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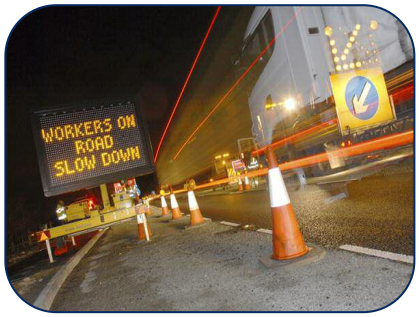


FINAL PROJECT REPORT CPR1335

Future Managed Motorways Concept Development

Task 1: Design Comparison Simulator Study

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Prepared for: Highways Agency,

Project Ref: 564(1308)HALC

Quality approved:

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Insert scan of signature

Nick Reed (Technical Referee)

2012

Disclaimer

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Referee
0.2	28/03/12	Draft	A.W.	N.R.
0.3	19/04/12	Amendments following client comments	P.B.	N.R.
1	14/05/12	Final	P.B.	N.R.

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Executive Summary

This report describes the findings of a driving simulator trial conducted by TRL for the Highways Agency entitled *Future Managed Motorways Concept Task 1: Design Comparison Simulator Study.* It is the first of two simulator trials being conducted to support the design advice provided in IAN161/12 *Managed Motorways Requirements – All-Lane Running.* These trials aim to provide intelligence regarding the safety and legality of the generic Managed Motorways (MM) All-Lane Running (ALR) design and concept of operations by investigating driving behaviour in a simulated environment.

MM schemes use technology to communicate on-road driver information to influence the behaviour of traffic. For MM-ALR schemes to achieve their objectives it is essential that they remain effective at communicating this information..

In a previous project, TRL developed a simulated environment for directly investigating the impact that the different means by which on-road driver information can be communicated has on driver behaviour within a permanent 4-lane environment. Two main means of communication were compared: fully equipped gantries with lane specific signalling and an MS4; and verge-mounted MS4s only. This work provided an understanding of the impact of using only verge-mounted MS4s to achieve the desired MM environment, but not the impact of presenting a combination of both verge-mounted MS4s and fully equipped gantries within a scheme.

Using both fully equipped gantries and verge-mounted MS4s within the same scheme is one of the key elements of the proposed future MM design and, hence, this task focussed primarily on that design aspect. This study examined driver behaviour in three situations: the 'mixed' design approach with verge-mounted MS4s and fully equipped gantries, compared directly with both 'all gantry' and 'all MS4s' layouts.

This was achieved by conducting a driving simulator study to enable participants to drive in simulated MM conditions (in different configurations) and examining behaviour in response to changes in driver information presented by gantries or verge-mounted variable message signs. Participants also completed a questionnaire to examine their subjective understanding of the MM scheme.

Overall, the results suggested that in the mixed route (i.e. the general design approach outlined in IAN161/12) participants understood the information presented to them and exhibited appropriate driving behaviour.

On all of the assessment measures used to study behaviour within the simulated environment, there was found to be no practical or statistically significant difference in behaviour between participants driving in the 'all gantry' route and the 'mixed' route, with the following exception: in the 70mph then 60mph sections following the second lane closure mean speeds were found to be higher on the Mixed route than on the Gantry route. However although achieving statistical significance, this only relates to a difference of 1mph so may represent little practical significance.

The questionnaire suggested that there was a statistically significant difference in the reported certainty of the speed limit between Mixed and Gantry routes. However, both results were high and the actual simulator speed data suggests that any uncertainty that participants had, had little or no discernible effect on driver behaviour.

1 Introduction

1.1 Background

The Highways Agency Roads Programme Steering Group have asked for work to be done to identify where additional savings can be made to the Spending Review 2010 (SR10) programme, whilst continuing to meet the Agency's safety objective. This has resulted in an approach known as Managed Motorways – All Lane Running (MM-ALR) and has received Secretary of State approval to proceed with development work and implement this enhanced approach.

The MM-ALR Concept of Operations document (an accompanying document to IAN161/12) presents the following case for evolving the MM design:

Evaluation of the M42 pilot demonstrated that managed motorways are able to deliver clear benefits in terms of: improved journey time reliability through reduced congestion; at lower cost and with less environmental impact than conventional widening programmes; and without negatively impacting the safety performance. The subsequent programme to roll-out managed motorways with dynamic hard shoulders designed to IAN 111/09 has delivered similar benefits to conventional road widening programmes, but at significantly lower cost. Experience from these schemes suggests that there is scope to further reduce both the capital and operating costs, whilst continuing to meet the congestion and safety objectives.[1]

Between November 2010 and March 2011, TRL conducted a series of six tasks which investigated several of the design features to be included in the proposed future MM design (task reference: 450(1308)HALC). Two of these tasks made use of TRL's driving simulator, a tool which has been used extensively to support the development of MM design and operation for several years.

This work identified the potential of reducing costs through increasing the overall spacing between the signs providing driver information and also using some verge-mounted signs as opposed to only portal gantries.

As a result of the MM2 programme being put on hold there was no final MM2 design to test on the simulator as part of this programme and this key task had to be cancelled. Since then a generic future MM design was agreed utilising these identified benefits and, hence, the Highways Agency approached TRL to conduct further simulator studies using the agreed future MM environment and study driver behaviour within it.

The *Design Comparison Simulator Study* is the first of two simulator trials being conducted to support the design advice provided in IAN161/12 *Managed Motorways Requirements – All-Lane Running*. These trials aim to provide intelligence regarding the safety and legality of the generic design and concept of operations by investigating driving behaviour in a simulated MM-ALR environment.

[1] http://www.dft.gov.uk/ha/standards/tech_info/files/MM-ALR_Concept_of_Operations_v1_0.pdf

1.2 Future MM Concept Development Task 1

MM schemes use technology to communicate on-road driver information to influence the behaviour of traffic. For MM-ALR schemes to achieve their objectives it is essential that they remain effective at communicating this information.

In the previous project, TRL developed a simulated environment for directly investigating the impact that the different means by which on-road driver information can be communicated has on driver behaviour within a permanent 4-lane environment. Two main means of communication were compared: fully equipped gantries with lane specific signalling and an MS4; and verge-mounted MS4s only. This work provided an understanding of the impact of using verge-mounted MS4s only at information update points, but not the impact of presenting a combination of verge-mounted MS4s and fully equipped gantries within a scheme.

Using both fully equipped gantries and verge-mounted MS4s within the same scheme is one of the key elements of the proposed future MM design and, hence, this task focussed primarily on that design aspect. This study examined driver behaviour in three situations: the 'mixed' design approach with verge-mounted MS4s and fully equipped gantries, compared directly with both 'all gantry' and 'all MS4s' layouts.

This was achieved by conducting a driving simulator study to enable participants to drive in simulated MM conditions (in different configurations) and examining behaviour in response to changes in driver information presented by gantries or verge-mounted variable message signs. Participants also completed a questionnaire to examine their subjective understanding of the MM scheme.

2 Task objectives

A single key objective was defined for this trial:

- To assess driver behaviour and compliance in response to on-road driver information communicated through a combination of verge-mounted MS4 variable message signs and fully equipped gantries in a controlled environment.

In addition to this there was a secondary objective:

- To assess driver awareness and comprehension of Emergency Refuge Areas (ERAs) and associated signing; and use of ERAs in a breakdown scenario.

This lead to the development of the following research questions:

1. Does the choice of signing configuration influence drivers':
    - average speed?
    - speed choice past specific sign locations?
    - overall adherence to the speed limit?
    - position when moving out of a lane that has been signalled as closing?
    - awareness of the speed limit?
    - awareness of which lanes are open and closed?
    - comprehension of lane closure signage?
    - perceptions of sign visibility?
    - perceptions of sign clarity?
    - understanding of the legal status of speed limit information?
    - understanding of the legal status of lane closure information?
2. Will drivers be able to identify and comprehend ERAs, and their associated signing, such that they successfully stop within an ERA when informed of their vehicle developing a fault?
3. Do drivers display a preference for one of the two available design options for displaying a national speed limit symbol on an MS4 variable message sign?

3 TRL's Driving Simulator

TRL's car driving simulator, DigiCar (see Figure 1), provides an immersive experience to users and enables assessment of driver behaviour through a range of simulated experiences and events. Drivers are required to travel through a route representing a stretch of motorway on the network, including junctions and links. Both internal and external information is accurately reproduced ensuring drivers feel as if they are sitting in a real vehicle performing a real driving task. Quality audio and visual systems, combined with detailed external graphics contribute to making the experience as real as possible. The simulator is programmed to move to replicate the impact of acceleration, braking and turning.

Figure 1 - TRL Driving Simulator, DigiCar

TRL has a comprehensive database of more than 1,500 trial participants from the local area. Previous work has investigated numerous issues for the Highways Agency in relation to network management. This includes a series of trials for the Support to Managed Motorways project, which investigated driver behaviour in response to changes to the network brought about through dynamic use of the hard shoulder and through-junction running. Simulator trials were also run to investigate the use of Emergency Refuge Areas and dedicated lane schemes. This research contributed to an understanding of the levels of safety and intuitiveness of proposed designs for MM schemes.

The driving simulator requires the development of visual environment databases and traffic scenarios. Sub-contractors are utilised to support the creation of these.

4 Methodology

The basic research methodology was to have members of the driving public complete three drives in the TRL simulator, in each of which they experienced the same short stretch of motorway, differing only in the manner of information provision. The basic route comprised a 23km stretch of four-lane motorway with no hard shoulder. Information and instruction regarding the speed limit and lane status was provided in the form of overhead gantries, verge-mounted MS4 signs, and a combination of the two, thus making up the three simulator routes. Participants experienced all three conditions and their behaviour in each was assessed based on objective measures of their vehicle control and subjective responses to questionnaire interrogation. The intention was to see if there were discernable differences in driving behaviours and/or attitudes between the three information display configurations.

4.1 Participant Sample

A sample of 48 participants from the TRL participant database was used for this trial, with roughly equal numbers in terms of gender. Participants selected had not participated in any previous MM driving simulator trials at TRL. The behaviour observed in the study, therefore, represented a 'worst case' whereby drivers entering the MM scheme needed to respond to the information presented by variable message signs (VMS) or gantries but without previous experience of doing so in a MM context.

Age

Participants were assigned to one of two age groups for this study. The younger driver group was defined as those aged 17-44 years; the older driver group was defined as those aged 45+ years. This definition was selected since Campbell and Stradling (2003)[2] found that drivers in the 17-44 age range exhibited significantly different driving behaviour when compared to older drivers in that the younger group were more likely to drive faster if late for a meeting than older drivers. Previous simulator studies have shown that younger drivers tend to make better use of and show a better understanding of MM schemes, but are also more likely to disregard traffic regulations.

[2] Campbell, M. and Stradling, S.G., 2003, Factors influencing driver speed choices. In Behavioural Research in Road Safety XIII, pp. 233-244 (London: Department for Transport).

4.2 Route Design Options

This study included three routes, each utilising a different means of communicating information and instructions to drivers.

Route 1 – Gantry configuration

In this route variable speed limits and lane closures were communicated using lane-specific gantry-mounted indicators, with an MS4 variable message sign for supplementary text and pictograms, i.e. as in current MM schemes.

Figure 2 - Gantry mounted speed limit and lane information

Route 2 – Verge-mounted MS4 configuration

In this route, variable speed limits, lane closures and any supplementary text and pictograms were communicated using MS4 variable message signs only.

Figure 3 - Verge-mounted speed limit and lane information

Route 3 – Mixed configuration

In this route, variable speed limits, lane closures and supplementary text were communicated using a combination of overhead gantries (as in Figure 2) at some locations and verge-mounted MS4s only (as Figure 3) at other locations. Nominally the

distribution of these followed a cyclical pattern, with the first message presented on a gantry/MS4 followed by the next two on an MS4 only; and so on until the end of the route.

As the purpose of this study was to investigate driver behaviour in response to different means of communicating on-road driver information, all other features of the three routes were kept constant. This included:

- The length of the route – The route was a 23km stretch of motorway with no junctions. Although an uninterrupted stretch of this length is unlikely to occur in reality, it was not expected that this would affect the validity of any elements of this study.
- The information being communicated at each point – This meant consistency in the speed limits and lane closures being communicated at equivalent points in each route, (as in the example above) but also included consistency in any text or pictograms used.
- The spacing of driver information update points – gantries/MS4s were presented at 1500m intervals.
- The presence of emergency refuge areas (ERAs) at intervals along the route - Each ERA was identified by a sign immediately prior to its location; in addition each had a sign ½ mile in advance informing drivers of the ERA ahead.
- The additional signing and lane markings to communicate the presence of enforcement measures, i.e. horizontal white lines and speed camera signs.
- Lanes available for driving – This meant 4 permanent running lanes without a hard shoulder on all routes, consistent with current thinking on the future MM generic design.
- Traffic and scenarios – Described in further detail in 4.3 below.

4.3 Simulated Traffic and Scenarios

On each route both the speed limit and available lanes were varied to assess driver response to this instruction. Table 1 describes the generic layout of all three routes.

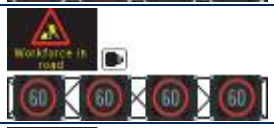
Table 1 - An overview of the generic route and important features

Section	Description of route features			
	Length (km)	Speed limit (mph)	Lane closures	Other
15	2.0	60	None	
14	1.5	60	None	In final drive only, participants told of a fault with vehicle
13	1.5	60	None	
12	1.5	70	None	
11.1	1.5	50	Lanes 3 & 4	Lanes 3 & 4 coned off
11				
10	1.5	50	Lanes 3 & 4	
9	1.5	50	Lanes 3 & 4 ahead	Message indicates workforce on the carriageway
8	1.5	60	None	
7	1.5	70	None	
6	1.5	70	None	Traffic introduced in lanes 1 & 2
5.1	1.5	50	Lane 1	obstruction in lane 1
5				
4	1.5	50	Lane 1 ahead	Message indicates obstruction in carriageway
3	1.5	60	None	
2	1.5	70	None	
1	0.5	70	None	
Lead-in	2.0	70	None	No other traffic on road

Direction of travel ↑

Table 2 shows the traffic management signing across the three routes.

Table 2 - Traffic management signs presented in each route

Section	Route 1 (gantry-only)	Route 2 (verge-only)	Route 3 (mixed)
15			
14			
13			
12			
11			
10			
9			
8			
7			
6			
5			
4			
3			
2			
1			

Direction of travel ➔

The purpose of this trial was to examine driver behaviour in response to on-road driver information. It was important, therefore, that the influence of other traffic was kept to a minimum. However, the presence of other traffic was necessary both to increase the realism of the simulated environment and to influence the lane in which participants were likely to choose to drive.

As the research required an understanding of how drivers respond to lane closure information it was important that in as many cases as possible the participant was driving in the lane (or one of the lanes) that was to be closed further downstream. The first closure, in Sections 4 and 5 (Table 1 and Table 2), was of Lane 1. Participants started the route in Lane 1 and traffic was sufficiently light that they did not need to leave Lane 1 to overtake another vehicle.

For the second closure, in Sections 9 through 11, traffic on approach (Sections 6 through 9) was slow moving relative to the variable speed limit being displayed. There was also no traffic in Lane 4. This encouraged the participant, who had been instructed to drive as if late for an important meeting, to position themselves into Lane 3 or Lane 4 as they approached the closure.

4.4 Experimental Groups

In addition to a familiarisation drive, each participant completed three drives in the simulator. The participant pool was split equally into six groups of eight so that the order in which participants experienced the three routes could be balanced to control for order effects. The table below shows the distribution of participants amongst the six groups.

Table 3 - Grouping of participants for trial order

Total (n=48)						
Drive	**Group 1 (n=8)**	**Group 2 (n=8)**	**Group 3 (n=8)**	**Group 4 (n=8)**	**Group 5 (n=8)**	**Group 6 (n=8)**
First	Route 1	Route 1	Route 2	Route 3	Route 2	Route 3
Second	Route 2	Route 3	Route 1	Route 1	Route 3	Route 2
Third	Route 3	Route 2	Route 3	Route 2	Route 1	Route 1

Before the start of each drive, all participants were instructed to "drive as if they were late for an important meeting." Previous TRL studies have shown that this instruction is effective at motivating participants to make good progress.

Once participants had passed the second gantry/MS4 of the lead-out section of their final drive they were informed that a fault had occurred with their vehicle and that they should bring the vehicle to a halt. This was to provide an indication as to how drivers may choose to react in a future MM environment in the event of a breakdown when no hard shoulder is provided. This is in addition to the main objectives of this trial but was included in the expectation that it would provide useful information about how drivers may behave in such a situation

4.5 Study Protocol

4.5.1 Participant Recruitment

Participants were selected from the TRL database of around 1,500 volunteers. Participants were members of the public who had (at least) previously attended a familiarisation session in the simulator and so were comfortable with its operation and driving in a simulated environment. As described in 4.1, participants recruited for this trial had not previously participated in trials relating to MM.

Participants were contacted over the phone and, if they were willing and able to participate in the trial, were sent an information pack including a confirmation letter. Participants were given a brief description of the study but were not provided with details regarding the research objectives to ensure that their behaviour was not influenced by such information when undertaking the trial.

The participants were scheduled to optimise utilisation of the driving simulator, allowing four to six participants to be trialled per day.

Appendix A provides an overview of TRL's policy relating to ethical integrity and data protection for research projects involving members of the public.

4.5.2 Trial Procedure

On the trial day, after an initial briefing, participants were asked to drive a short stretch of motorway in the simulator which allowed them to re-familiarise with the controls of the vehicle and to settle down to normal behaviour in the simulated environment. This took approximately 10 minutes.

The experimental design required each participant to drive on three test routes each lasting around 15-20 minutes. Participants were asked to complete short supporting assessment tasks (questionnaires). Each participant session lasted for approximately two hours; including introduction, familiarisation and debriefing.

Participants were instructed from beside the car to drive as they normally would. They were told that they should not drive as if they were on their driving test nor as if they were playing a computer game. They would not be judged so they should not feel anxious as TRL needed them to drive as they normally would in the real world. Participants were asked to drive as if late for an urgent meeting. This instruction has been successfully used in previous MM simulator trials and encourages participants to exploit whatever road space they consider appropriate in order to make best progress along the simulated route.

4.6 Analysis of Results

The data produced by the simulator trial contained measures of the behaviour of participants through each section of the driven routes.

The analysis focused on:

- Responsiveness to the on-road information being communicated – how accurately and quickly did participants respond;
- Speed choice – compliance with speed limits, "surfing" between information update points, acceleration or deceleration;
- Lane choice – If and when participants chose to move out of a lane that had been closed to traffic;
- Driver attitudes and perceptions towards a future MM environment; and
- How drivers chose to react when informed of a fault with their vehicle.

Participants each answered five questionnaires. The first was completed before the trial started and related to demographics. Participants then answered a questionnaire after each drive that asked them about their specific experiences related to the type of signing that they had just experienced; and finally they answered a questionnaire upon completion of all three drives that probed their overall experiences and asked them to make some comparisons between the three signing options.

Twelve key questions were asked over the course of the trial, typically requiring participants to rate their experience on a 10-point Likert scale (i.e. a bi-polar scale anchored at each end by an extreme statement/position with participants asked to mark the position that best reflected their own views).

Two approaches were adopted to interpret the data:

1. Within participants – examine the relative preference by each individual for the different conditions and count how frequently each condition is scored favourably.
2. Across participants – examine the scores for each condition as a whole to determine the average rating for each.

Method 1 provides information on the modal preference of one condition over another, but does not indicate the extent to which participants perceive the conditions to differ. Method 2 calculates a mean score and is thus open to possible skewing of the data from extreme or exaggerated values that may occur more frequently as result of the scale being ordinal rather than scalar, but does provide a measure of the size of the difference between conditions. Statistically Method 1 is more robust and so forms the primary analysis. Method 2 has been adopted as a secondary measure, to provide additional context.

All statistical tests, including for the simulator data, were performed using SPSS[3] (Version 19).

[3] Statistical Package for Social Sciences

4.6.1 Statistical and practical significance

In this analysis, statistical tests were used to determine whether or not differences between routes could be considered statistically significant. This study has only observed a sample of people over a limited number of drives and therefore there is a possibility that any differences between scenarios are the result of chance rather than a genuine trend in the population as a whole; statistical testing allows this possibility to be quantified. A difference is statistically significant if the probability of observing that difference, if the true difference is zero, is less than 5%, i.e. there is less than a 1 in 20 chance of that result occurring randomly.

Furthermore, even if a difference is found to be statistically significant, this does not mean that the difference is sufficiently large to be of practical importance. Practical significance is context specific and depends on the nature of the variables being studied and the application of the results. For example, when looking at vehicle speed a difference of 1mph may is unlikely to be viewed as practically significant.

Unless otherwise stated, the word 'significant' used in the following sections relates to statistical significance.

5 Key findings

This chapter is divided into four sections, as follows:

- 5.1: Driving behaviour – Speed choice
- 5.2: Driving behaviour – Changes in lane choice in response to lane closures
- 5.3: Driving behaviour – Response to vehicle fault
- 5.4: Questionnaires – Driver attitudes and perceptions

The results presented within these four sections relate to data collected from two distinct sources: Sections 5.1 to 5.3 relate to data taken from the simulator that provide objectives measures of driving behaviour; Section 5.4 relates to data obtained through participant questionnaires that provide subjective measures of participants' attitudes and perceptions. All 48 participants completed the simulator trials but the simulator data for three of these suffered some corruption and could not be included in the analyses. Sections 5.1 to 5.3 are therefore based on data from the remaining 45 participants. As all 48 successfully completed the practical aspects of the trials and completed the necessary questionnaires, Section 5.4 is based on data from all 48.

5.1 Driving behaviour – Speed Choice

5.1.1 Introduction

The driving simulator takes a measurement of the vehicle's speed and lateral position relative to the carriageway at 20Hz (i.e. every 20th of a second). These data were used to investigate participants' speed choice, how chosen speeds related to the instructions presented at each sign/gantry, and whether compliance with the speed limit was affected by the type of signing used or message displayed.

As an overview, Figure 4 illustrates the speed profiles generated by the simulator data across the entirety of the three routes, with average speed plotted every 50m. The lines

marked on the graphs indicate the location of the two obstructions (lane closures) that participants encountered.

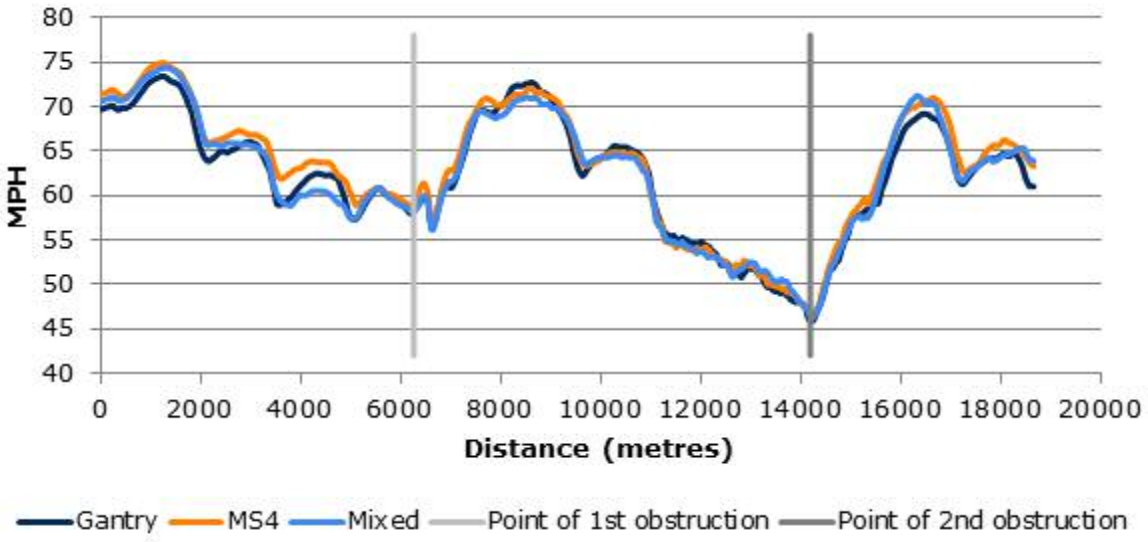


Figure 4 - Speed profiles for entire route averaged across all participants in each route configuration

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)

The following sub-sections address each of these three assessment measures, describing the key findings in relation to the speed choices of participants.

It should be noted that analysis of the speed assessment measures were not carried on all sections within the drives. The sections that were not included are described below (See Table 2 for an overview of the different sections along the route):

- Analysis was not undertaken for any speed assessment measures on the 'Gateway' sign (Section 1), since this was identical across signing layouts.
- No analysis was carried out on Sections 6 through 11 due to the presence of other traffic restricting participant speed choice.
- Within Sections 14 and 15 participants were informed of their vehicle developing a fault and that they needed to come to a stop. Given that this instruction was not given on all drives these Sections were also excluded from the analysis.

Because of the above sections being excluded, this resulted in speed data being analysed within two distinct parts of each route: The approach to, and transit through, the first obstruction (Sections 2 through 5); and the two sections immediately following the second obstruction (Section 12 and 13). These are herein referred to as Test Area 1 and Test Area 2 respectively.

5.1.2 Difference in speed profiles between drivers

Whilst Figure 4 gives an overview of average speeds across all drivers, it does not reveal how speed choice differed between drivers. Therefore, the participants were divided into four quartiles according to the average speed at which they drove through both test areas. Speed profiles for each of these quartiles were plotted. Only results for the mixed signing configuration were drawn as there was little difference between the three configurations (difference in speeds between signing configuration conditions are explored fully in 5.1.3).

Figure 5 shows driver speed for each of the four quartiles in Test Area 1 (in the mixed sign configuration). From this figure we can infer that there were two distinct groups of drivers; those who exceeded the speed limit by no more than 10mph and exhibited little 'surfing' behaviour (see 0 for an explanation of surfing behaviour), and those who exceeded the speed limit by a greater margin and exhibited the most surfing behaviour.

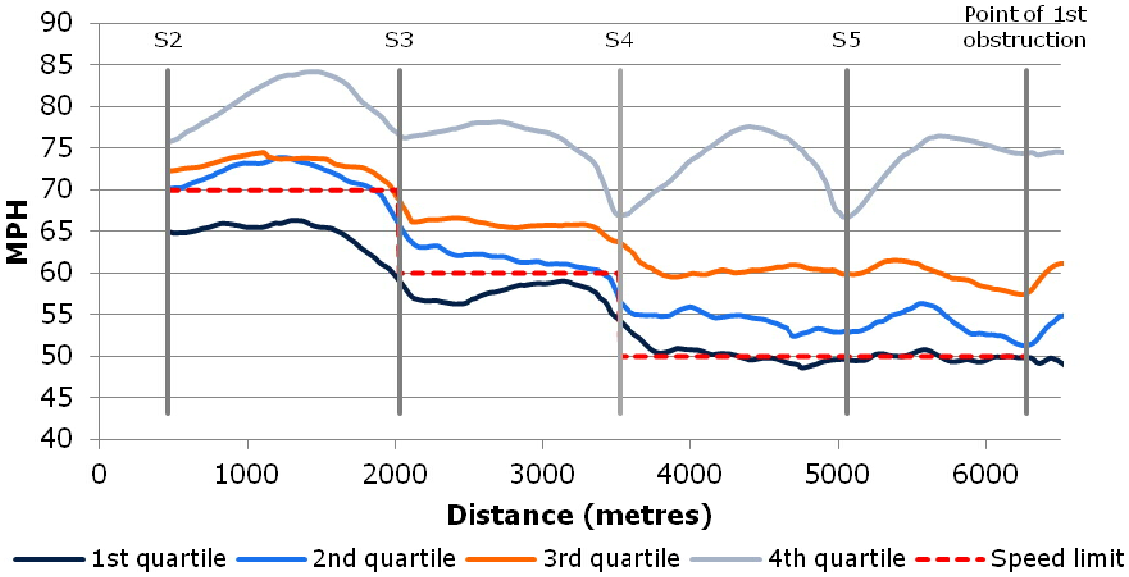


Figure 5 - Speed profiles for each speed quartile in Test Area 1.

The results for Test Area 2 can be seen in Figure 6. These results are similar to those for Test Area 1.

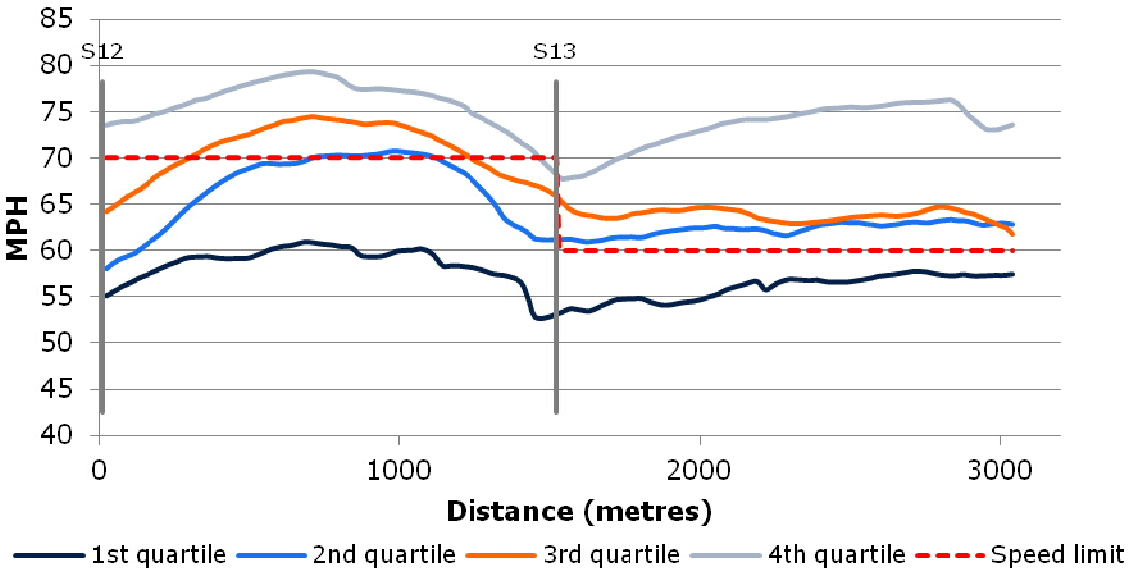


Figure 6 - Speed profiles for each speed quartile in Test Area 2.

Demographic information for those in each of the quartiles was extracted and reviewed for any different patterns between the quartiles (see Table 4). This information suggests the fastest drivers (4th quartile) were also the youngest (M = 34.2). Furthermore, there were marked more males in the 4th quartile than females (8 vs. 3). The 4th and the 1st quartile reported the lowest mean annual mileages of 7000 and 7900, respectively. Finally, there seemed to be little difference in the vehicle types normally driven between the quartiles, however, few participants drove vehicles other than cars, therefore it is unlikely that any differences could have emerged.

Table 4 - Demographic information for drivers within the four quartiles

	Quartile	Mean age (yrs)	Gender (M:F)	Mean years held licence	Mean estimated annual mileage	Count of vehicle types driven				
						M/cycle	Car	LGV	HGV	PSV
(Slowest)	1st	48.4	3:8	29.2	7900	0	11	1	0	0
	2nd	52.4	5:6	31.4	12950	0	11	2	0	0
	3rd	37.8	5:7	19.2	10000	1	12	1	0	0
(Fastest)	4th	34.2	8:3	15.1	7000	1	11	0	0	0

5.1.3 Differences in mean speeds between sign configuration conditions

Driver speed profiles for Test Area 1 (on approach to the first lane closure) can be seen in Figure 7.

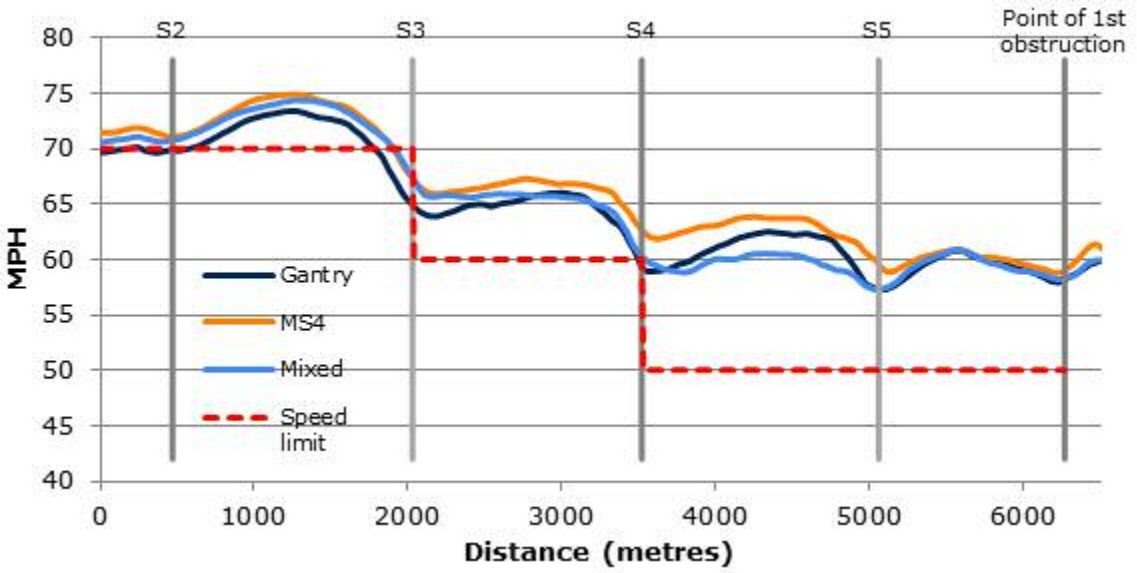


Figure 7 - Mean speeds across Test Area 1, for all sign configuration conditions

Driver speed profiles for Test Area 2 (after exiting the second lane closure) can be seen in Figure 8.

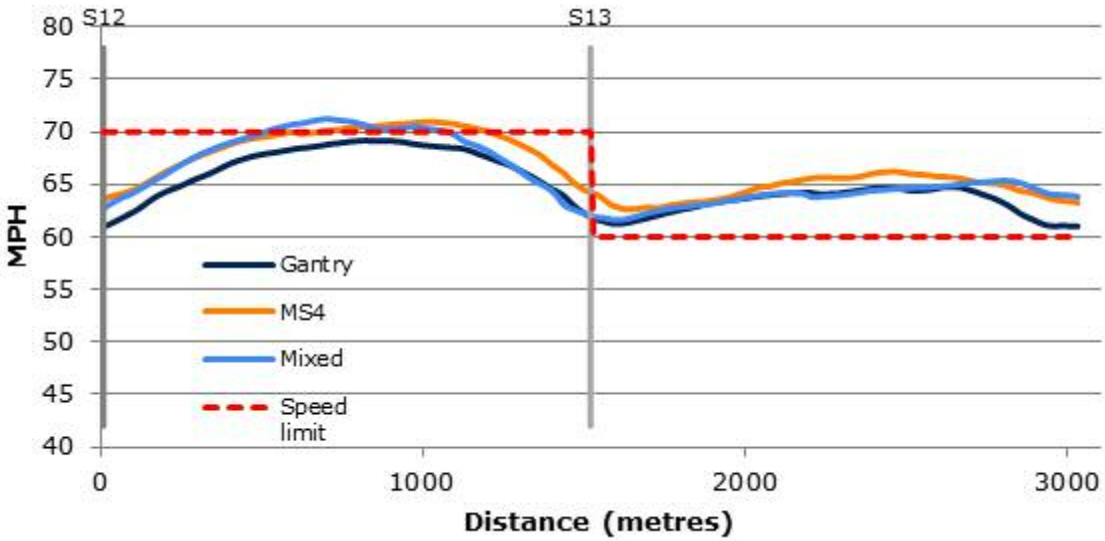


Figure 8 - Mean speeds across Test Area 2, for all sign configuration conditions

Inspection of these figures suggests limited difference in mean speeds between the three sign configurations in either test area. Across Test Area 1, mean participant speed was usually above the local speed limit, and tended to dip in the presence of a gantry/MS4 before climbing again shortly after it was passed. This behaviour is typically referred to as 'surfing'. Test Area 2 showed a similar pattern of surfing at the start of section 13, and mean speeds in section 13 were also generally above the local speed limit. However, in section 12, participant mean speeds were, for the most part, below the local speed limit. Note that section 11 included the second lane closure, therefore, participant speed in section 12 was likely to be a reflection of their acceleration back up to the national speed limit after passing the previous 50mph restriction.

The data were tested for any statically significant differences in mean speed between the three sign configuration conditions using the non-parametric Kruskal-Wallis Test. The results for Test Area 1 were significant ($H(2) = 53.07$, $p < .01$) - there was no significant difference in mean speed between the gantry and mixed conditions (M = 64.25, SD = 4.90; M = 64.45, SD = 5.60, respectively); however, the MS4 condition produced mean speeds of roughly 1mph higher the other two conditions (M = 65.79, SD = 5.00).

We can conclude that in Test Area 1, there was no difference between mean speeds in the mixed condition and the gantry condition. Drivers in the MS4 condition drove faster than in the other two conditions. Although this was statistically significant, the difference was slight in both cases (roughly 1mph).

A Kruskal-Wallis test was also performed on the data for Test Area 2 and this also produced a significant result ($H(2) = 57.85$, $p < .01$). Unlike the results for Test Area 1, the results for Test Area 2 showed more difference in their means (Gantry: M = 64.93, SD = 2.54; MS4: M = 66.57, SD = 7.10; Mixed: M = 65.93, SD = 8.60). Post-hoc Mann-Whitney tests showed that all three conditions are significantly different from each other (Gantry-MS4 – $U = 29626.0$, $p < .01$; MS4-Mixed – $U = 38499$, $p < .01$; Gantry-Mixed – $U = 36797.0$, $p < .01$).

In Test Area 2 only a very small (around 1mph), difference in mean speeds was observed. Mean speeds in the mixed condition were slower than the MS4 condition but faster than the gantry condition.

5.1.4 Variability in speed in relation to signs/gantries (i.e. "surfing")

Inspection of Figure 7 and Figure 8 suggests drivers reduced their speeds on approach to gantries/MS4s, and then accelerated away from them. This behaviour is labelled "surfing". The cause of surfing has been posited as driver speed choice adaptation to the presence of an enforcement camera or enforcement camera sign. In other words, in the presence of enforcement cameras drivers who are exceeding the speed limit reduce their speed to be compliant with signing, before returning to their preferred cruising speed.

Despite there being no sanction on drivers who exceed the speed limit in the simulator, observed behaviour suggested that drivers surfed during the trial. The magnitude of surfing was calculated as the difference in spot speed at a gantry/MS4 from the maximum speed the driver achieved in the subsequent section. This is plotted in Figure 9.

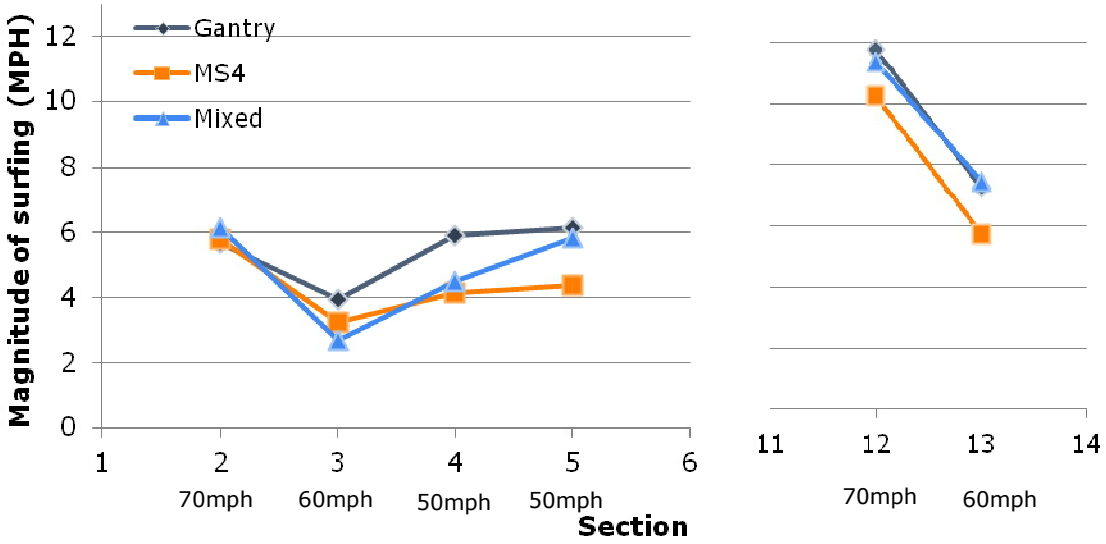


Figure 9 - Magnitude of surfing for Test Areas 1 and 2 (speed for each section listed below section number)

The differences in surfing magnitude between the three signing configuration conditions were analysed for each section using a Kruskal-Wallis Test. None of the differences reached statistical significance; see Table 19 in Appendix B for a full list of results.

These results demonstrate that there was no statistically significant difference in surfing behaviour between the three signing configuration conditions at any of the sections analysed within the two test areas.

5.1.5 Spot speeds at information update points

As observed in Figure 7 and Figure 8, mean participant speeds appeared to drop in the vicinity of each gantry; a behaviour associated with participants believing there to be speed cameras mounted at these locations. In order to determine whether the propensity for participants to slow down was influenced by the sign configuration, the spot speeds recorded at each gantry/MS4 location were compared (see Table 5).

Table 5 - Spot speeds at each gantry/MS4 within Test Areas 1 and 2 – Figures in blue represent gantries, those in orange represent MS4s.

	Section	Speed Limit	Spot speed at each gantry/MS4 in Test Areas 1 and 2			
			Gantry configuration	MS4 configuration	Mixed configuration	Total mean by section
Test Area 1	2	70	69.9	71.1	70.7	**70.5**
	3	60	65.2	67.7	67.8	**66.9**
	4	50	59.8	62.9	60.5	**61.1**
	5	50	57.4	59.8	57.3	**58.2**
Test Area 2	12	70	60.9	63.4	62.5	**62.3**
	13	60	61.8	64.2	62.0	**62.7**
		Total mean	**62.5**	**64.9**	**63.5**	**63.6**

A Kruskal-Wallis Test revealed a significant difference ($H(2) = 8.12$, $p = .02$) between the three signing configuration conditions. In order to determine how the conditions differed from each other pairwise comparisons were performed using the Mann-Whitney Test. These comparisons showed the spot speeds recorded during the mixed condition were not significantly difference from either the gantry or MS4 conditions. The mean spot speed in the MS4 condition was higher than the mean spot speed in the gantry condition to statistically significant level. However, this difference was only slight (2.5mph).

These results indicate that the mixed condition did not produce statistically significantly different spot speeds than the other two conditions. The MS4 condition produced spot speeds that were slightly higher than in the gantry condition.

5.1.6 Time spent exceeding speed limit

The percentage of time drivers spent above the speed limit was calculated for each section of Test Area 1 and Test Area 2 (see Figure 10). Initial analysis searched for an overall trend in the data, irrespective of the degree to which the speed limit was being exceeded. Subsequent to this, in order to understand any differences in behaviour between those who only slightly exceeded the speed limit from those who exceeded it to a higher degree, data were divided into two speed groups: those which were less than 10% over the speed limit; and speeds which were 10% or more over the speed limit. Figure 10 shows the data for both groups, with the total height of each column representing total time speeding across both speed groups.

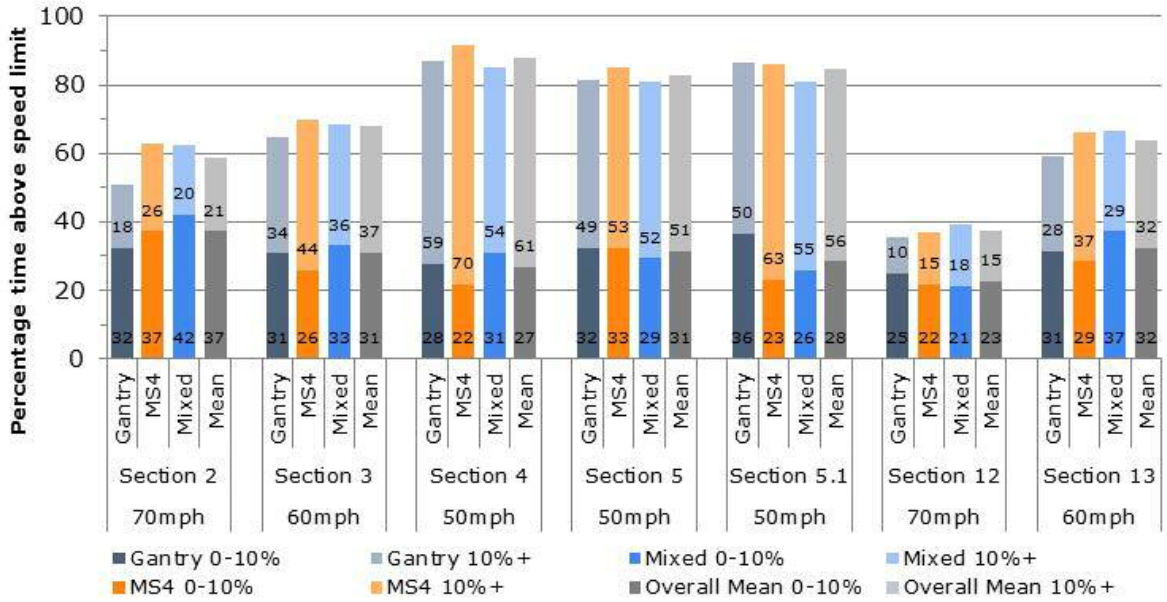


Figure 10 - Percentage of time spent above speed limit for each section, split by values less than 10% over the speed limit and values 10% or more over the speed limit

5.1.6.1 Results for time over the speed limit, irrespective of degree of infringement

Initial inspection of the data suggests the amount of time spent exceeding the speed limit in the test area (i.e. travelling at any speed greater than the displayed speed limit) was generally high, with a mean of 69% of time spent in excess of the speed limit (i.e. in non-compliance) for all drives. Following this, the data were examined for any differences in the time spent above the speed limit between the three sign configuration conditions across all test sections.

The difference in the overall time spent exceeding the speed limit between the three signing conditions across both test areas appears slight, with 66%, 71% and 69% time spent above the speed limit for the gantry, MS4 and mixed conditions respectively. However, a Kruskal-Wallis test showed this difference to be statistically significant ($H(2) = 6.29$, $p = .04$). Post-hoc Mann-Whitney tests showed the gantry vs. MS4 comparison was the only one to reach significance ($U = 44074.5$, $p = .01$).

Participants in the mixed condition spent 69% of the time exceeding the speed limit, which was not statistically different from the other two conditions. Participants spent significantly more time exceeding the speed limit in the MS4 configuration (71%) than the gantry configuration (66%) across all test sections.

5.1.6.2 Results for time over the speed limit for higher speed group

In order to understand the pattern of behaviour for those who exceeded the speed limit to a higher degree, the data was processed to retain cases where driver speed was at least 10% higher than the speed limit. The percentage of time spent 10% over the speed limit for each section, under each signing configuration condition, can be seen in Figure 11.

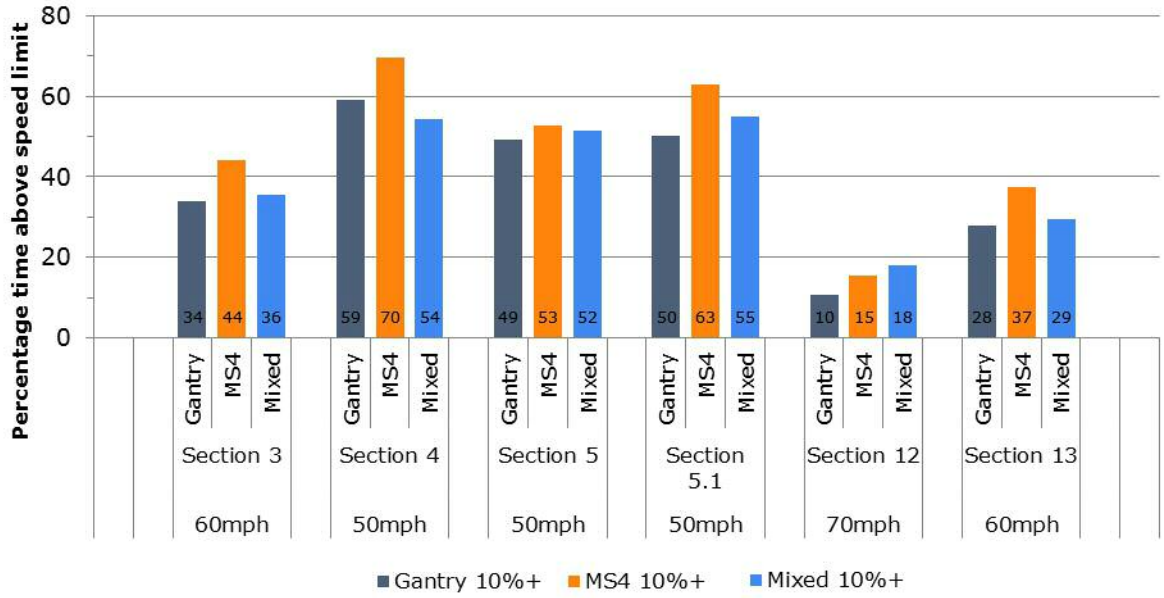


Figure 11 - Percentage of time spent above speed limit for each section, only for values 10% or more over the speed limit

This figure reveals that in all but one section (section 12) there was more infringement of the speed limit by at least 10% in the MS4 condition than in the other two conditions; and in all but Section 4 there was more infringement by at least 10% in the mixed condition than in the Gantry condition.

This interpretation is corroborated by inspection of the overall time spent more than 10% over the speed limit across all sections for the three conditions (gantry M = 35%; MS4 M = 44%; mixed M = 38%); the highest percentage of time is in the MS4 condition. In order to determine whether this apparent difference was statistically significant, a Kruskal-Wallis test was performed on the data. The results of this test narrowly failed to

reach significance ($H(2) = 5.52$, $p = .06$), but they do suggest the possibility of a pattern within the data which any similar future research could explore.

Subsequent to this, the data for the three signing configuration conditions were examined for any significant differences within each section; none of the results reached significance.

These results suggest that there was no statistical difference in the percentage of time spent more than 10% above the speed limit between any of the three signing configuration conditions.

5.2 Driving behaviour – changes in lane choice in response to lane closures

The number of drivers in the lane/lanes subject to closure at the first and second obstruction were analysed for differences in behaviour according to the sign configuration condition.

On approach to the first lane closure, signing indicated that drivers should begin to move out of Lane 1. This was followed by signing showing Lane 1 was then closed to traffic. See Figure 12 for an illustration of the signs seen in each signing condition.

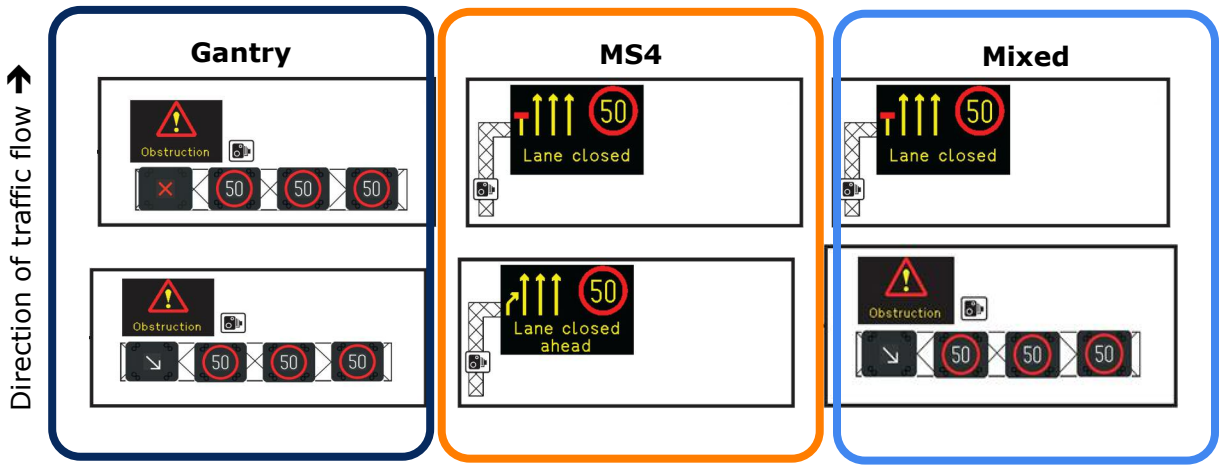


Figure 12 - Signing used in gantry, MS4 and mixed conditions on approach to first lane closure.

On approach to the second lane closure, signing also indicated that participants were to move out of Lanes 3 and 4, before the next two signing locations displayed information stating Lanes 3 and 4 were closed (see Figure 13).

Figure 13 - Signing used in gantry, MS4 and mixed conditions on approach to second lane closure.

5.2.1 First closure

Figure 14 shows the number of drivers in the lanes subject to closure on approach to the first obstruction (Sections 3 through 5.1). The figure shows that the majority of participants moved out of lane 1 upon, or shortly after, encountering the first sign warning of a lane closure ahead (dashed yellow line). Around 70% of participants in Lane 1 500m before the gantry/MS4 and had moved out of Lane 1 500m after the gantry/MS4 on all routes.

There is then a further group who moved out upon, or shortly after, encountering the second sign denoting the lane closure (dashed brown line). A very small minority continued to drive in the closed lane until shortly before the obstruction itself (dashed red line). There was a trend amongst drivers to comply with lane closure notification signing (the first dashed yellow line), however a small minority of drivers did not comply and drove in sections of the route which were closed to traffic (the dashed brown line marks the earliest position where the lane was closed).

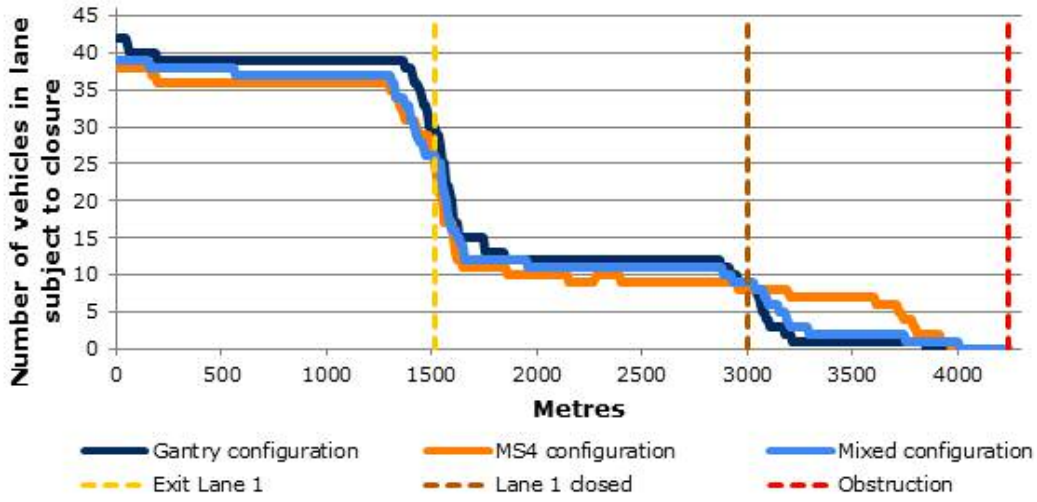


Figure 14 - Number of vehicles in Lane 1 on approach to, and throughout the first lane closure

The data can also be plotted to show the position at which each participant left lane 1 (see Figure 15) Note that it was possible for a participant to exit lane 1 and to move back into it again before the obstruction – in such cases only the final exit position is plotted. These data were then compared for any statistically significant differences using a Kruskal-Wallis test: the results of which were not significant ($H(2) = 2.4$, $p = .30$). Both Figure 14 and Figure 15 appear to show a greater propensity for drivers in the MS4 condition to remain in lane 1 beyond the start of the closure, however, as shown, this does not yield any statistical significance.

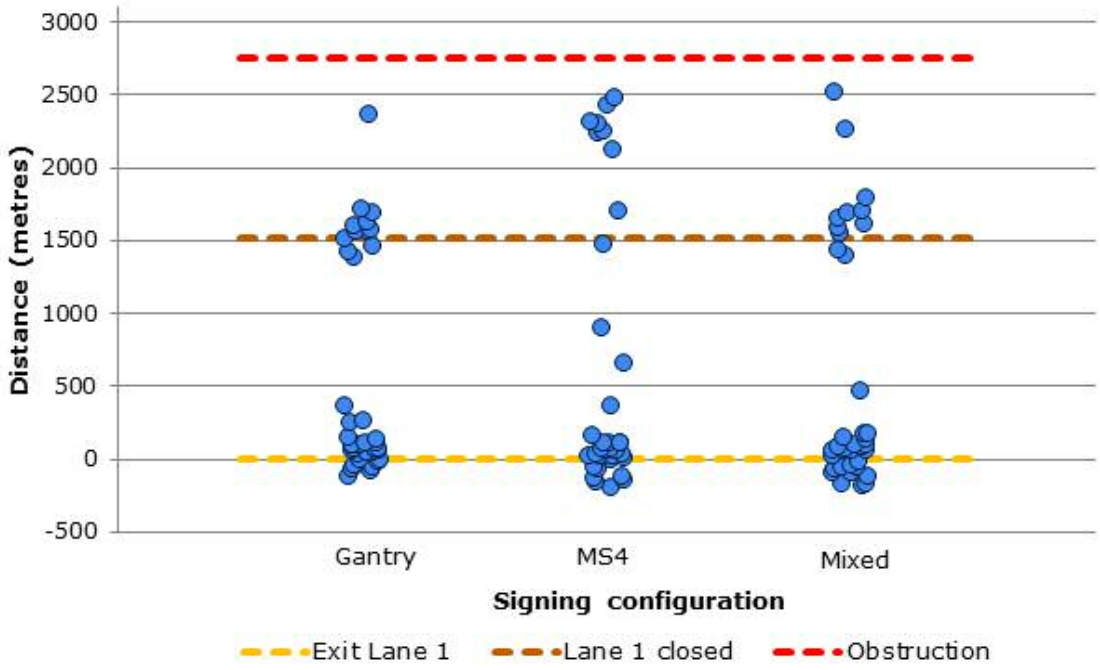


Figure 15: Position where each driver in the lane subject to closure exited the lane, for the first lane closure

There was no statistical difference across route configurations in the point where participants moved out of the lane subject to closure on the approach to the first obstruction. It was observed that the majority of participants moved out of lane 1 upon, or shortly after, encountering the first sign warning of a lane closure ahead on all routes.

5.2.2 Second closure

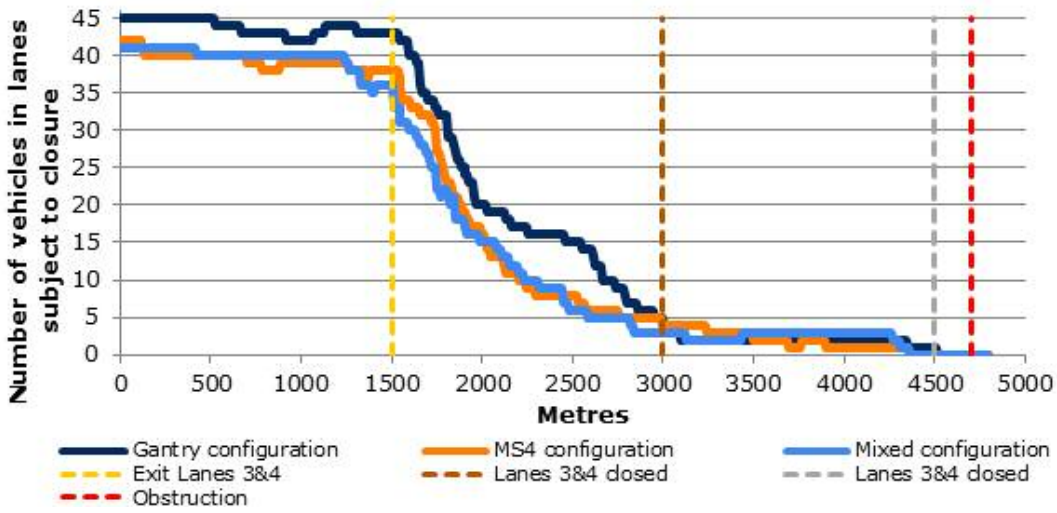


Figure 16 - Number of vehicles in Lane 3 or 4 on approach to, and throughout the second lane closure

In advance of the second obstruction, Lanes 3 and 4 were closed to traffic. As with the first closure the data can be plotted as the numbers of drivers remaining in lanes 3 and 4 on approach, and the position at which drivers moved out of lanes 3 and 4 (see Figure 16 and Figure 17 respectively). A similar trend to the first closure can be seen, with the majority moving out on first seeing the sign informing of a closure ahead, although in this case this is seemingly spread out over a longer distance. The data were compared for any statistically significant differences using a Kruskal-Wallis test: the results of which were not significant ($H(2) = 1.77$, $p = .41$).

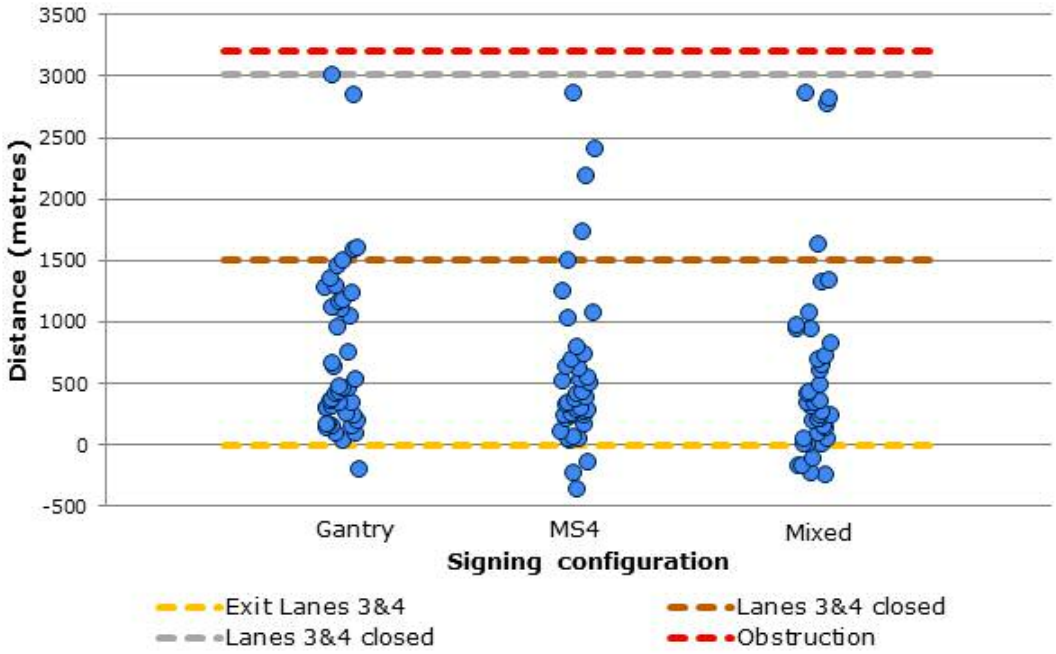


Figure 17 - Position where each driver in the lanes subject to closure exited the lanes, for the second lane closure

There was no statistical difference across route configurations in the point where participants moved out of the lanes subject to closure on the approach to the second obstruction. As with the first closure the majority of participants moved out of Lane 2 on first seeing the sign informing of a closure ahead, although spread out over a longer distance.

5.3 Driving behaviour – response to vehicle fault

At the end of their third drive, participants were given the following instruction: "Your vehicle has developed a fault; please stop the vehicle as soon as possible where you think it would be appropriate to do so". For all participants the instruction of a vehicle fault was given 1.25km upstream of an ERA and 400m upstream of a sign stating 'emergency refuge ½ mile ahead'. The reason for this instruction was to gain an insight into participants' awareness of ERAs with regards to their purpose and their distribution, as well as an indication of the practicalities of identifying and manoeuvring into the ERA. For each participant the lane in which they stopped and the position along the route was recorded.

Given that each participant only experienced a breakdown scenario once and the ordering of drives differed between groups, not all participants experienced the breakdown under identical experimental conditions. However, the three databases were designed to differ only in the presentation method of lane and speed limit information. The signs informing of ERAs, and the ERAs themselves, were consistent across all three databases and were thus the same for all participants in this scenario.

Table 6 shows the distribution of where participants brought the vehicle to a halt after being informed of a vehicle fault. The table starts 1250m before the ERA, at the point at which the instruction of the vehicle fault was given. At 850m before the ERA, participants passed the 'ERA ½ mile' sign. 48 participants participated in the trial; however three were ultimately excluded from the analysis due to corrupted data. Of the 45 participants included:

- 11 (24.4%) stopped before the ERA,
- 29 (64.4%) stopped successfully within the ERA, and
- 5 (11.1%) stopped beyond the ERA.

Table 6 – Numbers of participants stopping at different locations after being informed of a vehicle fault

Distance from ERA that participant stopped (m)	Lane in which participant stopped				
	ERA / Verge	Lane 1	Lane 2	Lane 3	Lane 4
+1400		1			
+1300					
+1200			1		
+1100		2			
+1000					
+900					
+800					
+700					
+600					
+500					
+400					
+300					
+200					
+100		1			
(ERA)	29				
-100					
-200	2				
-300		1			
-400					
-500		2			
-600		3			
-700		1			
-800		1			
-900					1
-1000					
-1100					
-1200					
Participant informed of vehicle fault 1250m from start of ERA					

Direction of travel ↑

In interpreting these figures, it must be stated that it is not known for sure what caused the 16 who did not stop within the ERA, not to do so. Of the 11 who stopped prematurely it is possible that some misheard or misunderstood the instructions, that some were not aware of the presence of an ERA ahead or simply that some chose to stop without thinking through the consequences of their actions. One stopped in lane 4, eight stopped in lane 1 and two stopped on the grass verge. Of the five who stopped beyond the ERA it is believed that one attempted to stop but slightly over-ran and that the remaining four may have intended to stop but did not successfully make it over to lane 1 in time due to other traffic. It is thought that upon failing to make it into the ERA they chose to continue, possibly to the next available ERA or to the next junction.

With regards to the drivers who may have failed to make it into the ERA due to other traffic, this perhaps represents a worst-case scenario. Typically drivers rate it slightly harder to merge into traffic within the simulator than on the real road network. As such some of those who felt unable to merge in this task may have been more successful in a real-world setting.

It was observed that the majority of participants (64%) stopped in the ERA. Two participants stopped on the verge prior to the ERA, one in Lane 2 and one in Lane 4. The remaining participants stopped in Lane 1.

5.4 Questionnaires – driver attitudes and perceptions

12 key questions were asked over the course of the trial and the following section presents the statistical analysis for the responses to each of these 12 questions. Note that the questions below have been adapted for brevity and some represent an amalgamation of two or three questions asked independently after each drive. For all questions the statistical tests performed were non-parametric tests (Kolmogorov-Smirnov and Shapiro-Wilk tests showed the distributions for all to be non-normal and therefore unsuitable for testing using parametric statistics.)

Question 1

'How often during each drive were you unsure of which lanes were open or closed?' (1 = never, 10 = always)

Table 7 – Frequency table of participant responses to Question 1

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Gantry-only	28	9	4	3	1		1		1	1	2.1
Verge-only	24	11	9		1			1		1	2.1
Mixed	25	11	6	2	1		2			1	2.1

A Friedman test was conducted which showed no statistically significant differences in within-participant scores across the three configurations. (p=0.669).

Participants reported an equally high degree of certainty about which lanes were open or closed across all three routes.

Question 2

'How often during each drive were you unsure of the speed limit?'
(1 = never, 10 = always)

Table 8 - Frequency table of participant responses to Question 2

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Gantry-only	30	10	6		1					1	1.7
Verge-only	29	8	5		1	2	1	1		1	2.1
Mixed	23	7	9	4	2	1	1			1	2.4

Participants' ratings suggest that they were rarely unsure of the speed limit in the all three routes. A Friedman test showed that there was a statistically significant difference in the scores within participants across the three drives (p=0.026). Post-hoc Wilcoxon sign-rank tests showed that the 'gantry-only vs mixed' pairing was the only one to reach a statistically significant difference (p=0.023); thus it can be said that participants were more likely to feel more unsure about the speed limit in the mixed condition than in the gantry-only condition. Comments from participants associated with the verge-only and mixed conditions incorporated the following themes:

- Participant was unsure if the speed limit applied to all lanes or to a single lane
- Participant didn't know if the speed cameras monitored all lanes or just the inside lane
- Participant was unsure if the speed limit was advisory or mandatory

Participants reported a high degree of certainty of what the speed limit was across all three routes, although participants were slightly less sure in the mixed route than in the gantry route.

Question 3

'"The pictures shown in Figure 18 clearly convey that lane 1 is closed to traffic" Please rate your level of agreement with this statement for each picture.'
(1 = strongly disagree, 10 = strongly agree)

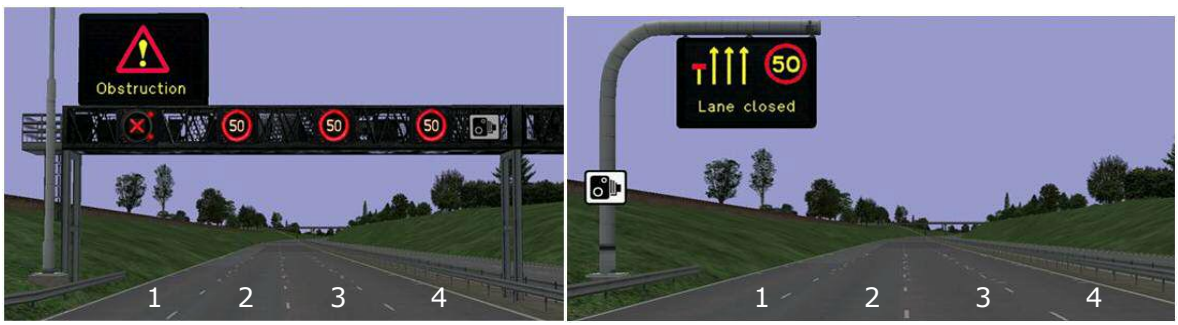


Figure 18 - Depictions of gantry and verge-mounted signs shown to participants

Table 9 - Frequency table of participant responses to Question 3

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Gantry	1				1		2	2	3	39	9.4
Verge	2					1	1	1	3	40	9.4

The mean scores indicate a high level of understanding for both conditions. A Wilcoxon sign-rank test showed no statistically significant difference in within-participant scores between the gantry and verge-mounted signs (p=0.758).

Question 4

'"The speed limits displayed in the pictures in Figure 18 would be clearly visible to traffic in all lanes" Please rate your level of agreement with this statement for each picture.' (1 = strongly disagree, 10 = strongly agree)

Table 10 - Frequency table of participant responses to Question 4

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Gantry			1		2			5	3	37	9.4
Verge		1	1	1	2	4	3	7	4	25	8.5

A Wilcoxon sign-rank test showed that there was a statistically significant difference in within-participant scores between the gantry and verge-mounted signs (p=0.006). Overall, the gantry signs were regarded as being more visible than the verge signs (19 participants rated the gantry as more visible, 3 the verge signs more visible and 26 rated them equally). It is likely that this relates in part to a feeling amongst some participants that the verge signs could be obscured by large vehicles, as this was commented on in relation to questions 1 and 2 and also to question 8. Despite this, the mean scores for both conditions remain high.

Question 5

'"In the pictures in Figure 18 the lanes which were open to traffic would be clearly visible to traffic in all lanes." Please rate your level of agreement with this statement for each picture.' (1 = strongly disagree, 10 = strongly agree)

Table 11 - Frequency table of participant responses to Question 5

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Gantry				1		2	3	5	3	34	9.3
Verge		1	1		2	4	3	8	3	26	8.6

A Wilcoxon sign-rank test showed that there was a statistically significant difference in within-participant scores between the gantry and verge-mounted signs (p=0.025). Overall, the gantry signs were regarded as being more visible than the verge signs (20 participants rated the gantry as more visible, 5 the verge signs more visible and 23 rated them equally). That both Questions 4 and 5 revealed the same finding is as expected because the information is presented in similar locations for both.

Question 6

'For each picture in Figure 18 *do you understand compliance with the speed limit to be:'*

- 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)*

Table 12 - Frequency table of participant responses to Question 6

	Answer			
Condition	Mandatory	Compulsory	Advisory	Informatory
Gantry	40	5	3	
Verge	39	6	3	

The vast majority of participants understood the speed limit to be either mandatory or compulsory regardless of whether presented on a gantry or MS4. A Wilcoxon signed rank test revealed no statistically significant difference in within-participant responses between the two signing options (p=0.317). Note that for the purposes of analysis for this question and question 7, responses were ranked ordinally with 'mandatory' assigned

a score of 0 down to 'informatory' as a 3 ('Mandatory' is the correct response to this question).

An equally high number of participants (45 out of 48) understood compliance with a variable speed limit to be either mandatory or compulsory on gantries and MS4s.

Question 7

'For each picture in Figure 18 do you understand compliance with the lane closure to be:'

- *Mandatory*
- *Compulsory*
- *Advisory*
- *Informatory*

Table 13 - Frequency table of participant responses to Question 7

	Answer			
Condition	Mandatory	Compulsory	Advisory	Informatory
Gantry	35	10	2	1
Verge	35	10	1	2

A Wilcoxon signed rank test revealed no statistically significant difference in the within-participant responses between the two signing options (p=0.655).

Questions 8 to 11 refer to Figure 19 below.

An equally high number of participants (45 out of 48) understood compliance with lane closure instructions to be either mandatory or compulsory on gantries and MS4s.

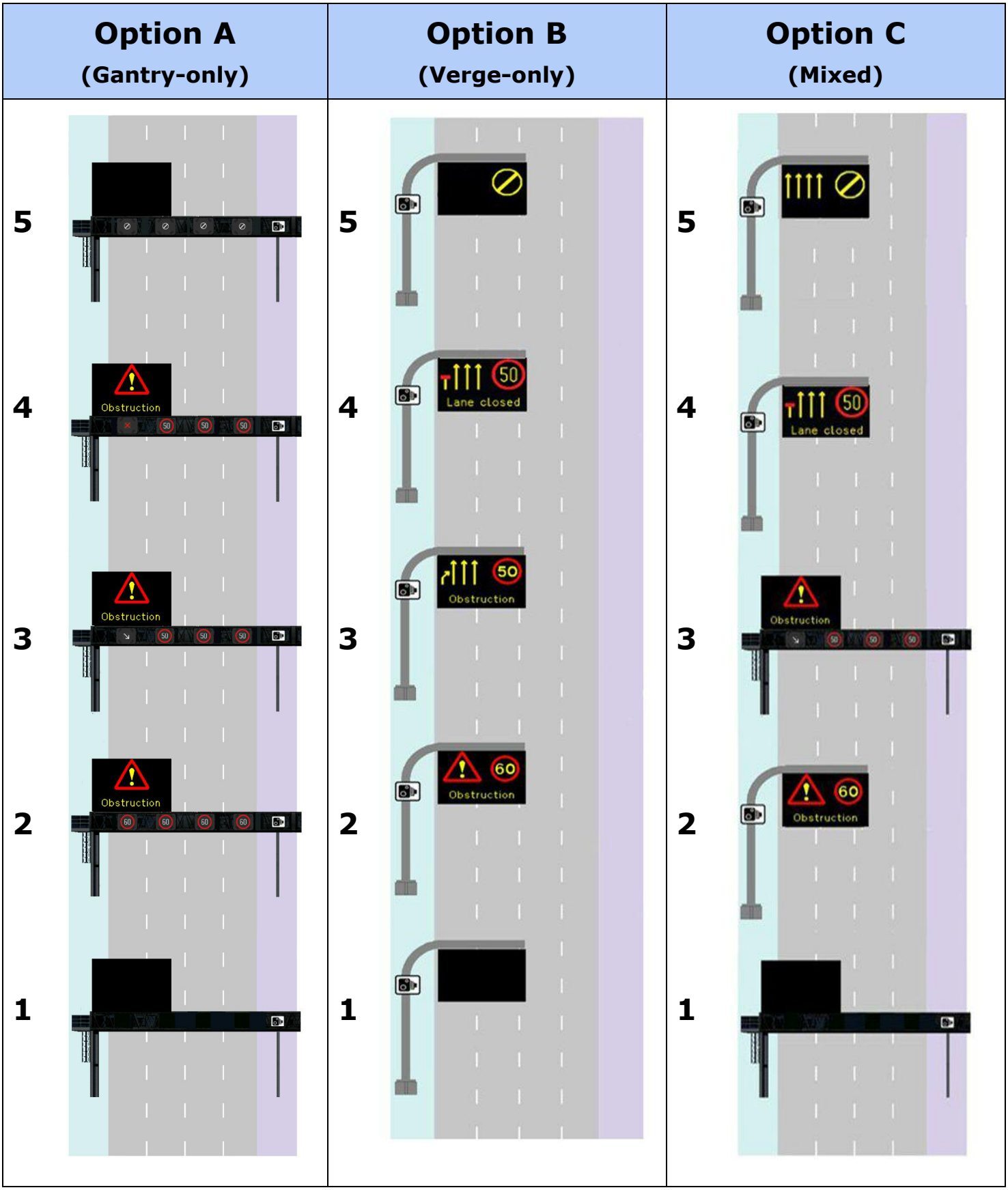


Figure 19 - Signing options presented to participants within questionnaire

Question 8

'Signs 2 to 4 for each option in Figure 19 show a lane 1 closure. Please rate how clearly you think each option shows this.' (1 = not at all clear, 10 = very clear)

Table 14 - Frequency table of participant responses to Question 8

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Option A (Gantry only)	2		4	4	4	3	3	5	10	12	7.2*
Option B (Verge only)					2	4	4	8	9	19	8.6*
Option C (Mixed)		1	2		7	5	7	10	6	9	7.4*

A Friedman test showed that there was a statistically significant difference in within-participant scores across the three options (p=0.008). However this difference was related primarily to differences between the verge-only condition and the other two. The gantry-only and mixed conditions both scored similarly. It is likely that this was in some way influenced by people finding it hard to discern the over-lane signs on the gantries because of their small size, as this comment was either made explicitly or alluded to by several participants. However, a few also said they liked that the information was all in one place for the verge signs and they did not need to scan several lanes. Negative comments for the verge-signs typically related to fears that the signs could be obscured by large lorries. One comment that was raised in relation to all options was that Sign 2 did not give any indication of which lane was obstructed, and none gave any indication of how far away the obstruction was. One participant also stated that he would prefer more information than simply 'obstruction'; e.g.: "breakdown", "accident", "repair work", "run-away-horse" or "lost load"; so that the driver can make a judgement about the likely hazards.

**Note that one participant failed to complete this question and so there are 47 scores relating to each condition.*

Question 9

'Signs 2 to 4 for each option in Figure 19 show a reduction in the speed limit to 50mph. Please rate how clearly you think each option shows this.'
(1 = not at all clear, 10 = very clear)

Table 15 - Frequency table of participant responses to Question 9

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Option A (Gantry only)	2	1		3		4	2	6	13	15	8.0*
Option B (Verge only)	1		2				5	4	12	22	8.7*
Option C (Mixed)	1	1		1	4	3	5	11	8	12	7.8*

A Friedman test revealed no statistically significant difference in within-participant scores across the three conditions (p=0.114).

**Note that two participants failed to complete this question and so there are 46 scores relating to each condition.*

Question 10

'Sign 5 for each option in Figure 19 shows that lane 1 is open to traffic again. Please rate how clearly you think sign 5 in each option shows this.'
(1 = not at all clear, 10 = very clear)

Table 16 - Frequency table of participant responses to Question 10

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Option A (Gantry only)	8	2	2	3	3	1	5	5	5	13	6.4
Option B (Verge only)	6	3	2	1	4	3	2	9	7	11	6.6
Option C (Mixed)							1	4	7	36	9.6

A Friedman test showed a statistically significant overall difference in within-participant responses across the three groups (p<0.001). Options A and B scored similarly but option C was rated as being clearer. It is worth noting that some participants made comments suggesting that they did not see the national speed limit signs above each lane in option A, instead believing it to be a depiction of a blank gantry. This is likely to have lowered the overall rating of clarity for option A, compared to what might have

been if it was presented at a larger scale. The findings do however show a clear preference for option C compared to option B. (i.e. an MS4 with a national speed limit symbol and four lane arrows rather than just the national speed limit symbol). However, because of the associate participant comments the result warrants further, more detailed investigation. If Option A is removed from the data, three participants rated Option B as clearer, 35 Option C as clearer and 10 rated them equally.

When presented with a layout of each of the signing options, participants reported the mixed route to be clearer in communicating that Lane 1 was open again to traffic following a closure.

Question 11

'Sign 5 in each option in Figure 19 shows that the national speed limit applies again. Please rate how clearly you think sign 5 in each option shows this.'
(1 = not at all clear, 10 = very clear)

Table 17 - Frequency table of participant responses to Question 11

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Option A (Gantry)	2	4	3	2	2		6	4	6	15	7.1*
Option B (Verge)	1		1	1	2	2	4	7	7	21	8.4*
Option C (Verge)			1		1		1	5	6	32	9.3*

This question was similar to Question 10 and invoked similar responses. A Friedman test again showed statistical significance ($p<0.001$) with a clear preference shown for Option C.

**Note that two participants failed to complete this question and so there are 46 scores relating to each condition.*

Question 12

'The two pictures in Figure 20 below both show how the national speed limit sign could be presented on a single large sign. For each picture please state how clear you think the meaning of the sign is.' (1 = not at all clear, 10 = very clear)

Sign 1 **Sign 2**

Figure 20 - Two options for national speed limit sign shown to participants

Table 18 - Frequency table of participant responses to Question 12

	Answer rating										
Condition	1	2	3	4	5	6	7	8	9	10	Mean score
Sign 1	1		3		2	3	4	3	4	27	8.4*
Sign 2	7	1	3	2	7	2	5	5	7	7	6.1*

A Wilcoxon signed rank test showed a statistically significant difference between within-participant scores for the two signs (p=0.001). with sign 1 rated preferentially. Sign 1 displays the national speed limit using the legend that is currently used on variable signs and signals. This is perhaps one reason why participants found it clearer.

**Note that one participant failed to complete this question and so there are 47 scores relating to each condition.*

Participants found the current means of displaying the national speed limit clearer than an 'inverted' image communicating the same thing.

6 Conclusions

In summary, the following conclusions can be drawn from this study:

- In Test Area 1, there was no difference between mean speeds in the mixed condition and the gantry condition. Drivers in the MS4 condition drove faster than in the other two conditions. Although this was statistically significant, the difference was slight in both cases (roughly 1mph).
- In Test Area 2 only a very small (around 1mph), difference in mean speeds was observed. Mean speeds in the mixed condition were slower than the MS4 condition but faster than the gantry condition.
- Results demonstrate that there was no statistically significant difference in surfing behaviour between the three signing configuration conditions at any of the sections analysed within the two test areas.
- Results indicate that the mixed condition did not produce statistically significantly different spot speeds than the other two conditions. The MS4 condition produced spot speeds that were slightly higher than in the gantry condition.
- Participants in the mixed condition spent 69% of the time exceeding the speed limit (i.e. travelling at any speed greater than the displayed speed limit), which was not statistically different from the other two conditions. Participants spent significantly more time exceeding the speed limit in the MS4 configuration (71%) than the gantry configuration (66%) across all test sections.
- Results suggest that there was no statistical difference in the percentage of time spent more than 10% above the speed limit between any of the three signing configuration conditions.
- There was no statistical difference across route configurations in the point where participants moved out of the lane subject to closure on the approach to the first obstruction. It was observed that the majority of participants moved out of lane 1 upon, or shortly after, encountering the first sign warning of a lane closure ahead on all routes.
- There was no statistical difference across route configurations in the point where participants moved out of the lanes subject to closure on the approach to the second obstruction. As with the first closure the majority of participants moved out of Lane 2 on first seeing the sign informing of a closure ahead, although spread out over a longer distance.
- The majority of participants (64%) stopped in the ERA. Two participants stopped on the verge prior to the ERA, one in Lane 2 and one in Lane 4. The remaining participants stopped in Lane 1.
- Participants reported an equally high degree of certainty about which lanes were open or closed across all three routes.
- Participants reported a high degree of certainty of what the speed limit was across all three routes, although participants were slightly less sure in the mixed route than in the gantry route.

- An equally high number of participants (45 out of 48) understood compliance with both variable speed limits and lane closure instructions to be either mandatory or compulsory on gantries and MS4s.
- When presented with a layout of each of the signing options, participants reported the mixed route to be clearer in communicating that Lane 1 was open again to traffic following a closure.
- Participants found the current means of displaying the national speed limit clearer than an 'inverted' image communicating the same thing.

Overall, the results suggested that in the mixed route (i.e. the general design approach outlined in IAN161/12) participants understood the information presented to them and exhibited appropriate driving behaviour.

7 Discussion

7.1 Primary objective

The primary objective of this driving simulator trial was:

To assess driver behaviour and compliance in response to on-road driver information communicated through a combination of verge-mounted MS4 variable message signs and fully equipped gantries in a controlled environment.

This was achieved by studying the following measures in a Mixed route (with gantries and MS4s) along with a Gantry and MS4 only route:

- Mean speed
- Spot speed
- Time exceeding the speed limit
- Surfing
- The location at which participants moved out of lanes subject to closure

7.1.1 Driver behaviour in the Mixed route

Mean speed in the mixed route was usually higher than the displayed speed limit and the average time spent exceeding the speed limit was found to be greater than 50% in most cases. The average time spent at speeds greater than the 'Speed Limit + 10%' was between 18% and 54%. The greatest levels of non-compliance were found in the 50mph sections, although it should be noted that these speed limits were displayed under free-flowing conditions and with participants driving under the instruction that they were 'late for an urgent meeting'.

The average spot speed under gantries/MS4s were also found to be higher than the displayed limit for all but one locations but were closer to the displayed limit than the mean speed on the related downstream section. This behaviour is further illustrated through the 'surfing' measure (the average difference between the spot speed under the gantry/MS4 and the maximum speed on the following section) which was between 2.7 and 11.4 mph depending on the section.

On the approach to the first closure 39 participants were in Lane 1. 28 of those moved out in the vicinity of the instruction to 'move out of lane', communicated by a gantry with a Lane Divert Right arrow. A further 10 moved out in response to the 'wicket' on the MS4. One participant apparently waited for the obstruction to become visible before moving out.

At the second closure 35 out of 41 participants moved out in response to the 'move out of lane' instruction, communicated this time by an MS4 with a wicket. The spread of the lane changes was greater than in the first closure, presumably due to participants taking time to find a suitable gap in the high proportion of traffic in Lanes 1 and 2. Again there were a small number of participants (three) that waited until reaching the physical closure before moving out of the closed lane.

7.1.2 Comparison with Gantry route

On all of the assessment measures listed above there was found to be no statistically significant difference in behaviour between participants driving in the Gantry route and the Mixed route, with the following exception: in the 70mph then 60mph sections following the second lane closure mean speeds were found to be higher on the Mixed route than on the Gantry route. However although achieving significant, this was only a difference of 1mph so is of little practical significance.

The questionnaire suggested that there was a statistically significant difference in the reported certainty of the speed limit between Mixed and Gantry routes. However, both results were high and the actual simulator speed data suggests that any uncertainty that participants had, had little or no discernible effect on driver behaviour.

7.1.3 Effect of gantries in the Mixed route

Some results of the trial suggest that the similarity in behaviour between the Gantry and Mixed layout does not simply imply that using MS4s instead of gantries has no impact on behaviour. This is because there were small but significant differences found between the Gantry-only and MS4-only routes; mean speed, spot speed and time spent exceeding the speed limit measures were all found to be significantly higher in the MS4 only route.

The fact that this small difference is less pronounced between Mixed and Gantry routes suggests an influence on compliance of the presence of occasional gantries (nominally 1 in 3), not just at those gantries but throughout the whole route. Looking at the spot speeds observed at particular locations on the Mixed route, it can be seen that when an MS4 is used to convey the speed the spot speed is closer to that of the MS4 only route, but the greater compliance at gantries brought the average down such that no significant difference between the Mixed and Gantry routes was found.

This observation in behaviour appears only to apply to speed. At both closures no significant difference was found between any of the routes in the average location that participants chose to leave the closing lane.

This is supported by the questionnaire; drivers were reported a low level of uncertainty about which lanes were open equally on all routes. Furthermore, the participants felt that a lane closure was communicated very clearly on both a gantry and on MS4 with wicket.

7.1.4 Other related questionnaire findings

The questionnaire also found that participants understood equally well the mandatory/compulsory nature of speed limits displayed on gantries and MS4s. So any misunderstanding of the status of limits is unlikely in itself to account for differences in behavioural response.

The questionnaire suggested that participants considered both the speed and the lane closure instruction displayed on an MS4 would be 'less clearly visible', although both results were high in favour of clear visibility.

7.2 Secondary objective

The secondary objective of this trial was:

To assess driver awareness and comprehension of ERAs and associated signing; and use of ERAs in a breakdown scenario.

This was achieved by informing participants, in advance on an ERA, that a fault has occurred with their vehicle and observing where they stopped. It was seen that the majority of participants (29 out of 45) stopped in the ERA. Two participants stopped on the verge in about 200m in advance of the ERA. Five participants drove past the ERA. Informal feedback suggested that this was due to an inability to move in to Lane 1 in time due to the presence of other traffic.

7.3 Additional findings

Participants reported that the MS4 with national speed limit (NSL) sign and 4 ahead arrows was significantly clearer at communicating the end of lane closure than an MS4 with only a NSL sign.

Also, the existing approach to displaying NSL sign was found to be significantly clearer than the 'inverted' approach.

Appendix A Ethics and data protection

Research at TRL is designed and executed to the highest scientific and ethical standards of professional integrity. TRL operates a quality management system as part of its Integrated Management System (IMS).

All project outputs are subject to TRL's Project Technical Review Procedure, whereby scientific reports are reviewed by the project Technical Referee before leaving TRL. In addition, TRL projects involving human participants are required to complete a TRL Ethical approval Checklist and Application Form, which is submitted for assessment by a specialist Ethics Panel to ensure that all study designs follow recognised ethical principles. During the trial, strict ethical procedures for participant handling are undertaken by trained TRL staff.

Standard operating procedures for secure data management, back-up and archiving implemented to ensure data confidentiality, intellectual property and human rights are maintained at all times. In line with the requirements of the Data Protection Act 1988, TRL operates a policy for non-disclosure of the identity of research participants and as all data outputs and reports will be kept anonymous. Participants are required to complete a Privacy Statement prior to partaking in a trial.

Appendix B Statistical Analysis Tables

Table 19 - Results of statistical analysis of surfing magnitude by section

Section	df	*H*	*p*
2	2	.36	.83
3	2	1.15	.56
4	2	1.48	.48
5	2	4.99	.08
12	2	.80	.67
13	2	1.59	.45

Table 20 - Results of statistical analysis (Mann-Whitney Test) of surfing magnitude by section

Comparison	*U*	*p*
Gantry – MS4	31266.0	<.01
MS4 – Mixed	33722.0	.13
Gantry - Mixed	34066.0	.19

Table 21 – Results of statistical analysis of time spent in excess of the speed limit by more than 10%

Section	df	*H*	*p*
2	2	.46	.80
3	2	2.56	.28
4	2	3.28	.19
5	2	.23	.90
12	2	1.87	.39
13	2	.66	.71