given situation therefore, consists of a set of several known and fixed variables (e.g. road geometry, sign location and dimensions), combined with a high level of complexity associated with individual driver behaviour. It was therefore determined that for a reasonable exploration of the factors affecting the visibility of signals, obscuration should be considered initially in terms of geometric principles. An attempt would then be made to express these considerations in terms of a population of traffic through the use of a simulation model.

The approach taken therefore was to:

- > Develop an analytical model beginning with geometric principles and making simplifying assumptions as necessary to incorporate other factors.
- > Use the analytical model as a basis to develop a simulation model, for the purpose of investigating the effect of obscuration on a population of traffic under varying traffic conditions.

Analysis was undertaken for both models, the results of which are presented in Section 4.7.1 (simulation model) and Section 4.7.2 (analytical model).

### **4.3.3 HA/SEA Simulation Tool**

During the course of this task the existence of a relevant simulation model was discovered. The MOMS (Modelling the Obscuration of Motorway Signals) tool was developed by SEA for the Highways Agency in 2006. A copy of this tool was given to TRL in December 2010 and analysis was undertaken using the tool to support the objectives of this task. A selection of results from this analysis is included in Section 4.7.3.

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<sup>15</sup> These factors were investigated further as part of Task 5 and the key findings are described in Section 4.8.

## 4.4 Literature Review

### 4.4.1 Summary of Main Research in the Field

Through the evidence capture task of TRL's work programme (see Task 1 in Section 1.2) a number of papers relevant to sign obscuration studies were identified. Stage 1 of Task 4 was then to review this existing knowledge. The evidence capture task found that there is very little previous work in this area; the main papers are:

- > Abramson P., *Blockage of Signs by Trucks*. Traffic Engineering April 1971, Vol. 41, No. 7, pp. 18-26
- > McDonald M and Starkey O (University of Southampton), *Obscuration of traffic signs and signals*. Unpublished contractor report for TRRL, 1988
- > McDonald M and Hall R D (University of Southampton), *Obscuration of signs by large vehicles*. Unpublished contractor report for TRRL, 1989
- > WS Atkins and TRL, *Operational Assessment of EMS and MS2*. Unpublished report for the Highways Agency (1995)
- > Cooper B R, Mitchell J C and Mustard D C, *The obscuration of MS4 and other signals on motorways*, TRL Ltd PR/T/171/2000

All of these studies attempted in different ways to calculate the level of sign obscuration by HGVs/trucks. They are largely inconclusive or not of direct relevance to the current investigation. However, HGV flow is generally seen as the most important factor. Also identified is the treatment of short, multiple exposures to signs by summation to provide a total viewing time, and the fact that drivers may modify their speed or manoeuvre into a position that reduces obscuration.

Cooper et al (2000) is the first work to explicitly consider MS4s and as such is the first that is of direct relevance to this task. Results from on-road surveys clearly show the increase in obscuration with increasing heavy vehicle flow and also the increase as the sign becomes more offset from the main traffic lanes.

Using a 2 second criterion for obscuration, the obscuration rate for an MS4 on straight road was 2.5% for 350 HGV/hr flow (the minimum HGV flow observed) and 4.4% for 700 HGV/hr (the maximum observed), i.e. for the lower flow 2.5% of drivers did not 'see the sign' for two or more seconds and for the higher flow 4.4% of drivers did not 'see the sign' for two or more seconds. Using a 4 second criterion the rates were 4.0% and 8.7% respectively.

#### 4.4.2 *Relevant Findings from Literature Review*

The key points that can be carried forward to the development of a model are:

- > The established use of a two second criterion for assessing obscuration. In addition, one paper recommends summing separate viewing opportunities of a sign to give a total viewing time.
- > Obscuration of verge-mounted cantilever signs can occur in all traffic lanes.
- > The main factor is HGV flow and distribution across the available traffic lanes.
- > Obscuration levels for MS4s seem to increase with increased HGV flow and with the offset (of the sign) from the main lanes.
- > Small variations in driver behaviour can have considerable effects on the outcome. For example, drivers may manoeuvre to minimise obscuration.
- > The problem is highly complex and difficult to model, and there is little previous work. Because of the complexity of the variables being modelled, results are highly sensitive to the assumptions made.

## 4.5 Assumptions and Parameters

Both the analytical and simulation models are dependent on a set of input parameters and assumptions. These are described in Table 11.

**Table 11: Input Parameters and Assumptions for the models**

Input Parameter	Assumptions
<ul style="list-style-type: none"> <li>&gt; HGV height, length and width</li> </ul>	<ul style="list-style-type: none"> <li>&gt; The length and width of the HGVs are fixed and constant</li> <li>&gt; For the analytical model, the HGV height is fixed and constant.</li> <li>&gt; For the simulation model, HGVs are generated with height assigned according to a defined input distribution</li> </ul>
<ul style="list-style-type: none"> <li>&gt; Position of drivers eyepoint (offset from left edge of lane and height from road surface)</li> </ul>	<ul style="list-style-type: none"> <li>&gt; The driver eyepoint is fixed and constant for all drivers</li> </ul>
<ul style="list-style-type: none"> <li>&gt; Height of the sign and offset from the verge</li> </ul>	<ul style="list-style-type: none"> <li>&gt; The road section is straight and flat</li> </ul>
<ul style="list-style-type: none"> <li>&gt; Maximum legibility distance of the signal</li> </ul>	<ul style="list-style-type: none"> <li>&gt; Daylight, good weather</li> </ul>
<ul style="list-style-type: none"> <li>&gt; Legibility angle of the signal (vertical and horizontal beam width and sign inclination)</li> </ul>	
<ul style="list-style-type: none"> <li>&gt; Lane width by lane</li> </ul>	
<ul style="list-style-type: none"> <li>&gt; HGV proportion by lane</li> </ul>	<ul style="list-style-type: none"> <li>&gt; HGVs travel in the centre of the lane</li> <li>&gt; For the analytical model, HGVs are evenly distributed in the lane; for the simulation model all vehicles are generated randomly.</li> </ul>
<ul style="list-style-type: none"> <li>&gt; Speed by lane</li> </ul>	<ul style="list-style-type: none"> <li>&gt; Vehicles travel at a constant speed. Different lanes can have different speeds.</li> </ul>
<ul style="list-style-type: none"> <li>&gt; Flow by lane (and number of lanes)</li> </ul>	<ul style="list-style-type: none"> <li>&gt; No lane changing</li> </ul>

### Fixed parameter values

These parameters will be fixed for the purposes of analysis.

- > **Number of lanes** – 4 permanent running lanes.
- > **HGV length and width** – recommended maximum HGV in the UK is length 16.5m, 2.55m width and 4.9m height. These length and width values will be fixed and constant in the models for convenience. HGV height is expected to have a greater effect on obscuration and hence this will be a variable parameter (see below), with a maximum value of 4.9m.
- > **Position of driver's eyepoint** -1.05m from the road surface for car drivers, 2.7m from the road surface for HGV drivers, 2.5m from the left edge of the lane.
- > **Maximum legibility distance of the signal** – 192m. This is the maximum distance at which it is possible to read characters the height of a speed limit on an MS4 with 20/60 vision<sup>16</sup>, i.e. this describes a worst-case scenario.
- > **Legibility angle of the signal** – beam width of an MS4 is -5 degrees vertically and  $\pm 10$  degrees horizontally. Additionally an MS4 on a straight flat road section is inclined downwards by approximately 2 degrees and angled towards the running lanes by approximately 4 degrees. This gives a total of -7 degrees vertically and -14 degrees horizontally.
- > **Lane width by lane** – 3.40m for LBS1, 3.70m for LBS2, 3.65m for LBS3 and 3.55m for LBS4. (Note that for permanent hard shoulder running the lane width of LBS1 may be greater but it is not believed to be noteworthy for analysis).

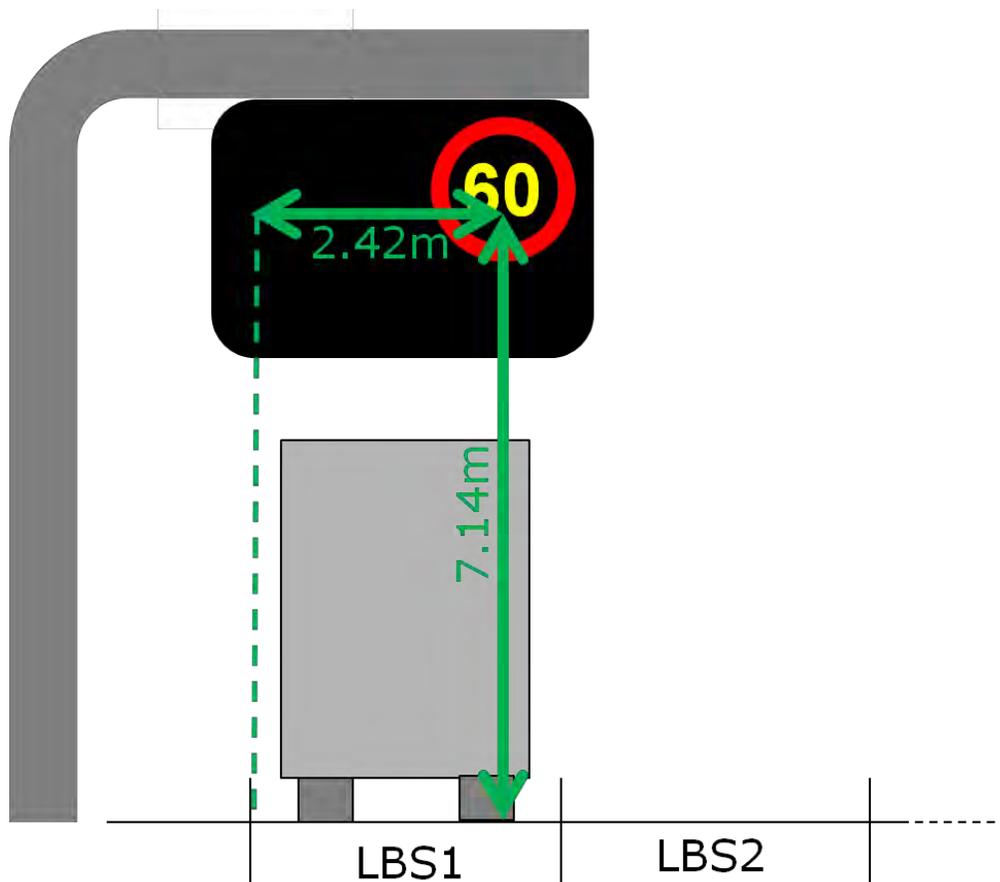
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<sup>16</sup> According to the World Health Organization classifications, when the vision in the better eye with best possible glasses correction is 20:60, it is considered as mild vision loss, or near-normal vision.

### Variable parameter values

These parameters will be varied for the purposes of analysis. Flow, HGV proportion and speed are highly variable and dependent on site, time of day, day of week etc. and therefore it is sensible to consider a range of values. It is also important that location of the sign is analysed as a variable since there is the potential of changing the sign location to mitigate obscuration problems. In addition, a key objective of this task is to assess the difference between verge-mounted and overhead gantry-mounted information provision and this is of course dependent on location. The range of values used for the variable parameters is detailed below.

- > **Height of the sign and offset from the verge** – for MS4 the default clearance 5.7m, which gives a height of 7.14m to the bottom of the speed limit text area. A default lateral position of 2.42m from the edge of LBS1 will be used for the bottom of the text area, which corresponds to the MS4 being centred directly over LBS1 (see Figure 71 below).



**Figure 71: Height and lateral position of point of measurement**

For comparison the analysis will also consider obscuration of AMIs installed on overhead gantries directly over the centre of each lane; the default height for an AMI is 6.12m (to the bottom of the text area) and the default lateral positions (from the edge of LBS1) for the middle of the text area is the centre of each lane, i.e. 1.7m, 5.3m, 8.9m, 12.5m for each lane respectively.

- > **HGVS height** – For the analytical model, the HGVS height is fixed and constant at the maximum of 4.9m, and as such results describe a ‘worst-case scenario’ in terms of obscuration. For the simulation model, HGVS are generated according to a HGVS height distribution. This distribution is described by four height categories, each with an associated proportion of the overall HGVS population. The HGVS distribution used for the default scenario is detailed in Table 12 below.

**Table 12: HGVS distribution in default scenario (simulation model)**

Height (m)	Proportion
4.00 - 4.25	0.47
4.25 - 4.50	0.19
4.50 - 4.75	0.25
4.75 - 5.00	0.09

- > **Speed by lane** – for the analytical model, speed is assumed to be the same across all lanes (as well as constant within a lane). For the simulation model, the speed by lane in the default scenario is described in Table 13 below.

**Table 13: Speed by lane for default scenario (simulation model)**

Lane	Speed (mph)
LBS1	52
LBS2	54
LBS3	56
LBS4	58

- > *Flow and HGV proportion by lane* – Note that for the analytical model these variables are only used to calculate the ‘HGV headway’ in each lane (in conjunction with the speed). The ‘HGV headway is in effect the distance to the nearest HGV ahead in the same lane and the ‘gaps’ between HGVs in the other lanes. For convenience therefore, in the analytical model, the headway values are varied in the analysis rather than the flow and HGV proportion. For both models, the default values used are described in the respective sections.

### *Two sequential signs*

For Task 5B, an additional option was added to the simulation model which allowed the specification of a second sign further down the road section. The input parameters describing this second sign are the same as above for the first sign, with respect to the height and offset from the verge and the legibility distance. The parameters are defined separately for each sign and therefore can take different values, however in the analysis it has been assumed that in reality both signs would be the same.

An additional parameter that is introduced is the separation distance between the two signs. In the analysis this has been assumed to be 1500m.

## 4.6 Model Descriptions

### Analytical model

For an individual driver passing through the road section where the signal is physically legible, the model first calculates **for how long the drivers' view of the sign is blocked by an HGV ahead in the same lane**, based on geometric principles applied to lines of sight. The model then calculates which of the other lanes will **block a driver's view if an HGV was present in that lane, i.e. it identifies whether the sign can be seen over the top of an HGV in the particular lane or if it can only be viewed through gaps in the flow of HGVs.**

The analytical model provides an indication of the obscuration that an individual driver, on average, will experience when approaching and passing the sign. As such, it does not provide overall percentage obscuration rates for the traffic as a whole. It also does not calculate the possibility of viewing the signal through gaps in the HGV flow in other lanes, it merely ascertains whether that will be necessary.

### TRL simulation model

The simulation model builds on the basis provided by the analytical model and extends it to include the possibility of seeing through gaps in the HGV traffic in other lanes. Simulated vehicles are generated and each is continually assessed, to ascertain exactly and for how long it is obscured. In this way the simulation model produces overall obscuration rates for the whole population of simulated traffic. This section briefly describes this process.

Simulated vehicles are generated randomly and enter the road section. After an initial warm-up period equal to the time taken for the first vehicle to travel the distance of the road section in each lane, the following process is carried out for each vehicle on the road, for a predefined timestep:

- > Using the equations derived for the analytical model, the simulation checks whether there is **an HGV ahead that is blocking the driver's line of sight to the signal** and if there is, whether the driver can see over the top of the HGV.
- > **If the driver's view is not blocked, it is then checked whether HGVs in other lanes are obscuring the sign.** For each lane, it is checked whether there is an **HGV blocking the drivers' line of sight.**

At each timestep the simulation records whether the signal is currently obscured from each vehicle. Once a vehicle reaches the end of the road section (and goes past the sign) the simulation calculates the longest continuous length of time that the signal was unobscured, and compares this to the required viewing criterion to **ascertain whether the driver of that vehicle has 'seen' the signal.**

If two signs have been specified for investigation, each vehicle that has passed the first sign continues through the simulation. When the vehicle reaches the legibility distance for the second sign the above calculations are again carried out for each timestep. For each vehicle the simulation will calculate whether the driver has seen each sign separately as described above, and also whether that individual driver has seen both signs, one sign or neither. This allows the calculation of an overall obscuration rate of drivers who have seen neither sign.

## **4.7 Key Findings of Obscuration Models**

### **4.7.1 TRL Simulation Model**

#### **4.7.1.1 Outputs and configurations**

The main outputs of the simulation model are:

- > The percentage of traffic in each lane that has an obscured/unobscured view of the signal for a given minimum time;
- > Percentage of overall traffic that has an obscured/unobscured view of the signal for a given minimum time.

The analysis carried on the output of the simulation model looked at the effects of varying parameters. The following parameter configurations were investigated:

1. Default (i.e. those parameters most likely to be relevant for a verge-mounted signal in an MM2 environment)
2. Gantry mounted signals (speed, flow and HGV conditions as above to provide verge/gantry comparison)
3. Maximum traffic conditions
4. Varying HGV percentage
5. Varying HGV lane utilisation
6. Varying traffic speed
7. Maximum HGV heights
8. Varying MS4 position
9. Two consecutive MS4s

As for the analytical model, the fixed parameters such as legibility distance and HGV width, for which a range of values would be reasonable, the most conservative values have been chosen.

The recommended viewing requirement used in previous studies is 2 seconds. However, given the findings of Task 3 relating to participant response times to speed limit information (see Section 0), a shorter viewing requirement may be sufficient when considering signals alone. Therefore, values have also been calculated for 0.5 second and 1 second criteria.

### *Margin of error in the model*

The simulation model generates vehicles randomly subject to minimum headway restrictions. The type of vehicle and height (if the vehicle is an HGV) are assigned according to the input HGV distribution and HGV height distribution. This randomness in the vehicle generation leads to small differences in output between runs where the same input parameters are used.

To account for this random error, a large set of model runs with the same input parameters was performed and the standard deviation for this sample was calculated. It was assumed that the error was consistent between samples and therefore the standard deviation was the same between samples.

**The “independent two-sample t-test” was used to test for statistically significant differences between model runs (to a 99% confidence interval) which resulted in a margin of error of 0.3%. This means that if there is a difference between model runs of 0.3% or more, there is a 1 in 100 chance that this difference is due to chance.**

4.7.1.2 Findings

**Parameter configuration 1: Default**

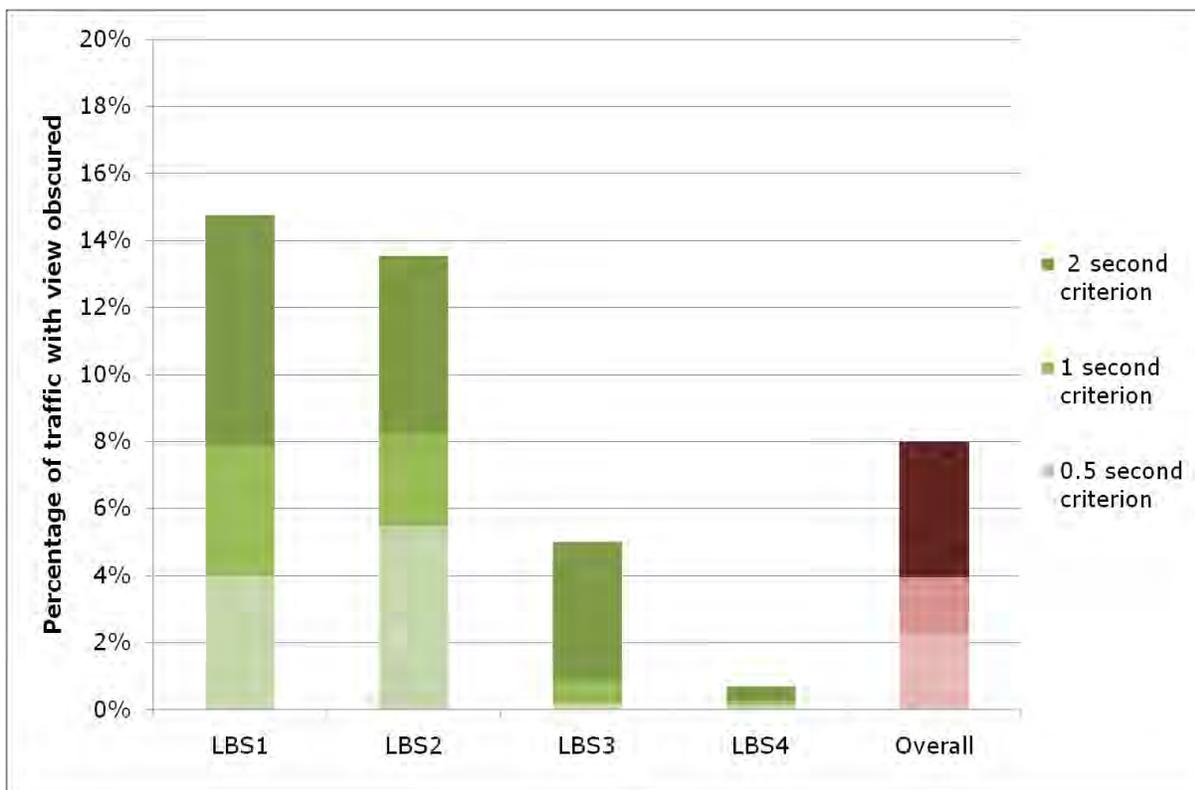
The default scenario is that which has been predicted to represent conditions during a peak-hour in an MM2 scheme. Input traffic flows are 6000 veh/hr and distributed reasonably across lanes (assuming a greater proportion of vehicles would use a permanent LBS1 than a dynamic hard shoulder).

The HGV percentage in the default scenario is 15% which is towards the higher end of motorway HGV percentages (e.g. M42 J3a-7 is approximately 11%; the northern quadrant of the M25 is approximately 17%).

The individual lane speeds were between 52 and 58mph.

The position of the signal in the default scenario is as described in Section 4.5.

Figure 72 displays the percentage of traffic with view of the signal obscured in the default scenario for each lane.



**Figure 72: Percentage of traffic with view of signal obscured in the default scenario, for each lane**

Using default parameters during peak traffic flows, it was estimated that a verge-mounted signal will be visible for less than 2 seconds for 8% of drivers.

Using a 1 second and 0.5 second criteria for visibility lower values of 3.9% and 2.3% respectively were estimated.

### *Causes of obscuration*

As discussed in relation to the analytical model, obscuration of a verge-mounted signal can occur for two reasons:

- > A driver's view is obscured by an HGV in the same lane downstream; or
- > A driver's view is obscured by an HGV in a lane to the left.

By considering the effect of HGVs in each individual lane, the extent to which obscuration occurs due to each of these reasons was investigated, supported by the analytical model.

With the MS4 in the default position the following results were found:

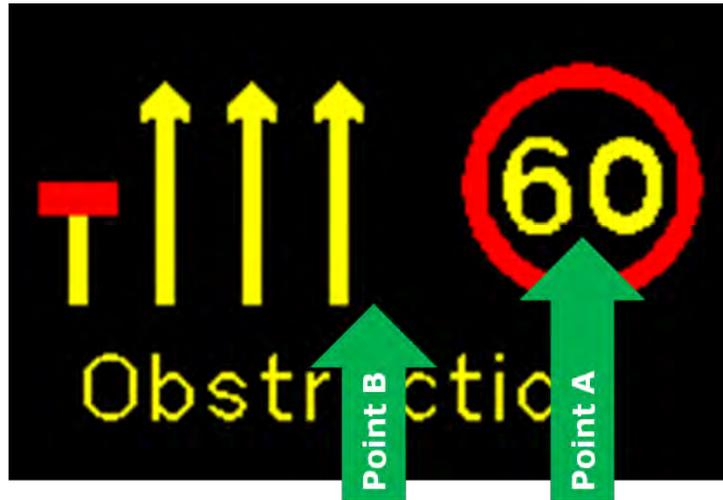
- > In LBS1 all obscuration is due to HGVs in the same lane downstream;
- > In LBS2 all obscuration is due to HGVs in the same lane downstream;
- > In LBS3 most obscuration is due to HGVs in LBS2; and
- > In LBS4 most obscuration is due to HGVs in LBS3 and some because of HGVs in LBS2.

Broadly applying these to the default scenario, using a 2 second viewing time, gives the following:

- > Obscuration caused by HGVs in the same lane makes up for approximately 79% of all obscured vehicles (6.3% of all traffic); and
- > Obscuration caused by HGVs in a lane to the left makes up for approximately 21% of all obscured vehicles (1.7% of all traffic).

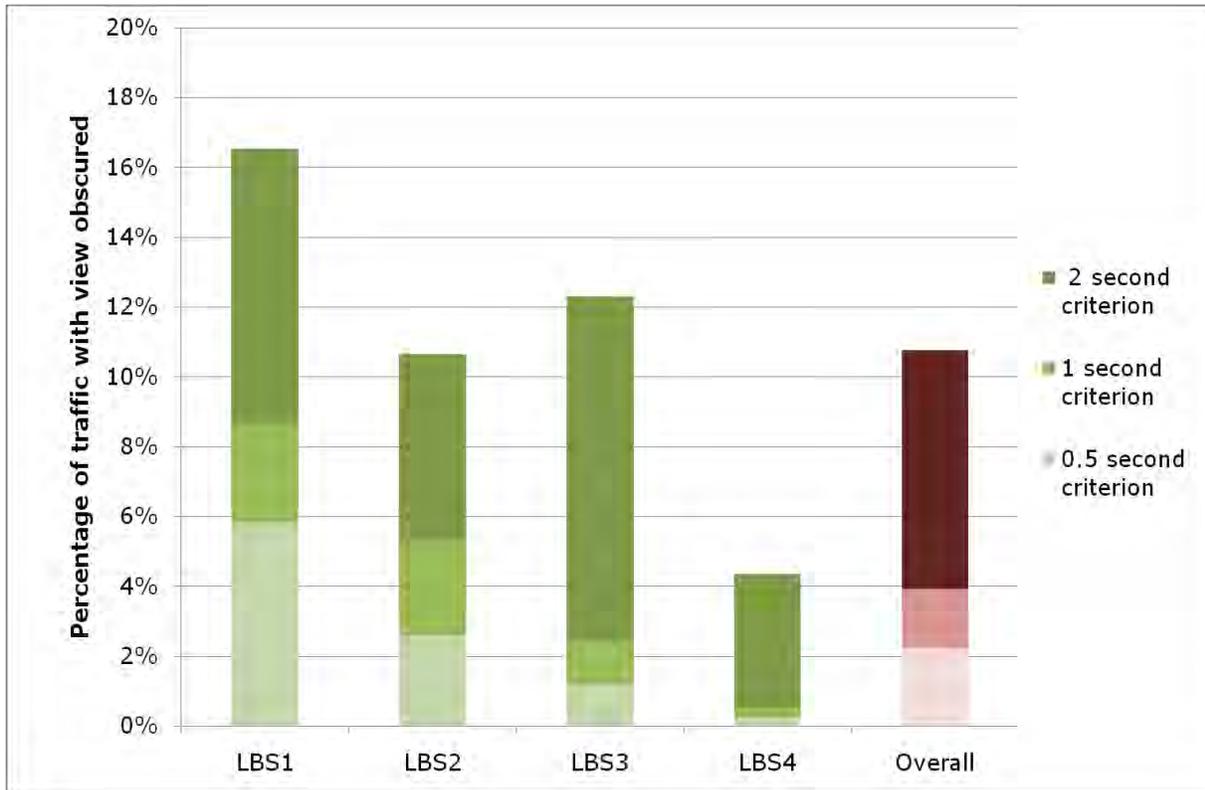
*Obscuration of the lane closure aspect*

Unless otherwise stated, for all parameter configurations, the position of the point being obscured is where the bottom of the numeric within a speed limit would be expected to be on a verge-mounted MS4 (Point A in the Figure 73 below and as shown in Figure 71).



**Figure 73: An example MS4 message displaying lane closure and speed limit information**

However, the other safety critical information which is likely to be communicated alongside a speed limit is information relating to lane closures. Figure 74 displays the percentage of traffic with view of the lane closure obscured in the default scenario for each lane, measuring the bottom right point of the aspect, i.e. Point B in Figure 73 above.



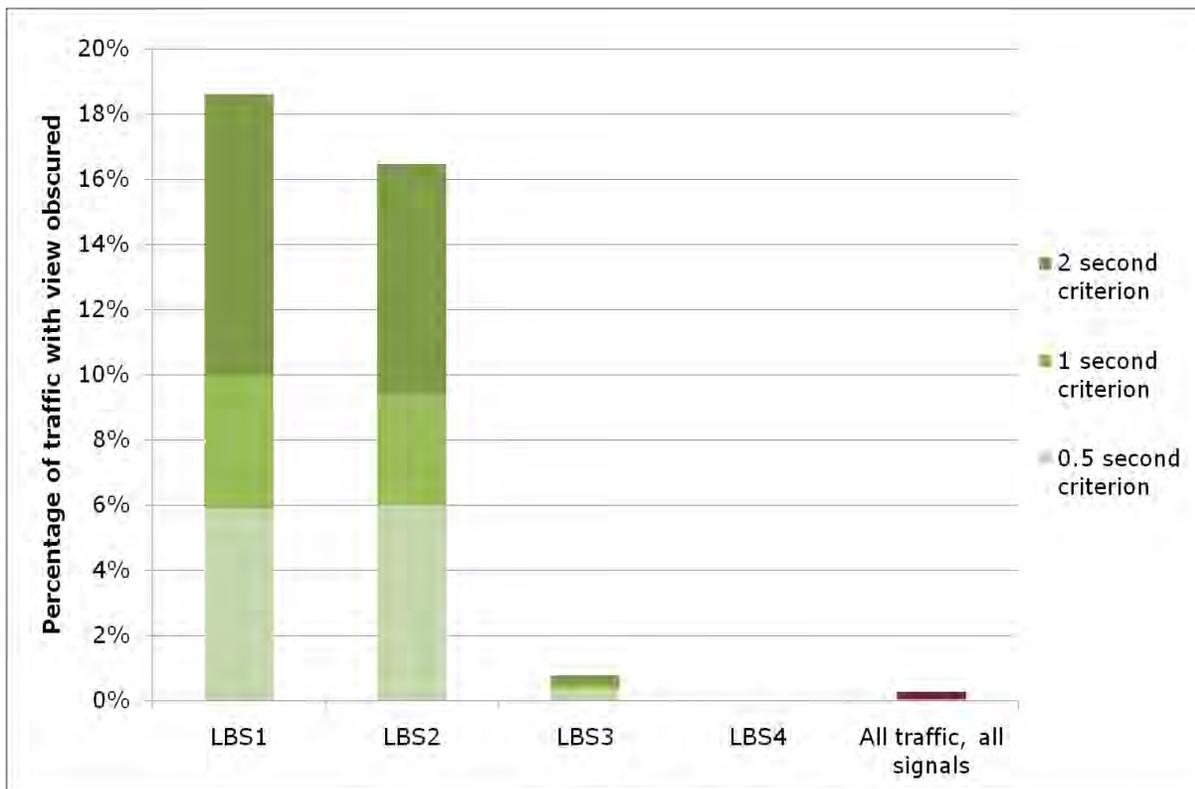
**Figure 74: Percentage of traffic with view of the lane closure aspect obscured in the default scenario, for each lane**

The difference in obscuration between the lane closure aspect and the speed limit signal is within the margin of error for both 0.5 and 1 second viewing times. Using a 2 second viewing time, overall obscuration is greater than that for the speed limit signal by 2.8%. This is largely because obscuration in LBS3 by HGVs in LBS2 is increased.

***Parameter configuration 2: Gantry-mounted signals***

To provide a comparison with the default scenario, the obscuration of speed limit signals on gantry-mounted signs was also investigated. It was assumed that these would be gantry-mounted signs installed at minimum clearance (5.7m) directly over the centre of each lane. The points being analysed for obscuration are the bottom centre points of the numeric within each of the four signals.

Figure 75 displays percentage traffic in each lane for which the signal in its own lane is obscured, as well as the percentage of traffic for which all signals are obscured. The same speed, flow and HGV conditions as in the default scenario above have been used.



**Figure 75: Percentage of traffic in each lane with the view of a gantry-mounted signal in the same lane obscured, and percentage of all traffic with the view of all signals obscured**

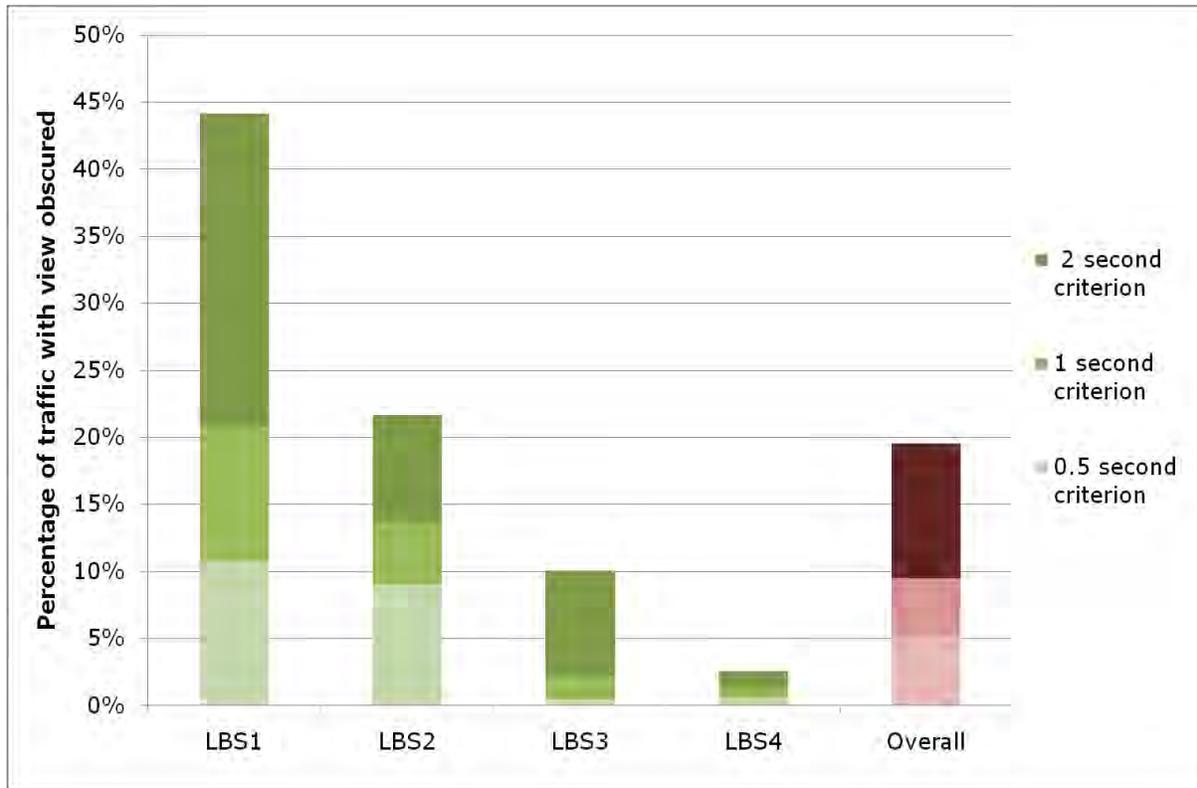
Whether a driver needs to be able to see the signal specific to their current lane, or whether it is adequate to see any of the four signals depends on what information is being provided. For example, for lane closure information it is assumed that a driver must see the signal displayed over the same lane, but for speed limit information it may be adequate to see any of the four signals, since all will show the same speed limit.

For all three viewing criterion, for vehicles in LBS1 and LBS2 obscuration of an individual gantry-mounted signal in the same lane is greater than for a signal or lane closure aspect displayed on a verge-mounted MS4 in the default position.

However, using default parameters the overall percentage of drivers unable to see *any* of the four gantry-mounted signals is considerably less than for a single verge-mounted signal and within the margin of error of the simulation.

Parameter configuration 3: Maximum traffic conditions

Figure 76 illustrates the percentage of traffic with view obscured in what can be considered 'maximum' peak flow conditions. This uses flows close to 2000 veh/hr in each lane and an overall HGV percentage of 25%. All other parameters are equal to those used in the default scenario.



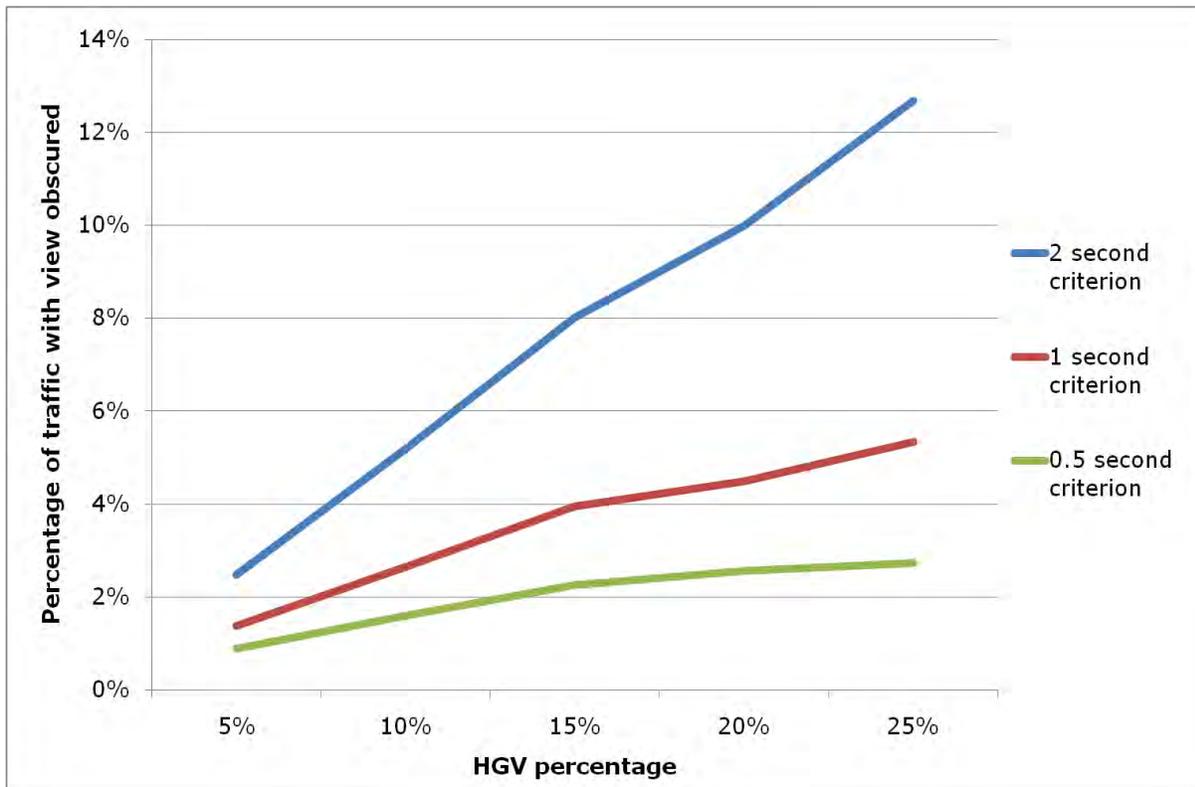
**Figure 76: Percentage of traffic with view obscured in maximum traffic conditions, for each lane**

Use of the maximum traffic conditions scenario more than doubled the percentage of overall drivers who were unable to see a verge-mounted MS4 (for all three viewing criteria). In LBS1 this percentage was as high as 10.1% of vehicles using a 0.5 second criterion.

***Parameter configuration 4: Varying HGV percentage***

Previous work – and common sense – suggests that obscuration rates are greatly influenced by the number of HGVs in a traffic population. Parameter configurations 4 and 5 consider the influence on obscuration of both the number of HGVs and the spread of HGVs across lanes.

Figure 77 represents the effect on obscuration rates of varying HGV percentage. Overall traffic flows have been kept constant at the default values, as well as the ratio of HGV percentage across lanes.



**Figure 77: Percentage of traffic with view obscured for varying HGV percentages**

As expected, results show that obscuration increases with the proportion of traffic consisting of HGVs. With a 5% HGV proportion only 0.9% of traffic is obscured using a 0.5 second viewing time. With a 25% HGV proportion the percentage of traffic with their view obscured was 2.7%, using the same viewing time.

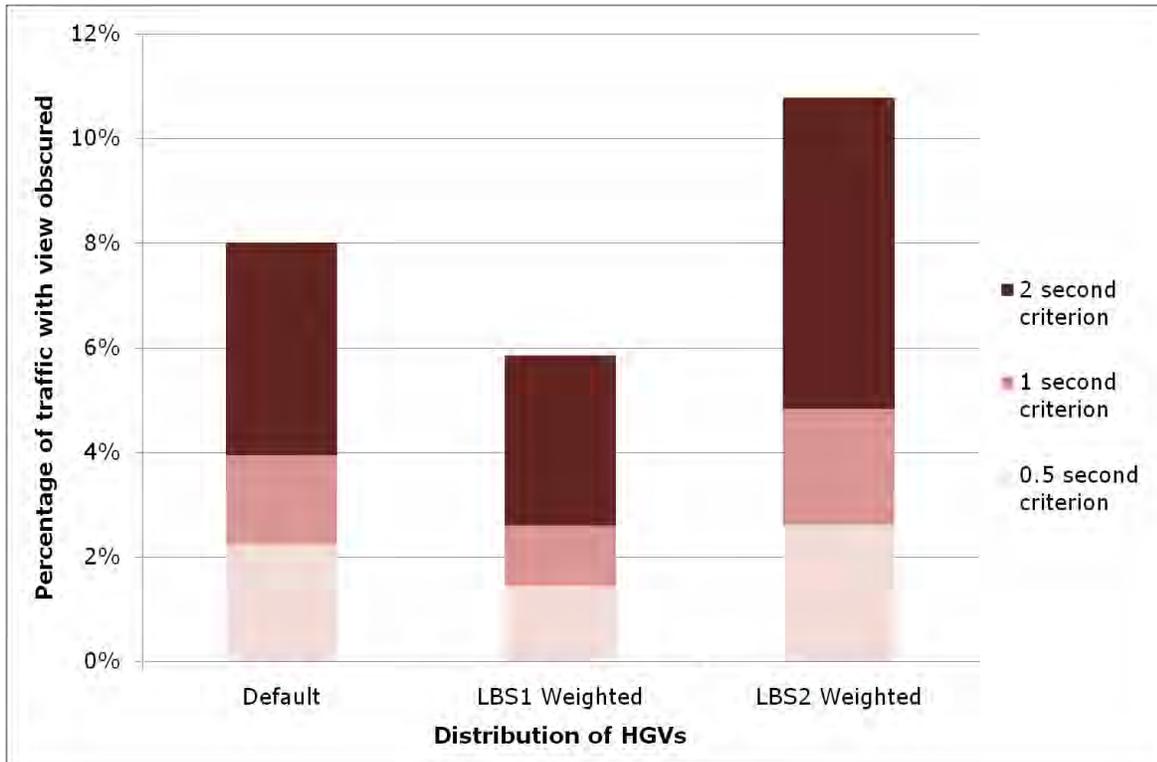
*Parameter configuration 5: Varying HGV lane utilisation*

In the default scenario an HGV percentage of 15% is used, distributed based on a reasonable estimate for HGV lane utilisation within a permanent 4-lane running situation. Table 14 describes the distribution for the default scenario as well as for two other scenarios: one where the distribution of HGVs is heavily weighted to LBS1 and another in which it is heavily weighted to LBS2.

**Table 14: Distribution of HGVs in three scenarios analysed**

	Overall HGV percentage	Approximate percentage of total HGVs in each lane			
		LBS1	LBS2	LBS3	LBS4
<b>Default scenario</b>	15%	65%	35%	5%	0%
<b>LBS1 weighted scenario</b>	15%	80%	20%	0%	0%
<b>LBS2 weighted scenario</b>	15%	20%	80%	0%	0%

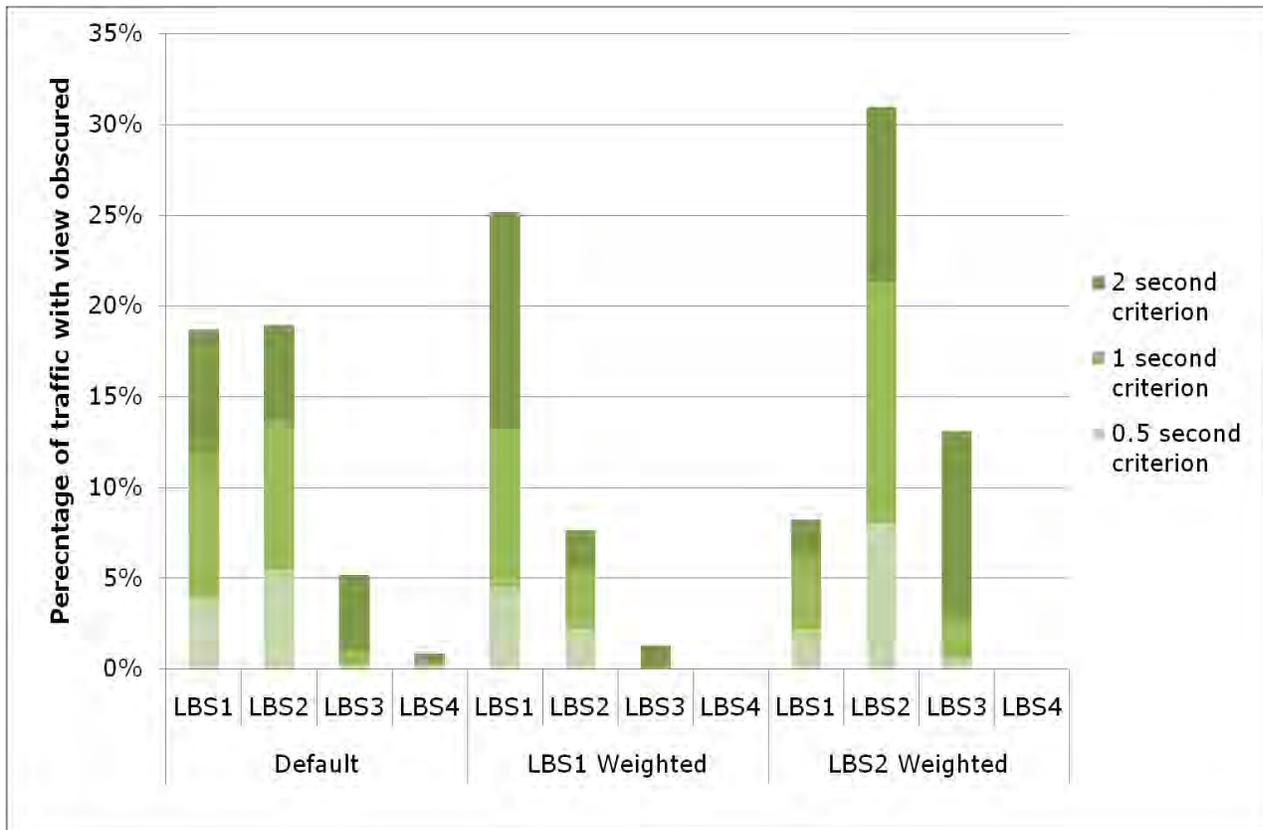
Figure 78 illustrates the overall percentage of traffic with view of the signal obscured for each distribution of HGVs.



**Figure 78: Percentage of all traffic with view obscured under three different HGVD distributions**

With 80% of HGVs in LBS1, overall obscuration is decreased. Conversely if 80% of HGVs are in LBS2, obscuration is substantially increased.

Figure 79 illustrates how traffic in each lane is affected the three different HGV distributions.

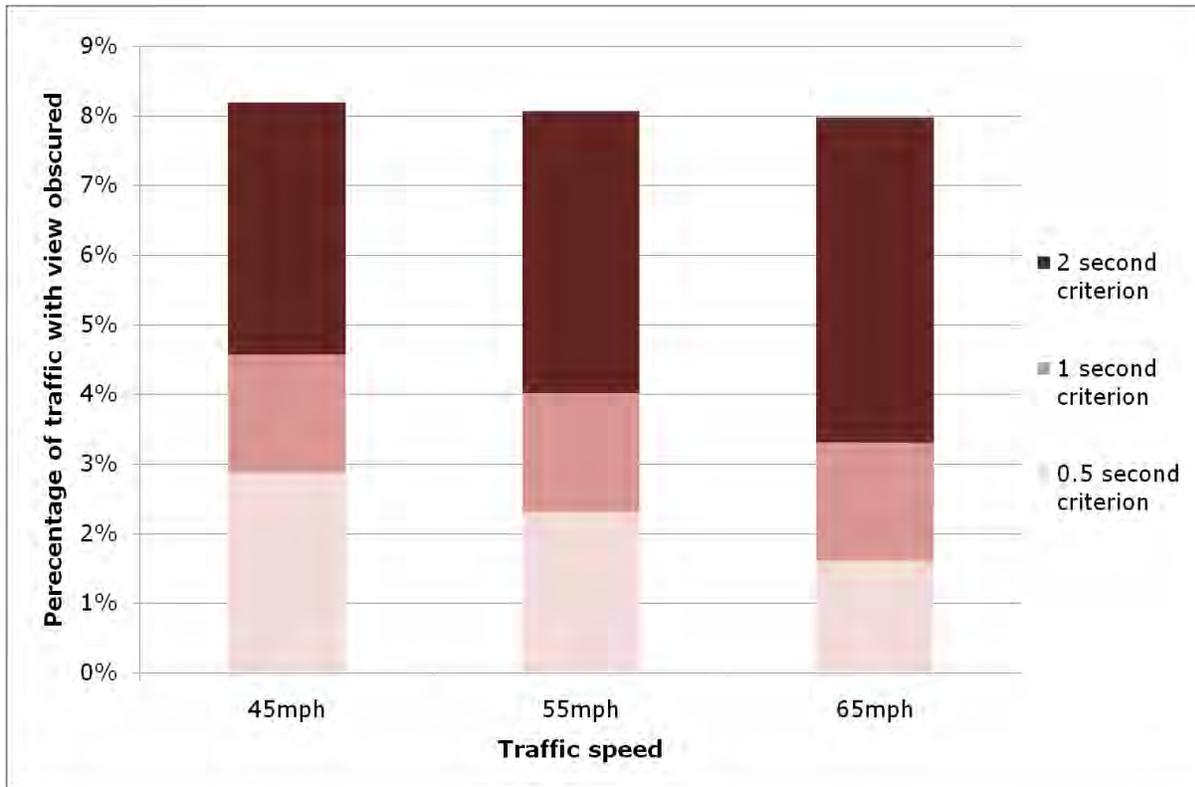


**Figure 79: Percentage of traffic in each lane with view obscured, for three different HGV distributions**

The LBS2 Weighted distribution has a greater effect on LBS2 obscuration than the LBS1 Weighted distribution has on LBS1. This will be due to the fact that, in the default scenario, flows are greater in LBS2 than in LBS1. This, and the increased level of obscuration in LBS3 due to HGVs in LBS2 explains why overall obscuration for the LBS2 Weighted HGV distribution is greater than the two other distributions.

***Parameter configuration 6: Varying traffic speeds***

The default scenario uses varying traffic speeds, with the speed gradually increasing from 52mph to 58mph across the lanes. Figure 80 illustrates the percentage of all traffic with the view of the signal obscured using three different traffic speeds, where the speed is constant across all lanes.

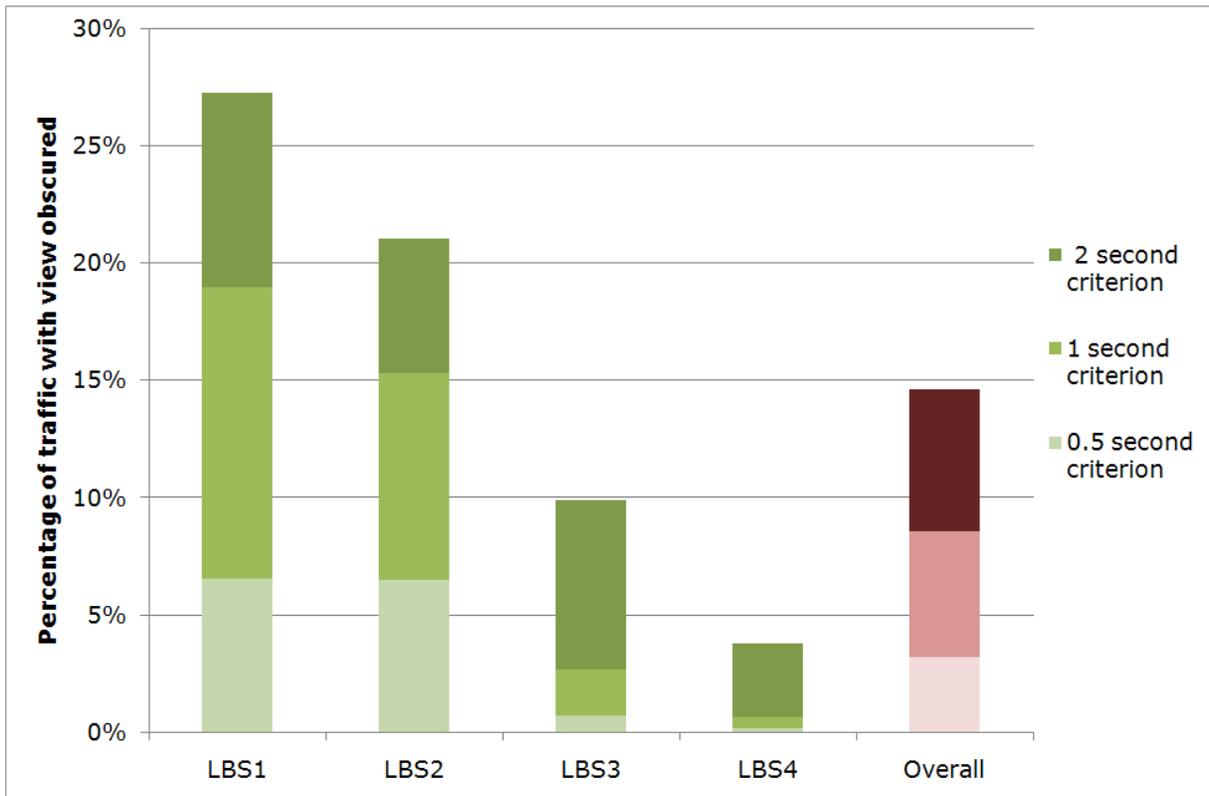


**Figure 80: Percentage of all traffic with view of signal obscured using three different traffic speeds**

The effect of speed on obscuration will be a balance between increased headways between vehicles (in terms of distance not time) which will decrease obscuration rates, and decreased overall time in which the signal is legible, which will increase obscuration rates. The results shown in Figure 80 suggest that this balance is slightly in favour of increased headways, i.e. the positive effect of increased headways is greater than the negative effect of decreased viewing window. This effect is greater for the shorter required viewing criteria, as would be expected, since the overall increase in viewing opportunity required would be less.

***Parameter configuration 7: Maximum HGV heights***

The default scenario uses a range of HGV heights, assigned from a typical distribution. Figure 81 illustrates the case when all HGVs are assigned the maximum height of 4.9m and as such represents a worst-case scenario in terms of obscuration. All other parameters are as defined in the default scenario.



**Figure 81: Percentage of all traffic with view obscured when all HGVs are of maximum height**

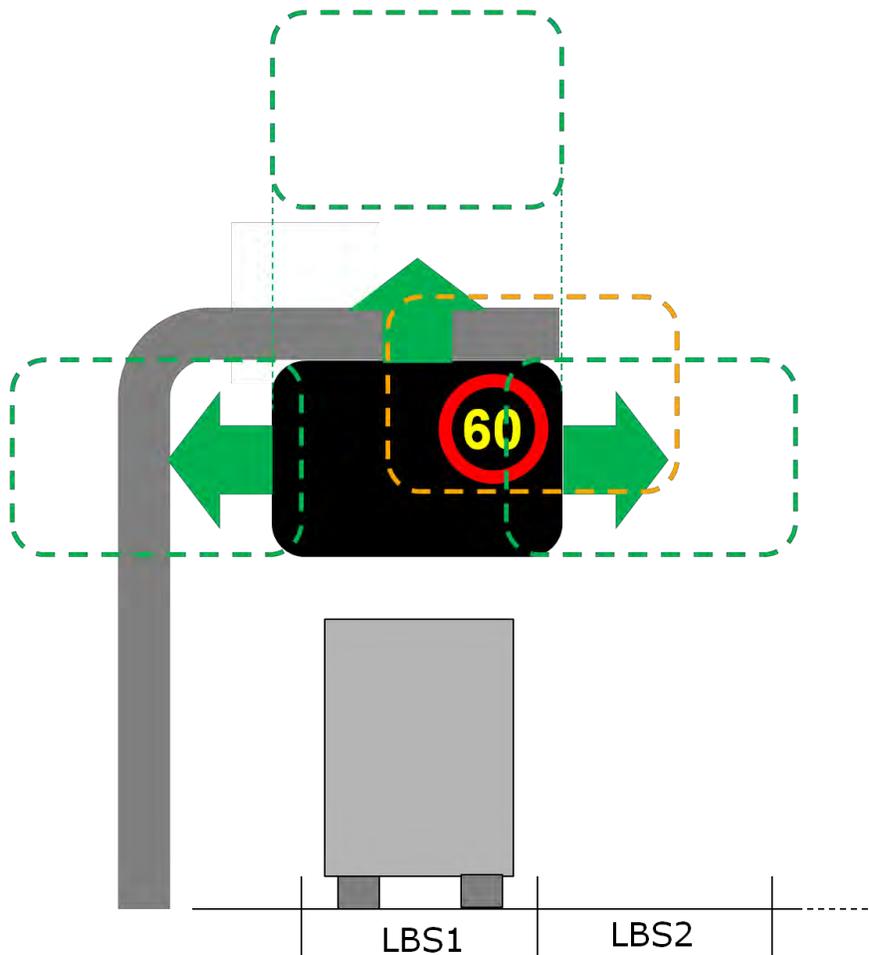
As expected the obscuration rates when all HGVs are of maximum height are significantly higher than when they cover a range of values, for all lanes and for all viewing criteria.

***Parameter configuration 8: Varying MS4 position***

The location of a verge-mounted MS4 can be varied in two ways:

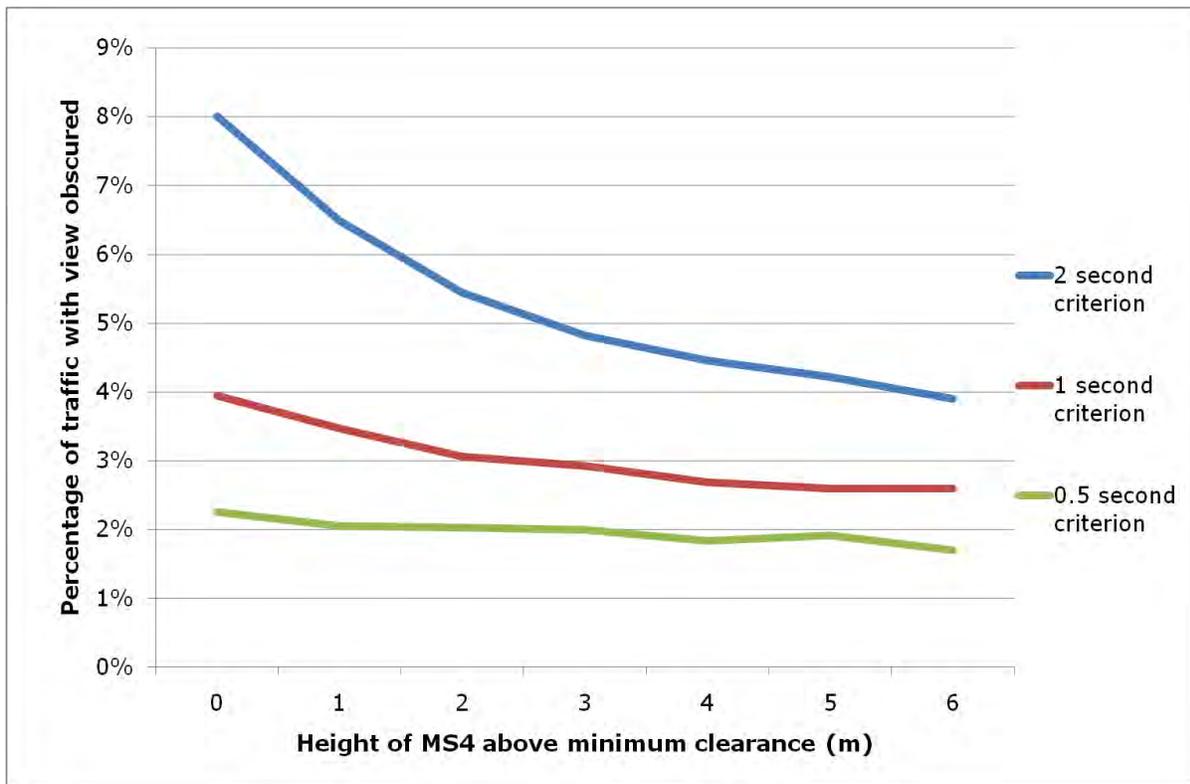
- > Increasing the height;
- > Moving the sign laterally with respect to the carriageway.

The range of locations considered within this analysis is illustrated in Figure 82 below. The position represented in orange is a specific example of lateral and vertical repositioning also investigated.



**Figure 82: An illustration of the range of MS4 locations considered within this analysis**

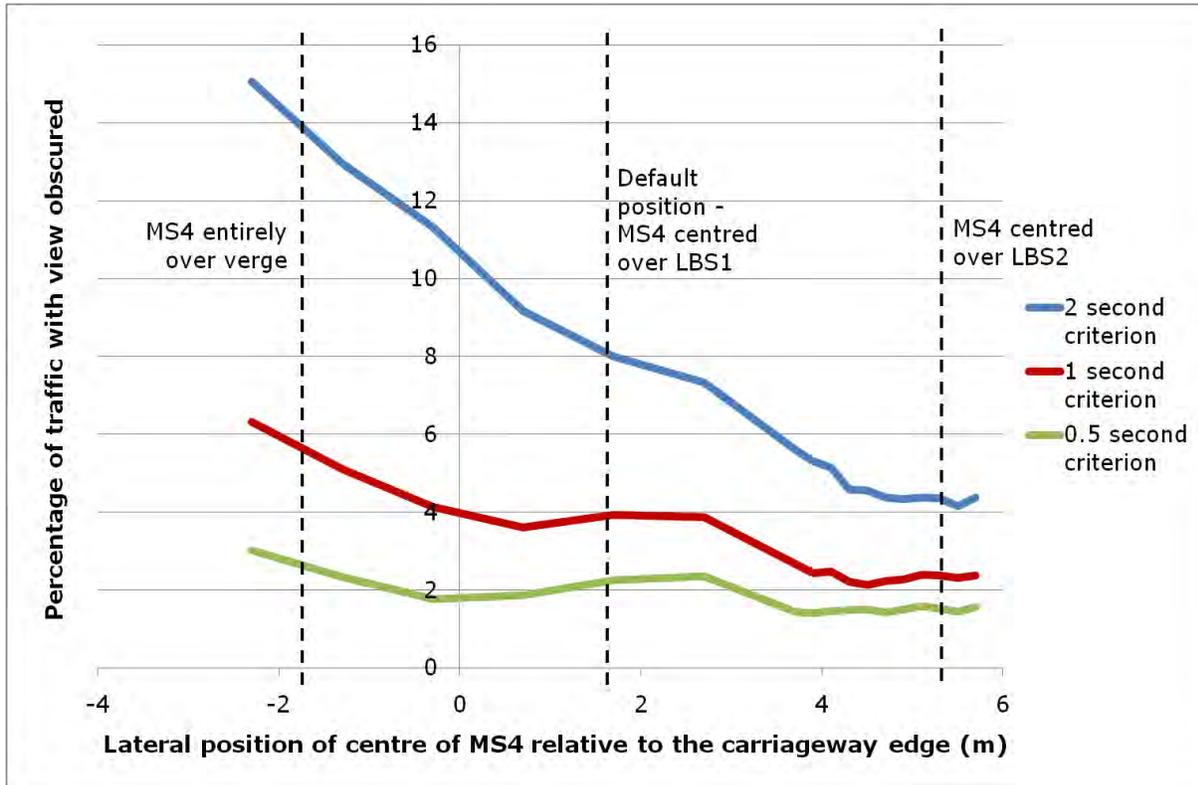
Figure 83 illustrates the percentage of traffic obscured at seven different heights, at the default lateral position and for default traffic conditions.



**Figure 83: Percentage of traffic with view of signal obscured with varying MS4 heights**

Increasing the height of the MS4 decreases overall obscuration for all viewing times. Looking at the extreme case of a sign 6m above the required minimum clearance height, obscuration was decreased by 0.6% for a 0.5 second viewing time and 4.1% for a 2 second viewing time.

Figure 84 illustrates the percentage of traffic obscured at a range of lateral positions, at the default sign height and for default traffic conditions. It has been assumed that moving the MS4 any further than being centred over LBS2 becomes too impractical to implement and is therefore not of interest to this investigation.



**Figure 84: Percentage of traffic with view of signal obscured with lateral MS4 positions (measured from the centre of the MS4)**

This illustrates how, in this scenario, moving the MS4 laterally to the left of the default position generally increases obscuration. It can also be seen that obscuration decrease as the MS4 is moved further out over the carriageway towards the central reservation.

The optimum lateral position of an MS4 within the simulation model should be considered as the position at which the overall obscuration rate is at its lowest. As stated previously, the margin of error being used within this analysis is 0.3%. Therefore, any fluctuation between obscuration rates within this range should be disregarded. Within the results of this analysis, then, there are a range of positions for which obscuration is at a minimum.

It has been assumed that the closer the MS4 is to the verge the more practical it would be to install and maintain, so the optimum position, therefore, has been defined as the point closest to the nearside of carriageway for which obscuration rate is within 0.3% of the minimum recorded value. Table 15 presents the optimum lateral MS4 position for the three different viewing times used in this analysis:

**Table 15: Optimum lateral MS4 positions for three different viewing times**

<b>Viewing criterion (secs)</b>	<b>Optimum lateral position (metres from nearside edge of carriageway to of centre of MS4)</b>
<b>2</b>	4.7m
<b>1</b>	4.3m
<b>0.5</b>	3.7m

To achieve the level of obscuration estimated for these optimum positions by only adjusting the height of the MS4 requires an increase of more than 6m for 1 and 0.5 second viewing times. For a 2 second viewing time the MS4 would need to be raised by 4m from the minimum clearance height to achieve an equivalent level of obscuration as that of the optimum lateral position.

Obscuration in the simulation model can, then, be reduced by either increasing the height of the MS4 or moving it towards the central reservation. Analysis was also carried out to investigate the combined effects of these two movements. Table 16 looks at the effects of moving the MS4 1m higher and to left, centred over the line between LBS2 and LBS2 (as in Figure 82) compared with the default position and both movements separately.

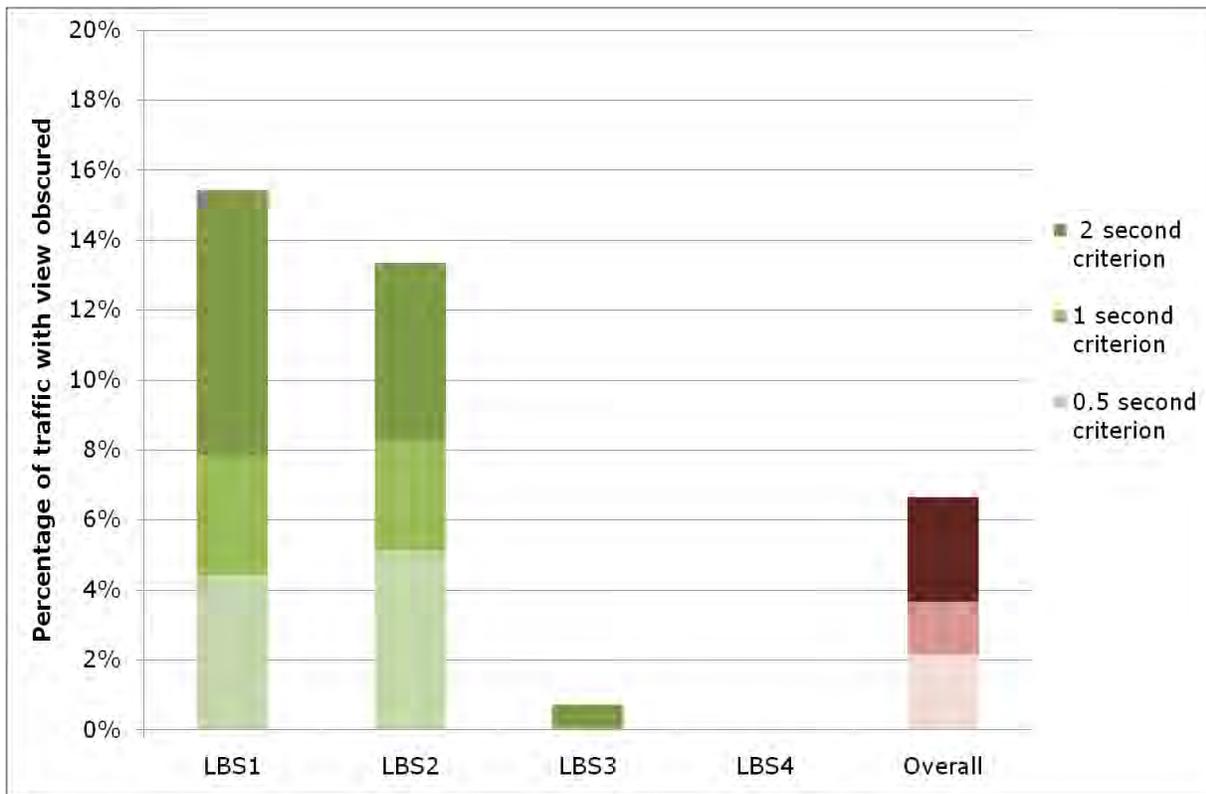
**Table 16: Overall obscuration at with MS4 in 4 different positions for 2 second (blue), 1 second (red) and 0.5 second (green) viewing times**

<b>1m higher</b>	<b>6.5%, 3.5%, 2.0%</b>	<b>5.5%, 3.2%, 1.7%</b>
<b>Default height</b>	<b>8%, 3.9%, 2.3%</b>	<b>5.6%, 2.9%, 1.6%</b>
	<b>Default position</b>	<b>Centred over line between LBS1 and LBS2</b>

These results suggest that, although raising the height by 1m for a sign located over LBS1 decreases the obscuration rate, when the sign is located between LBS1 and LBS2, raising it by 1m from the default position has very little effect (changes are within the margin of error of the simulation).

***Parameter configuration 9: Two consecutive MS4s***

Figure 85 illustrates the percentage of traffic in the default scenario with the view of two consecutive signals obscured. The distance between the two signals has been set to 1500m, although the distance is likely to have very little influence on the output of the simulation model.



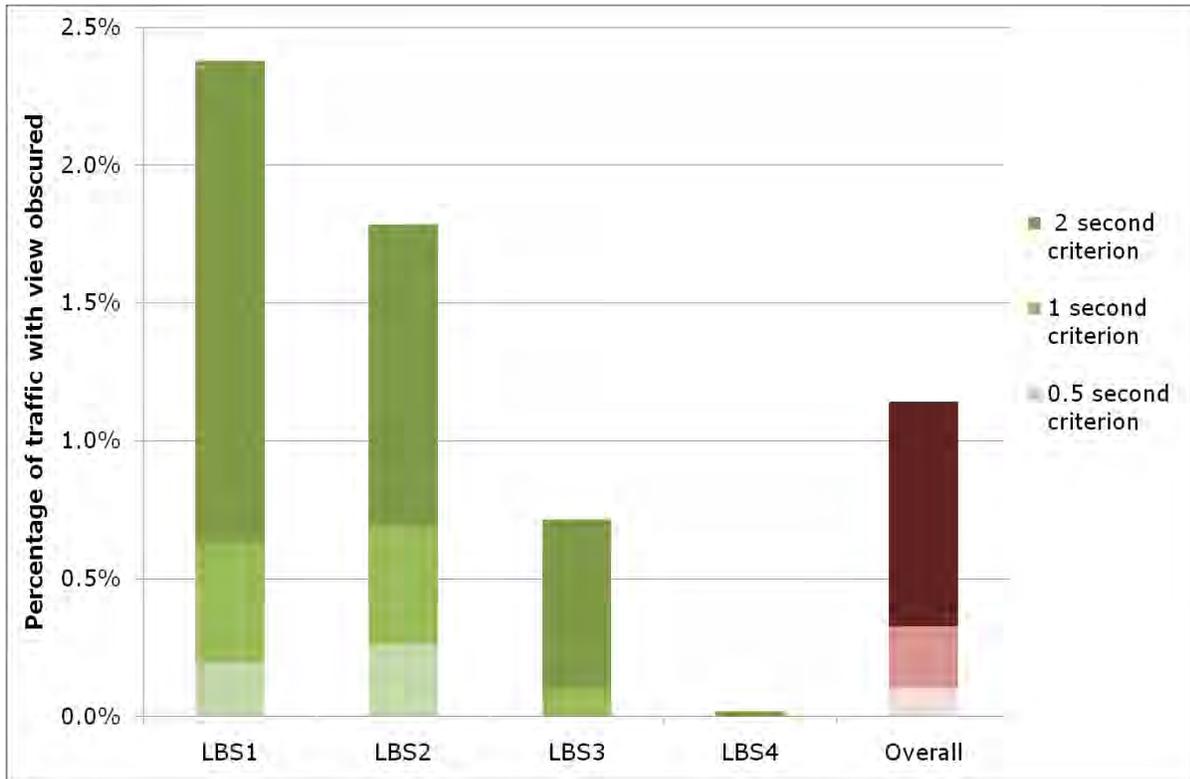
**Figure 85: Percentage of all traffic with view of two consecutive signals obscured, in the default scenario for each lane**

Comparing obscuration rates in LBS1 and LBS2 in Figure 85 with those in Figure 72 shows that any differences between obscuration of one signal and two signals in these two lanes are within the margin of error. As discussed previously, the simulation model used in this analysis does include lane changing. Whilst this has been determined to be the most suitable approach for measuring obscuration of one signal (see Section 4.8 for a full exploration of this issue), this becomes problematic when the obscuration of two signals is modelled.

Parameter Configuration 1 identified that in the default scenario, all obscuration in LBS1 and LBS2 is caused by HGVs further downstream. The simulation model assumes that the position of a vehicle relative to vehicles in the same lane remains constant. Therefore, a driver in either LBS1 or LBS2 who is obscured for one signal remains in an obscured position by the time they reach the second.

Because of this the only influence on the obscuration rates is caused by drivers obscured laterally, i.e. in LBS3 or LBS4. Using a 0.5 second viewing time the number of vehicles obscured in LBS3 and LBS4 is within the margin of error, therefore, there is no significant difference between the obscuration rate for one signal as with two signals. Using a 2 second viewing time this accounts for a 1.4% decrease in traffic with the view of two signals obscured.

An approach to estimating the effects of lane changing on obscuration in LBS1 and LBS2 would be to assume that all lane changing between the two MS4s would be to overtake only and that all desired lane changes are complete by the time they reach the next signal. This would in effect be saying that all vehicles in either LBS1 or LBS2 remain in the same lane for both signals but that the likelihood of being obscured is the same for all vehicles for each signal. Figure 86 illustrates the estimated obscuration rates applying these assumptions.



**Figure 86: Percentage of all traffic with view of two consecutive signals obscured, in the default scenario for each lane assuming lane changing assumptions are applied**

Here it can be seen that applying the assumptions above, the estimated percentage of traffic being obscured of two consecutive signals for a 0.5 second viewing time is within the margin of error in all lanes. Using a 2 second viewing time the estimated obscuration rate is 1.1%.

## 4.7.2 Analytical Model

Obscuration is probably best understood if expressed in terms of the proportion of traffic that is unable to see a sign or signal for a defined period of time. In that sense the main purpose of the analytical model is to form a basis from which the simulation model can be run.

The analytical model does also provide useful findings in its own right, based on the **consideration of boundary conditions, or 'worst-case' scenarios**. These findings are discussed below.

### 4.7.2.1 Outputs

The analytical model provides an opportunity to assess potential worst-case scenarios from the **drivers' perspective**. The outputs of the model provide:

- > The percentage of the total time possible that the sign is unobscured; and
- > The time in seconds that this percentage represents.

The worst-case scenario considered is defined as the situation in which the driver is following an HGV at 1.2 seconds headway and is surrounded by HGVs in all adjacent lanes.

The fixed parameter values, such as legibility distance and HGV dimensions, also describe a worst-case scenario. It is also assumed that there is no visibility through gaps between HGVs.

The results of the worst-case scenario analysis are based on the 2 second viewing time and are presented in two parts; the obscuration of MS4s and gantry-mounted AMIs for a driver in each lane; and the obscuration of an MS4 based on its height and lateral position relative to the carriageway.

#### 4.7.2.2 Findings

##### MS4 and AMI differences by lane

Table 17 provides a description of which signals (MS4 or AMI) are obscured by which HGV, for a driver in each lane independently. The main findings are highlighted in the blue box following this table and were reached through a process of logical deduction from the information below.

**Table 17: Signals obscured in 'worst-case scenario'**

	<b>Verge-mounted MS4 (Default location)</b>	<b>Four gantry-mounted AMIs</b>
<b>Driver in LBS1</b>	The view of a driver in LBS1 is obscured for all speeds (40mph – 70mph) due to the HGV ahead in the same lane.	The view of the LBS1 AMI is obscured for all speeds by the HGV ahead in the lane. The view of the AMIs in both LBS2 and LBS3 is obscured by HGVs in LBS2. The view of the LBS4 AMI is obscured by HGVs in LBS2, LBS3 and LBS4.
<b>Driver in LBS2</b>	As for LBS1, the view of a driver in LBS2 is obscured for all speeds (40mph – 70mph) due to the HGV ahead in the same lane.	The view of the LBS1 AMI and the LBS2 AMI is obscured for all speeds by the HGV ahead in the lane. The view of the AMI in LBS3 is obscured by HGVs in LBS3. The view of the LBS4 AMI is obscured by HGVs in LBS3 and LBS4.
<b>Driver in LBS3</b>	The view of a driver in LBS3 is obscured at 40mph (by the HGV ahead) but at higher speeds there is a window of opportunity to view the signal that is longer than the required 2 seconds. However, for all speeds the view of the driver will be obscured by an HGV in LBS2 and therefore in this worst-case scenario the view will be obscured.	The view of the LBS2 AMI and the LBS3 AMI is obscured for all speeds by the HGV ahead in the lane. The view of the AMI in LBS1 is obscured by HGVs in LBS2. The view of the LBS4 AMI is obscured by HGVs in LBS4.
<b>Driver in LBS4</b>	The view of a driver in LBS4 is unobscured by the HGV ahead for all speeds; however the view will be obscured by HGVs in both LBS2 and LBS3.	The view of the LBS3 AMI and LBS4 AMI is obscured for all speeds by the HGV ahead in the lane. The view of the AMI in LBS2 is obscured by HGVs in LBS3. The view of the LBS1 AMI is obscured by HGVs in LBS2 and LBS3.

For the worst-case scenario, regardless of lane, the driver will not be able to see either an MS4 or a gantry-mounted AMI.

Additionally, altering the worst-case scenario slightly so that there are no HGVs in LBS3 and LBS4, no driver behind an HGV at a 1.2 second headway, in any lane, will be able to see the verge mounted MS4.

Conversely in this second scenario, only the driver in LBS1 would not be able to see at least one of the AMIs.

### ***Lateral positioning and height of MS4***

Still considering the worst-case scenario described above, the effect of moving the MS4 relative to the carriageway edge is also investigated.

- > Moving the sign further from the road (i.e. to the left) produces less obscuration due to HGVs directly ahead of the driver but increases the obscuration caused by HGVs in other lanes.
- > As the location of the sign moves further out over the carriageway (i.e. to the right) there are always at least two lanes **in which drivers' view will be obscured** by HGVs ahead.

Similarly the height of the MS4 can be increased:

- > At 70mph, for a signal height of 20m (which is of course far beyond practicality in any case) drivers in all lanes can view the signal for approximately 1 second (the limitation is due to the physical angles rather than HGV obscuration). This is the longest that is possible for LBS1.
- > At 40mph, there is no possible height at which drivers in all lanes can all view the signal for any length of time.

For the worst case scenario the lateral position and height of the sign do not affect obscuration levels and therefore cannot be used for mitigation.

Consideration of varying headways

It has already been stated that for HGV headways of 1.2 seconds no driver in any lane can see a verge-mounted MS4 (in the default position of 2.42m from carriageway edge and height 7.14m). The minimum HGV headway can be **calculated such that a driver’s view** of the signal is NOT obscured by the HGV ahead and there is at least a 2 second window of opportunity to view the signal. These minimum headways are presented in Table 18 **Error! Reference source not found.**

**Table 18: Minimum HGV headways at which a driver’s view is not obscured by the HGV in front**

	<b>Min HGV Headways - 40mph</b>	<b>Min HGV Headways - 70mph</b>
<b>LBS1</b>	54m (3.02 secs)	71m (2.27 secs)
<b>LBS2</b>	48m (2.68 secs)	63m (2.01 secs)
<b>LBS3</b>	24m (1.34 secs) <i>(but signal is obscured by HGVs in LBS2)</i>	31m (0.99 secs) <i>(but signal is obscured by HGVs in LBS2)</i>
<b>LBS4</b>	16m (0.89 secs) <i>(but signal is obscured by HGVs in LBS2 and LBS3)</i>	21m (0.67 secs) <i>(but signal is obscured by HGVs in LBS2 and LBS3)</i>

It is feasible that HGV headways in real life are likely to be larger than these minima – in particular in LBS3 and LBS4 which will have very large gaps between HGVs (or no HGVs at all). However whether a driver in either of those two lanes can **actually view the signal unobscured depends on the ‘gaps’ between HGVs in LBS2.**

Considering the gantry-mounted AMIs for comparison purposes, a driver in any lane needs a headway (to the HGV ahead) of 59m (3.3 seconds) at 40mph and 79m (2.52 seconds) at 70mph to be able to see the sign installed directly over the same lane. As stated earlier in the analysis, if there are no HGVs in LBS3 or LBS4 then all drivers can see at least one of the AMI, except those in LBS1. So for drivers in LBS1 to be able to see at least one signal the HGV headway in LBS1 needs to be as above OR the gaps in LBS2 need to be large enough to be able to view an alternative AMI. For verge-mounted MS4s, drivers do not have an alternative signal to their right.

Provided a vehicle, in any lane, is at least 3.3 seconds behind an HGV, the driver will have at least a 2 second window to view a gantry-mounted AMI for all speeds, regardless of traffic in other lanes. For the same headway, MS4 obscuration is dependent on the HGV flow in other lanes. See Section 0 for an exploration of the mitigating actions available to drivers if they are obscured.

### 4.7.3 HA/SEA Simulation Tool

#### 4.7.3.1 Description

The MOMS (Modelling the Obscuration of Motorway Signals) simulation tool has been developed to assist road engineers optimise sign post and sign location when designing traffic management road schemes. The software generates signal obscuration data by running a traffic simulation from a user-defined setup. The output data includes a number of graphs, the most relevant for the current task being time (seconds) against the cumulative percentage of vehicles in the simulation that have the signal observable (unobscured) for at least that length of time.

There are a large number of setup parameters that need to be defined by the user. Unless otherwise stated in the analysis, the parameter values are taken to be the MOMS software default values described below.

- > **Motorway Geometry** – A 5000m stretch of straight road, with three main carriageway lanes and a hard shoulder (with lane widths 3.6m for hard shoulder and 3.7 for main carriageway). Unless otherwise stated, hard shoulder running is implemented for all the analyses described in this report and therefore there are four live traffic lanes.
- > **Traffic** – traffic flow and ratio of vehicle types was set automatically from a default MIDAS file (from a peak period on the M42) which resulted in a flow per lane of approximately 1480 veh/hr and 8% Class 4 vehicles (HGVs). The speed limit is set to be 60mph.
- > **Signal** – the sign is located at 3000m from the start of the road section to allow sufficient distance before and after for the traffic to be simulated correctly. The default height and transverse location of the sign are taken to be 5.7m clearance and -6m respectively. (Transverse location is measured from the hard shoulder rumble strip dividing the hard shoulder from the main carriageway to the base of the supporting post. The -6m offset of the supporting post positions the MS4 roughly over the hard shoulder.) **The driver's field of view is taken to be 10 degrees, i.e. a driver does not look more than 10 degrees out of the straight ahead position in any direction.** The signal is set up as a standard MS4 which, in the software, is set with the following specifications.

- **Width:** 4.44m
- **Height:** 3.16m
- **Beam width:** 10 degrees horizontal, 5 degrees vertical
- **Legibility distance:** 250m
- **Sign orientation:** 1.96 degrees (direction), 1.78 degrees (inclination)

Whilst the input parameters are user-defined, it must be noted that there is little information available as to the assumptions made to create and run this simulation model and therefore the results must be used with caution. Too little is known about the assumptions to draw any definite conclusions about the validity of the model for assessing obscuration of signals within an MM2 environment. For example it is not known what assumptions have been made with regards to lane changing and flow – usually each vehicle in such a simulation will have a desired speed and will change lanes to achieve this speed. Unlike the TRL simulation model, lane changing is permitted and the flow and HGV proportion are therefore not broken down by lane. Another example is the lack of knowledge of the assumptions made regarding the vehicle sizes in the model, most crucially the heights of the HGVs.

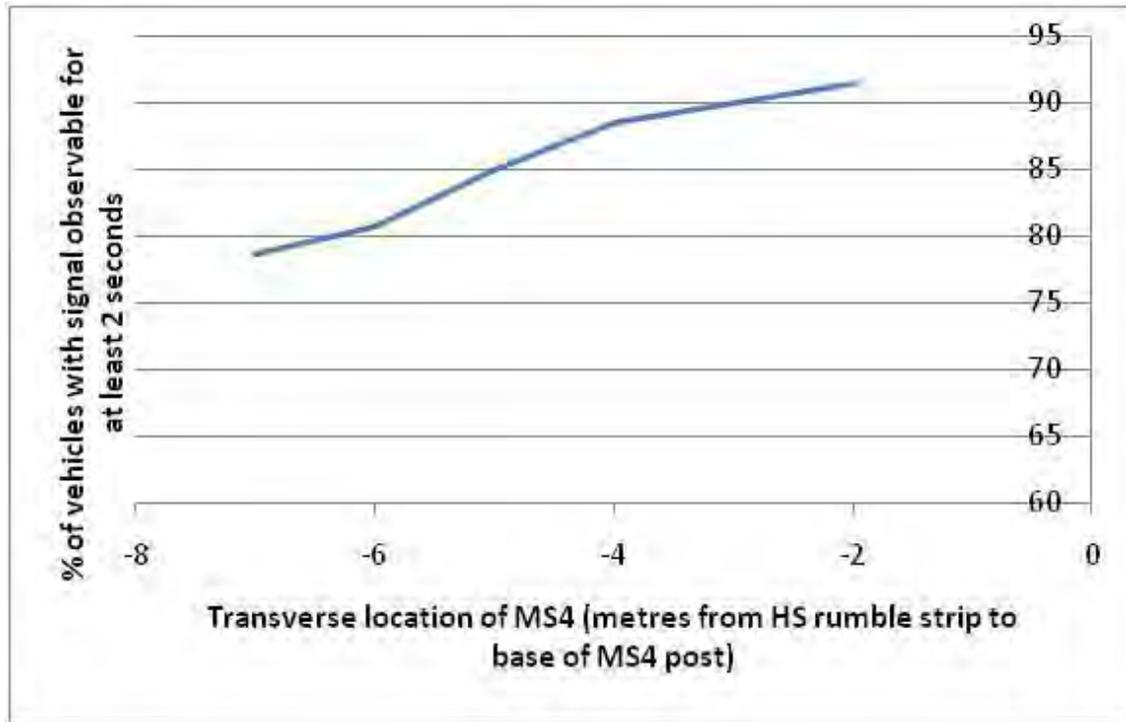
#### 4.7.3.2 Analysis

The software was run using a 2 hour simulation time which was the recommended minimum. Longer simulation runs were carried out to assess if accuracy was increased. However, changes in the accuracy were sufficiently small and the minimum was deemed suitable.

Unless otherwise stated all parameters are as described above with hard shoulder running in place. The viewing time criterion is taken to be 2 seconds in all cases. The output is therefore the percentage of vehicles that have the signal observable for at least 2 seconds.

As mentioned earlier, without knowledge of the assumptions used, direct comparison with the TRL model is not valid. Therefore this analysis will concentrate on the relative effects of varying the default input parameters.

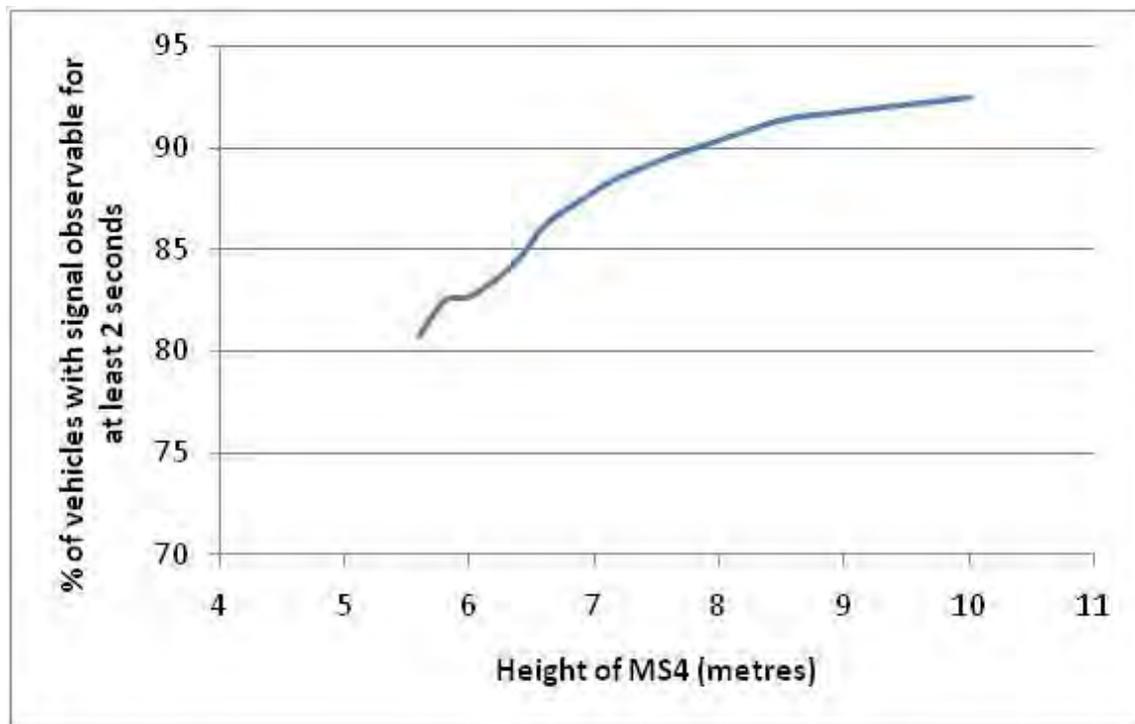
Varying transverse location produces the results shown in Figure 87.



**Figure 87: Overall percentage of drivers that have an unobscured view for at least 2 seconds for a range of transverse locations of the MS4**

Allowing for random noise variation there is clearly a monotonically increasing trend in percentage of vehicles that have a sufficiently long unobscured view of the signal as the sign location moves from setback from the hard shoulder to over LBS2.

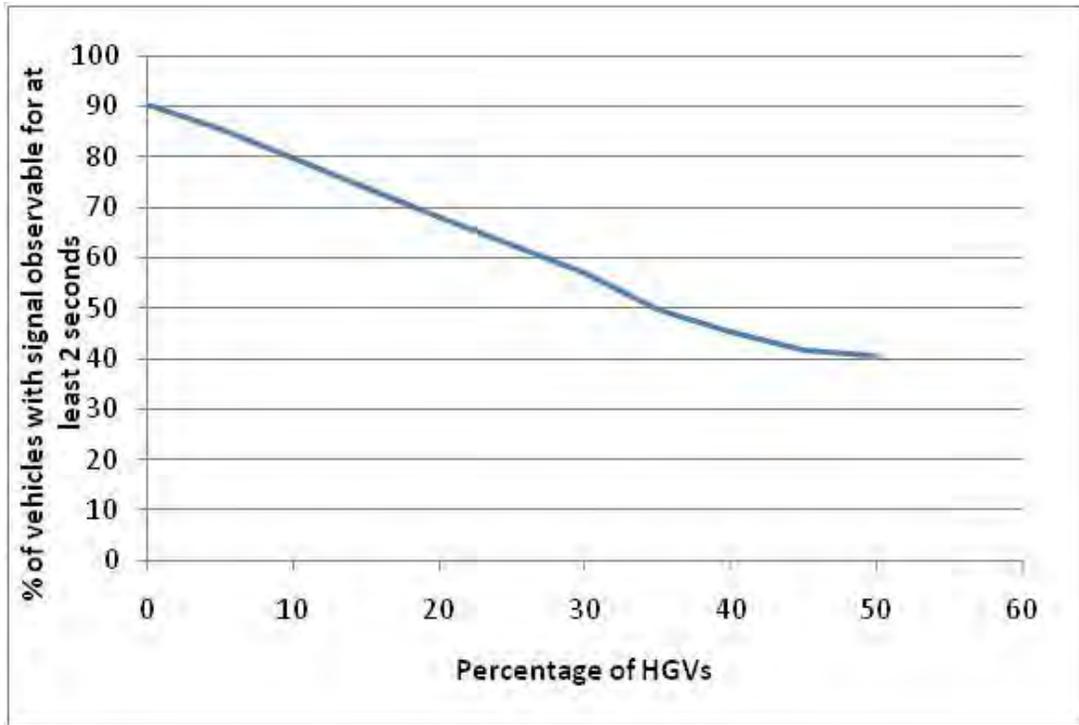
Varying sign height produces the results shown in Figure 88.



**Figure 88: Overall percentage of drivers that have an unobscured view for at least 2 seconds for a range of MS4 heights.**

Clearly as the height of the MS4 increases, the percentage of vehicles that see the signal for sufficiently long also increases, although the rate of increase is much faster initially, suggesting that a relatively large benefit may be achieved by a relatively small increase in MS4 height.

Varying HGV proportion (with overall flow remaining constant) produces the results shown in Figure 89.



**Figure 89: Overall percentage of drivers who have an unobscured view for at least 2 seconds for a range of HGV proportions.**

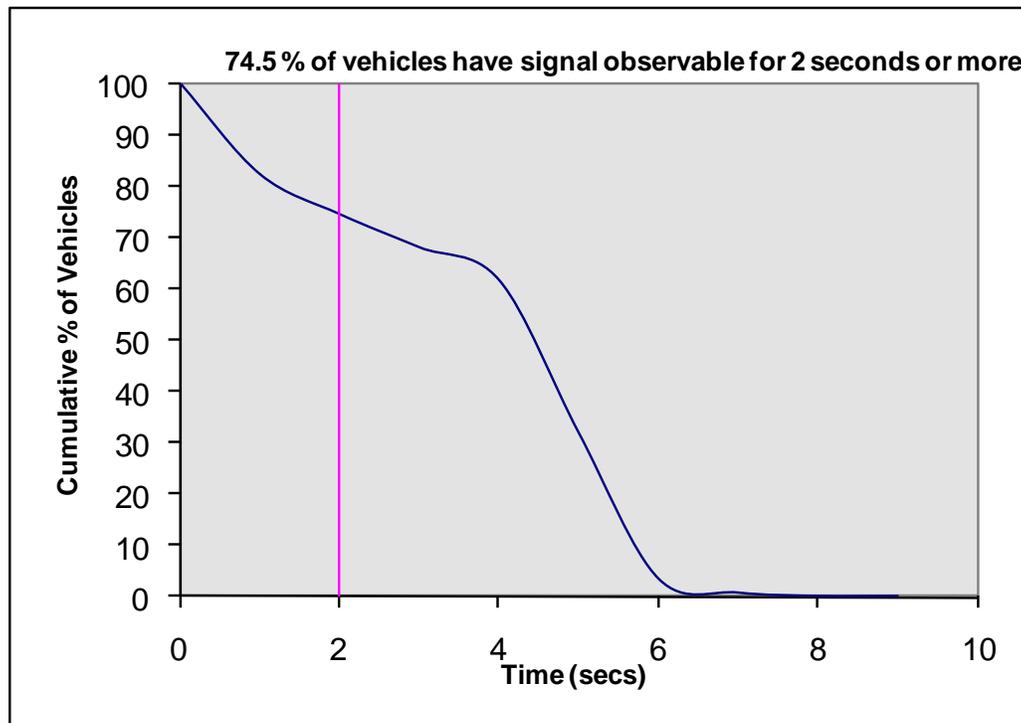
This graph confirms the expected trend and shows that, allowing for random noise, simulations suggest that the obscuration levels are linearly dependent on the HGV percentage in the traffic flow.

**Varying only the flow levels (and keeping the HGV proportion the same) doesn't** seem to have an impact on the obscuration levels that could not be attributed to the random noise in the simulation model. The simulation software does of course not allow different flow levels to be specified in individual lanes.

When varying the speed limit the results are otherwise inconclusive and any differences may be due to random noise. It is important to note that these are speed limits rather than speeds – without greater understanding of the assumptions governing speed choice in the model it is difficult to draw any definitive conclusions from these data.

### 4.7.3.3 Comparison with TRL simulation model

As mentioned previously, direct comparison with the TRL simulation model is not possible without further knowledge of the assumptions used. However, it is possible to run the simulation for a set of parameters similar to the default scenario used in Section 4.7.1, i.e. overall flow of 6000 veh/hr, overall HGV percentage of 15%, speed limit of 55mph, legibility distance of 192m and a sign in the default position. The output for this scenario is shown in Figure 90.



**Figure 90: Overall percentage of drivers that have an unobscured view of the signal for a range of required viewing lengths. The vertical line represents the default 2 second viewing time.**

This suggests that 25.5% of drivers do not see the signal for at least 2 seconds. This is clearly a considerable increase from the results obtained from the TRL simulation model in Section 4.7.1. Due to a lack of knowledge of the differences between the two models it is not possible to provide an explanation as to why the predictions are so diverse. Factors which may have had an influence are:

- > The distribution of traffic across lanes, particularly HGVs, due to the lane changing within the MOMS tool;

- > Assumptions regarding the use of the hard shoulder, as opposed to the four permanent running lanes assumed by TRL;
- > The point, or selection of points, on the MS4 for which obscuration is being measured;
- > The HGV heights and driver eye heights used;
- > The speed of vehicles, as the MOMS tool only requires the speed limit to be defined; and
- > The approach used for vehicle generation and headway assignment.

In summary, the results from the MOMS tool suggested much greater obscuration rates overall. This difference cannot be explained or justified without further knowledge of the assumptions used to create and run the simulation used in the software.

The results show similar general trends to the TRL simulation model – specifically that obscuration rates appear to decrease with increasing sign height, and increase with increasing HGV proportion.

The TRL model shows increasing obscuration rates with increasing flow (since this increases absolute numbers of HGVs), whereas the MOMS tool suggests no effect of increasing flow levels. However, the small effects noticed in the TRL simulation model are difficult to compare directly with the software results because of random noise effects.

## 4.8 Investigation into the Effects of Driver Behaviour on Obscuration

### 4.8.1 Introduction

In Section 0 it was described how obscuration may be influenced or mitigated by actions of individual drivers. These actions and their possible effects on overall obscuration rates are considered in more detail in this section and the conclusions drawn complement the outputs of the simulation model.

This study considered the effects of the following two aspects of driver behaviour:

1. The actions that an individual driver may take (including lane-changing, but also speed variation and head-turning) to mitigate their own obscuration; and
2. The impact of downstream lane changing (for whatever reason and for all vehicles).

These are both considered in terms of an individual driver's obscuration, based on the analytical model. Implications are then drawn from this analysis and are applied to the overall obscuration rates as described by the simulation model.

### 4.8.2 Individual Driver Mitigation

If a sign or signal is obscured to an individual driver, there are a number of things that the driver may do to tackle this obscuration. The analysis here is limited to the reasonable and likely changes that drivers can make, such as mild deceleration or single lane changes. Unrealistic and unsafe actions, such as sudden braking and crossing three lanes to see a sign, while possible, are excluded.

The actions that an individual driver may take to be able to see a sign fall into four broad categories:

- > Lane changing;
- > Speed adjustment;
- > Change of lateral position within lane; and
- > Increased angle of view (e.g. by head movement).

The analytical model has been used to investigate each of these and examples for the default scenario (see section Parameter Configuration 1 in Section 4.7.1.2) are included where appropriate.

#### 4.8.2.1 Lane changing

It may be possible for a driver to change lane in order to prevent themselves from being obscured. The possible scenarios for this taking place are listed below along with some discussion of the likelihood of the manoeuvre being taken to reduce obscuration, given the traffic conditions expected during peak hour conditions:

1. ***A vehicle in LBS1 obscured by an HGV in front moves into LBS2:*** Using the default signal position, an HGV obscuring a driver in LBS1 would not also be obscuring a vehicle the same distance away in LBS2. However, this may not be intuitive to drivers and in most cases deceleration would be easier for a driver to implement.
2. ***A vehicle in LBS2 obscured by an HGV in front moves into LBS1:*** It would be expected that if there is an HGV in LBS2 there will usually be an HGV in a similar position in LBS1 which it is in the process of passing. Moving into LBS1, therefore, may mean that the driver moves from one obscured position to another. Also, some drivers may not be inclined to move into LBS1 as it would be likely to mean a decrease in speed.
3. ***A vehicle in LBS2 obscured by an HGV in front moves into LBS3:*** This has the potential to reduce obscuration for the driver moving into LBS3. This movement does, however, require a gap for the driver to move into and in normal peak hour traffic conditions, this type of movement will be restricted due to traffic density. Furthermore, if a driver moves into LBS3, they will leave a gap which is likely to be filled by another driver, who is likely then to become obscured.
4. ***A vehicle in LBS3 obscured by an HGV in front moves into LBS2:*** This would be an unlikely manoeuvre for the same reason as that in scenario 2. Because of the decreased likelihood of an HGV being in LBS3 it is even more likely that it would be overtaking another obscuring HGV in LBS2.
5. ***A vehicle in LBS3 obscured by an HGV in front moves into LBS4:*** See scenario 3 above.
6. ***A vehicle in LBS3 obscured by an HGV in LBS2 moves into LBS2:*** In most cases, if a driver is far enough behind an HGV to safely move into LBS2 behind it, then it will be far enough behind the HGV to see over the top of the HGV, so a lane change for this reason would not be necessary. Deceleration is likely to be the more favoured option.

7. *A vehicle in LBS3 obscured by an HGV in LBS2 moves into LBS4:* See scenario 3 above.
8. *A vehicle in LBS4 obscured by an HGV in LBS2 moves into LBS3:* See scenario 6 above.
9. *A vehicle in LBS4 obscured by an HGV in LBS3 moves into LBS3:* Vehicles are extremely unlikely to be obscured at all in LBS4 and if they are, changing lanes into LBS3 will not reduce their obscuration. Deceleration is likely to be the more favoured option.

These scenarios indicate that lane changing alone is unlikely in most cases to reduce the likelihood of an individual driver being obscured.

Furthermore, if a driver is in a situation where changing lanes would be an effective measure to take to make a signal visible, there would need to be an acceptable gap between vehicles in the destination lane to be able to do so. In the default scenario, with a flow of 6000 veh/hr the average time headway would be 2 seconds. The acceptable gap between vehicles will vary between drivers. Previous work<sup>17</sup> has found that a gap of over 3.5 seconds would be preferred for naturalistic, unforced discretionary lane changes. Lane changing within a Managed Motorway environment is also actively discouraged at times through the use of on-road driver information.

### **Overall impact**

For the reasons described above it seems highly unlikely that in the default scenario a driver would choose to change lane to prevent themselves from being obscured. It is, therefore, reasonable to assume that any effect on obscuration rates can be effectively discounted.

It is, of course, possible that if drivers effectively judge the effect of HGVs near them they will pre-emptively position themselves in a lane on approach to a sign to minimise their risk of being obscured. However, this may in turn mean that another vehicle would be in an obscured lane 'in their place' so this is likely to cancel out any visibility improvements of individuals.

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<sup>17</sup> <http://www.le.ac.uk/eg/embedded/pdf/ESL04-02.pdf>

4.8.2.2 *Speed adjustments: Obscuration from an HGV ahead*

In this scenario, where a driver is obscured by an HGV downstream in the same lane, a driver’s obscuration depends on the height of the HGV and the headway to the HGV directly in front. If the vehicle in question is close enough to the HGV in front so that the signal is obscured then the option exists to increase the headway by reducing their speed.

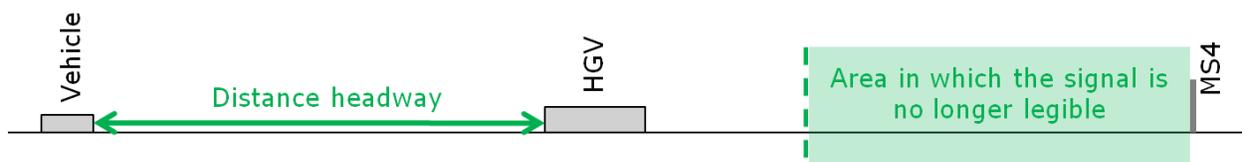
If the driver begins creating this headway at a sufficient distance from the sign, they will always be able to stop themselves being obscured by the HGV in front (assuming another HGV doesn’t move into the gap left between the vehicles). The point at which the driver decides to begin decelerating is, therefore, of great importance.

Example based on ‘default’ scenario

The ‘default’ scenario was investigated through the use of the analytical model and the application of standard kinematic equations.

Taking the default speed of 55mph, in order for a driver in LBS1 to view a signal for at least 0.5 seconds within a legibility distance of 192m (i.e. the ‘legibility zone’), a minimum distance headway of 29.6m is required.

If both vehicles are initially travelling at 55mph with a distance headway of 14.7m (the minimum headway used in the simulation model), the driver would then have to increase their headway by 14.9m, 0.5 seconds before reaching the point at which the signal is no longer legible (in this case, 34.5m before the sign).



**Figure 91: Obscuration by an HGV in front**

At 55mph, a reasonable maximum deceleration rate is  $-1.2\text{m/s}^2$ <sup>18</sup>, which is equivalent to lifting off the accelerator. With a maximum speed differential of 10%, this means a vehicle would require a distance of 136.6m to reasonably increase its distance headway from the HGV in front by 14.9m. In practice this means a driver dropping vehicle speed from 55mph to 49.5mph in 2 seconds and then maintaining a constant speed for 4 seconds.

Therefore, a driver would only be able to safely achieve the required headway to make the sign visible for 0.5 seconds if they began decelerating at least 171m before the sign.

In the scenario described above, for a 2 second viewing time the driver would need to begin decelerating at least 381m before the sign. This would therefore require a driver to begin decelerating before they are within the legible distance to the sign.

### **Overall impact**

In the default scenario, around 80% of vehicles are obscured by HGVs downstream in the same lane. If allowance was to be made for all of those drivers safely decelerating in time not to be obscured, then all obscuration to the front could effectively be removed.

However, although the option to decelerate is open to all drivers, it is difficult to say how many drivers would choose to act in this way. This would depend on a variety of factors including whether or not the driver is aware of the presence of the sign and the perceived threat of enforcement.

Furthermore, there is potential with this kind of mitigation that drivers would create a gap between themselves and an HGV which, in busy traffic, may be filled by another vehicle which would be obscured instead. As described in the scenario above, a gap of only 29.6m would be required for drivers to be able to see the sign just before they reach the area where the sign is no longer legible. However, drivers attempting to see the sign before that point may start decelerating earlier than is necessary and the gap they would be required to create to the HGV in front becomes larger. For drivers to be able to see the sign at 192m, they need to be 104m from the HGV in front, which is an appropriate gap for another vehicle to move in to.

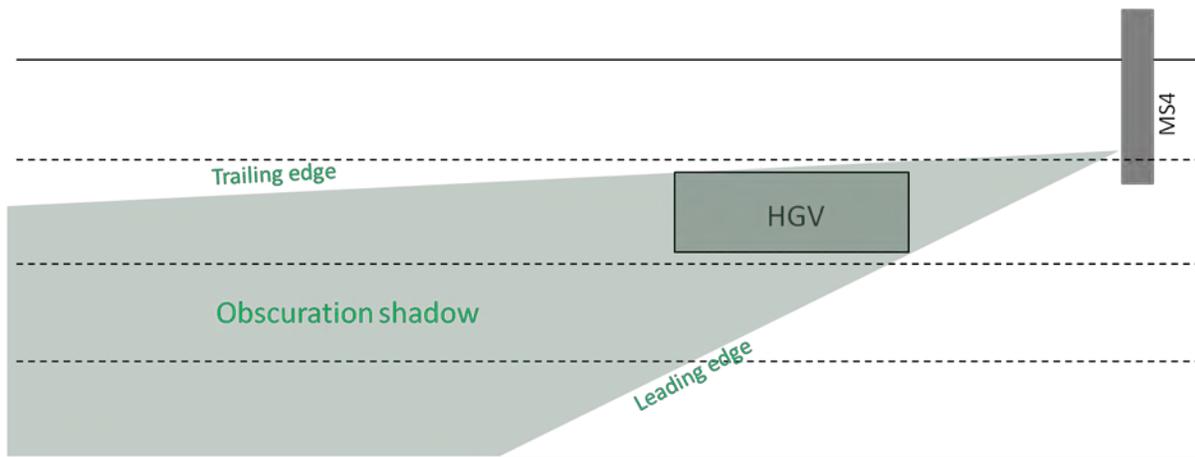
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<sup>18</sup> Bennett, C. R., & Dunn, R. C. M. (1994). Driver Deceleration Behaviour on a Motorway in New Zealand.

**4.8.2.3 Speed adjustments: Obscuration from an HGV to the side**

Lateral obscuration (obscuration by HGVs to the side) depends on the width and number of lanes between the two vehicles in question and how far downstream HGVs are in relation to the driver. The vast majority of lateral obscuration in the scenarios considered within Section 4.7.1.2 is of vehicles in LBS3 caused by HGVs in LBS2, so only this situation is considered here.

Lateral obscuration is perhaps best thought of in terms of the 'shadow' of the HGV. Figure 92 depicts the 'obscuration shadow' that an HGV in LBS2 casts (in this case, when it is very close to the MS4).



**Figure 92: Obscuration shadow caused by an HGV in LBS2**

**Example: Obscuration by a single HGV**

The obscuration shadow of an HGV is continually changing in shape as the HGV gets closer to the sign. For the default scenario, where the MS4 is centred over LBS1, assuming HGVs are travelling at 55mph, the leading edge of the obscuration shadow will always be travelling at 76.7mph relative to the driver. Therefore, if a driver cannot see around the front of an HGV (i.e. they are already in the obscuration shadow) as they enter the legibility zone they will not be able to reasonably accelerate out of it.

For a driver in LBS3 to be obscured by an HGV in LBS2 (i.e. in its obscuration shadow) as they enter the legibility zone, their distance to the HGV must be at least 86m. At 192m from the sign this distance is not sufficient for a driver to be able to see over the top of the HGV. However, if the vehicle were to maintain the same speed as the HGV (or plus or minus 10%), the distance between them would mean that they were able to see over the top of the HGV for at least 2 seconds before they pass the sign. Therefore, a single HGV, of any height, in LBS2 cannot laterally obscure a vehicle in LBS3 for the entire distance for which the sign is legible. There is no requirement for a driver to accelerate or decelerate to enable this

### *Example: Obscuration by two or more HGVs*

The analytical model has shown that obscuration of drivers in LBS3 by HGVs in LBS2 must be due to two or more consecutive HGVs, as drivers may be able to see around the front of one HGV but not around the back or over the top of the one ahead.

Drivers that are obscured in this way would have to be extremely close to or alongside the second of the two consecutive HGVs. To mitigate this obscuration, a driver has the option of decelerating a suitable distance in a similar way to the example in the section above. This deceleration, however, would need to begin **earlier as a greater distance would need to be achieved, relative to the vehicle's starting point**, i.e. rather than just extending an already existing headway as in the above example, the driver would need to gain the distance of the entire headway required (29.6m) plus the length of the HGV.

This, of course, becomes much less achievable if there is a third obscuring HGV behind the second.

### *Overall impact*

Based on the results of the simulation model, approximately 20% of vehicles that are obscured are obscured to the side. This equates to 1.6% of all vehicles if 8% of all vehicles are obscured using a 2 second viewing time.

Based on an HGV proportion of approximately 25% in LBS2, the expected probability of an HGV being directly followed by another HGV is 6.25% (25% of 25%, if they are independent).

The simulation model, which includes HGV height and vehicle headway distributions, produces a lateral obscuration rate of around 5% in LBS3 based on approximately 25% HGVs in LBS2. This is of the order of the expected probability of an HGV being directly followed by another HGV.

As with obscuration by an HGV in the same lane, most of this obscuration can potentially be mitigated through deceleration but similarly it is difficult to say how many drivers would choose to act in this way. This would depend on a variety of factors including whether or not the driver is aware of the presence of the sign and the perceived threat of enforcement.

#### **4.8.2.4** *Change of lateral position within lane*

A driver may adjust their lateral position within lane to ensure they are not obscured. Drivers are limited to only slight in-lane positional adjustments (up to 50cm to the right and left). This kind of movement will only make a difference when the driver is close to the leading edge of the obscuration shadow. It is therefore unlikely that a change of lateral position will reduce obscuration rates significantly.

#### **4.8.2.5** *Increased field of view*

Drivers may choose to specifically extend their active field of view to remove any obscuration, through extending their head and eye movements.

Previous work recommends that drivers should finish reading a sign before they have had to divert their eyes more than 10 degrees from the straight ahead position<sup>19</sup>. This is also the established value used in when considering sign design, hence this is the value used in both the analytical and simulation models, in both the vertical and horizontal axes.

Although it is outside the scope of this task to fully investigate the adjustments drivers can make to their field of view, it is worthwhile considering the effects of these sorts of adjustments on obscuration. Further work<sup>20</sup> suggests that drivers can and do safely look up to 15 degrees in the vertical axis. This reduces the size of the 'dead zone' in which the sign is no longer visible.

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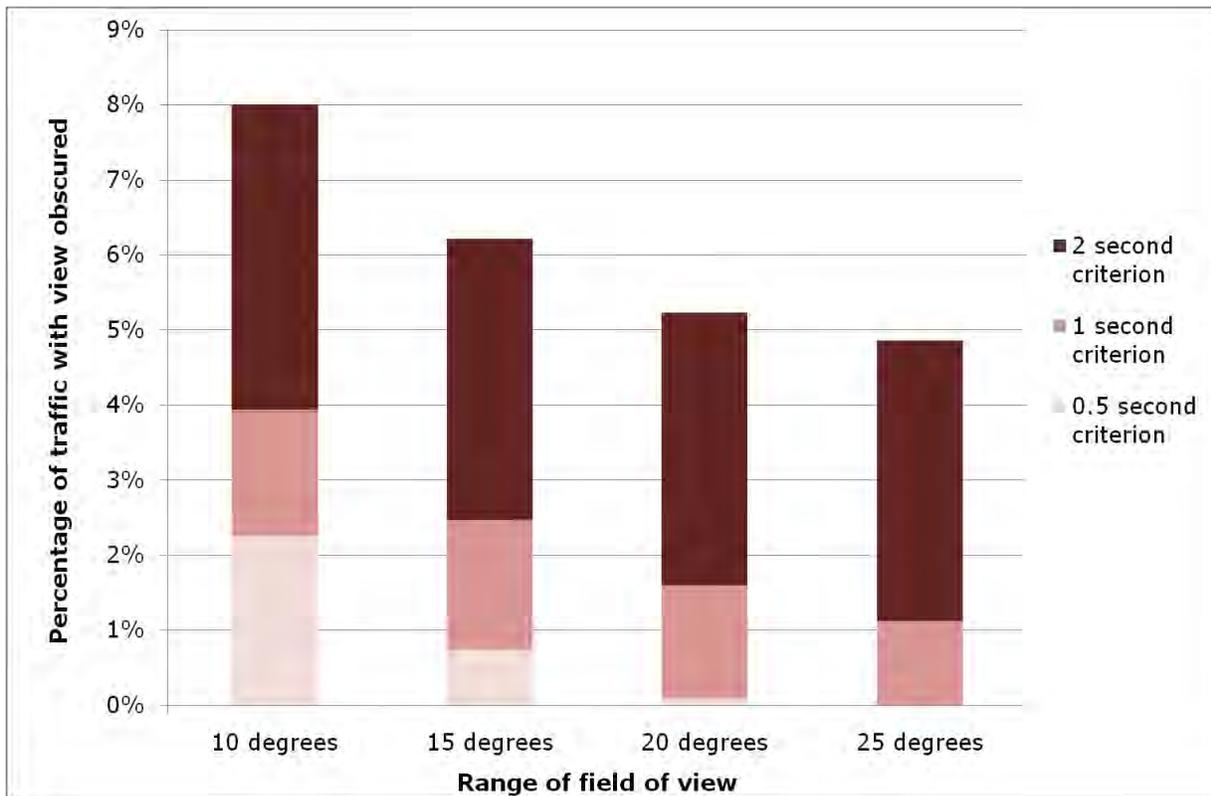
<sup>19</sup> Baguley, P. (1995). *Absorption of information from signs: a literature search and proposals for future work*. TRL Unpublished Project Report. PR/TT/145/95.

<sup>20</sup> Simlinger et al. (2005). *Proposal on unified pictograms, keywords, bilingual verbal messages and typefaces for VMS in the TERN*. In-Safety Deliverable.

This could increase the legible viewing time of the sign and therefore increase the time in which the driver could be able to see the sign. Further investigation is therefore warranted.

***Example based on 'default' scenario***

Figure 93 below shows the effect of increased driver fields of view through different simulation model runs.



**Figure 93: Percentage of traffic with view obscured for four different fields of view**

As the field of view increases, the overall obscuration rate, using a 2 second viewing time, decreases from 8% overall obscuration at a 10 degree field of view, to 5% at a 25 degree field of view. Using the more realistic 15 degree field of view, used in the research referenced above, overall obscuration falls to just over 6%.

## Overall impact

If all drivers are able to increase their field of view to 25 degrees, then all drivers will be able to see the sign for at least 0.5s. This means that all drivers will have the opportunity to see the sign. However, this is not currently considered to be a practical possibility. Increasing the field of view to 15 degrees (a more appropriate increase) could reduce overall obscuration to less than 1% for 0.5 second viewing time.

### **4.8.3 Downstream Lane Changing**

#### **4.8.3.1 General discussion**

It is possible that certain actions by other drivers will have an impact on an **individual's obscuration**. Lane changing by vehicles downstream could force a driver to readjust their headway and put themselves in an obscured position, although, as seen in the previous section, such an adjustment could equally reduce the likelihood of an individual being obscured.

In terms of lane changing directly obscuring other vehicles, car movements make no difference. Lane changing by HGVs, however, could cause obscuration from different positions to those already considered within this study.

HGVs would be expected to change lanes to overtake another vehicle travelling at a lower speed. It would also be expected that after doing so they would move back into their original lane as soon as they are safely able to do so. Based on typical speed differentials between an overtaking HGV and the vehicle it is overtaking, a full overtake manoeuvre could not be executed within the 192m legibility zone.

HGVs may also change lane from LBS1 to LBS2 on the approach to an on-slip, to avoid traffic joining the motorway or a dedicated off-slip to stay on the motorway.

In the scenarios investigated in Section 4.7.1.2, it has been assumed that the HGV flows are sufficiently high that the presence of HGVs would not be restricted to LBS1. In this sense, the effects of HGV lane changing have been considered through the assigned HGV lane distributions in the simulation model.

Parameter Configuration 5 in Section 4.7.1.2 shows that redistributing HGVs such that the percentage of HGVs in LBS2 increases, causes an increase in the overall proportion of traffic that is obscured. This is because, with the sign in the default position, HGVs in LBS2 can obscure traffic in LBS2, LBS3 and LBS4 rather than just LBS1. So in this sense there is a strong relationship between the amount of HGV overtaking and obscuration rate which is captured within the findings of the simulation model.

Furthermore, during an HGVs lane change manoeuvre, their obscuration effect on surrounding vehicles may change, allowing some to see the sign while yet obscuring others. This is not accounted for in the simulation model but is likely to produce a net zero effect on obscuration, as described. The following section looks at the amount of lane changing that could be expected within the section of motorway on approach to a sign for which the signal is legible.

#### **4.8.3.2** *Likelihood of an HGV changing lane in the legible section*

To assess the potential impact of HGV lane changes, the lane changing rate must be known. TRL carried out research in 2005 as part of a SISTM (Simulation of Strategies for Traffic on Motorways) re-calibration programme<sup>21</sup> that included an assessment of real lane changing rates for different motorway scenarios.

For a stretch of motorway with no junctions nearby, either upstream or downstream, the lane changing rate for all vehicles was found to be 1000 lc/km/h.

If it is assumed that the lane changing rate for HGVs is proportional to that of non-HGVs, then the HGV lane changing rate is 150 lc/km/h, based on 15% HGVs. This is likely to a lot less in reality.

The simulation model performs runs over a distance of 200m and for 2 hours, therefore, 60 HGV lane changes could be assumed to occur in the time frame of the simulation model and within the legibility distance of the sign.

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<sup>21</sup> Baguley, P. C., Hardman, E. J., Lunt, G. M., Rees, T. R., & Smith, R. (2005). Development of an enhanced lane changing algorithm for SISTM ( No. UPR/T/004/05). Crowthorne: TRL Limited. (Location 1, 4-lane M42 site, open motorway).

### Overall impact

Using the 2 second viewing time, in the default scenario at a flow of 6000 veh/h, 480 vehicles (8%) will be obscured per hour.

As discussed above, HGV lane changing in the legibility zone is likely to produce a net zero effect on obscuration. However, if we were to assume, say, that all HGV lane changes result in at least one vehicle no longer being obscured, obscuration rates could reduce from 8% (480 vehicles/h) to 7% (420 vehicles/h) in the default scenario. On the contrary, if all lane changes result in a further vehicle being obscured, the total obscuration rate would increase to 9% (540 vehicles/h).

#### **4.8.4 Summary**

This investigation has found that drivers have three realistic options available to them to avoid obscuration: change lanes, decelerate or increase their field of view. These actions can significantly reduce both lateral and longitudinal obscuration rates. If the correct mitigating action is taken by a driver at the correct time it is conceivable that all instances of obscuration can be removed.

Although it is unlikely in reality that all drivers will take the correct action, this investigation has shown that in practice obscuration rates are likely to be smaller than those indicated in the simulation model.

The effects of lane changing by other drivers were also explored. It is expected that this will have no significant net effect on the obscuration rates produced by the simulation model.

## 4.9 Discussion and Recommendations

### Key findings

This task used a modelling approach to investigate and assess the likelihood of obscuration of signs and signals within an MM2 scheme, with particular focus on the difference between overhead gantry-mounted driver information provision and verge-mounted driver information provision.

The findings suggested that only a small proportion of traffic would have its view of a signal on an MS4 obscured; for an expected MM2 environment with typical peak-hour traffic, the proportion obscured was estimated to be 8% using a 2 second viewing criterion, which reduces to 2.3% if drivers are only required to see the signal for 0.5 seconds.

In this scenario, using a 2 second viewing time, obscuration caused by HGVs in the same lane made up for approximately 79% of all obscured vehicles. Obscuration caused by HGVs in a lane to the left made up for approximately 21% of all obscured vehicles.

As would be expected, obscuration rates are greatly influenced by the number and spread of HGVs. With a 5% proportion of HGVs only 0.9% of traffic was obscured using a 0.5 second viewing time. With a 25% proportion of HGVs the percentage of traffic with their view obscured was 2.7%, using the same viewing time.

Obscuration rates are also dependent on the distribution of HGVs; results suggested that for the same overall number of HGVs, the overall obscuration rate was reduced when HGVs are weighted heavily towards LBS1, and increased when HGVs were weighted towards LBS2 (compared with the standard distribution). Although the latter scenario is not commonly expected to occur, it may be encountered when LBS1 is closed to traffic or possibly on the approach to a dedicated off slip.

Increasing the height of the MS4 decreased overall obscuration for all viewing times. Looking at the extreme case of a sign 6m above the required minimum clearance height, obscuration was decreased by 0.6% for a 0.5 second viewing time.

Obscuration rates can be decreased by moving the MS4 laterally towards the central reservation. The optimum lateral location of the centre of the MS4, if at the default height, was 3.7m from the verge, using a 0.5 second viewing time.

The obscuration rate for two consecutive verge-mounted signals was investigated. If no lane changing is assumed between the two locations then the obscuration rate was only decreased slightly. However, making some reasonable assumptions regarding lane changing, the estimated percentage of traffic being obscured for two **consecutive signals, using a 0.5 second viewing time, was within the model's** margin of error in all lanes. Using a 2 second viewing time the estimated obscuration rate is 1.1%.

The obscuration of gantry-mounted signals was also investigated. Using default parameters the overall percentage of drivers unable to see any of four gantry-mounted signals was within the margin of error of the model.

However, for a situation where lane-specific information is displayed on gantry-mounted AMIs, a driver must see the signal directly above the lane (such as for lane closures). The results suggested that compared with a single AMI, using a verge-mounted sign actually reduced the obscuration rate for vehicles in LBS1 and LBS2.

The findings of the models are highly dependent on the assumptions made, in particular the exclusion of individual driver behaviour effects. The possible impact of these effects was also considered.

This investigation has found that drivers have three realistic options available to them to avoid obscuration: change lanes, decelerate or increase their field of view. These actions can significantly reduce both lateral and longitudinal obscuration rates. If the correct mitigating action is taken by a driver at the correct time it is conceivable that all instances of obscuration can be removed.

Although it is unlikely in reality that all drivers will take the correct action at the correct time, this investigation has shown that in practice obscuration rates are likely to be smaller than those indicated in the simulation model.

The effects of lane changing by other drivers were also explored. It is expected that this will have no significant net effect on the obscuration rates produced by the simulation model.

### Recommendations for further investigation

This work has estimated the level of obscuration that would occur for a sign (or two signs) under a variety of parameter configurations. Further investigation may be required to help enable the application of these findings to real-world settings.

For example, to increase confidence in the models used within this investigation it may be necessary to carry out an on-road trial using a camera mounted on an MS4. There may also benefit in validating some of the assumptions used. One option would be to consider the effect of individual driver behaviour more fully with the use of a driving simulator trial or similar approach.

Closer consideration should be given to the choice of the 2 second criterion which was used in previous work. The findings suggested that the required viewing time has a large effect on the obscuration rates. The work carried out for Task 3 suggests that a shorter viewing requirement may be sufficient, when considering signals alone, but it is unknown how long would be required to process as signal, a lane closure aspect and some text. It would be useful to investigate the relevance and pedigree of the 2 second criterion and consider what would be an acceptable choice and the associated impact on obscuration and an MM2 scheme as a whole.

Consideration should also be given to the level of obscuration that is tolerable, particularly with regards to compliance with the variable speed limits. It would be useful to investigate the implications of small levels of obscuration on compliance and, in turn, the safety and effectiveness of an MM2 scheme. For example, a key question is what proportion of vehicles in certain traffic conditions need to be able to see the signal to get the required level of compliance with the speed limit?

Finally, one of the assumptions used within this investigation is that the section of motorway approaching a sign is both straight and flat. Site-specific geometric differences could have a strong effect on obscuration rates. This could be either a positive or negative effect. The models could be developed to have input parameters associated with road geometry. With this type of capability the simulation model could be used to assess the suitability of a specific on-road location to aid future scheme design.

## 5 Task 5A MM2 Design Evaluation Simulator Study

### 5.1 Background

Task 5 comprised of a driving simulator trial to investigate driver comprehension and behavioural response to on-road driver information provision via verge-mounted variable message signs on a stretch of motorway with 4 permanent running lanes and no hard shoulder. More specifically, the study compared driver responses to driver information displayed on gantry-mounted signs and signals versus verge-mounted MS4 signs only.

Currently in Managed Motorway schemes, lane specific information is displayed above each individual lane using gantry-mounted AMI signals. This study investigated whether the same lane specific information can be successfully conveyed to drivers via verge-mounted MS4s, e.g. do drivers interpret a speed limit displayed on a verge-mounted MS4 to apply to all four running lanes.

The findings of Tasks 1 to 4 were used to inform the route specifications for the trial, in relation to the appropriate spacing of information update points and the design of MS4 messages when communicating speed limit and lane closure information.

### 5.2 Task Objectives

The initial Task 5 objectives were:

- > To understand driver behaviour within and response to an MM2 environment;
- > To evaluate the safety, effectiveness and driver acceptance of proposed MM2 designs;
- > To propose design recommendations for MM2 schemes; and
- > To provide a toolkit of options for MM2 information provision and guidance for effective application.

Following the decision to reorganise Task 5, the sub-objectives below were defined for the simulator trial:

- > To assess driver behaviour in response to on-road driver information communicated through verge-mounted MS4 variable message signs only;
- > To compare driver response to identical information being communicated through a fully equipped Managed Motorways schemes, i.e. consisting of gantries mounted with four AMI signals and an MS4; and
- > To compare two different approaches to communicating information using MS4s only.

### 5.3 Methodology

This study consisted of a trial using TRL's driving simulator, as well as a questionnaire assessment of participants' attitudes and perceptions of on-road driver information provision. A full methodology for this study is recorded in the Task 5A Study Plan, which was issued at the beginning of the task and agreed with the MM2 Programme Board. The key points are summarised below.

The simulator driving routes were based on an MM2 environment with four permanent running lanes without a hard shoulder. This study focussed on investigating differences in participants' behaviour to speed limit and lane closure instructions that were communicated within this environment through three different signing layouts:

- > **Gantry layout:** gantry-mounted signing (i.e. four AMI signals and an MS4 at each information update point);
- > **Verge Red X layout:** verge-mounted signing (i.e. a single MS4 at each information update point) that displayed lane closure instructions using 'Hooked Arrow' and 'Red X' lane closure aspects;
- > **Verge Wicket layout:** verge-mounted signing (i.e. a single MS4 at each information update point) that displayed lane closure instructions using 'Wicket' lane closure aspects.

Besides the 'Hooked Arrow', 'Red X' and 'Wicket' aspects, there were additional differences in the design of MS4 messages displayed in the two verge layouts. These included small differences in the reinforcing text accompanying the lane closure aspects, the position of the speed limit aspect if displayed on its own and the use of an 'All lanes open' aspect following the end of a closure (see Table 19 below).

The participants experienced two drives in the simulator; one drive with the gantry layout and one drive with the verge signing layout. The participants were separated into two experimental groups; all participants drove through the gantry layout and then half the participants drove the verge Red X layout whilst the other half drove verge Wicket layout.

The spacing of the information update points was approximately 1500m and was consistent across all three layouts. The scenarios and instructions that were communicated along the route on signs/gantries located at each update point were also identical across the three layouts.

### Description of test areas

Within each route, there were two test areas which were evaluated with regard to participants' speed and lane choice. In each test area participants were subject to different speed limits and lane closure scenarios:

- > **Test Area 1** started with a 'gateway' sign (consistent across all signing layouts), followed by a blank sign/gantry. Participants then drove through the 'obstruction' scenario, which involved a reduction in speed limit to 50mph and an LBS1 closure. Following the closure, the National Restriction (NR) was displayed. There was no other traffic present in this test area<sup>22</sup>. This was to ensure drivers responses to the different sign configurations only and avoid any confounding effects of other traffic.

Table 19 illustrates the order in which the information was displayed at each sign/gantry in the Test Area 1 for all three signing layouts.

An 'obstruction' was present along the route in the form of a stationary vehicle, located in LBS1 around 300m before the end of the closure (i.e. just before sign/gantry 6 in Table 19).

- > **Test Area 2** started with a 'road works' scenario, involving a reduction from the NR to a 40mph speed limit, and a LBS3 and 4 closure. Following the closure, the NR was displayed. There was then a section of 60mph speed limit with all lanes open. Heavy traffic was present in LBS1 and 2 of this test area, with very light traffic in LBS3 and no traffic in LBS4.

Table 20 illustrates the order in which the information was displayed at each sign/gantry in Test Area 2 for all three signing layouts.

Participants' were provided with visual evidence of the reason for the closure in the form of a stationary maintenance vehicle, which was parked across LBS3 and LBS4 midway through the closure, around 250m before sign/gantry 11 in Table 20 below.

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<sup>22</sup> This is a deviation from the methodology laid out in the study plan, which indicated that light traffic would be used. It was determined that no traffic would be present to ensure that participants remained in LBS1 when approaching the LBS1 closure and therefore their response to the lane closure instructions could be analysed. The absence of other traffic also allowed investigation of driver response to the signing alone without the **influence of other drivers' behaviour**.

**Table 19: Order in which sign/gantries were displayed in each sing layout for Test Area 1**

Ref	Gantry	Verge Red X	VergeWicket
<b>6</b> NR			
<b>5</b> Lane Closed			
<b>4</b> Lane Closed Ahead			
<b>3</b> Warning			
<b>2</b> Blank			
<b>1</b> Gateway			

**Table 20: Order which signs/gantries were displayed in each signing layout for Test Area 2**

Ref	Gantry	Verge Red X	VergeWicket
<b>15</b> 60mph (3)			
<b>14</b> 60mph (2)			
<b>13</b> 60mph (1)			
<b>12</b> NR			
<b>11</b> Lane Closed (2)			
<b>10</b> Lane Closed (1)			
<b>9</b> Lane Closed Ahead			
<b>8</b> Warning			

Additional details relating to the methodology of the trial are provided below.

- > Participants were only recruited if they had not had previous experience of driving in a Managed Motorway environment in the simulator.
- > Before completing any experimental drives, participants undertook an initial familiarisation drive in a standard three-lane motorway environment to ensure that they were comfortable with both the driving simulator controls and simulated environment.
- > All participants were asked to *'drive as if they were late for an important meeting'* in order to motivate them to make good progress. This maximised the likelihood of 1) **participants' willingness to exceed the speed limit** to allow for a comparison of compliance across the layouts, and 2) participants driving LBS3 and LBS4 on approach to the closure in Test Area 2 to ensure they responded to the lane closure signs/gantries.
- > Enforcement of speed limits was implied through the provision of enforcement signing and secondary speed check markings as provided in existing Managed Motorway schemes. These were present at all information update points in each route.
- > **At the end of the second drive only, participants' were told that there was a fault with their vehicle and were asked to stop where they thought it would be appropriate to do so.** This was to **test participants' response to a scenario** where they must stop their vehicle on a live carriageway with no hard shoulder.
- > Following the completion of each drive, participants filled out the NASA-TLX questionnaire as a measure of workload<sup>23</sup>. Additional questions were included to assess their perceived level of risk, safety, difficulty and confidence whilst driving the route.
- > At the end of the trial, participants were required to fill out a longer questionnaire that investigated their subjective response to the two drives they had just experienced, their awareness and perception of information provision within the drives as well as general attitudes towards on-road driver information provision in an MM2 environment.

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<sup>23</sup> Hart, S., & Staveland, L. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. [in:] Hancock PA and Meshkati N (eds.) *Human Mental Workload*. Elsevier Science Publishers, North-Holland.

The analysis of results focused on the Areas of Measurement outlined in the following sections of this report. These sections describe the Key Findings of the trial.

**Note on intervisibility between signs/gantries**

Intervisibility between signs/gantries was not usually achieved within any of the routes. Appendix A provides example images to illustrate a participants' view as they pass under a sign/gantry in a verge and gantry signing layout. These are for information only as due to the resolution of the image, it is not possible to accurately illustrate the extent to which the scene is visible within the driving simulator itself.

**Note on participant sample size**

Initially 24 participants were recruited in each experimental group. An additional 3 participants were then recruited towards the end of the trial as contingency (e.g. if a particular participant was unable to complete the trial). Their data was also included in the analysis.

The total sample sizes that drove through each signing layout are shown in Table 21 below.

**Table 21: Sample sizes for the three routes used in this study**

n = 51		
Gantry (n = 51)	Verge (n = 51)	
	Verge Red X (n = 27)	Verge Wicket (n = 24)

Within the analysis in the following sections, the data from the two different verge layouts was combined to provide averages for an overall comparison of gantry and verge signing layouts (with equal sample sizes of 51 participants). The verge Red X and verge Wicket datasets were then also compared. The Key Findings section therefore refers to four signing layouts; gantry, verge, verge Red X and verge Wicket.

For some of the assessment measures it was only meaningful to investigate data of participants that drove in a particular lane at a particular point or within a section, meaning that the total sample size was reduced. This is detailed further where appropriate.

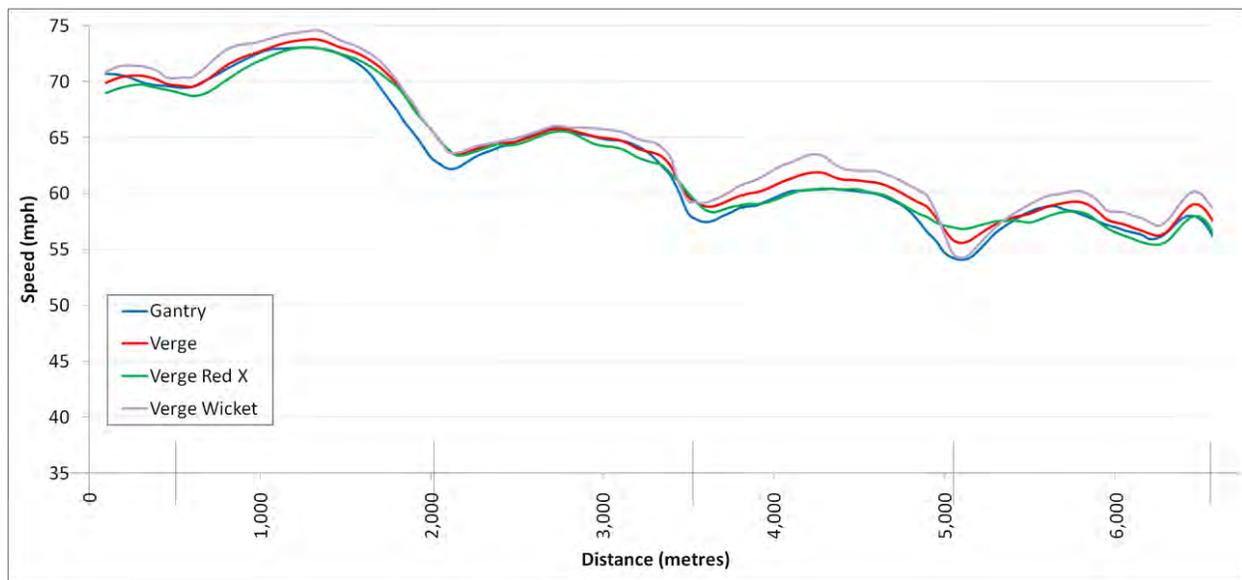
## 5.4 Key Findings

### 5.4.1 Driving Behaviour – Speed and Lane Choice

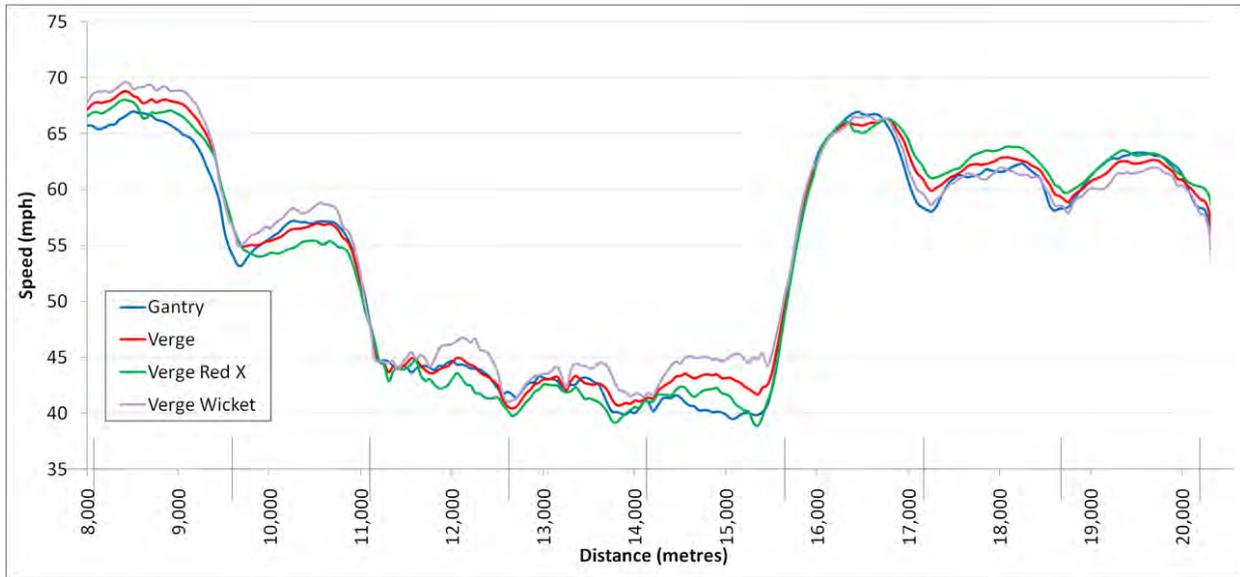
#### 5.4.1.1 Assessment measures

The driving simulator takes a measurement of the vehicle’s speed and lateral position relative to the carriageway every 0.05 seconds. This data was used to **investigate participants’ speed** and lane choice, how chosen speeds and lane changing movements related to the instructions presented at each sign/gantry, and whether compliance with the speed limit and lane closure instructions was affected by the type of signing used or message displayed.

Figure 94 and Figure 95 illustrates the speed profiles generated by the simulator data for the two test areas of the drive. Data has been averaged over every 50m for each of the signing layouts. The lines marked on the graphs indicate the location of each sign / gantry.



**Figure 94: Test Area 1 speed profiles for each signing layout averaged across all participants**

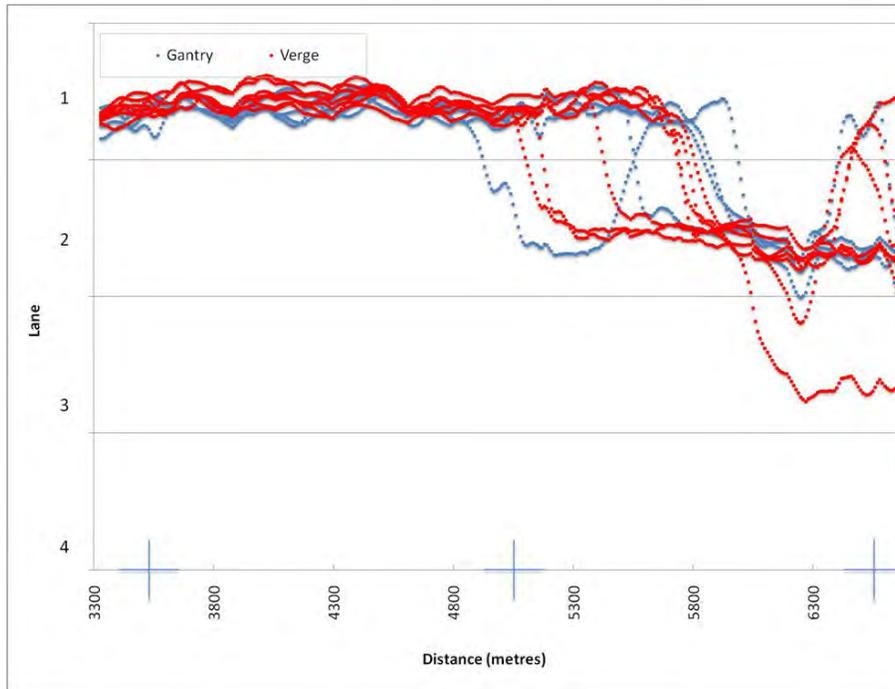


**Figure 95: Test Area 2 speed profiles for each signing layout averaged across all participants**

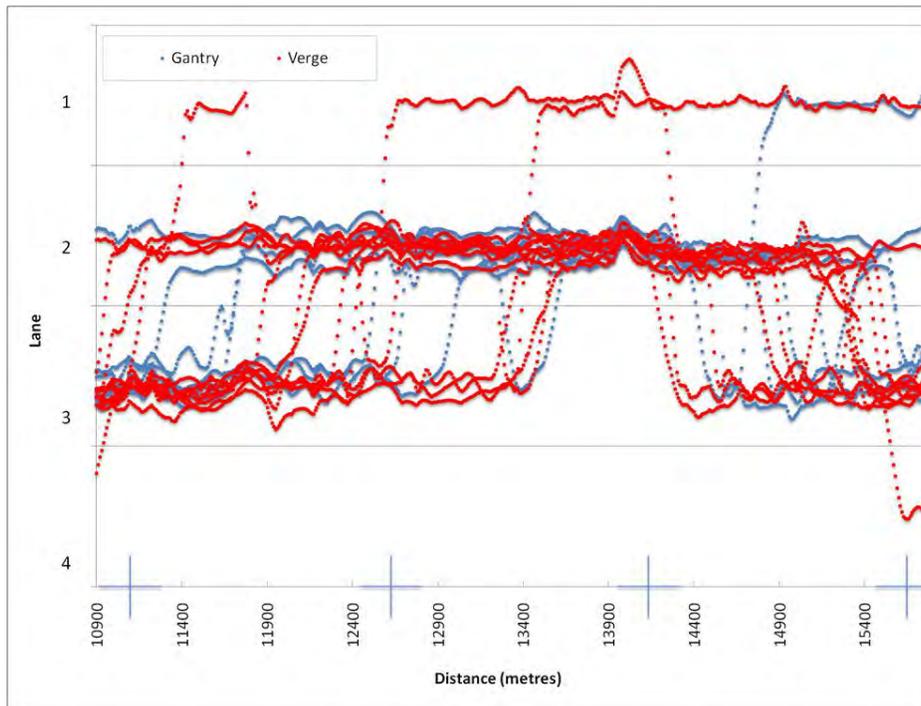
From this overview, different characteristics of **the participants’** speed choice can be observed. The assessment measures listed below were used to determine the **relationship between drivers’ speed** choice and the signing layout in which they were driving:

1. Mean speed
2. Spot speed at information update points
3. Time spent travelling at speeds higher than the displayed speed limit (i.e. non-compliance)
4. Variability in speed, particularly in relation to information update points (i.e. “surfing”)

From the data it is also possible to investigate individual participants’ **lane choice**, particularly in relation to their behaviour on approach to and during the lane closures. For example, Figure 96 and Figure 97 display the lateral positions of non-compliant participants within each lane closure section of Test Areas 1 and 2.



**Figure 96: Lateral lane position of non-compliant participants on approach to and during LBS1 closure for gantry and verge layouts**



**Figure 97: Lateral lane position of non-compliant participants during LBS3/4 closure for gantry and verge layouts**

For each lane closure, the assessment measures listed below were used to determine the **relationship between differences in characteristics of drivers' utilisation of the closed lane (s) and the signing layout in which they were driving:**

5. The number of participants moving into / driving in the lane closed to traffic (i.e. non-compliance with the lane closure); and
6. The location at which participants move out of the closing lane(s).

**Factors relating to individuals' speed** and lane choice are numerous and complex. Some effort has been made within the experimental design to account for these features. For example, it was arranged for the age group and gender of participants to be distributed amongst drives. Also, the order in which the gantry and verge signing layouts were driven was varied between participants, to account for learning effects.

**Furthermore, due to the observed variation in individual participants' driving behaviour, where appropriate, statistical tests were carried out to assess the extent to which this variation can be attributed to the difference signing layouts. These tests are described below in relation to each assessment measure.**

#### **Note on speed assessment measures**

Analysis of the speed assessment measures were not carried on all sections within the drives. Below are described the sections that were not included:

- > Analysis was not undertaken for any speed assessment measures on the **'Gateway' sign (1), since this was identical across signing layouts.**
- > For the mean speed, compliance and surfing magnitude measures, the section following the final 60mph sign/gantry (15) was excluded as participants were requested to end their drive after passing this sign/gantry.
- > The spot speed at the NR sign/gantry (6) has been excluded from the spot speed assessment measure because the increase in traffic within Test Area 2 is likely to be visible from this point and will have a strong influence on **drivers' speed choice.**

- > Analysis was not undertaken for any speed assessment measures for the first part of Test Area 2. In this area all participants moved at some point into LBS1 or LBS2 due to the closure of LBS3 and LBS4. As a consequence, **participants' speed was largely** determined by the speed of the heavy traffic present in LBS1 and LBS2, travelling at or near the displayed speed limit. The mean speed data showed only small differences between the layouts (i.e. speed difference < 0.5mph in most cases).

In addition, the full dataset was not used for speed assessment:

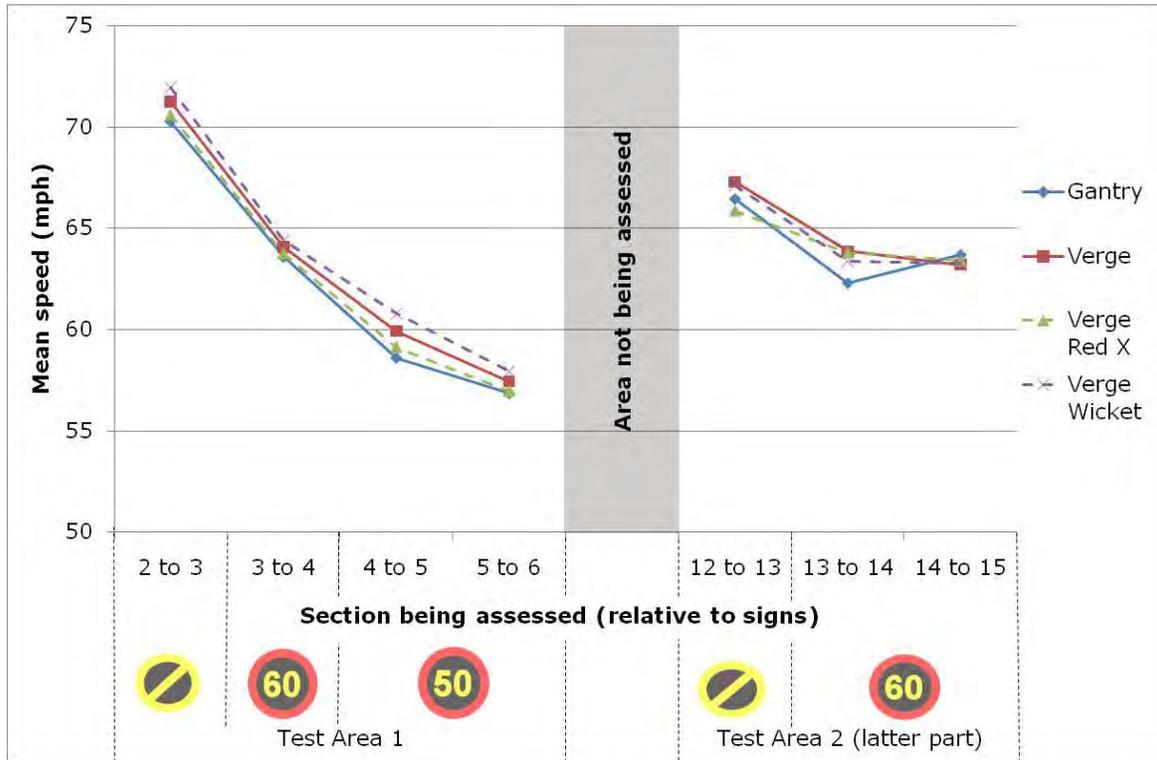
- > **One participants'** data was not included in the speed data analysis since they drove at an extreme speed for most of their drives (therefore maximum sample size for speed assessment measures was 50).
- > Participants driving in LBS1 or LBS2 were removed from analysis of the latter part of Test Area 2 due to the influence of simulator traffic. Most participants' chose to drive in LBS3 and LBS4, perhaps encouraged by the instruction **received at the start of the drive, which was 'to drive as if you are late for an important meeting'**. Details of the data used in the analysis for each assessment measure are provided in Appendix D.

The following sections describe the key findings in relation to speed and lane choice of participants, addressing each of the assessment measures.

5.4.1.2 Findings

**Assessment Measure 1: Mean speed**

Figure 98 (below) shows for each signing layout the mean speed for the section after each sign/gantry within Test Area 1 and the latter part of Test Area 2<sup>24</sup>.



**Figure 98: Mean speed in Test Area 1 and the latter part of Test Area 2, for each signing layout)**

On initial inspection it can be seen that for all signing layouts, mean speeds were higher than the displayed speed limit for each section of the route, aside from the NR section in Test Area 2 (signs/gantries 12 to 13). The mean speed in this section was slightly below the displayed limit, likely to be due to the 40mph speed limit previous to this and that some participants would have been traffic moving from LBS2 following the lane closure.

<sup>24</sup> Note that the standard error of the mean (SEM) have not been included in the graphs presented in the following sections for clarity of presentation. Information on SEMs is given in Appendix D.

It can further be seen that in both test areas, mean speeds were marginally higher for the verge layout than the gantry layout for each speed limit section. The only exception to this is in the second 60mph section in Test Area 2 (signs/gantries 14 to 15), where participants travelled slightly faster in the gantry than verge layouts.

The data also indicated that participants travelled faster in the verge Wicket layout than in the verge Red X layout for most of the test areas being assessed.

Further analysis was carried out to determine the statistical significance<sup>25</sup> of these results, i.e. whether or not any differences in mean speed can be assigned to the difference in signing layouts in the test area rather than randomness or variability between participants.

To assess whether or not signing layout had a significant effect on mean speed, paired and independent samples t-tests were undertaken. A paired samples t-test was carried out to determine if any difference between gantry and verge signing layouts was significant; an independent samples t-test was performed to determine if differences between the Red X and Wicket verge layouts were significant<sup>26</sup>.

The significant results are detailed below, and the full table of comparisons is presented in Table 39 in Appendix D.

### ***Gantry and Verge Comparison***

Results showed a significant difference in mean speeds between gantry and verge signing layouts for the following sections:

- > The section immediately following the first '**Blank**' sign/gantry (2) – Mean speeds in the verge layout were, on average, 1.0mph higher than in the gantry layout. This difference was just significant at the 10% level ( $t=-1.693$ ,  $df=49$ ,  $p=.097$ ).
- > **50mph** section following '**Lane closed ahead**' sign/gantry (4) – Mean speeds in the verge layout were, on average, 1.3mph higher than in the gantry layout. This difference was just significant at the 10% level ( $t=-1.678$ ,  $df=49$ ,  $p=.100$ ).

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<sup>25</sup> For efficiency of communication, if not explicitly stated, all references to the findings in this report being *significant* will be referring to *statistical* significance.

<sup>26</sup> Statistical significance is assigned in both tests to any comparison with a p-value at the 10% level or less.

All other differences in mean speeds between gantry and verge signing layouts were found to be non-significant, although the difference for the 60mph section between signs/gantries 13 and 14 was approaching significance.

### *Verge Red X and Verge Wicket Comparison*

None of the differences in mean speeds between the Verge Red X and Verge Wicket signing layouts were found to be significant.

The results showed **that participants' mean speeds in Test Area 1 were** slightly higher in the verge signing layout compared to the gantry signing layout for each speed limit section. However, the vast majority of differences in mean speed were found to be only small or not statistically non-significant. The maximum difference in speed in Test Area 1 was 1.3mph **in the 50mph section following the 'Lane closed ahead' sign/gantry.**

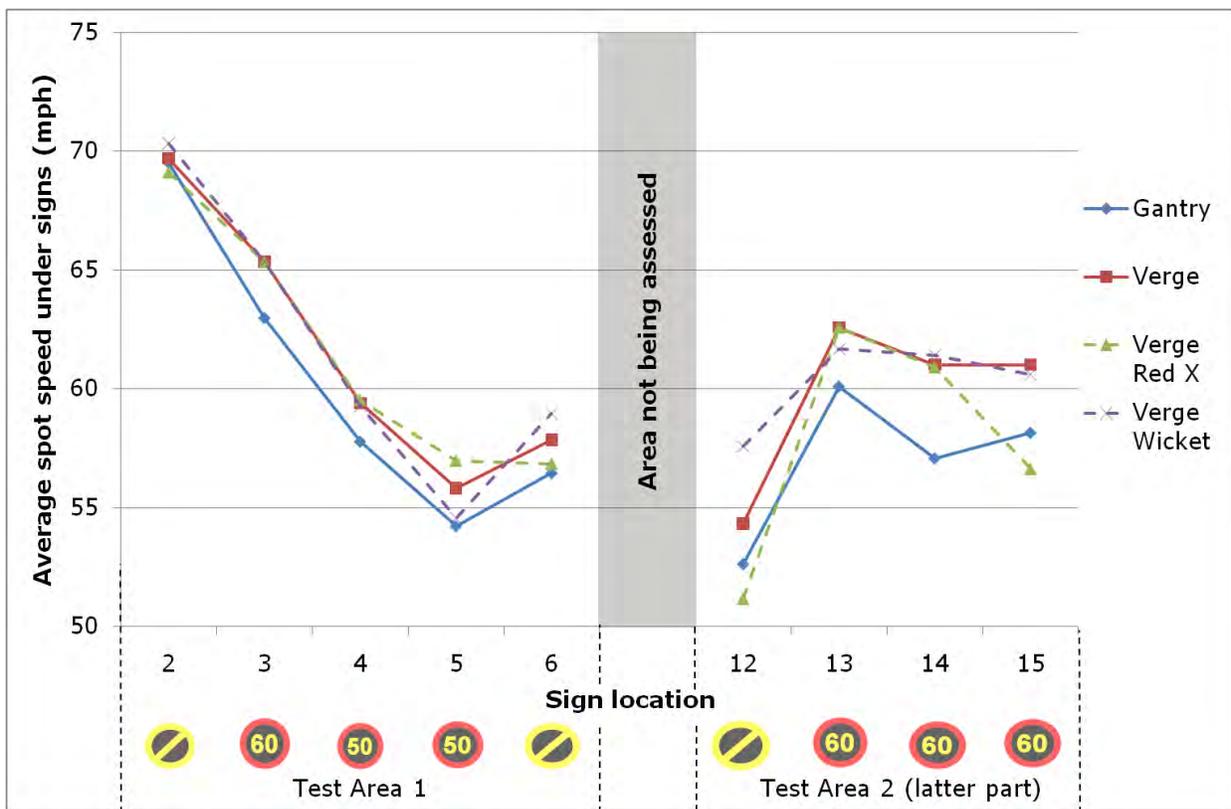
Whilst mean speeds in the latter part of Test Area 2 were in general slightly higher for verge layouts than gantry layouts, these differences were not found to be significant.

The use of different messages designs in the verge Red X and Wicket layouts did **not have significant effect on participants' mean speed.**

**Assessment Measure 2: Spot speed**

Spot, or instantaneous, speed refers to an individual speed measurement data point taken at a particular point on a route. This assessment measures seeks to investigate spot speeds at the point at which participants pass under a sign (i.e. either a gantry or verge-mounted MS4).

Figure 99 shows the average spot speed of participants when passing under a sign/gantry within Test Area 1 and the latter part of Test Area 2 for each signing layout.



**Figure 99: Average spot speeds under signs/gantries in Test Area 1 and the latter part of Test Area 2, for each signing layout**

The average spot speeds under signs/gantries displaying reduced speed limits within Test Area 1 were higher than the displayed speed limit by around 5 to 10mph. It is worth noting that spot speeds are likely to be strongly influenced by the speed limit displayed on the preceding sign/gantry.

The average spot speeds under signs/gantries in Test Area 2 were more aligned with the displayed speed limit, and in the case of the NR section were well below the limit. This is most likely because spot speeds in the NR section were affected by the 40mph limit in the previous section.

Figure 99 also shows that the spot speeds under signs/gantries in the gantry layout were slightly lower than for the verge signing layout throughout both test areas, with a large difference between the layouts observed in spot speed under the 60mph signs/gantries in Test Area 2.

Some differences in spot speed were observed between the two verge layouts, Red X and Wicket, however these differences were variable across the test areas with no clear pattern emerging.

As for the mean speed assessment measure, statistical analysis was carried out to determine the statistical significance of these results. The significant results are detailed below, and the full table of comparisons is presented in Table 40 in Appendix D.

### Gantry and Verge Comparison

Results showed that spot speed in the verge layout was higher than the gantry layout at most of the signs/gantries that were assessed, detailed in Table 22.

**Table 22: Significant differences in spot speed**

Location	Difference in average spot speed	Significance level
Sign/gantry 3 <b>'Warning'</b> sign displaying <b>60mph</b> speed limit	2.4mph	Significant at the 5% level (t=-2.556, df=49, p=.014).
Sign/gantry 4 <b>'Lane closed ahead'</b> sign displaying <b>50mph</b> speed limit	1.6mph	Significant at the 10% level (t=-1.829, df=49, p=.073)
Sign/gantry 5 <b>'Lane closed'</b> sign displaying <b>50mph</b> speed limit	1.6mph	Significant at the 5% level (t=-2.237, df=49, p=.030)
Sign/gantry 13 First <b>60mph</b> sign in Test Area 2	2.5mph	Significant at the 5% level (t=-2.261, df=40, p=.029)
Sign/gantry 14 Second <b>60mph</b> sign in Test Area 2	4.0mph	Approaching significance at the 5% level (t=-1.995, df=42, p=.053)
Sign/gantry 15 Third <b>60mph</b> sign in Test Area 2	2.9mph	Significant at the 5% level (t=-2.039, df=42, p=.048)

### *Verge Red X and Verge Wicket Comparison*

Results showed a significant difference in mean speeds between verge Red X and verge Wicket signing layouts for the following sign only:

- > **NR** sign/gantry in Test Area 2 (12) – Spot speed in the verge Wicket layout was on average 6.4mph higher than in the verge Red X layout. This difference was significant at the 5% level ( $t=-2.705$ ,  $df=25$ ,  $p=.012$ ).

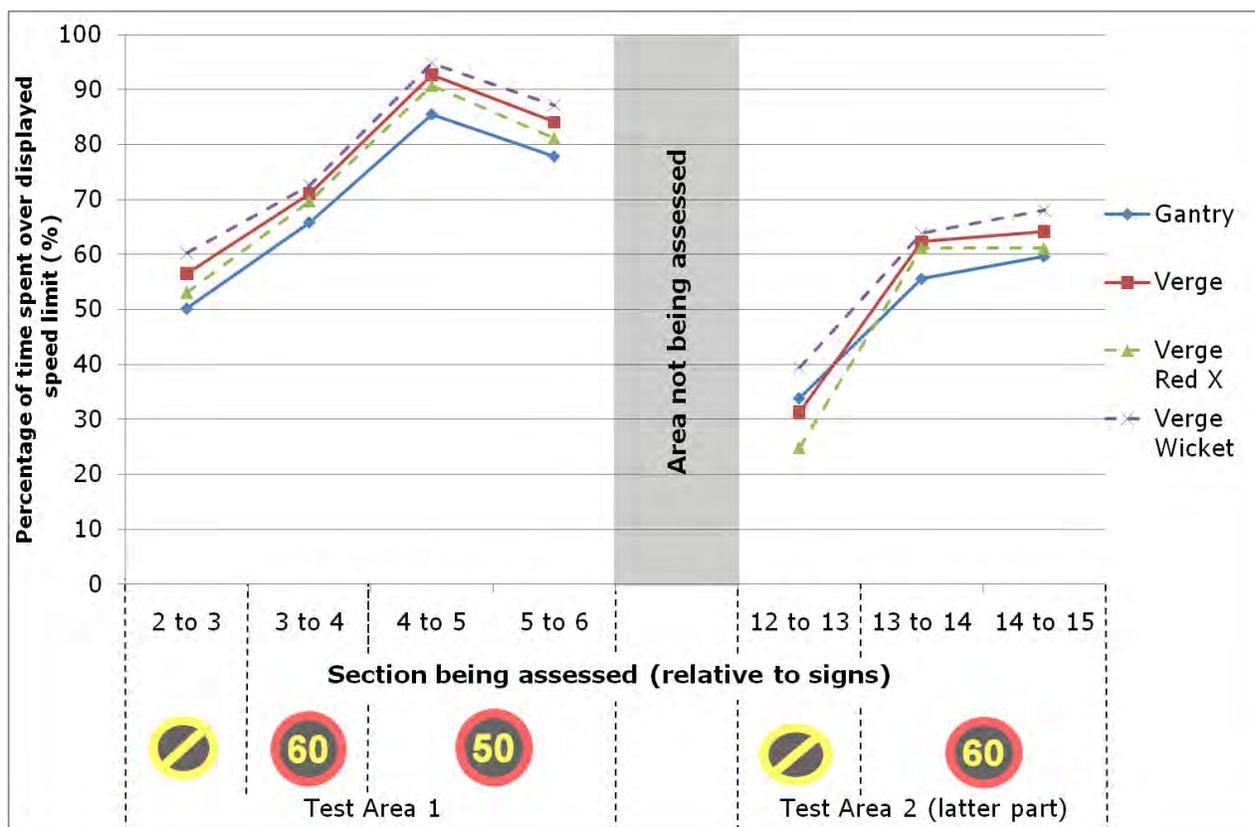
There is very little difference in the information displayed on these two signs, the **main difference being the presence of four arrows indicating 'all lanes open' on the Red X layout**. This perhaps encouraged participants to move into LBS3 earlier and achieve higher speeds passing under sign 12.

**Participants' spot** speeds under signs in the verge signing layout were consistently higher than in the gantry layout. The results showed **that participants'** average spot speeds under signs in the verge layout were up to 2.4mph higher than in the gantry layout in Test Area 1 and up to 4.0mph higher in Test Area 2.

**Assessment Measure 3: Time spent travelling at speeds higher than the displayed speed limit (i.e. non-compliance)**

To investigate compliance with the displayed speed limit, the time spent by each participant over the speed limit was analysed.

Figure 100 represents the average percentage of participants' time spent travelling above the displayed speed limit for Test Area 1 and the latter part of Test Area 2 under each signing layout.



**Figure 100: Average percentage of time spent travelling at speeds above the displayed speed limit in Test Area 1 and the latter of Test Area 2, for each signing layout**

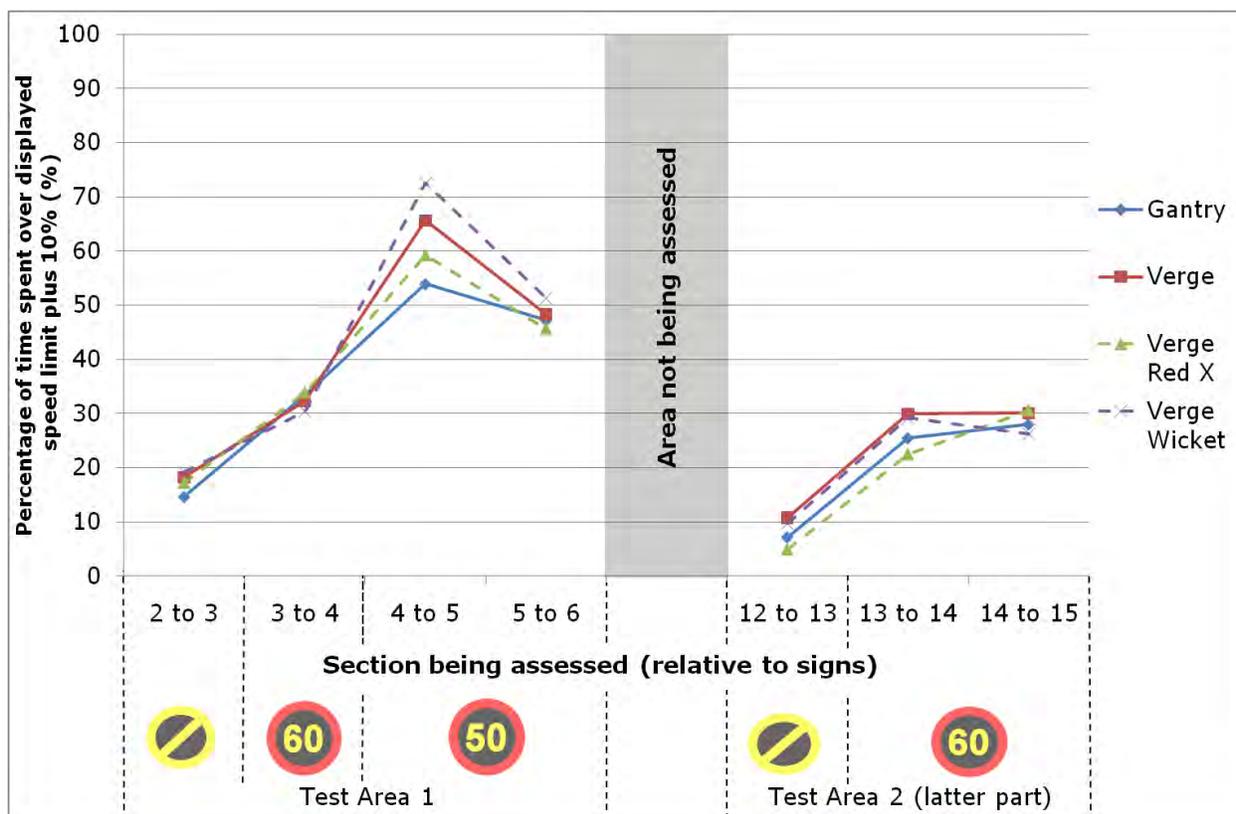
In all layouts, participants on average spent a significant proportion of each section driving above the displayed speed limit, particularly in Test Area 1. Furthermore, compliance levels, appear to be lower under lower speed limits.

Also worth noting is that compliance varies greatly between different sections with the same speed limit. This could be for a variety of reasons such as the presence of other traffic or the speed limit of the previous section.

As shown in Figure 100, participants spent a greater proportion of time over the displayed speed limit within each section in the verge layout than the gantry layout. The only exception to this is in the section following the NR sign/gantry (12 to 13) in Test Area 2, where it was in the verge layout that participants were more compliant. However, the difference in percentage of time between the two layouts was very small.

The results also indicated that participants' spent longer above the speed limit in the verge Wicket than the verge Red X layout throughout both test areas.

Figure 101 represents the average percentage of participants' time spent travelling above the displayed speed limit plus 10% (i.e. 55mph, 66mph and 77mph) for Test Area 1 and the latter part of Test Area 2 under each signing layout.



**Figure 101: Average percentage of time spent travelling at speeds above the displayed speed limit plus 10% in Test Area 1 and the latter part of Test Area 2, for each signing layout**

As illustrated in Figure 101 above, participants in the verge layout were more likely to travel above the speed limit plus 10% throughout the two test areas, however it is only during the section in Test Area 1 where LBS1 is closed (4 to 5) that there is

a large difference between the signing layouts. This appears to be as a result of a high level of non-compliance exhibited by participants in the verge Wicket layout.

Compliance with the speed limit plus 10% was particularly low in the 50mph sections of Test Area 1 across all layouts, with participants on average driving above 55mph for half or more of each section. Compliance with the displayed limit plus 10% was similar for equivalent speed limit sections in each test area.

Statistical tests were carried out on the data relating to the percentage of time above the speed limit plus 10% only. The full table of comparisons is presented in Table 41 in Appendix D; details of significant results are provided below.

### *Gantry and Verge Comparison*

Results showed a significant difference in the percentage of time above the speed limit plus 10% between gantry and verge signing layouts for the following section only:

- > **50mph section** following '**Lane closed ahead**' sign/gantry (4 to 5) – The percentage of time spent above the speed limit plus 10% in the verge layout was on average 11.7% higher than the gantry layout, significant at the 5% level ( $t=-2.112$ ,  $df=49$ ,  $p=.040$ ).

### *Verge Red X and Verge Wicket Comparison*

None of the differences in the percentage of time spent above the speed limit plus 10% between the Red X and Wicket verge signing layouts were found to be significant.

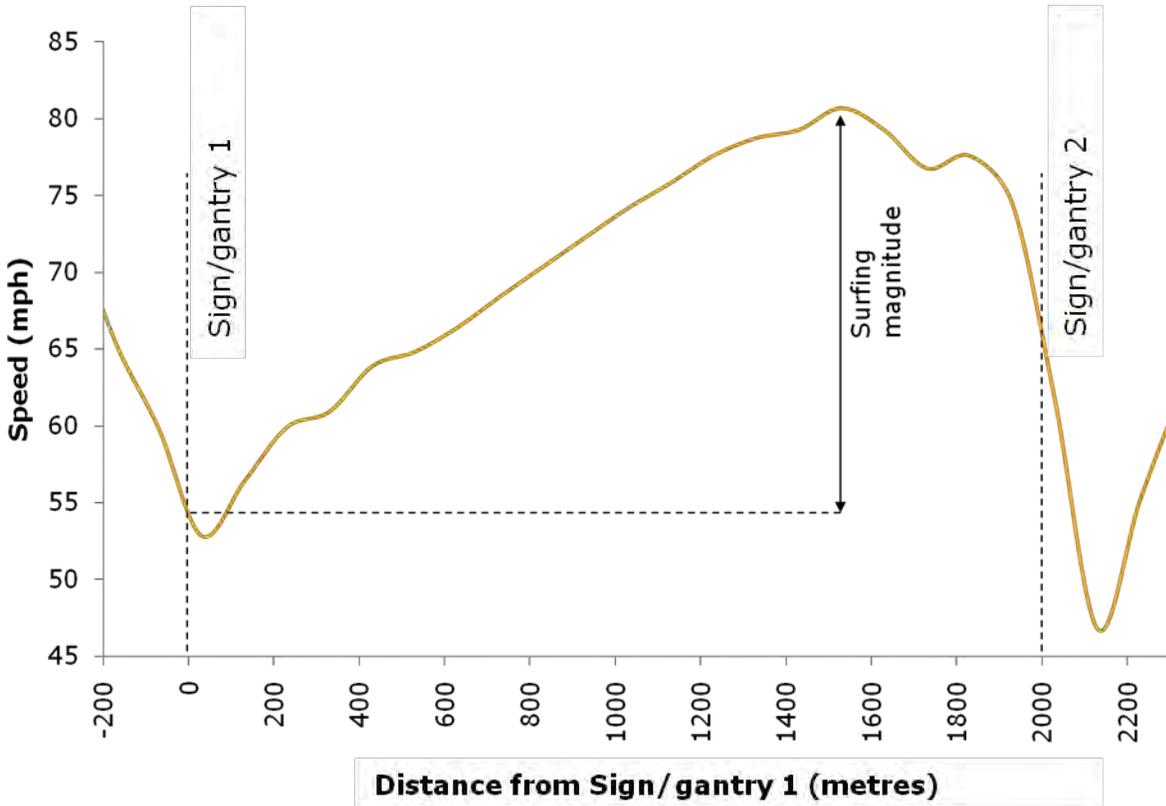
In most sections, participants exceeded the speed limit plus 10% for a greater proportion of time in the verge layout compared to the gantry layout, however only one significant difference was identified. Participants spent 11.7% more of their time above 55mph in the verge layout than for the gantry layout during the section where LBS1 was closed and a 50mph speed limit was displayed.

The use of Red X vs Wicket lane closure aspects on verge signing was not found to **have a significant effect on participants' time spent** above the speed limit plus 10%.

***Assessment Measure 4: Variability in speed, particularly in relation to signs/gantries (i.e. "surfing")***

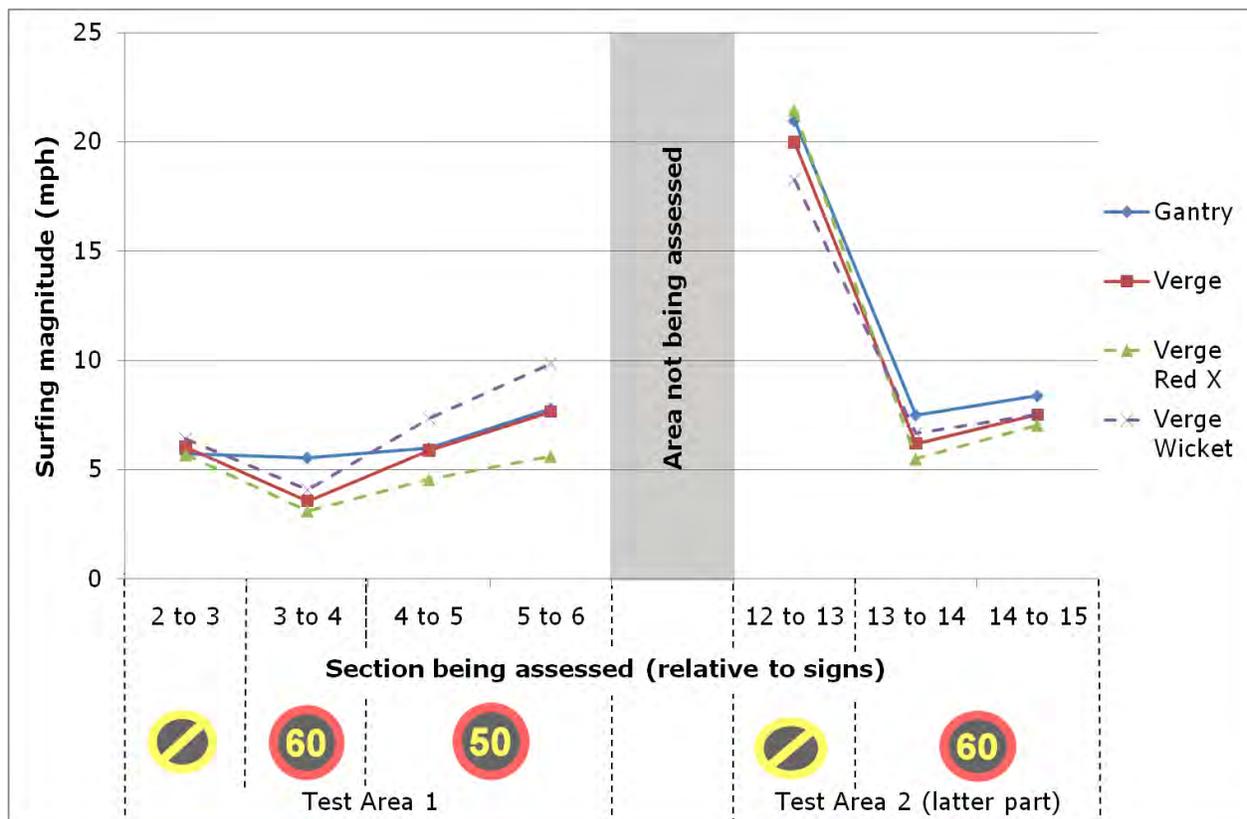
In current MM schemes, gantries used for displaying VMSL can be equipped with speed enforcement cameras and at each gantry location there are outward indicators that spot speed enforcement is possible. This is mainly in the form of enforcement camera signs and horizontal road markings used for measuring **drivers' speed. Whilst cameras are not present on all gantries** within a MM scheme, drivers would generally not be aware of which gantries are equipped in this way. As a result of this threat of enforcement, many drivers exhibit a driver behaviour which **will be referred to here as "surfing"**. Surfing is when drivers reduce their speed to below the speed limit (or below a perceived speed limit enforcement threshold) to pass under a gantry before speeding up to speeds higher than the speed limit then slowing down again to pass under the next gantry.

Both the gantry and verge signs used within this simulator trial have been equipped with the same indicators of enforcement as would be used in an MM environment, and despite there being no means of enforcement in the simulated environment, many participants exhibited surfing behaviour similar to that which can be observed in actual schemes. This behaviour can be seen to some extent in the speed profiles displayed in Figure 94 and Figure 95. To quantify and compare how surfing may differ between signing layouts a measure was used to assess the extent of **participants' surfing behaviour by** looking at the difference between a participant's speed under a sign/gantry and the maximum speed reached after that sign/gantry but before reaching the next one (see Figure 102). This investigates the height of the peaks in the speed profiles (Figure 94 and Figure 95) caused by surfing, and for ease of reference will be referred to as the *surfing magnitude*.



**Figure 102: Example of an individual participant's speed profile between two signs/gantries, with surfing magnitude indicated**

Figure 103 shows the average surfing magnitude between consecutive signs/gantries for each signing layout and speed limit section within Test Area 1 and the latter part of Test Area 2.



**Figure 103: Average surfing magnitude in Test Area 1 and the latter part of Test Area 2, for each signing layout**

As shown in Figure 103, a degree of surfing occurred in all signing layouts. In Test Area 1, the magnitude of surfing tended to be almost identical for gantry and verge layouts except for the 60mph section after the warning sign/gantry (3 to 4), where surfing magnitude was higher for the gantry then verge layout.

In Test Area 2, the surfing magnitude was slightly higher for the gantry layout then the verge layout across all sections. The surfing magnitude for the 60mph section in Test Area 2 was roughly similar to that exhibited in the 60mph section for Test Area 1; however for the NR section it was significantly higher.

Surfing magnitude was slightly higher for the verge Wicket layout then the verge Red X layout throughout both test areas, aside from in the NR section following the lane closure in Test Area 2 (12 to 13).

Statistical analysis was carried out to determine the statistical significance of these results. The full table of comparisons is presented in Table 42 in Appendix D; details of significant results are provided below.

### *Gantry and Verge Comparison*

Results showed a significant difference in surfing magnitude between gantry and verge signing layouts for the following sign only:

- > **60mph section** following the obstruction lane closure **'Warning'** sign/gantry (3 to 4) – Surfing magnitude in the gantry layout was 2.0mph higher than in the verge layout. This difference was significant at the 5% level ( $t=2.170$ ,  $df=49$ ,  $p=.035$ ).

### *Verge Red X and Verge Wicket Comparison*

Results showed a significant difference in surfing magnitude between verge Red X and Wicket signing layouts for the following sign/gantry only:

- > **50mph section** following the **'Lane Closed'** sign/gantry (5 to 6) – Surfing magnitude in the verge Wicket layout was 4.2mph higher than in the verge Red X layout. This difference was significant at the 5% level ( $t=-1.720$ ,  $df=48$ ,  $p=.034$ ).

The results indicated that there was very little difference in surfing magnitude between the gantry and verge signing layouts for the majority of sections in the **test areas, apart from in the section following the 60mph 'Warning'** sign/gantry, where surfing magnitude was significantly higher in the gantry layout (by 2.0mph).

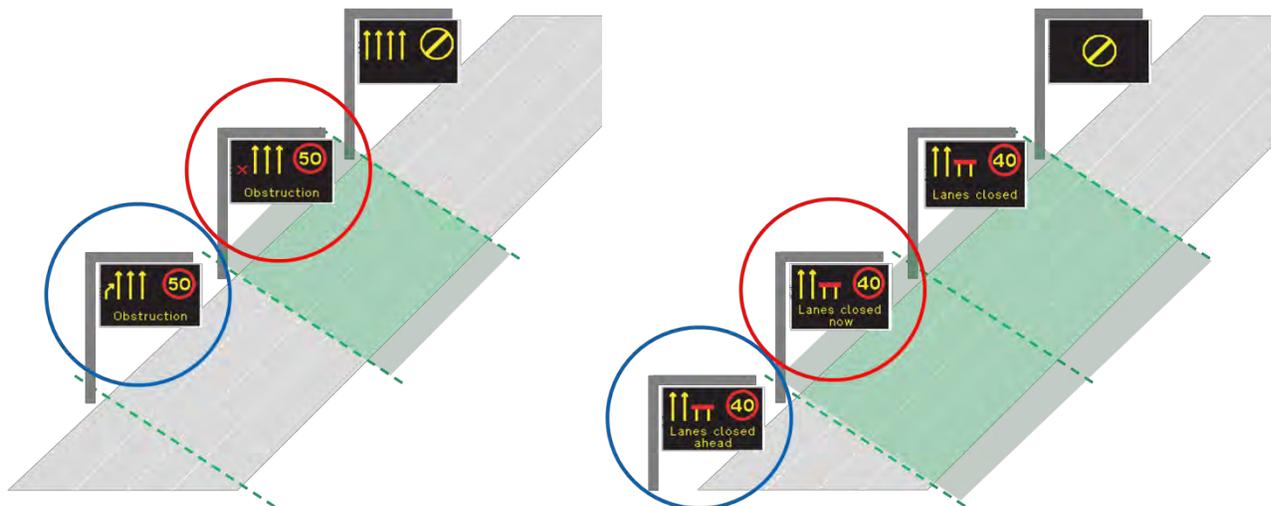
For most of the sections within each test area, surfing magnitude was similar for both verge Red X and Wicket layouts, although a significant difference was identified in relation to the section where LBS1 was closed in Test Area 1 (5 to 6). In this section, surfing magnitude was 4.2mph higher in the verge Wicket than verge Red X layout.

***Assessment Measure 5: The number of participants moving into / driving in the lane which is closed to traffic***

In each drive, participants encountered two different lane closures:

- > Within Test Area 1, LBS1 was closed due to an obstruction for approximately 1500m between signs/gantries 5 and 6. A stationary vehicle was present in LBS1 around 300m before the end of the closure. All participants were therefore forced to move out of LBS1 at this point.
- > Within Test Area 2, LBS3 and LBS4 were closed for approximately 3000m between signs/gantries 10 and 12. A stationary vehicle was positioned across LBS3 and LBS4 midway through the closure (around 250m before sign/gantry 11). It was therefore not possible for participants to drive through LBS3 and LBS4 at this point.

During each test area, participants were first informed of a 'Lane closed ahead'<sup>27</sup>, e.g. the signs circled in blue in Figure 104. The subsequent sign/gantry indicated that the lane was now closed to traffic<sup>28</sup>, e.g. the signs circled in red in Figure 104.



**Figure 104: Area of LBS1 closure, using the Red X Verge layout as an example (left) and area of LBS3/4 closure, using the Wicket Verge layout as an example (right)**

The aim of Assessment Measure 5 is to investigate any non-compliance with lane closure instruction within the two closures, i.e. participants driving in a closed lane within the shaded regions in Figure 104.

<sup>27</sup> Signs/gantries 4 and 9 for the LBS1 and LBS3/ 4 closures respectively, shown in Table 19.

<sup>28</sup> Signs/gantries 5 and 10 for the LBS1 and LBS3/ 4 closures respectively, shown in Table 20.

Non-compliance can be split into three broad categories:

- A. Participants not exiting a closed lane until after the 'Lane closed' sign/gantry (see Figure 104);
- B. Participants moving from an open lane into a closed lane for a period of time (e.g. to overtake); and
- C. Participants moving into the closed lane while the end of the closure is visible (i.e. signs/gantries 6 and 12) but before passing under the sign/gantry.

Movements in category C, while technically non-compliant, would be unlikely to cause a safety risk. Therefore, movements into a closed lane within 200m of the end of the closure were removed from the analysis, but were explored with Assessment Measure 6.

Out of 102 drives, there were 11 drives for the LBS1 closure and 19 drives LBS3/4 closure where participants travelled in the closed lanes. Some participants undertook movements in both categories A and B above.

Table 23 provides a summary of non-compliance within the two test areas. As well as figures representing categories A and B above, there is also an indication of '**extreme**' non-compliance, i.e. occasions of participants being in a closed lane for more than 50% of the closure.

**Table 23: Summary of non-compliance with lane closures**

	LBS1 closure			Lane 3 / 4 closure		
	All	Gantry	Verge	All	Gantry	Verge
<b>No. drives where participant did not exit a closed lane until after the 'Lane closed' sign/gantry</b>	10	3	7 (Red X - 4, Wicket - 3)	11	4	7 (Red X - 4, Wicket - 3)
<b>% of drives in sample</b>	10%	6%	14% (Red X - 15% Wicket - 13%)	11%	8%	12% (Red X - 15% Wicket - 13%)
<b>No. occasions where a participant moved from an open lane into a closed lane</b>	1	1	0	14	5	9 (Red X - 2, Wicket - 7)
<b>% of drives in sample</b>	1%	2%	0%	14%	10%	18% (Red X - 7% Wicket - 32%)
<b>No. drives where participant travelled in LBS1 whilst it was closed for &gt;50% of closure</b>	6	2	4 (Red X - 1, Wicket - 3)	3	0	3 (Red X - 1, Wicket - 2)
<b>% of drives in sample</b>	6%	4%	8% (Red X - 4%, Wicket - 13%)	3%	0%	6% (Red X - 4% Wicket - 8%)

Out of 102 drives, there was only one occasion when a participant returned to LBS1 when it was closed to traffic and before the 'NR' sign/gantry (reference 6) became visible, whereas in 14% of drives the participant moved into LBS3 while it was closed to traffic. This is likely to be because of the heavy traffic in LBS1 and LBS2 encouraging drivers to overtake. Furthermore, the LBS3/4 closure was twice as long and the road works vehicle was situated just before the midpoint of the closure. Having passed this, participants may have perceived it more acceptable to move into LBS3. Of the occurrences of participants moving back into LBS3 during the closure all but one were after the road works vehicle.

Similarly there was a greater number of participants that left the closed lane after **passing the 'Lane closed' sign/gantry** in the LBS3/4 closure than the LBS1 closure. This too is likely to be because of the presence of heavy traffic in LBS1 and LBS2, i.e. participants would have to drop their speed and wait for suitable gap before moving out of the closed lane.

**Most of the participants who waited till after the 'Lane closed' sign/gantry before leaving the closed lane** for in LBS1 did not leave until at least 400m after the sign/gantry, i.e. not in response to the sign/gantry but more likely in response to the obstructing vehicle. See Assessment Measure 6 (Figure 105 and Figure 106) for the locations of the movements.

**Instances of 'extreme' non-compliance** were greater for the first closure. However, it is worth noting that this closure was half the length of the second closure.

In Table 23 it can be seen that for all three measures listed, there was a greater level of non-compliance when driving in the verge layouts than the gantry layouts (except for the one drive where a participant moved into LBS1 during the first closure). Furthermore, in most cases there were greater numbers of non-compliance for the Wicket layout than the Red X layout, although the proportion of **participants remaining in LBS1 and LBS3 after passing the 'Lane closed' signs** was almost identical.

For a fuller understanding of whether these differences were meaningful further considerations was given to the participants moving into a closed lane during a closure (usually LBS2 to LBS3 in Test Area 2) and to the extent to which this action was the result of the information being presented to them. This is explored further below.

### **Non-compliant drivers**

Of all the non-compliant drivers, 76% were male and the average age was only slightly lower than the participant average (41 compared with 44). Most had only **on 'occasionally' or 'rarely'** driven on a section of motorway with mandatory variable speed limits. When completing the questionnaire<sup>29</sup>, the majority of non-compliant drivers viewed lane closure instructions as mandatory or compulsory. A full description of the non-compliant participants is included in Appendix E.

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<sup>29</sup> For a full analysis of the questionnaire data see Section 5.4.2.

Participants that were observed to be non-compliant for either a significant proportion of one lane closure, or for more than one lane closure, were asked to fill out a short questionnaire after completing their second drive. This questionnaire asked participants to write down their interpretation of gantry and verge signs **displaying a 'Lane closed' or 'Lane closed ahead' instruction, similar to those shown in the routes they had just completed.** They were also asked to indicate how they might respond to the signs/gantries if driving in the lane to be closed, and to indicate when they might respond. This was to help determine whether or not non-compliance was due to misunderstanding of the information being presented.

The following was found:

- > All participants that completed the questionnaire demonstrated that they correctly understood the instructions displayed on the signs/gantries and suggested that they would respond as required (i.e. by moving out of the closing lane).
- > There was some variation in terms of when participants thought they should respond to the sign/gantry, with some participants believing they should act **'in a short while'**.
- > Two participants believed that they should **'wait until the next warning sign/gantry' before responding.** Both these participants did not exit the closing lane for a significant distance into the lane closure.
- > One participant did not make specific reference to changing lane when describing the required action, but it could not be implied from this alone that they did not understand this requirement.

Whilst it appears that some of the participants may have responded belatedly to these signs/gantries as a result of their interpretation of the immediacy of the instruction, the questionnaire data suggests that participants were primarily acting in a non-compliant manner as a result of choice as opposed to a poor comprehension of what they were required to do.

Furthermore, over a third of the participants who were non-compliant were non-compliant to some extent on both of their drives, suggesting for these participants that non-compliance is even less likely to be the result of sign layout in the drive.

Evidence of non-compliance with lane closure instructions was observed in both lane closures and all signing layouts. Overall, there was slightly less non-compliance by participants when driving in the gantry signing layouts than with the verge signing layouts, although the overall non compliance levels were low in all layouts. Furthermore, in most cases there were slightly greater numbers non-complying for the Wicket layout than with the Red X layout. However, results from the post-drive questionnaire indicated that this difference was unlikely due to poor comprehension of the different layouts.

Although, the majority of participants responded to the instruction presented to them on the sign/gantry, for a few participants this was not always enough to ensure compliance. It **appears that the physical presence of an 'obstruction' in the closed lane was necessary for these participants to change lane.**

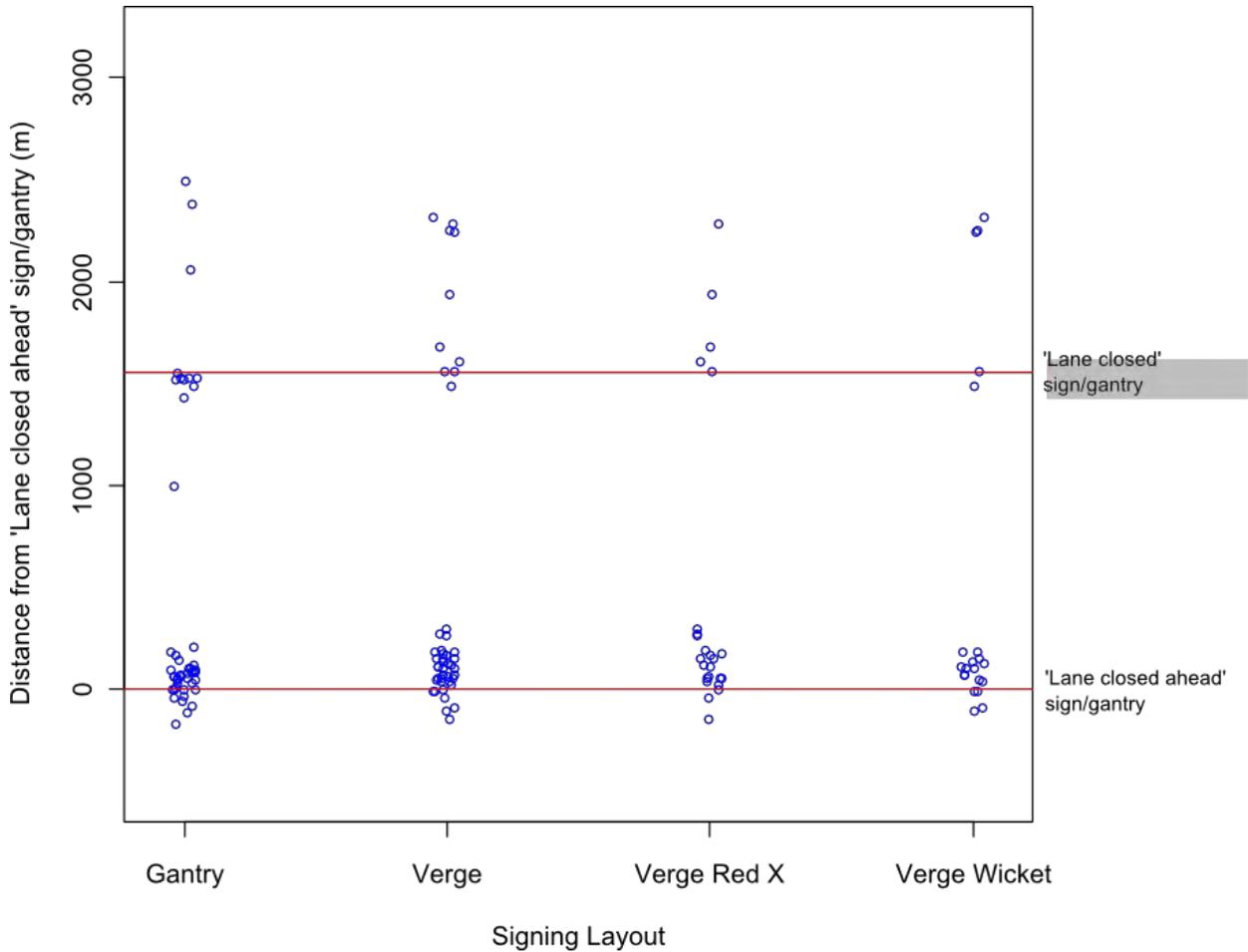
***Assessment Measure 6: The location at which participants move out of the closing lane(s)***

This measure seeks to investigate whether there is any variation between signing layouts in relation to the immediacy with which participants move out of the closing lane(s) once instructed to do so via the signs/gantries. As illustrated in Table 19 and Table 20, for the lane closures in both test areas participants were presented **firstly with a sign/gantry communicating a 'Lane closed ahead' instruction, followed by a subsequent sign communicating a 'Lane closed' instruction.**

For each closure, Figure 105 and Figure 106 **indicate participants' location of departure from the closing lane (either LBS1 or LBS3), relative to the sign/gantry displaying the 'Lane closed ahead' instruction, for each signing layout.**

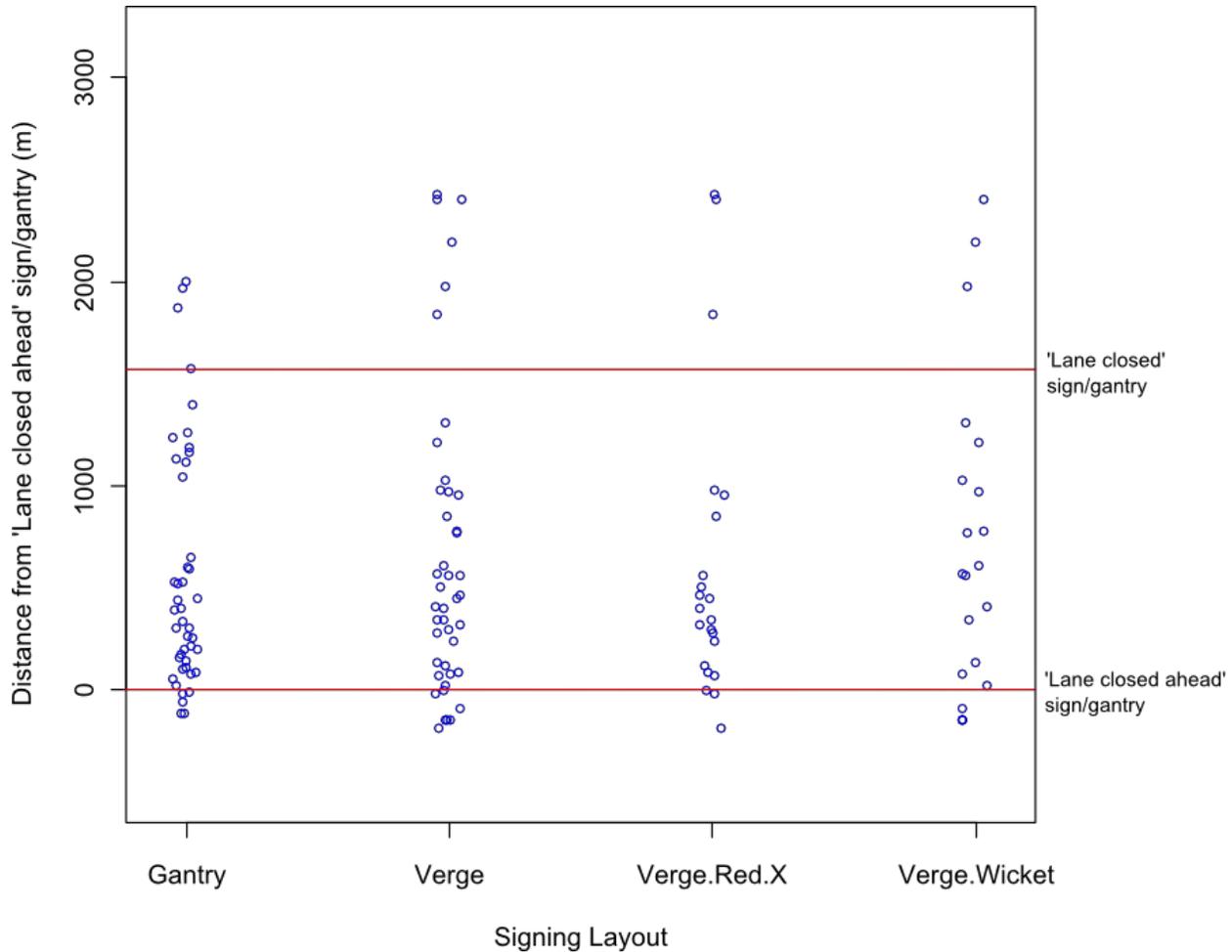
For all signing layouts, most participants were in the lanes to be closed when approaching **the 'Lane closed ahead' signs/gantries for both** closures. The data for participants who had already moved out of the closing lane 200m before the **sign/gantry displaying the 'Lane closed ahead instruction'** was not included in this analysis. This was because at approximately 200m before the sign/gantry it was expected that the information would not be legible to the driver and as such any movement out of the lane would not be a direct response to the sign/gantry. Therefore, the data in the graphs shown below represent a sample of 46 participants (LBS1 closure) and 44 participants (LBS3 and LBS4 closure) out of the total 51 participants.

**This analysis also only considered the departure location of participants' first movement out of the closing lane.** A minority of participants then returned to the closing lane; if those participants had not moved back out of this lane before the **'Lane closed' sign/gantry then they were considered to be non-compliant, as defined in Assessment Measure 5.**



**Figure 105: Location of LBS1 departure relative, in metres, to the 'Lane closed ahead' sign/gantry (4), for each signing layout (LBS1 closure, Test Area 1)**

On initial inspection, it can be seen that the large majority of participants moved out of LBS1 within 500m of passing the sign/gantry, and the distribution of locations where participants' move out of LBS1 is very similar across the signing layouts.



**Figure 106: Location of LBS3 departure relative, in metres, to the 'Lane closed ahead' sign/gantry (9) for each signing layout (LBS3/ 4 closure, Test Area 2)**

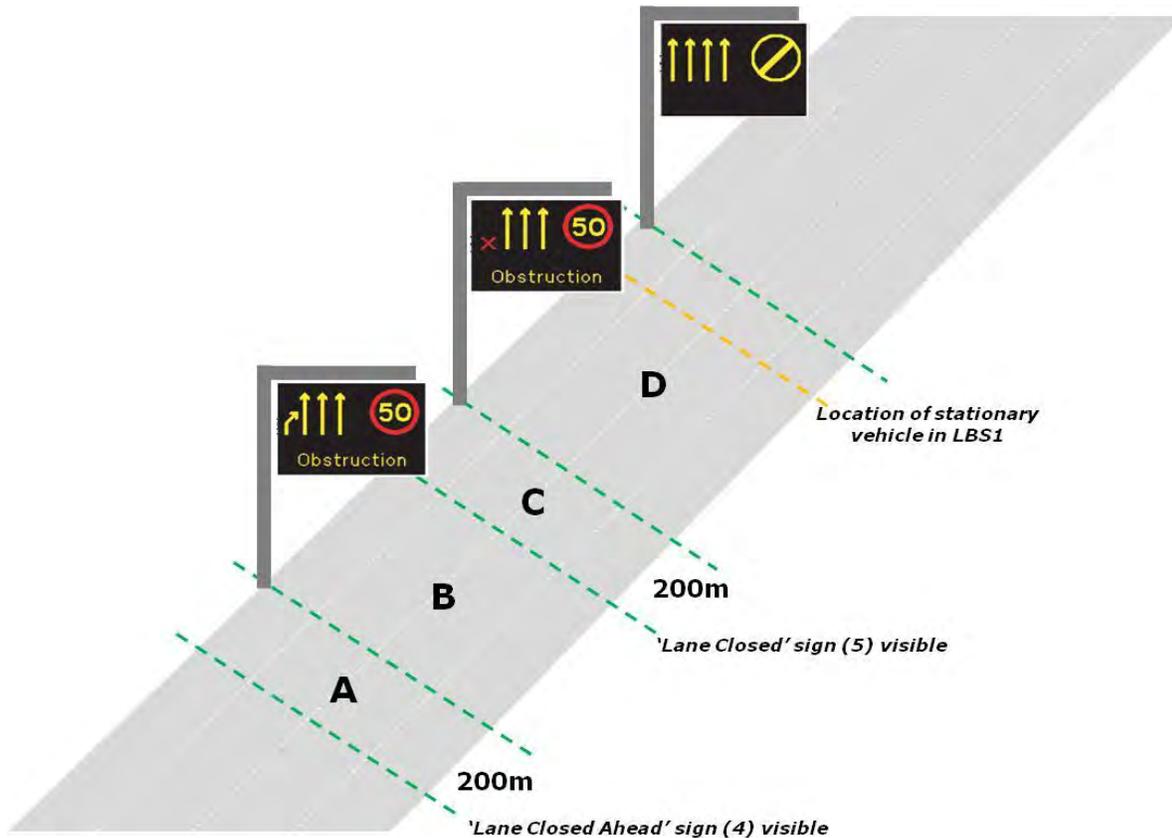
The distribution of departure locations for the LBS3 and 4 closure (Figure 106) was also similar across signing layouts, however the data showed a wider spread.

A possible explanation for this is that there was no traffic in the LBS1 closure scenario and as such participants' could move freely into the other lanes. In the LBS3/4 closure there was heavy traffic in the open lanes (1 and 2) and therefore participants moving out of LBS3 were required to wait for an appropriate gap in the traffic.

For the LBS3/4 closure, the variability in headway of the simulator traffic, as well as the variability of participants 'gap acceptance', would have had a strong influence on when they changed lane. This means that the level of influence of the signing layout on their decision when to move out of the closing lane was much lower.

Further analysis was therefore not undertaken on the data for the LBS3/4 closure for this assessment measure.

To assist in analysing the LBS1 closure data further, the departure points of participants from LBS1 were considered in terms of the following zones, as illustrated in Figure 107 below.



**Figure 107: Zones relative to lane closure signs/gantries used in analysis of participants' departure distance from the closing lane**

Table 24 contains the average and standard deviation of the points represented in Figure 105 for the LBS1 closure. The mean departure distances have been calculated for the following three categories:

- > All participants in the sample for this assessment measure;
- > Participants that departed in zones A and B (i.e. in response to the 'Lane closed ahead' sign/gantry)
- > Participants that departed in zones C and D (i.e. in response to the 'Lane closed' sign/gantry).

**Table 24: Average departure from LBS1 relative to 'Lane closed ahead' sign/gantry (reference 4), with standard deviation, in metres**

	Gantry	Verge	Verge Red X	Verge Wicket
<b>Mean departure distance in metres (SD)</b> All participants	464 (755)	484 (779)	456 (726)	517 (853)
<b>Mean departure distance in metres (SD)</b> Participants departing after the 'Lane closed ahead' sign/gantry (zones A and B)	67 (180)	84 (102)	100 (112)	64 (88)
<b>Mean departure distance in metres (SD)</b> Participants departing after the 'Lane closed' sign/gantry (zones C and D)	1726 (388)	1886 (349)	1807 (301)	1965 (411)

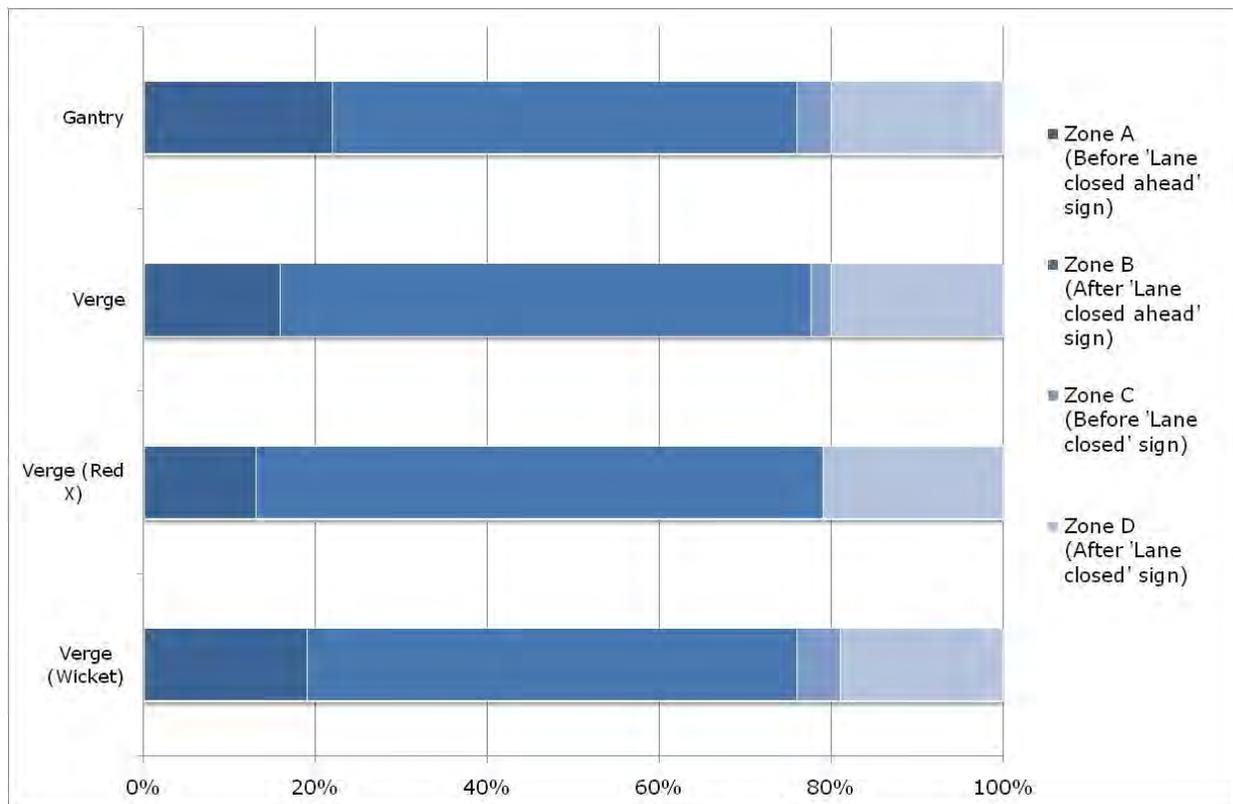
The scores in Table 24 indicated that there were small differences in the mean departure location of participants between the layouts. However, the standard deviation figures indicated that there was high variability between participants.

As with the speed assessment measures, further analysis was undertaken to determine the statistical significance of these results i.e. whether or not any differences in mean departure location can be assigned to the difference in signing layouts rather than randomness or variability between participants. Paired samples t-tests were used to analyse the difference between the gantry and verge layouts; Independent samples t-tests were used to assess differences between the verge Red X and verge Wicket layouts. The results of the statistical analysis showed that none of the differences were found to be significant at either the 5% or 10% level. Details of the comparisons are presented in Table 43 in Appendix D.

Figure 108 indicates for each signing layout the percentage of vehicles departing from LBS1 in relation to the zones detailed in Figure 107.

For example, the percentage of participants departing LBS1 within:

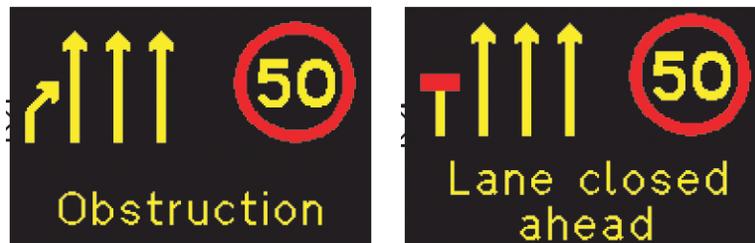
- > **Zone A** - Before passing under the 'Lane closed ahead' sign/gantry;
- > **Zone B** - After passing under the 'Lane closed ahead' sign/gantry, but before the 'Lane closed' sign/gantry is visible;
- > **Zone C** - Before passing under the 'Lane closed' sign/gantry once it becomes visible; and
- > **Zone D** - After passing under the 'Lane closed' sign/gantry before the end of the closure.



**Figure 108: Percentage of vehicles departing from LBS1 to LBS2 in each zone, for each signing layout**

These results suggest that the signing layout may have affected the immediacy with which participants responded to instruction. Overall, a smaller proportion of participants moved out of LBS1 immediately upon seeing the 'Lane closed ahead' sign in the verge layout than the gantry layout.

In particular, participants were less likely to leave LBS1 before passing under the 'Lane closed ahead' sign in the verge Red X layout than the verge Wicket layout. This appears to be primarily due to the fact that participants were responding with less urgency to the verge Red X sign than the verge Wicket sign. The 'Lane closed ahead' sign in the verge Red X layout used a Hooked arrow aspect, whereas the verge Wicket layout used a standard wicket aspect with text stating 'lane closure ahead', as illustrated in Figure 109.



**Figure 109: 'Lane closed ahead' sign for verge Red X and verge Wicket layouts**

However, the proportion of participants that departed before the 'Lane closed' sign became visible was roughly consistent between the verge and gantry layouts, with equal proportions of participants (80%) having exited LBS1 before the lane closure commenced.

There were 10 participants in total who waited until after the 'Lane closed' sign/gantry before moving out of LBS1. Of these, 2 participants (both in the verge Red X layout) moved out of LBS1 within 200m of entering the lane closure, however the remaining participants did not leave LBS1 until much later. These participants are discussed in Assessment Measure 5 relating to non-compliance.

A final analysis was undertaken to investigate, for each individual participant, the difference in departure location between their gantry and verge drives. It was found that within the sample for this assessment measure, 62% of participants moved out of LBS1 earlier in their gantry drive than in their verge drive. On average, an individual participant departed from LBS1 12m earlier in their gantry than verge drive.

The distribution of **participants'** departure distances from the closing lane(s) was very similar across gantry spacing layouts.

In the LBS1 closure, the majority of participants moved out of LBS1 within 500m of passing the 'Lane closed ahead' sign/gantry. **80% of participants that were in LBS1 on approach to the closure had moved out before passing under 'Lane closed' sign/gantry in both layouts.** The absence of simulator traffic during this closure ensured **that there was no other influence on participants' departure location other than the way in which the information was communicated via the signing layouts.**

Differences in the mean departure distances between signing layouts in the LBS1 closure were found to be non-significant.

**Whilst the results suggested that participants' may be more likely to take longer to leave LBS1 in the verge Red X layout (e.g. in response to the Hooked arrow aspect), overall the proportion of participants that had exited LBS1 before the lane closure commenced was almost identical across all four layouts.**

## 5.4.2 Questionnaire

### 5.4.2.1 Areas of investigation

Immediately after each drive in the simulator, participants completed a questionnaire based on the NASA-TLX methodology, which measures driver workload.

After finishing both drives, participants then completed another longer questionnaire. The purpose of the questionnaire was to provide further information **surrounding results obtained from participants' driving behaviour** (e.g. as in Appendix E) as well as to investigate self-reported experience of driving the **different layouts. Participants' perceptions of different options for communicating** driver information were also investigated.

The following areas were investigated through the questionnaire:

- > Previous experience of VMSL environments
- > Awareness and interpretation of enforcement indicators and CCTV equipment throughout the simulator drives
- > Awareness of the speed limit and lane status displayed throughout the drives
- > Interpretation of speed limit and lane status instructions displayed throughout the drives
  - Perception of the instructions as mandatory or otherwise
  - Comprehension of which lanes a speed limit applies to
- > Perceptions of the clarity of communication of speed limit and lane closure information between verge Red X and verge Wicket signing layouts
- > Perceptions of supplementary information
- > Awareness and perceptions of gateway signs within the simulator drives

Participants were also provided the opportunity within the questionnaire to provide other general comments of relevance to this task.

The key findings from both questionnaires are reported below.



Additional questions were also included based on the following categories:

<b>Difficulty</b>	How difficult did you find it to drive this motorway section?
<b>Risk</b>	How much risk did you experience driving this motorway section?
<b>Safety</b>	How safe did you feel whilst driving this motorway section?
<b>Confidence</b>	How confident did you feel whilst driving this motorway section?

The results were analysed to determine if there were any statistically significant differences in the ratings given by participants between their gantry and verge drives. No significant results were found.

The NASA-TLX results indicated that there were no differences in driver workload between the gantry and verge drives. Furthermore, participants judged both drives to be equal in terms of difficulty, risk, safety and confidence.

### 5.4.2.3 *Perceptions and attitudes questionnaire*

#### Previous experience of VMSL environments

Participants were asked specifically how often they had driven (not as a passenger) on a section of motorway equipped with variable speed limits (e.g. M25 / M42) in the last 12 months. An example image of a gantry from the M42 scheme was presented in the questionnaire. The categories used were:

**Never**

**Very Rarely**      Once or twice only

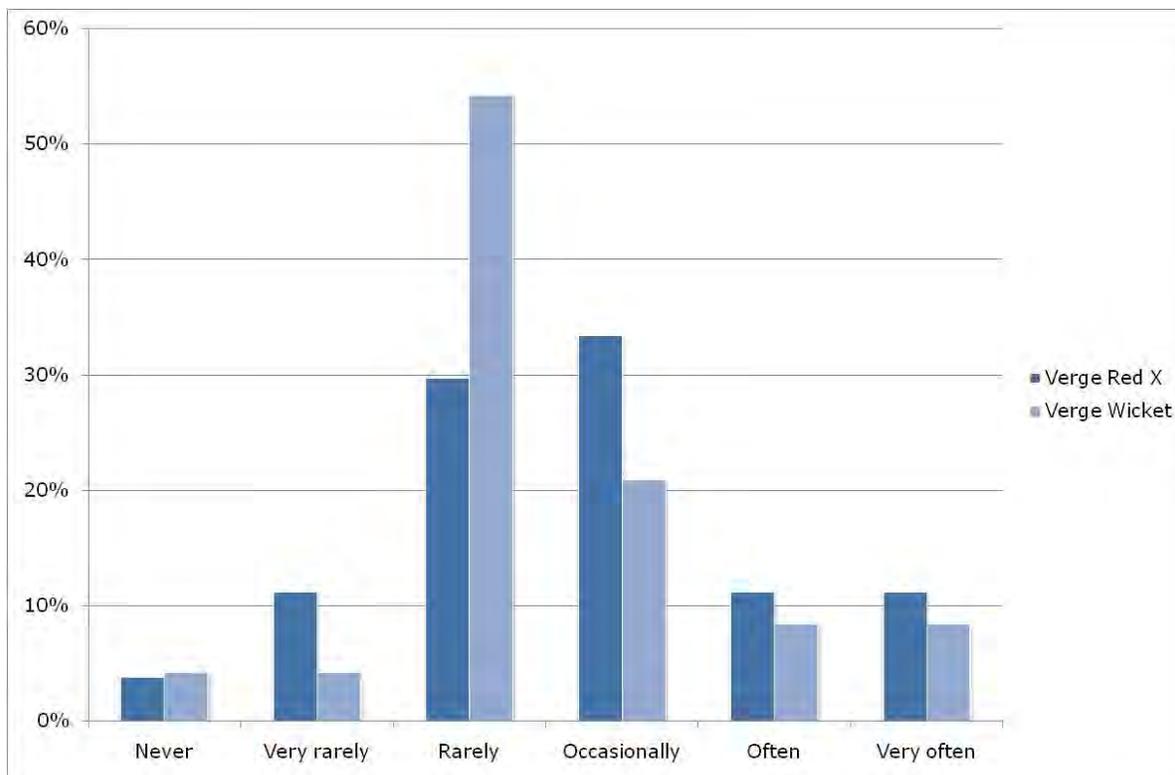
**Rarely**            About once every few months

**Occasionally**    At least once a month

**Often**             Once a week or more

**Very Often**      Daily, or almost daily

Figure 111 illustrates the level of experience that participants in the two experimental groups (verge Red X and verge Wicket) had of driving in VMSL environments within the last 12 months.



**Figure 111: Histogram of participants’ responses in relation to the frequency with which they have driven through VMSL schemes in the past 12 months**

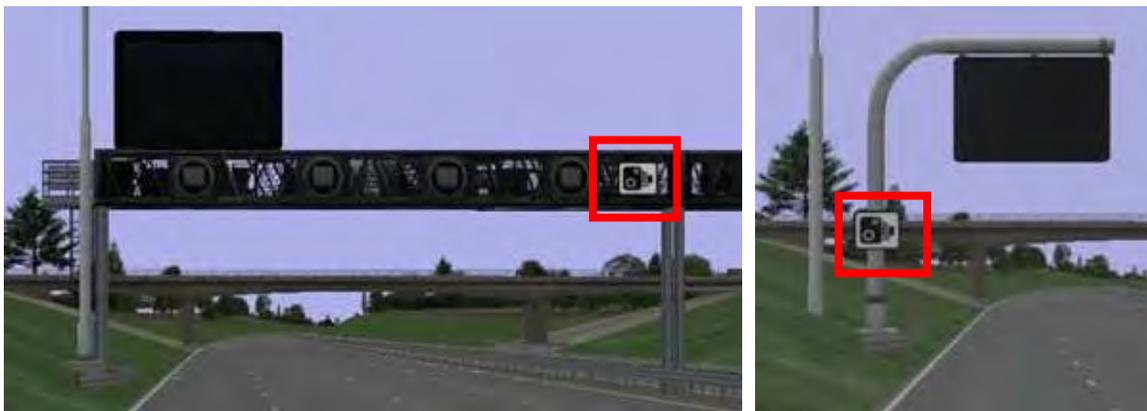
From the results it can be seen that most participants had driven infrequently in VMSL schemes in the past year, with only 22% (verge Red X group) and 16% (verge Wicket group) of participants having experienced them on a weekly or daily basis.

**Awareness of enforcement indicators and CCTV equipment throughout the simulator drives**

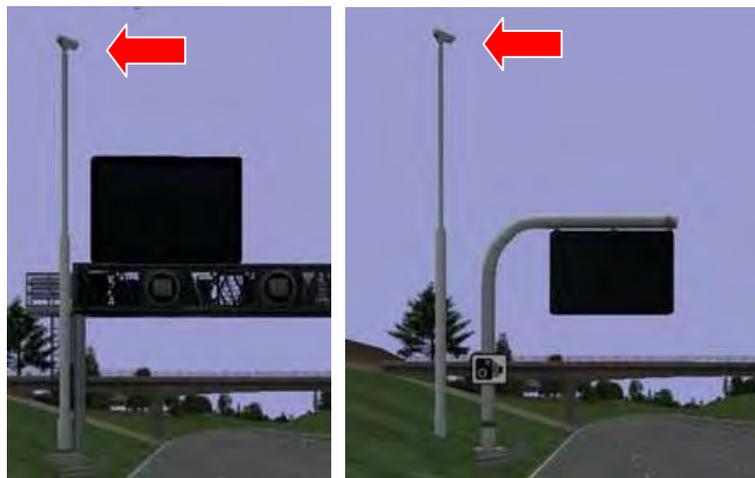
Participants were asked about visual indications of enforcement measures as well as CCTV equipment presented at each information update point on all drives with reference to the three images below.



**Figure 112: Enforcement markings used within the simulated environment**



**Figure 113: Enforcement speed camera sign located on each information update point within the simulator route, as displayed within the simulator environment in gantry (left) and verge (right) layouts**

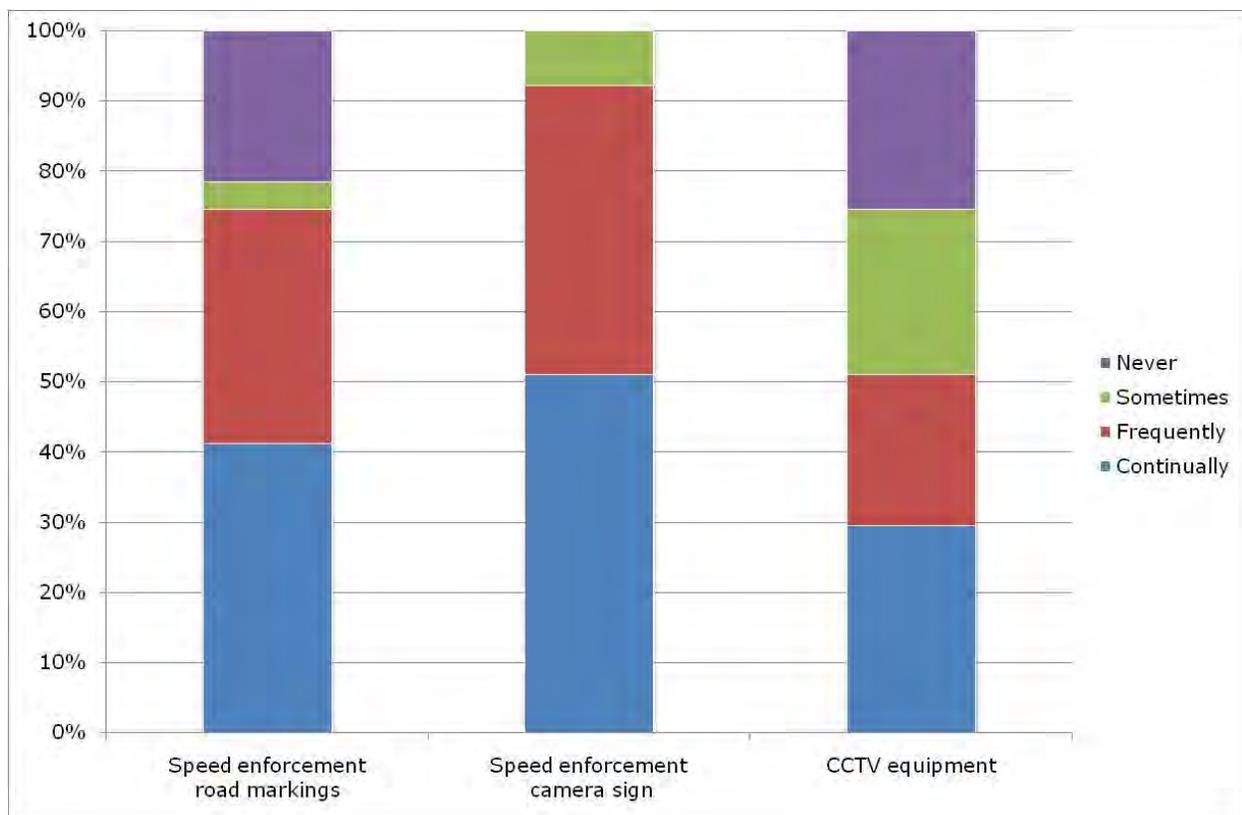


**Figure 114: CCTV detection camera equipment located at each information update point on gantry and verge routes**

Participants were asked the following question: *'how aware were you of the presence of these markings / signs / equipment whilst driving the routes?'*

Participants were also asked to describe what they thought the enforcement indicators meant and what the CCTV detection equipment was used for, and how they would change their driving in response to seeing these features.

Figure 115 shows the proportion of participants reporting the level of awareness of the different enforcement features. Given that these indicators were identical between the two verge routes, the results are presented for all participants across both experimental groups.



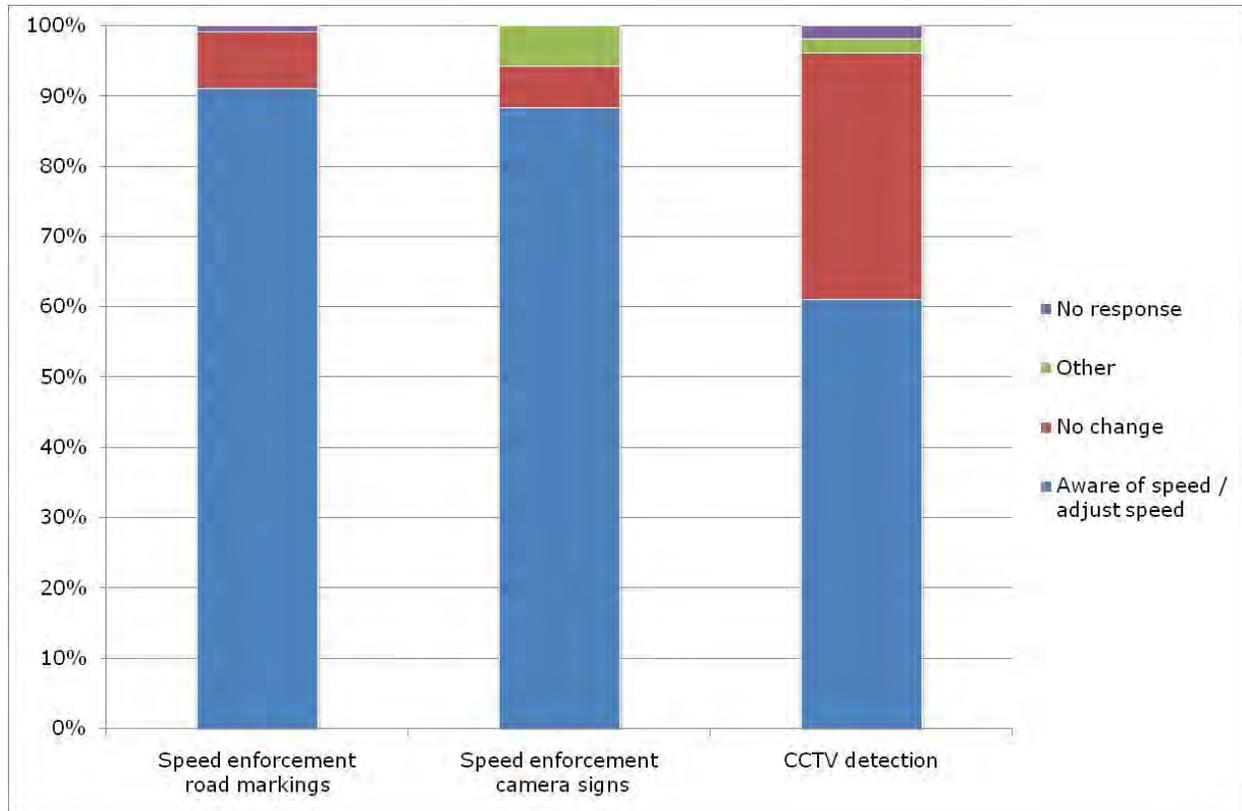
**Figure 115: Participants' responses in relation to their awareness of enforcement indicators and CCTV equipment within the simulator route**

As illustrated in Figure 115, awareness of road markings and enforcement signs was high, with all participants reporting that they were aware of the speed camera sign during their drives. Awareness of the CCTV incident detection equipment was lower, with 25% of participants reporting that they had not noticed this equipment whilst driving within the routes.

Almost all participants (92%) correctly interpreted the meaning of the sign as relating to *speed* enforcement cameras, with the remaining participants referring to **them as 'enforcement cameras'**. The majority of participants (92%) also interpreted the road markings to be related to speed limits / cameras, although only 41% of participants captured the exact meaning of the markings (i.e. used for speed enforcement calculation). The remaining **responses were incorrect or 'don't know'**.

With regards to the CCTV equipment, participants were more varied in their interpretation of what the equipment is used for. 41% of participants correctly understood that the equipment is used for traffic monitoring. 45% of participants reported that the equipment may be a speed camera, although just under half of these (20%) provided a correct response as well.

Figure 116 illustrates participants' responses in relation to how they might change their driving behaviour in response to these features.



**Figure 116: Participants’ responses in relation to how they might change their driving behaviour of enforcement indicators and CCTV equipment**

As illustrated in Figure 116, for both speed camera signs and enforcement road markings the majority of participants (88% and 91% respectively) reported that they would adjust their driving behaviour if appropriate. For example, by being aware of their speed, slowing down or driving at the displayed speed limit.

For both types of enforcement indicator, a number of participants (18% - road markings, 6% - speed camera signs) explicitly stated that they would only slow down or observe the speed limit in the vicinity of the sign and may accelerate afterwards.

The majority of participants’ (61%) also indicated that they would adjust their driving behaviour in relation to speed in response to the CCTV equipment. This highlights participants’ uncertainty as to whether this equipment measures vehicle speeds. However, 35% of participants’ also indicated that they would not change their driving behaviour in response to this equipment.

The questionnaire data highlights that participants' were highly aware of the presence of enforcement indicators and CCTV equipment at information update points throughout the route, and suggested that they might respond to these features by adjusting their speed.

Whilst there are no legal implications for speed compliance in the simulator environment, these results suggested that participants perceived the environment within which they were driving to be one where speed limits would be enforced and as such they may have adjusted their driving as they would in the real world.

### **Awareness and interpretation of the speed limit and lane status**

Participants were asked to indicate whether there were any points during their drive within either the gantry or verge signing layouts when they were unsure of the speed limit or lane status (see Figure 117 for an example question). They were provided with a reference sheet to illustrate the difference in signing provision between the two routes. Participants were also provided the opportunity to comment on the reasons why they were unsure of these instructions.

<b>Statement: The [overhead gantries / verge signs] indicate whether individual lanes are open or closed to traffic.</b>			
Were there any times during the drive when you were unsure of which lanes were open or closed?			
Yes		No	
<input type="checkbox"/>		<input type="checkbox"/>	
If you answered 'yes', please indicate how often during the drive you were unsure:			
<i>Always</i>	<i>Frequently</i>	<i>Occasionally</i>	<i>Once or twice</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Statement: The [overhead gantries / verge signs] also indicate the speed limit.</b>			
Were there any times during the drive when you were unsure of the speed limit?			
Yes		No	
<input type="checkbox"/>		<input type="checkbox"/>	
If you answered 'yes', please indicate how often during the drive you were unsure:			
<i>Always</i>	<i>Frequently</i>	<i>Occasionally</i>	<i>Once or twice</i>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Figure 117: Questions asked in relation to certainty of speed limit and lane status throughout the gantry and verge drives**

In relation to both their gantry and verge drives, 90% or more participants indicated that there were *no* occasions when they were unsure of the speed limit or lane status. There was only a very small difference in responses between the verge Red X and verge Wicket groups.

Table 25 indicates the proportion of participants that indicated they were unsure of the speed limit during a drive, in terms of whether it occurred 'once or twice', 'occasionally', 'frequently' or 'always'.

**Table 25: Proportion of participants that were unsure of the speed limit or lane status at least once during a drive**

	Speed limit		Lane status	
	Gantry	Verge	Gantry	Verge
Once or twice	2%	6%	4%	6%
Occasionally	2%	4%	2%	4%
Frequently	4%	0%	2%	0%
Always	0%	0%	0%	0%
<b>Total</b>	<b>8%</b>	<b>10%</b>	<b>8%</b>	<b>10%</b>

The questionnaire results indicated that the large majority of participants were confident of the speed limit and lane status throughout the Managed Motorways scheme in both the gantry and verge drives.

*Interpretation of speed limit and lane status instructions*

Throughout the drive, participants encountered speed limit and lane closure instructions displayed on gantry AMI signals and verge-mounted MS4s (see Figure 118).



**Figure 118: Speed limit and lane closure instructions displayed on gantry AMI signals and verge-mounted MS4s (Red X and Wicket aspects)**

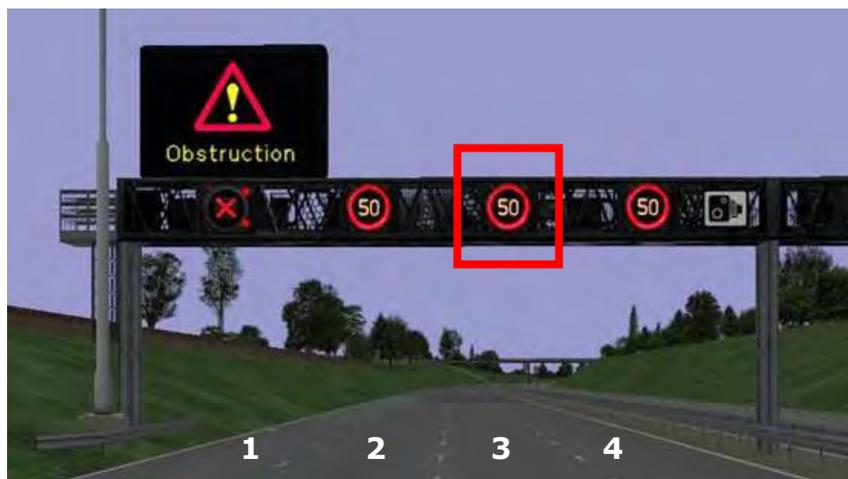
Participants were asked to choose one of the following options to describe the speed limit and lane closure instructions that they had seen displayed on the gantry and verge signing.

- Mandatory**      Illegal not to do so
- Compulsory**    Not illegal, but could constitute driving without due care and attention
- Advisory**        Not illegal, but strongly advised by the authorities
- Informatory**    No legal consequences for ignoring

For both speed limit and lane closure instructions, the majority of participants believed the instruction to be mandatory. A similar proportion of participants believed the speed limits (90%) and lane closure instructions (92%) to be either mandatory or compulsory for both gantry and verge signing layouts. Perception of the lane closure aspects for display on a verge MS4 was highly consistent across the Red X and Wicket designs.

Participants were then presented with the image displayed in Figure 119 and asked to indicate which lane(s) they believed the speed limit to apply to from the following options: 'Lane 3 only', 'Lanes 2, 3 and 4' or 'All Lanes'.

They were then asked to provide a rating of confidence in their response on a scale of 1 (not at all confident) to 10 (very confident).



**Figure 119: Image presented in questionnaire to participants when asked which lanes the speed limit highlighted in the red box applies to**

The results are presented in Table 26 below, including the mean confidence rating for each response.

**Table 26: Participants’ interpretation of speed limits displayed on a gantry-mounted AMI signal**

	<b>% of total sample</b>	<b>Mean confidence rating (SD)</b>
<b>Lane 3 only</b>	39%	8.7 (1.8)
<b>Lanes 2, 3 and 4</b>	45%	8.9 (1.7)
<b>All lanes</b>	16%	8.8 (1.5)

The most common response from participants was that the speed limit above LBS3 in the image of the gantry applied to the three lanes open to traffic. However, over a third of participants also interpreted the speed limit displayed on the gantry signal to be relevant to the lane that it is directly above only.

Later on in the questionnaire, participants were asked a similar question in relation to the speed limit displayed on a verge-mounted MS4, as encountered during their drive (see Figure 120 below). Participants were asked if the speed limit applied to; ‘Lane 1’, ‘Lanes 2, 3 and 4’ or ‘All lanes’.



**Figure 120 : Example image presented in questionnaire to participants when asked which lanes the speed limit shown in the image applies to**

Table 27 details the results, including the mean confidence rating given for each response.

**Table 27: Participants' interpretation of a speed limit displayed on a verge-mounted MS4**

	<b>% of total sample</b>	<b>Mean confidence rating (SD)</b>
<b>Lane 1 only</b>	2%	10.0 (N/A)
<b>Lanes 2, 3 and 4</b>	61%	8.9 (1.5)
<b>All lanes</b>	37%	9.2 (1.1)

The majority of participants believed that the speed limit related to the lanes open to traffic.

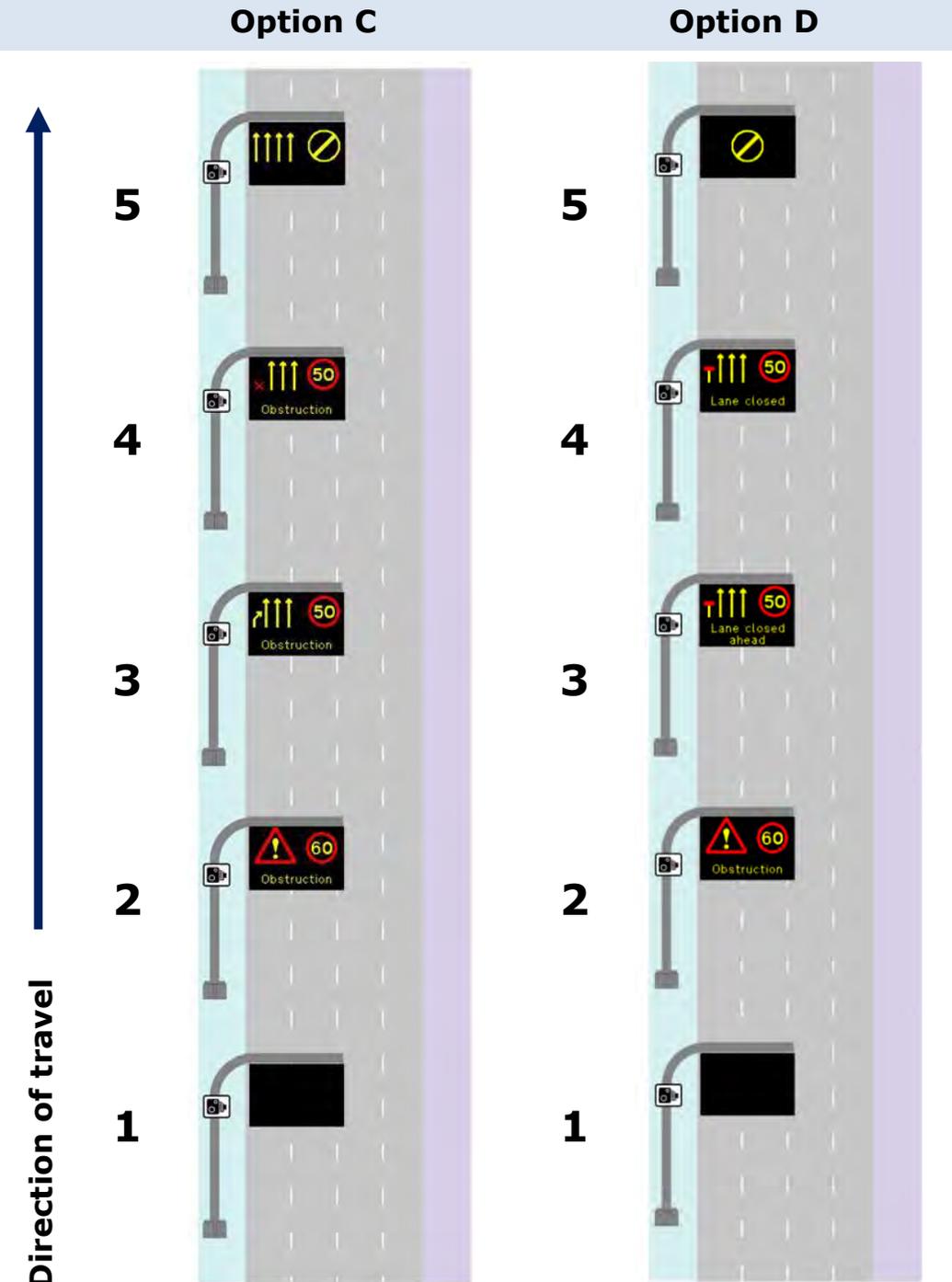
Participants perceptions of the mandatory nature of speed limit and lane closure instructions were almost identical across the gantry and verge layouts, with the vast majority of participants believing they could be considered as driving illegally or '*without due care and attention*' if they did not obey the instructions. In general, participants believe the speed limit and lane closure instructions to apply to all lanes open to traffic.

*Perceptions of the clarity of communication of speed limit and lane closure information*

Within the questionnaire, participants were presented with a reference sheet, each displaying two design options for the LBS1 closure signing sequence communicated via verge-mounted signs (see Figure 121).

The lane closure signing sequence included 5 signs **from the 'Blank'** sign/gantry (2) **to the 'NR'** sign/gantry (6). The two options that were provided were based on the verge Red X and verge Wicket layouts used in the simulator drives.

**REFERENCE SHEET - 3**



**Figure 121: Questionnaire reference sheet displaying verge Red X and verge Wicket sign sequence options**

Participants were asked to score the two options on a scale of 1 to 10 in terms of clarity in communication of specific information and instructions. 1 was scored as not at all clear and 10 as very clear.

An example of the format of each question is provided below. Participants were also asked to comment on the reasons behind their scores.

<p>In reference sheet 2, please look specifically at signs 2 to 4 for both options.</p> <p><b>These signs communicate a lane 1 closure. The signs inform drivers when to move out of lane 1 and at what point the lane is closed.</b></p> <p>Please indicate below how clearly you think each option communicates this information.</p> <p>(Please circle the number that you feel is most appropriate)</p>									
<b>OPTION C</b>									
<i>Not at all clear</i>					<i>Very clear</i>				
1	2	3	4	5	6	7	8	9	10
<b>OPTION D</b>									
<i>Not at all clear</i>					<i>Very clear</i>				
1	2	3	4	5	6	7	8	9	10

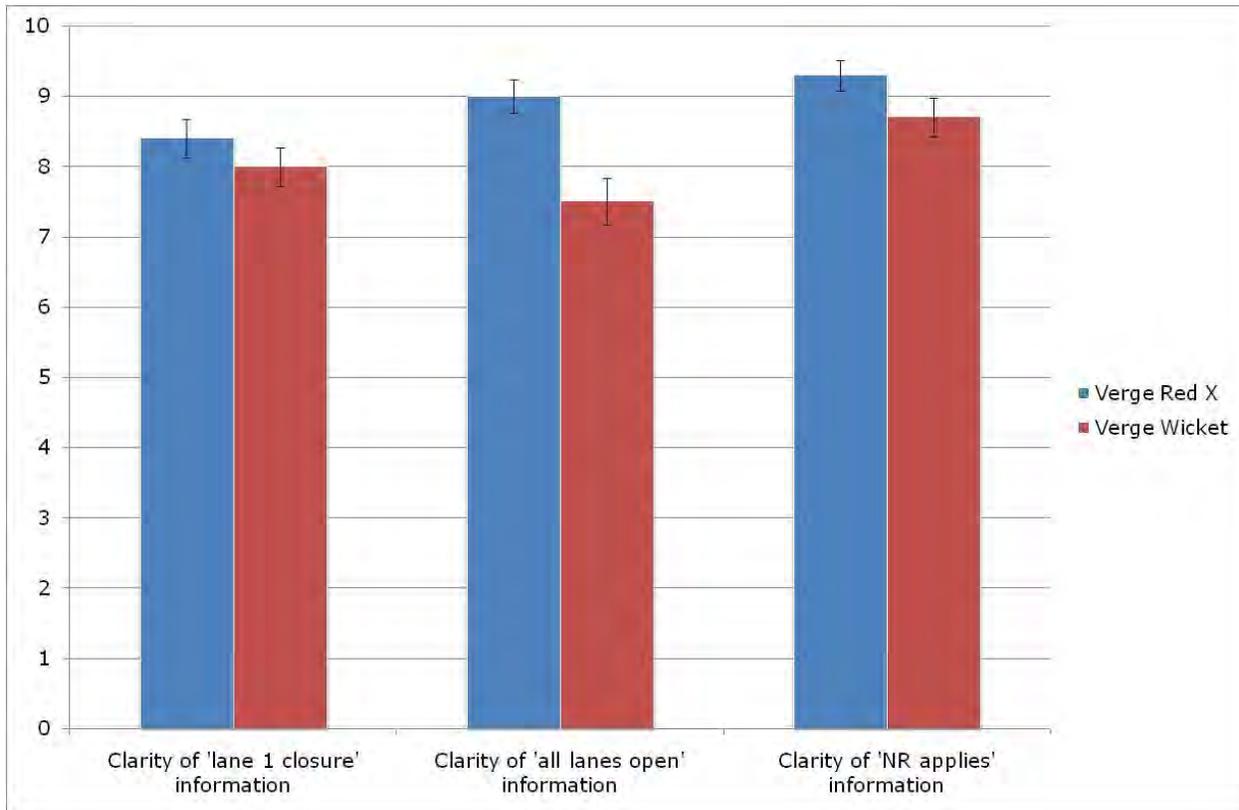
**Figure 122: Example of questions relating to perceived clarity of two signing options**

For each question, participants were asked about a different aspect of the information that the signing sequence aimed to communicate. As illustrated in Figure 122, for each question one of the following statements was presented to participants before asking them to score the two design options for clarity in communication:

- *'These signs communicate a lane 1 closure. The signs inform drivers when to move out of lane 1 and at what point the lane is closed'* (referring to signs 3 to 5);
- *'These signs communicate that lane 1 is open to traffic again'* (referring to sign 6 only); and
- *'These signs communicate that the national speed limit now applies for all lanes open to traffic'* (referring to sign 6 only).

Participants were asked to compare the same signing sequence (signs 2 to 6) based on the verge Red X and verge Wicket design options. All participants had therefore experienced a drive with one of these verge layouts.

The mean scores given by participants for the verge Red X and verge Wicket design options are provided in Figure 123 below.



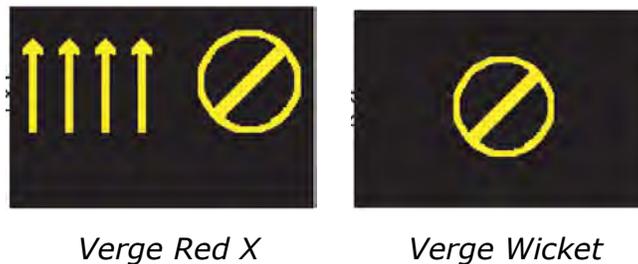
**Figure 123: Mean scores for clarity in communication of lane closure and speed limit information by verge Red X and verge Wicket signing options**

Overall, participants scored both verge layouts highly in terms of clarity in communication of lane status and speed limit information. On average, participants scored the verge Red X sequence as more clearly communicating information about lane status and changes to the speed limit. In particular, participants indicated that the verge Red X sequence provided better clarity in informing drivers that all lanes were reopened following a closure than the verge Wicket sequence.

Further analysis was also undertaken on these results to determine if any of the differences in the mean scores were statistically significant. The significant results are detailed below, and the full table of comparisons is presented in Table 44 in Appendix D.

- > **Perceived clarity in communication of 'all lanes open' information (sign 5):** The difference in mean scores was 1.5, with verge Red X sign scoring higher than the verge Wicket sign. This difference was highly significant at the 5% level ( $t=3.342$ ,  $df=49$ ,  $p=.002$ ).
- > **Perceived clarity in communication of 'return to NR' information (sign 5):** The difference in mean scores was 0.6, with verge Red X sign scoring higher than the verge Wicket sign. This difference was significant at the 5% level ( $t=2.449$ ,  $df=49$ ,  $p=.018$ ).

Both significant results relate to the information presented to participants in sign 6, which is displayed at the end of the lane closure. The difference between the two verge design options for sign 6 is illustrated in Figure 124 below.



**Figure 124: Verge Red X and verge Wicket designs for the 'NR' sign (6)**

Table 28 below indicates the percentage of participants that scored the Red X option higher, equal and lower than the Wicket option.

**Table 28: The percentage of participants scored the Red X option higher, equal and lower than the Wicket option**

	<b>Total (lane 1 closure)</b>	<b>Total (all lanes open)</b>	<b>Total (return to NR)</b>
<b>Red X &lt; Wicket</b>	32%	16%	12%
<b>Red X = Wicket</b>	28%	18%	54 %
<b>Red X &gt; Wicket</b>	40%	66%	34%

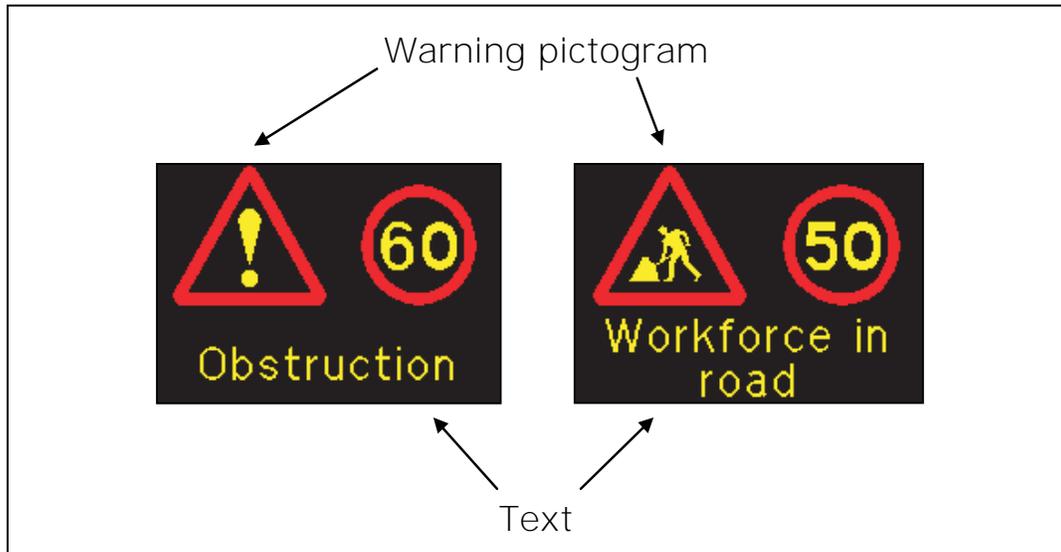
**Participants' comments** explaining the reasoning behind their scores provides some insight into why the verge Red X design performed better than the verge Wicket. In general, the comments suggested that:

- > **Most participants' preferred use of the 'all lanes open' aspect (i.e. illustrating four running lanes) in the verge Red X design to inform drivers that the lane closure has ended and the national speed limit applies to *all lanes*.** It was suggested that this design provides reassurance to drivers / improves **drivers' confidence of lane status**.
- > **A few participants thought that the 'all lanes open' aspect within the Verge Red X design was unnecessary and led to the sign looking overcrowded.**
- > Participants reported that the Red X design gives a clearer instruction about when to move out of lane and when the lane is actually closed, however other participants suggested that the Wicket design gave a stronger message to drivers to change lanes and is more familiar.

Participants indicated a preference for the aspect consisting of four straight arrows as well as the NR to be displayed on an MS4 message following the end of a closure in order to confirm that the lane has reopened and the NR applies to all lanes.

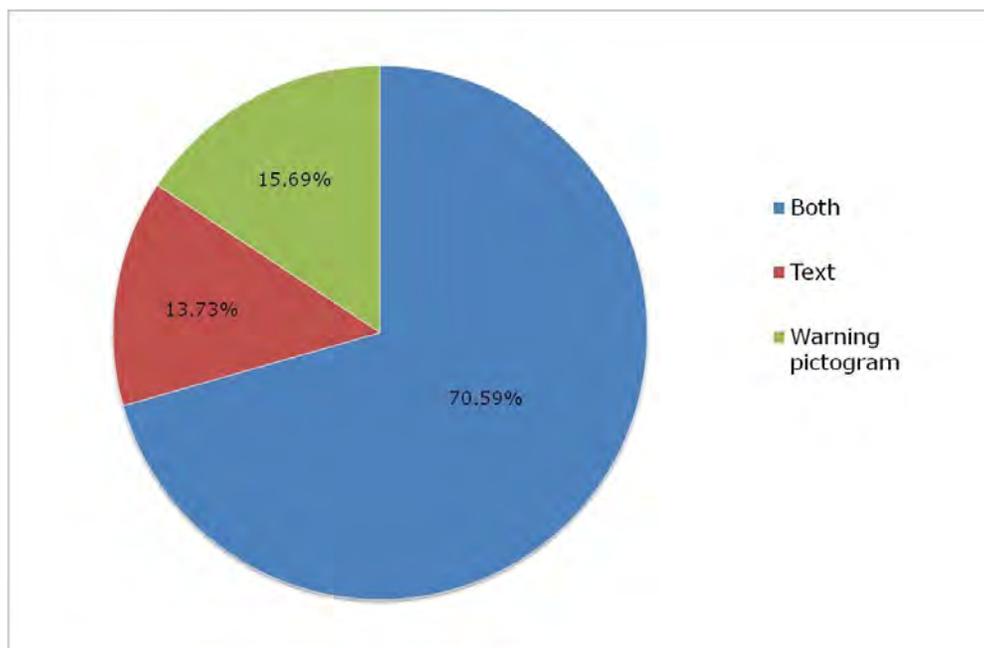
### **Perceptions of supplementary information**

Participants were shown an image of MS4 messages they had encountered on the verge drive, where supplementary information was displayed in addition to the speed limit and lane closure instructions. The supplementary information consisted of warning pictograms and text (see Figure 125).



**Figure 125: Image presented to participants in the questionnaire illustrating supplementary information in the form of warning pictograms and text as displayed on an MS4 message**

Participants were then asked which form of supplementary information was most likely to influence their driving behaviour, with the following options: 'Text', 'Pictogram', 'Both' and 'Neither'. Participants' responses are detailed in Figure 126 below.



**Figure 126: Pie chart of participants' preference in the use of supplementary information on MS4 messages**

The results indicate that participants' believed both warning texts and pictograms to be most likely to influence their driving behaviour.

Participants were then presented with the image illustrated in Figure 127 and informed that *'a variety of text messages can be used in conjunction with a lane closure symbol on a verge sign'*.



**Figure 127: Image presented to participants in the questionnaire illustrating an MS4 message which includes supplementary information**

They were asked to rank a set of 5 different types of information in order of what would most helpful to them as a driver if displayed on the sign. The types of information were as follows:

Text describing **why** there is a lane closure and change in speed limit  
(i.e. 'Accident', 'Obstruction', 'Workforce in road')

Text describing **when** the lane closure occurs  
(i.e. '1 mile ahead')

Text describing for **how long** drivers will be affected  
(i.e. '30 minutes delay')

Text which **reinforces** the instructions provided by the symbols  
(i.e. 'Lane closure')

Text providing additional advice to drivers about how to **behave**  
(i.e. 'Stay in lane' and 'Slow down')

The mean scores for each type of supplementary text information are recorded in Table 29.

**Table 29: Mean scores for each type of supplementary text information**

<b>Information Type</b>	<b>Mean rank (SD)</b>
When	2.09 (1.16)
Why	2.18 (1.17)
How long	3.20 (1.36)
Reinforce	3.33 (1.09)
Behave	4.20 (1.14)

The results indicated in a lane closure scenario, participants would most prefer to receive supplementary information on an MS4 regarding how far ahead the lane closure occurs, followed by the reason for why the lane is closed / speed limit is reduced.

Participants were then asked to indicate how they felt about the amount of information displayed on the message illustrated in Figure 127 by scoring a value on a scale of 1 (not at all overcrowded) to 10 (very overcrowded).

The mean average score across all responses was 5.4, with a standard deviation of 2.6. This suggests that overall participants did not feel strongly either way with regards to the level of information displayed on the most complex configuration of an MS4 message.

**The questionnaire indicated that participants' perceived supplementary information that can be displayed on MS4 messages as likely to influence their driver behaviour, and would like to receive additional information relating to the lane closure such as how far ahead it occurs and why it is in place. Participants on average do not think that an MS4 message with lane closure, speed limit and supplementary information is too overcrowded.**

**Awareness and perceptions of gateway signs within the simulator drives**

Within the simulator routes, the first sign encountered at the start of the Managed Motorway scheme is a 'gateway' sign informing drivers that mandatory variable speed limits are in operation ahead (see Figure 128 below).



**Figure 128: Gateway sign for Managed Motorways scheme present at the start of each simulator route (Sign reference 1)**

Participants were asked a number of questions relating to their awareness of gateway signs within the simulator drives, as well as their perceptions of the use of gateway signs to provide information to drivers about Managed Motorway schemes. The responses are detailed in Table 30.

**Table 30: Participants' awareness of gateway signs within the simulator drives (Question 1) and perceptions of gateway signs within Managed Motorway schemes**

	Yes	No
<b>Question 1:</b> Did you see the sign whilst driving?	88%	12%
<b>Question 2:</b> If you saw answered yes to Question 1, did the sign have any effect on your response to the information and instructions provided by subsequent signs?	82%	18%
<b>Question 3:</b> Do you feel this sign provides adequate information to drivers about what to expect ahead?	96%	4%
<b>Question 4:</b> Do you think this sign should be repeated throughout the scheme?	71%	29%

The results indicated that the vast majority of participants were aware of the gateway sign at the start of the scheme, and that these participants believed the sign affected their response to the information and instructions provided by subsequent signs.

Nearly all participants believed that this sign provided appropriate information in advance of the Managed Motorways scheme, and a large majority also think that the sign should be repeated throughout the scheme.

Participants were given the opportunity to comment in relation to the information provided on the gateway sign. The two comments received are as follows:

- *'It is a pointless sign, future signs give me all the information I need'*
- *'Wasn't sure if speed limit was advisory'*

Participants perceived that the gateway sign provided appropriate information and believe it had some influence on their driving behaviour in the simulator.

### General comments

Within the questionnaire, all participants were given the opportunity to comment on the drives they had experienced in the trial, as well as more general opinions on the provision of driver information on the motorway network.

Participants were explicitly asked about their perceptions of verge and gantry information provision:

- > Following their experience in the driving simulator, many participants indicated a preference for verge-mounted over gantry-mounted signing provision. They believe that the verge sign provides clarity that the speed limit applies to all lanes, with all information displayed on a single large sign making it easier to read.
- > However, some participants raised concerns about the obscuration potential for verge signs, or felt that there was too much information on the sign, or **that the information was 'less forceful' in this format**. Participants also highlighted that they are more familiar with the gantry layout and lane specific information provision.

The comments most frequently raised by participants have been summarised in Table 31.

**Table 31: Additional comments raised by participants during the trial**

Theme	Comments
<b>On road driver information provision</b>	<ul style="list-style-type: none"> <li data-bbox="412 323 1435 386">&gt; Larger signs are more informative and can be seen from greater distances</li> <li data-bbox="412 394 1435 457">&gt; A single sign is easier to understand compared to a dedicated sign for each lane</li> <li data-bbox="412 466 1175 493">&gt; Verge signing is clearer than overhead gantry signing</li> <li data-bbox="412 501 1435 606">&gt; <b>Too much information on one sign doesn't give drivers enough time to process all the information; recommends that only essential information is shown</b></li> <li data-bbox="412 615 1435 678">&gt; Too many vertical lines on some of the verge mounted signs make them overly complicated and will make them difficult to read at a distance</li> <li data-bbox="412 686 1435 791">&gt; Simple, precise information shown on the signs gives drivers confidence that they need to take actions to the information shown and will increase compliance</li> <li data-bbox="412 800 1435 863">&gt; Repeater signs, particularly for speed limits would be useful, especially in fast flowing traffic</li> <li data-bbox="412 871 1435 934">&gt; When approaching road works or congestion, signs telling drivers how long a lane closure is in place would be useful</li> <li data-bbox="412 942 1435 1005">&gt; The pictogram format shown on signs is useful, especially for foreign drivers</li> <li data-bbox="412 1014 1435 1119">&gt; Signs showing information on time delays / causation of delay would be useful for drivers; if given early enough, this may give drivers the opportunity to find alternative routes</li> <li data-bbox="412 1127 1435 1232">&gt; Where a lane closure ahead occurs, the signs should tell drivers in the lane that is closing to merge with traffic in the open lanes as soon as possible to prevent a bottleneck occurring</li> <li data-bbox="412 1241 1159 1268">&gt; Satisfied with the motorway signing currently in use</li> </ul>
<b>Other</b>	<ul style="list-style-type: none"> <li data-bbox="412 1266 1435 1329">&gt; Possible obscuration problems for verge mounted signs due to HGVs, particularly in lanes 1 and 2</li> <li data-bbox="412 1337 1435 1400">&gt; Concern about the lack of safe stopping areas in cases of an emergency – where do drivers stop when there is no hard shoulder?</li> <li data-bbox="412 1409 1435 1472">&gt; There should be a bigger campaign to educate drivers on the meaning of the new signs being used</li> <li data-bbox="412 1480 1435 1543">&gt; There are too many markings on the road to indicate speed cameras when the cameras are absent</li> </ul>

## 5.5 Discussion and Recommendations

Task 5 has compared the effect of using gantry versus verge signing layouts (with 1500m spacing) to communicate on-road driver information. The key findings are summarised and discussed below.

### *The effects of verge and gantry layouts on speed choice*

For both verge and gantry signing layouts, mean and spot speeds under signs/gantries were generally higher than the displayed speed limit, except in relation to the NR signs/gantries. Therefore, on average, participants travelled above the displayed speed limit for a large proportion of the drive.

It should be noted that participants were encouraged to drive at higher speeds by the instruction given at the start of the drive (i.e. to '*drive as if late for an important meeting*'). This instruction was given to allow comparison of compliance between the two layouts and to ensure participants were in the required lane to respond to lane closure instructions.

Across all of the assessment measures, in general, only small differences in speed were observed:

- > **On average, participants' speed** when driving in the verge layout tended to be higher than when driving in the gantry layout, the differences in mean speed being approximately 1mph. However, this difference was not statistically significant for most of the route within the test areas.
- > Most of the statistically significant differences were found in the spot speed measure for all 50 and 60mph signs/gantries. Participants drove slower under gantries than when passing verge-mounted signs, a difference on average of 1.6mph for 50mph signs/gantries and between 2.4 and 4mph for 60mph signs/gantries.

The differences in spot speed between the two layouts may have been related to **participants' perception of enforcement at gantries compared to verge signs**. However, the questionnaire highlighted that the speed limits were believed to be mandatory or compulsory by the large majority of participants for both layouts, and that participants were highly aware of speed enforcement indicators during the drives. It also confirmed that the vast majority of participants understood that the verge-mounted speed limit applied to all open lanes.

Therefore, the slightly lower spot speeds may have been caused by a more subtle effect of verge signing. For example, the physical presence of the gantries may have suggested **a stronger element of 'control' within the environment**. Also, there may be an effect relating to **participants' perception of how enforcement equipment is operated and used on gantry infrastructure**.

The unfamiliarity with the verge signing layout relative to the gantry layout may also have had an influence, as most participants had experienced VMSL environments with gantry-mounted signing such as the M42 or M25 within the past year and may therefore have made a greater association between gantries and enforcement.

Differences in mean speed and compliance were less pronounced and fewer differences were statistically significant. This suggested that although the signing **layout may have made a difference in participants' speed choice at enforcement points**, this difference was not necessarily maintained over a longer distance.

The surfing magnitude assessment measure further reflects this observation. The degree of surfing in the gantry signing layouts tended to be higher, although again few differences in surfing magnitude between the layouts were found to be statistically significant. Here the smaller difference between spot speed and the speed following the sign/gantry indicated that participants in the verge-mounted signing layouts were driving at a more consistent speed.

Other statistically significant differences in speed were observed at particular locations within the drives. The first two signs/gantries displaying variable speed limits (i.e. **the 'Warning' sign/gantry for LBS1 closure followed by the 'Lane closed ahead' sign/gantry**) were commonly found to influence speed choice, with participants travelling at higher mean and spot speeds in the verge layout but surfing to a greater magnitude in the gantry layout. The fact that these were the first active instructions given to participants on each drive may have heightened the difference in response to speed limits between the verge and gantry-mounted signs.

Also, a small but statistically significant difference in mean speed was found for the **section following the 'Blank' sign/gantry; participants travelled on average 1mph faster in the verge than gantry layout**. This suggested that the signing infrastructure itself, not just the information displayed on it, may have an effect on **participants' speed choice**.

When compared with the findings of the 1500m spacing layout in Task 2, mean speeds and spot speeds under gantries were very similar for the gantry spacing layout. Also seen in both studies was the increase in non-compliance with lower speed limits.

### *The effects of verge and gantry layouts on lane choice*

The study demonstrated that participants' were able to comprehend the lane status instructions communicated through the aspects displayed on verge-mounted MS4s and responded as they would to the same instructions displayed on lane specific signals on gantries. This indicates that overall, verge-mounted MS4 signing was as effective as gantry-mounted signing at influencing driver behaviour in lane closure scenarios.

The majority of participants' demonstrated good compliance with instructions for a single and double lane closure in both gantry and verge layouts. For the LBS1 closure, the absence of other traffic meant that participants were responding to the information displayed on the signs/gantries alone without being influenced by the behaviour of other drivers.

- > For both signing layouts, most participants moved out of LBS1 within 500m of passing the 'Lane closed ahead' sign/gantry, and only small and statistically non-significant differences were found in the mean departure distance (relative to the 'Lane closed ahead' sign/gantry) between layouts.
- > 80% of participants that were in LBS1 on approach to the closure had exited the lane before passing under the 'Lane closed' sign/gantry.

These findings correlate well with those from Task 2. The mean departure distance relative to the 'Lane closed ahead' gantry was shorter in the Task 2 study by 200-300m, meaning that on average participants had moved out earlier. However, participants in Task 2 may have been influenced by the presence of simulated traffic as well as the fact that they were driving on the hard shoulder rather than a permanent lane.

There was evidence of slightly lower compliance levels in the verge layout, particularly in the LBS3/4 closure. This was both in relation to the proportion of participants departing the closed lane belatedly and the proportion of participants re-entering the closed lane mid-way through the closure.

However, the post-drive questionnaire suggested that non-compliance in either layout was not as a result of participants' poor comprehension of the lane closure instructions but was more likely to be conscious decision about whether to comply. For over half of the participants' that drove in a closed lane, they were non-compliant for more than one closure and / or drive suggesting that the signing layout was not the primary influence on their behaviour. Furthermore, within the questionnaire only a small minority of participants reported that they were unsure of lane status during either of their drives. It may be the case that, as with speed choice, participants' perceived the gantry environment to have a stronger element of 'control' and therefore were more likely to comply.

In both closures, a minority of participants did not depart after passing the 'Lane closed' sign/gantry. In LBS3/4 closure, a proportion of participants in both groups returned to closed lanes after passing the maintenance vehicle and remained in lane even after passing through a second 'Lane Closed' sign/gantry. This perhaps suggests that minority of drivers will respond to what they see downstream rather than the instruction presented to them.

#### *The effects of different verge Red X and verge Wickets layout on speed and lane choice*

The driving simulator results highlighted that the use of verge Red X compared to verge Wicket layouts had almost no differential influence on participants' speed and lane choice.

In general, participants travelled at slightly higher speeds in the verge Wicket than verge Red X layout which suggests there may be a 'global effect' of the Red X on influencing participants' driving behaviour in terms of speed as well as lane choice. However, across all of the speed assessment measures, the differences were small and only a few were found to be statistically significant.

Whilst the results suggested that participants' may be more likely to take longer to leave LBS1 in the verge Red X layout (e.g. in response to the 'Hooked arrow' aspect), overall the proportion of participants that had exited LBS1 before the lane closure commenced was almost identical across both layouts.

### Participant preference – Gantry versus Verge

Following their experience in the driving simulator, many participants indicated a preference for verge-mounted over gantry-mounted signing provision. It was commented that the verge sign provided clarity that the speed limit applies to all lanes, and that having all information displayed on a single, large sign makes it easier to read.

This correlates with the findings from Task 3, which highlighted that lane closure information was comprehended more easily when displayed on a single verge-mounted sign than on a gantry due to a reduced visual search time.

Some participants felt that there was too much information on the MS4 sign, or that **the information was 'less forceful' in this format**. However, the results from Task 3 indicated that participants' comprehension of speed limit and lane closure information within an MS4 message was only marginally affected by the presence of supplementary information, and the Task 5A questionnaire further clarified that most participants were not likely to perceive the most complex configuration of an MS4 as being overcrowded.

Participants showing a preference for the gantry over verge layout also highlighted that they were more familiar with gantry signing environments and preferred lane specific information provision.

Despite the novelty of the verge-mounted MS4 signing layout, the results from the driving simulator study demonstrated that participants' compliance with, and understanding and user acceptance of, this type of signing provision was high. It can be expected that this would be improved with further exposure to such signing layouts, as drivers were familiarised with the new approach.

Some participants raised the issue of obscuration of verge-mounted signs by HGVs. However the findings of Tasks 4 and 5B suggest that there may be a difference between this perception of obscuration and the actual likelihood of it occurring.

### Participant preference - Red X versus Wicket lane closure aspects

When asked to compare the Red X and Wicket design options for lane closure sequences, participants reported that the use of Hooked Arrow and Red X aspects gives a clearer instruction about when to move out of lane and when the lane is actually closed. However, other participants suggested that the Wicket design option is clearer and more familiar, and some expressed a preference for the use of a single Wicket aspect rather than both Hooked Arrow and Red X aspects in a lane closure sequence.

The driving simulator study indicated that there was very little difference in **participants' behavioural response to either signing layout, and as such when** investigating further the design of lane closure aspects consideration should focus on the operational requirements and the issues relating to network consistency.

For verge-signing options, participants indicated a preference for the inclusion of an aspect illustrating four running lanes in addition to the NR aspect following the end of a lane closure. This suggested that, when using verge-mounted signing, providing confirmation to drivers that all lanes are reopened may have a beneficial influence on driver confidence and behaviour.

## 6 Conclusion

This document described the key findings of four tasks undertaken by TRL in support of the development of the MM2 concept, which focus on investigating the provision of on-road driver information within a Managed Motorways environment. These tasks were **Task 2** (Gantry Spacing Simulator Study), **Task 3** (MM2 Sign Comprehension Study), **Tasks 4 and 5B** (MM2 Sign Obscuration Study) and **Task 5A** (MM2 Design Evaluation Simulation Study).

Methodology and approach has been included where necessary to provide explanation of results. Further description of methodology can be found in each task's Study Plan issued between October 2010 and January 2011.

In general, the findings described in this document suggest that the approaches being considered for communicating on-road driver information within an MM2 environment are feasible. However, consideration should be made to the findings of Tasks 2 to 5 when developing the design and operation of MM2 schemes.

More specifically, these tasks addressed three key questions relating to the design of on-road driver information provision in an MM2 environment. The conclusions related to each question are summarised below:

### **When should driver information be communicated?**

*i.e. spacing and frequency of driver information update points*

The findings suggested that there was a relationship between the spacing of information update points and the speed of individual drivers; in Task 2 participants' mean speed and spot speed under gantries were higher when gantries were spaced further apart. Participants exhibited a greater degree of "surfing" behaviour as gantry spacing increased.

This study used a light traffic scenario to investigate experimentally the influence of **variable mandatory speed limits on an individual driver's speed choice**. It should be recognised that in a heavy traffic situation an individual's speed characteristics would be more dependent on other traffic, and that overall traffic conditions could be considered as the culmination of those individual drivers' behaviours.

None of the findings indicated that increasing the spacing between information update points would adversely influence driver compliance with lane closure instruction.

## **How should driver information be communicated?**

*i.e. the type of sign or signal used and whether it is gantry-mounted or verge-mounted*

Through the use of visualisation and response monitoring software, a driving simulator trial and questionnaires it was determined that, in general, equivalent options for verge- and gantry-mounted information provision can be comprehended equally well. Within the **driving simulator trial, participants' driving behaviour was comparable** in response to either signing option.

The findings of the obscuration study suggested that, in general, there would be only a small proportion of traffic that would have a verge-mounted signal obscured by an HGV in peak hour conditions, especially when considering the required viewing time to process speed limit information indicated by Task 3 and the adjustments that drivers can make to be able to see the sign.

Whether or not this estimated extent of obscuration would have an impact on *when* driver information should be communicated, would depend on how much obscuration would be the acceptable given operational and enforceability considerations.

This study also determined that moving the lateral position of the sign towards the central reservation or increasing the height of the sign could reduce obscuration rates. However, the benefit in terms of reduced obscuration should be considered in light of the design implications of such a movement.

## **What information should be communicated?**

*i.e. what information should be displayed at an update point at any given time and location*

The findings highlighted some pros and cons of different approaches to communicating lane closure information and the options for supplementary information. While some options were more familiar to drivers, others presented a greater association with enforcement and were less ambiguous in terms of the location of the closure.

The findings also indicated that presenting several information elements on a single verge-mounted sign had a minimal impact on driver comprehension. Participants' subjective responses suggested that the use of supplementary information when communicating speed limit and lane closure instructions may have a positive influence on driver behaviour.

These and other conclusions were discussed in more detail for each task individually, and recommendations made for further related areas of investigation.

## Glossary of Terms and Abbreviations

**AMI:** Advanced Motorway Indicator

**EMI:** Enhanced Motorway Indicator

**ERA:** Emergency Refuge Area

**HGV:** Heavy Goods Vehicle

**HS:** Hard Shoulder

**HSR:** Hard Shoulder Running

**LBS1:** Lane Below Signal 1 (equivalent to the Hard Shoulder for Managed Motorway 1 schemes)

**LBS2:** Lane Below Signal 2

**LBS3:** Lane Below Signal 3

**LBS4:** Lane Below Signal 4

**LDR / LDL:** Lane Divert Right / Lane Divert Left

**MM1:** Managed Motorways 1

**MM2:** Managed Motorways 2

**MS4:** Motorway Signal Mark 4 (VMS)

**VMS:** Variable Message Sign

**VMSL / VSL:** Variable Mandatory Speed Limit / Variable Speed Limit

Table 32 provides TRL's definitions for the terms used within this document.

**Table 32: TRL's definitions for terms used in this document**

<b>Term</b>	<b>Definition</b>
<b>Aspect (EMI Aspect)</b>	A graphical representation of driver information to be communicated in a message displayed on a VMS panel i.e. information relating to speed limits or lane closures.
<b>MS4 Message Configuration / Format</b>	The number and arrangement of elements within a message displayed on a MS4 that communicates on-road driver information.
<b>Element</b>	A component of a message displayed on a VMS. Different types of element include speed limit and lane closure aspects, pictograms and text.
<b>Lane closure information / instruction</b>	Information regarding lane closures and instruction for drivers to move out of a particular lane, communicated to road users via a LDR/LDL or Red X signal on a gantry-mounted AMI or a single aspect displayed on a verge-mounted VMS.
<b>Message</b>	The complete set of elements displayed on a sign at a particular point of time. For example, a message may consist of one or more elements (including aspects, pictograms and text) that seek to inform drivers of traffic conditions ahead and / or instruction to change their driving behaviour. For verge-mounted signing provision, the message is displayed on a single VMS. For gantry-mounted signing provision, the message is displayed through AMIs and a VMS.
<b>On-road driver information</b>	Any information provided to drivers whilst driving on a stretch of motorway e.g. variable mandatory speed limit instruction, lane status instruction and other tactical or strategic information. This information can be provided through means of fixed signing, variable signing or signals.
<b>On-road driver information update point</b>	The geographical location at which On-Road Driver Information is provided, e.g. the location of a signalised gantry or a verge-mounted VMS.
<b>Signing provision</b>	Referred to in this report as the physical infrastructure used to display On-Road Driver Information. For example, verge-mounted signing provision consisting of an MS4 or gantry-mounted signing provision consisting of 4 AMIs and an MS4.
<b>Signal</b>	In Section 4 of this report (Key Findings from the Task 4 and 5B: MM2 Sign Obscuration Study), 'signal' is used to refer specifically to a mandatory speed limit aspect displayed on a gantry AMI or in the top right hand corner of a verge-mounted MS4. Note: this has been defined purely for the purposes of this report.
<b>Speed limit instruction</b>	Instruction regarding the maximum speed limit, communicated to road users via an advisory / mandatory speed limit aspect displayed on either gantry-mounted AMIs or verge-mounted VMS.
<b>Surfing</b>	When drivers reduce their speed to below the speed limit (or below a perceived speed limit enforcement threshold) to pass under a gantry before accelerating up to speeds higher than the speed limit, then slowing down again to pass under the next gantry.
<b>Surfing Magnitude</b>	<i>Surfing magnitude</i> is an assessment measure used in Task 2 Speed Choice data analysis and is defined as the difference between a participant's driving speed under a gantry and the maximum speed reached after that gantry but before reaching the next (see Figure 12).
<b>Test area</b>	The sections of the routes in the Task 2 and Task 5A simulator studies used for data analysis.
<b>Variable Message Sign</b>	An electronic traffic sign used to communicate dynamic On-Road Driver Information. This report refers to both verge and gantry-mounted VMS, specifically the MS4.

## Appendix A – Images from driving simulator routes for Tasks 2 and 5A

The following images are screenshots taken from the driving simulator control room during drives carried out for Tasks 2 and 5A. These are for information only as due to the resolution of the image, it is not possible to accurately illustrate the extent to which the scene is visible within the driving simulator itself.

### Task 2 Images



**Figure 129: Passing under a gantry in the 500m spacing test area**



**Figure 130: Approaching a gantry in the 500m spacing test area**



**Figure 131: Two over-bridges obstructing a subsequent gantry in the 500m spacing test area**



**Figure 132: Passing under a gantry in the 800m spacing test area**



**Figure 133: A gantry becomes visible after being obstructed by two over-bridges in the 800m spacing test area**



**Figure 134: Passing a gantry in the 1000m spacing test area**



**Figure 135: Passing under a gantry in the 1500m spacing test area**

## Task 5A Images



**Figure 136: Passing a gantry on the Task 5A Gantry route (1500m spacing)**



**Figure 137: Passing an MS4 sign on the Task 5A Verge Red X route (1500m spacing)**

## Appendix B – Data Tables for Task 2 Statistical Analysis

**Table 33: Percentage above the speed limit as a function of speed limit and gantry spacing**

Spacing (m)	Speed limit			Total
	40mph	50mph	60mph	
<b>500</b>	9.3%	5.2%	2.0%	5.5%
<b>800</b>	13.6%	6.1%	1.6%	7.1%
<b>1000</b>	20.9%	15.7%	6.5%	14.4%
<b>1500</b>	27.3%	16.6%	8.4%	17.5%
<b>2000</b>	31.8%	18.6%	8.2%	19.5%
<b>3000</b>	38.7%	21.9%	11.9%	24.2%

**Table 34: P-values of post hoc comparisons (Tukey's HSD) for the mean speed/speed limit ratio in each gantry spacing for the 40, 50 and 60mph speed limit sections**

Speed limit		Gantry spacing (m)					
40mph		500	800	1000	1500	2000	3000
	<b>500</b>	-	0.976	0.355	<b>0.030*</b>	<b>0.003**</b>	<b>0.000**</b>
	<b>800</b>		-	0.810	0.186	<b>0.031*</b>	<b>0.001**</b>
	<b>1000</b>			-	0.890	0.466	<b>0.042*</b>
	<b>1500</b>				-	0.976	0.409
	<b>2000</b>					-	0.862
	<b>3000</b>						-
50mph		500	800	1000	1500	2000	3000
	<b>500</b>	-	1.000	<b>0.087*</b>	<b>0.048**</b>	<b>0.013**</b>	<b>0.001**</b>
	<b>800</b>		-	0.154	<b>0.090*</b>	<b>0.027**</b>	<b>0.002**</b>
	<b>1000</b>			-	1.000	0.981	0.648
	<b>1500</b>				-	0.997	0.785
	<b>2000</b>					-	0.965
	<b>3000</b>						-
60mph		500	800	1000	1500	2000	3000
	<b>500</b>	-	1.000	0.500	0.135°	0.171	<b>0.003**</b>
	<b>800</b>		-	0.402	<b>0.094*</b>	0.121°	<b>0.002**</b>
	<b>1000</b>			-	0.978	0.988	0.305
	<b>1500</b>				-	1.000	0.753
	<b>2000</b>					-	0.715
	<b>3000</b>						-

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance

**Table 35: P-values of post hoc comparisons (Tukey's HSD) for the spot speed/speed limit ratio in each gantry spacing for the 40, 50 and 60mph speed limit sections**

Speed limit	Gantry spacing (m)					
	500	800	1000	1500	2000	3000
<b>40mph</b>						
500	-	0.999	0.248	<b>0.053*</b>	<b>0.018**</b>	<b>0.004**</b>
800		-	0.434	0.122°	<b>0.047*</b>	<b>0.013**</b>
1000			-	0.985	0.894	0.662
1500				-	0.999	0.959
2000					-	0.998
3000						-
<b>50mph</b>						
500	-	0.997	<b>0.052*</b>	0.107°	0.121°	0.375
800		-	<b>0.014**</b>	<b>0.032**</b>	<b>0.038**</b>	0.162
1000			-	1.000	1.000	0.951
1500				-	1.000	0.991
2000					-	0.993
3000						-
<b>60mph</b>						
500	-	0.851	0.846	0.914	1.000	<i>n/a</i>
800		-	0.265	0.353	0.936	<i>n/a</i>
1000			-	1.000	0.752	<i>n/a</i>
1500				-	0.839	<i>n/a</i>
2000					-	<i>n/a</i>
3000						-

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 36: P-values of post hoc comparisons (Tukey’s HSD) for the percentage of time spent 10% above the speed limit in each gantry spacing for the 40, 50 and 60mph speed limit sections**

Speed limit	Gantry spacing (m)					
	500	800	1000	1500	2000	3000
<b>40mph</b>						
<b>500</b>	-	0.994	0.588	<b>0.073*</b>	<b>0.005**</b>	<b>0.001**</b>
<b>800</b>		-	0.889	0.242	<b>0.025**</b>	<b>0.006**</b>
<b>1000</b>			-	0.874	0.318	0.135°
<b>1500</b>				-	0.932	0.736
<b>2000</b>					-	0.736
<b>3000</b>						-
<b>50mph</b>						
<b>500</b>	-	1.000	<b>0.096*</b>	0.199	<b>0.015**</b>	<b>0.016**</b>
<b>800</b>		-	0.160	0.303	<b>0.028**</b>	<b>0.032**</b>
<b>1000</b>			-	1.000	0.981	0.985
<b>1500</b>				-	0.909	0.921
<b>2000</b>					-	1.000
<b>3000</b>						-
<b>60mph</b>						
<b>500</b>	-	1.000	.302	<b>.012**</b>	.108°	<b>.005**</b>
<b>800</b>		-	.382	<b>.018**</b>	.149°	<b>.007**</b>
<b>1000</b>			-	.791	.995	.600
<b>1500</b>				-	.975	.999
<b>2000</b>					-	.893
<b>3000</b>						-

\*,\*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 37: P-values of post hoc comparisons (Tukey's HSD) for the standard deviation of speed in each gantry spacing for the 40, 50 and 60mph speed limit sections**

Speed limit		Gantry spacing (m)					
		500	800	1000	1500	2000	3000
<b>40mph</b>	<b>500</b>	-	0.835	0.866	0.325	0.114°	<b>0.043**</b>
	<b>800</b>		-	1.000	0.957	0.735	0.485
	<b>1000</b>			-	0.947	0.711	0.462
	<b>1500</b>				-	0.994	0.940
	<b>2000</b>					-	0.999
	<b>3000</b>						-
<b>50mph</b>	<b>500</b>	-	0.993	0.719	0.548	<b>0.046**</b>	<b>0.002**</b>
	<b>800</b>		-	0.956	0.872	0.175	<b>0.015**</b>
	<b>1000</b>			-	1.000	0.659	0.153
	<b>1500</b>				-	0.812	0.259
	<b>2000</b>					-	0.943
	<b>3000</b>						-
<b>60mph</b>	<b>500</b>	-	0.949	0.998	0.476	<b>0.027**</b>	<b>0.001**</b>
	<b>800</b>		-	0.998	0.943	0.225	<b>0.025**</b>
	<b>1000</b>			-	0.757	<b>0.090*</b>	<b>0.007**</b>
	<b>1500</b>				-	0.768	0.240
	<b>2000</b>					-	0.953
	<b>3000</b>						-

\*,\*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 38: P-values of post hoc comparisons (Tukey’s HSD) for the magnitude of surfing in each gantry spacing for the 40, 50 and 60mph speed limit sections**

Speed limit	Gantry spacing (m)					
	500	800	1000	1500	2000	3000
<b>40mph</b>						
500	-	0.817	0.801	0.138°	<b>0.042**</b>	<b>0.000**</b>
800		-	1.000	0.810	0.503	<b>0.022**</b>
1000			-	0.838	0.543	<b>0.028**</b>
1500				-	0.996	0.396
2000					-	0.728
3000						-
<b>50mph</b>						
500	-	0.879	0.705	0.207	<b>0.006**</b>	<b>0.000**</b>
800		-	0.999	0.840	0.130°	<b>0.002**</b>
1000			-	0.959	0.272	<b>0.006**</b>
1500				-	0.777	<b>0.068*</b>
2000					-	0.699
3000						-
<b>60mph</b>						
500	-	0.798	0.508	<b>0.003**</b>	<b>0.000**</b>	<i>n/a</i>
800		-	0.989	<b>0.083*</b>	<b>0.001**</b>	<i>n/a</i>
1000			-	0.244	<b>0.005**</b>	<i>n/a</i>
1500				-	0.536	<i>n/a</i>
2000					-	<i>n/a</i>
3000						-

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

## Appendix C – Task 3 PC Comprehension Test Images

### Session 1 – Comparison of Gantry and Verge

The following images are examples of the verge-mounted and gantry-mounted options presented to participants in Session A of the PC Comprehension Test. If a gantry-mounted option was identified that did not have an equivalent verge-mounted option then it was not included (e.g. if there was insufficient space in the verge-mounted MS4 message to include all elements that were included in the gantry option). It should also be noted that not all of lane closure aspects illustrated in Section 3.4.1 of this report were used in this test.

For the static version, each verge and gantry option was presented to participants four times at each exposure level (12 presentations in total) and for the dynamic version, there were four presentations of each option in total. Within the 12 (or 4) presentations, the arrangement of the elements was kept the same but changes were made to the traffic scenario (e.g. different speed limit or lane number(s) that were closed, or variation in the content of the pictogram or text used).

One verge-mounted option (A2) also has a 1500mm diameter speed limit aspect as opposed to the 1300mm diameter used in the remaining configurations.

The images are grouped according to the type of statement that was displayed prior to the image (e.g. 'Speed', 'Lane closed' or 'Move out of lane').

**'Speed' Statement - Speed limit aspect only**



**A1 - Verge**  
*Speed limit aspect (1300mm diameter)*



**A2 - Verge**  
*Speed limit aspect (1500mm diameter)*



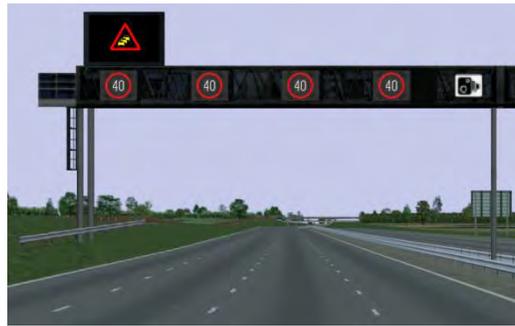
**A3 - Gantry**  
*AMI Speed limit aspect*

**'Speed' Statement – Speed limit aspect and pictogram / text**



**B4 - Verge**

*Speed limit aspect (1300mm diameter) + pictogram*



**B5 - Gantry**

*AMI speed limit aspect + pictogram*



**B6 - Verge**

*Speed limit aspect (1300mm diameter) + text (2 lines)*



**B7 - Gantry**

*AMI speed limit aspect + text (2 lines)*



**B8 - Verge**

*Speed limit aspect 1300mm diameter) + pictogram + text (1 line)*



**B9 - Gantry**

*AMI speed limit aspect + pictogram + text (1 line)*



**B10 - Verge**

*Speed limit aspect (1300mm diameter) +  
pictogram + text (2 lines)*



**B11 - Gantry**

*AMI speed limit aspect + pictogram + text (2  
lines)*

**'Lane Closed' Statement**



**C12 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (wicket)+ text (2 lines)*



**C13 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (1 Red X) + text (2 lines)*



**C14 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (1 Red X with lane markings)+ text (2 lines)*



**C15 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (3 Red X) + text (2 lines)*



**C18 - Gantry**

*AMI speed limit aspect + Red X signal + text (2 lines)*

**'Move Out of Lane' Statement**



**C16 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (European variant)+ text (2 lines)*



**C17 - Verge**

*Speed limit aspect (1300mm) + lane closure aspect (Hooked Arrow) + text (2 lines)*



**C19 - Gantry**

*AMI speed limit aspect + LDR signal + text (2 lines)*

*Note: The verge-mounted designs used in accordance with the 'move out of lane' statement did not include a two-lane closure.*

## Session 2 – Comparison of MS4 Message Configurations

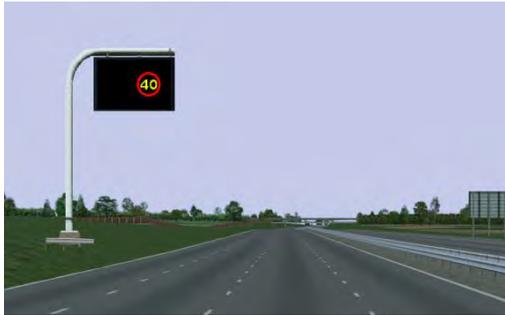
The following images are examples of the verge-mounted MS4 message configurations presented to participants in Session 2 of the PC Comprehension Test.

For the static version, each verge message configuration was presented to participants four times at each exposure level (12 presentations in total). Within the 12 presentations, the arrangement of the elements was kept the same but changes were made to the traffic scenario (e.g. different speed limit or lane number(s) that were closed, or variation in the content of the pictogram or text used).

Two configurations (D4 and D8) also have 1500mm diameter speed limit aspects as opposed to the 1300mm diameter used in the remaining configurations.

The images are grouped according to the type of statement that was displayed prior to the image (e.g. 'Speed' or 'Lane closed'). For MS4 message configurations with speed limit and lane closure aspects, both speed limit and lane closed statements were used (image references D9, D10, D11 and E7, E8, E9).

**'Speed' Statement**



**D1**  
*Speed limit aspect (1300mm diameter)*



**D2**  
*Speed limit aspect (1300mm diameter) + text (1 line)*



**D3**  
*Speed limit aspect (1300mm diameter) + text (2 lines)*



**D5**  
*Speed limit aspect (1300mm diameter) + pictogram*



**D6**  
*Speed limit aspect (1300mm diameter) + pictogram + text (1 line)*



**D7**  
*Speed limit aspect (1300mm diameter) + pictogram + text (2 lines)*



**D4**

Speed limit aspect (1500mm diameter) + text (2 lines)



**D8**

Speed limit aspect (1500mm diameter) + pictogram + text (2 lines)



**D9**

Speed limit aspect (1300mm diameter)+ Lane closure aspect (wicket)



**D10**

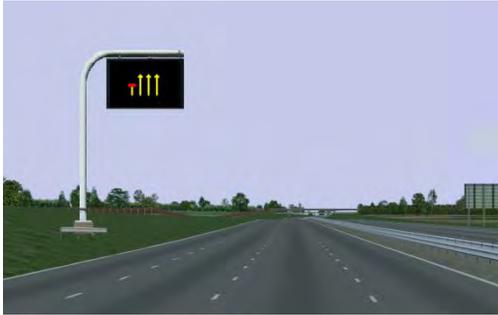
Speed limit aspect (1300mm diameter)+ Lane closure aspect (wicket) + text (1 line)



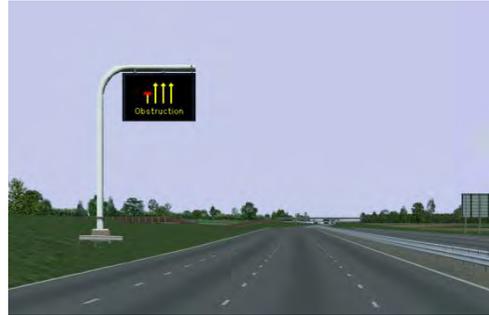
**D11**

Speed limit aspect (1300mm diameter)+ Lane closure aspect (wicket) + text (2 lines)

**'Lane Closed' Statement**



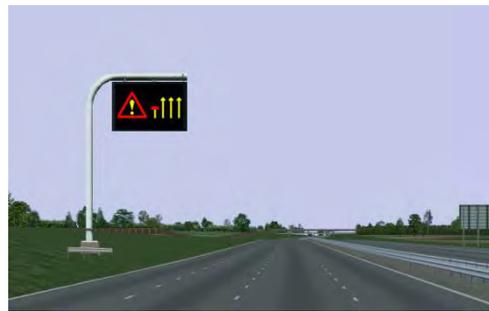
**E1**  
*Lane closure aspect (wicket)*



**E2**  
*Lane closure aspect (wicket) + text (1 line)*



**E3**  
*Lane closure aspect (wicket) + text (2 lines)*



**E4**  
*Lane closure aspect (wicket) + pictogram*



**E5**  
*Lane closure aspect (wicket) + pictogram + text (1 line)*



**E6**  
*Lane closure aspect (wicket) + pictogram + text (2 lines)*



**E7**

*Speed limit aspect (1300mm diameter)+ Lane closure aspect (wicket)*



**E8**

*Speed limit aspect (1300mm diameter)+ Lane closure aspect (wicket) + text (1 line)*



**E9**

*Speed limit aspect (1300mm diameter)+ Lane closure aspect (wicket) + text (2 lines)*

## Appendix D - Data Tables for Task 5A Statistical Analysis

**Table 39: P-values of paired and independent samples t-tests for Assessment Measure 1 (Mean Speed)**

Sign	Pair	Mean	SD	SEM	t	df	Sign (2 tailed)	Test
2 to 3	Gantry	70.29	5.88	.83	-1.693	49	<b>.097*</b>	Paired
	Verge	71.25	6.04	.85				
3 to 4	Gantry	63.60	6.07	.86	-.790	49	.433	Paired
	Verge	64.08	6.40	.91				
4 to 5	Gantry	58.62	7.71	1.09	-1.678	49	<b>.100*</b>	Paired
	Verge	59.93	7.09	1.00				
4 to 5	Red X	60.27	7.53	1.48	-.258	48	.797	Independent
	Wicket	60.80	8.86	1.40				
5 to 6	Gantry	56.86	7.41	1.05	-.905	49	.370	Paired
	Verge	57.44	7.13	1.01				
5 to 6	Red X	56.98	7.31	1.43	-.479	48	.634	Independent
	Wicket	57.95	7.04	1.44				
12 to 13	Gantry	59.79	9.54	1.35	-1.227	49	.226	Paired
	Verge	61.35	9.82	1.39				
12 to 13	Red X	60.33	8.97	1.76	-.761	48	.450	Independent
	Wicket	62.45	10.75	2.19				
13 to 14	Gantry	66.47	4.95	1.13	-.817	18	.424	Paired
	Verge	67.29	5.08	1.16				
13 to 14	Red X	65.87	6.55	1.64	-.566	26	.583	Independent
	Wicket	67.12	4.91	1.42				
14 to 15	Gantry	62.31	6.01	.96	-1.662	38	.105°	Paired
	Verge	63.87	7.25	1.16				
14 to 15	Red X	63.81	7.65	1.50	.184	42	.855	Independent
	Wicket	63.39	7.25	1.71				
2 to 3	Gantry	63.71	6.68	1.07	-.236	38	.815	Paired
	Verge	63.21	6.60	1.06				
3 to 4	Red X	63.40	7.32	1.56	.056	38	.956	Independent
	Wicket	63.28	6.63	1.56				

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 40: P-values of paired and independent samples t-tests for Assessment Measure 2 (Spot Speed)**

Sign	Pair	Mean	SD	SEM	t	df	Sign (2 tailed)	Test
2	Gantry	69.5274	5.37279	.75983				
	Verge	69.6971	6.75870	.95582	-.213	49	.832	Paired
3	Gantry	62.9829	7.03905	.99547				
	Verge	65.3502	6.83294	.96632	-2.556	49	<b>.014**</b>	Paired
4	Gantry	57.7762	7.53357	1.06541				
	Verge	59.3984	6.58177	.93080	-1.829	49	<b>.073*</b>	Paired
4	Red X	59.5186	6.48338	1.27150				
	Wicket	59.2682	6.82396	1.39294	.133	48	.895	Independent
5	Gantry	54.2177	7.02987	.99417				
	Verge	55.8144	6.48622	.91729	-2.237	49	<b>.030**</b>	Paired
5	Red X	56.9724	6.95045	1.36309				
	Wicket	54.5598	1.18957	1.18957	1.324	48	.192	Independent
6	Gantry	56.4489	9.82029	1.38880				
	Verge	57.8584	8.15003	1.15259	-1.363	49	.179	Paired
6	Red X	56.8455	8.23971	1.61594				
	Wicket	58.9557	8.08066	1.64946	-.913	48	.366	Independent
12	Gantry	52.62	5.11	1.02				
	Verge	54.33	6.99	1.40	-.973	24	.340	Paired
12	Red X	51.16	6.43	1.66				
	Wicket	57.57	5.72	1.65	-2.705	25	<b>.012**</b>	Independent
13	Gantry	60.10	5.24	.82				
	Verge	62.58	7.18	1.12	-2.261	40	<b>.029**</b>	Paired
13	Red X	62.58	6.69	1.34				
	Wicket	61.67	7.75	1.78	.420	42	.676	Independent
14	Gantry	57.07	13.71	2.09				
	Verge	61.02	5.40	.82	-1.995	42	<b>.053*</b>	Paired
14	Red X	60.90	5.43	1.11				
	Wicket	61.42	5.56	1.31	-.304	40	.763	Independent
15	Gantry	58.15	10.07	1.54				
	Verge	61.02	6.11	.93	-2.039	42	<b>.048**</b>	Paired
15	Red X	56.63	17.82	3.50				
	Wicket	60.61	5.61	1.29	-.938	43	.353	Independent

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 41: P-values of paired and independent samples t-tests for Assessment Measure 3 (percentage time spent above the speed limit +10%)**

Sign	Pair	Mean	SD	SEM	t	df	Sign (2 tailed)	Test
2 to 3	Gantry	14.626	25.945	3.669				
	Verge	18.171	29.632	4.191	-1.109	49	.273	Paired
3 to 4	Red X	33.419	37.892	5.359				
	Wicket	32.223	40.341	5.705	0.352	49	.726	Paired
4 to 5	Gantry	53.903	41.751	5.904				
	Verge	65.638	38.250	5.409	-2.112	49	<b>.040**</b>	Paired
4 to 5	Red X	59.285	41.058	8.052				
	Wicket	72.521	34.492	7.041	-1.229	48	.225	Independent
5 to 6	Gantry	47.157	42.016	5.942				
	Verge	48.348	39.977	5.654	-0.393	49	.696	Paired
5 to 6	Red X	45.591	40.200	7.884				
	Wicket	51.335	40.377	8.242	-0.504	48	.617	Independent
12 to 13	Gantry	7.149	18.260	4.189				
	Verge	10.752	17.994	4.128	-0.990	18	.335	Paired
12 to 13	Red X	4.858	14.243	3.454		17		
	Wicket	9.741	16.249	4.507	-.876	13	.389	Independent
13 to 14	Gantry	25.464	35.298	5.652				
	Verge	29.927	38.179	6.114	-0.871	38	.389	Paired
13 to 14	Red X	22.447	37.152	7.286		26		
	Wicket	29.177	36.768	8.222	-.612	20	.544	Independent
14 to 15	Gantry	28.013	37.873	6.065				
	Verge	30.051	38.619	6.184	-0.366	38	.716	Paired
14 to 15	Red X	30.605	40.794	8.697		22		
	Wicket	26.246	35.940	8.245	.360	19	.721	Independent

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 42: P-values of paired and independent samples t-tests for Assessment Measure 4 (Surfing Magnitude)**

Sign	Pair	Mean	SD	SEM	t	df	Sign (2 tailed)	Test
2 to 3	Gantry	5.7306	6.27814	.88786				
	Verge	6.0343	5.17487	.73184	-0.372	49	.711	Paired
3 to 4	Gantry	5.5421	7.03969	.99556				
	Verge	3.5749	5.52611	.78151	2.170	49	<b>.035**</b>	Paired
4 to 5	Gantry	5.9869	8.76515	1.23958				
	Verge	5.8919	7.53404	1.06547	.107	49	.915	Paired
4 to 5	Red X	4.553	6.553	1.285				
	Wicket	7.343	8.368	1.708	-1.318	48	.256	Independent
5 to 6	Gantry	7.7973	7.86537	1.11233				
	Verge	7.6573	8.88015	1.25584	.193	49	.848	Paired
5 to 6	Red X	5.622	6.367	1.249				
	Wicket	9.862	10.686	2.181	-1.720	48	<b>.034**</b>	Independent
12 to 13	Gantry	20.979	6.82	1.57				
	Verge	19.974	9.60	2.20	.434	18	.669	Paired
12 to 13	Red X	21.432	8.524	2.201				
	Wicket	18.269	8.664	2.501	0.951	25	.898	Independent
13 to 14	Gantry	7.508	7.09	1.14				
	Verge	6.199	7.64	1.22	1.218	38	.231	Paired
13 to 14	Red X	5.496	6.605	1.321				
	Wicket	6.673	8.403	1.981	-0.514	41	.497	Independent
14 to 15	Gantry	8.384	7.88	1.26				
	Verge	7.514	6.39	1.02	1.051	38	.300	Paired
14 to 15	Red X	7.040	5.882	1.227				
	Wicket	7.517	7.088	1.671	-0.236	39	.648	Independent

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Table 43: P-values of paired and independent samples t-tests for Assessment Measure 6 (Departure distance from closing lane relative to 'Lane Closed Ahead' sign)**

	Pair	Mean	SD	SEM	t	df	Sign (2 tailed)	Test
1	Gantry	463.9728	754.60457	111.26037				
	Verge	484.4906	779.24667	116.16324	-.088	44	.930	Paired
1	Red X	456.1031	725.99049	148.19219				
	Wicket	516.9335	853.05458	186.15177	-.258	43	.797	Independent
2	Gantry	67.4208	180.00645	30.42664				
	Verge	83.9572	101.80966	17.20897	-.473	68	.638	Independent
2	Red X	100.4777	112.02327	25.69990				
	Wicket	64.3392	87.63095	21.90774	1.048	33	.302	Independent
3	Gantry	1725.5455	388.20339	117.04773				
	Verge	1886.4000	349.37411	110.48179	-.993	19	.333	Independent
3	Red X	1807.4000	300.87423	134.55504				
	Wicket	1965.4000	410.50250	183.58230	-.693	8	.508	Independent

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

**Where:**

- 1 – All participants in the sample for this assessment measure
- 2 – Participants that departed in Zones A and B i.e. in response to the 'Lane closed ahead' sign
- 3 – Participants that departed in Zones C and D i.e. in response to the 'Lane closed' sign

**Table 44: P-values of paired samples t-tests for questionnaire data (Perceived clarity of sign design options)**

Question	Pair	Mean	SD	SEM	t	df	Sign (2 tailed)	Test
C9a and b	Red x	8.42	1.92	.271	1.144	49	.258	Paired
	Wicket	7.98	1.94	.275				
C11a and b	Red x	9.02	1.72	.243	3.342	49	<b>.002**</b>	Paired
	Wicket	7.54	2.36	.333				
C13a and b	Red x	9.26	1.52	.215	2.449	49	<b>.018**</b>	Paired
	Wicket	8.74	1.94	.274				

\*, \*\* indicate statistical significance at the 10% and 5% level, respectively. ° indicates values approaching significance.

## Appendix E – Details of non-compliant participants in Task 5A

The following tables provide details of participants that were non-compliant with lane closure instructions in the LBS1 and LBS3/4 closure in Task 5A.

**Table 45: Participants driving in LBS1 whilst it is closed as a running lane**

<b>Participant No.</b>	10	13*	15*	16	18	36*	40	41*	47
<b>Gantry / Verge</b>	Verge	Gantry	Verge	Verge	Verge	Gantry, Verge	Verge	Gantry	Gantry, Verge
<b>Verge Layout</b>	Red X	-	Red X	Red X	Red X	Wicket	Wicket	Gantry	Wicket
<b>Drive No.</b>	1	1	2	1	1	1, 2	1	1	1, 2
<b>% lane closure non-compliant</b>	28%	22%	4%	9%	<b>55%</b>	<b>63%, 58%</b>	<b>52%</b>	<b>72%</b>	38%, <b>53%</b>
<b>Drives on a section of motorway with mandatory variable speed limits...</b>	Occasionally	Often	Occasionally	Often	Occasionally	Rarely	Occasionally	Rarely	Never
<b>Considers compliance with lane closure to be...*</b>	Compulsory	Mandatory	Compulsory	Advisory	Mandatory	Mandatory (both)	Compulsory	Advisory	Compulsory
<b>Age</b>	19	40	52	31	27	44	57	39	54
<b>Estimated Annual Mileage</b>	4500	10000	15000	7000	2000	9000	10000	4000	7000
<b>Years driving</b>	2	23	29	15	10	26	40	61	37
<b>Sex</b>	Male	Male	Male	Male	Female	Female	Male	Female	Female

\* Participant was also non-compliant in LBS3 and 4 closure.

**Table 46: Participants driving in LBS3 and 4 whilst they are closed as a running lane**

<b>Participant No.</b>	13*	15*	21	24	26	31	33	35	36*	41*	44	48
<b>Gantry / Verge</b>	Gantry, Verge	Verge	Verge	Verge	Gantry, Verge	Gantry, Verge	Verge	Gantry, Verge	Gantry, Verge	Gantry, Verge	Verge	Gantry, Verge
<b>Verge Layout</b>	Red X	Red X	Red X	Wicket	Wicket	Red X	Wicket	Wicket	Wicket	Wicket	Wicket	Wicket
<b>Drive No.</b>	1, 2	2	1	2	2, 1	1, 2	2	1, 2	1, 2	1, 2	2	2, 1
<b>% lane closure non-compliant</b>	32%, <b>77%</b>	4%	33%	5%	24%, 8%	17%, 12%	5%	11%, 19%	18%, <b>74%</b>	26%, <b>58%</b>	6%	18%, 17%
<b>Drives on a section of motorway with mandatory variable speed limits...</b>	Often	Occasionally	Occasionally	Rarely	Rarely	Occasionally	Very often	Occasionally	Rarely	Rarely	Very Often	Rarely
<b>Considers compliance with lane closure to be...*</b>	Mandatory	Compulsory	Compulsory	Mandatory	Mandatory (both)	Mandatory (both)	Compulsory	Advisory	Mandatory (both)	Advisory	Compulsory	Compulsory (both)
<b>Age</b>	40	52	40	22	35	26	33	59	44	39	46	32
<b>Estimated Annual Mileage</b>	10000	15000	15000	4000	15000	14000	30000	5000	9000	4000	15000	9000
<b>Years driving</b>	23	29	23	4	16	8	37	38	26	61	28	15
<b>Sex</b>	Male	Male	Male	Male	Male	Male	Male	Male	Female	Female	Male	Male

\* Participant was also non-compliant in LBS1 closure





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