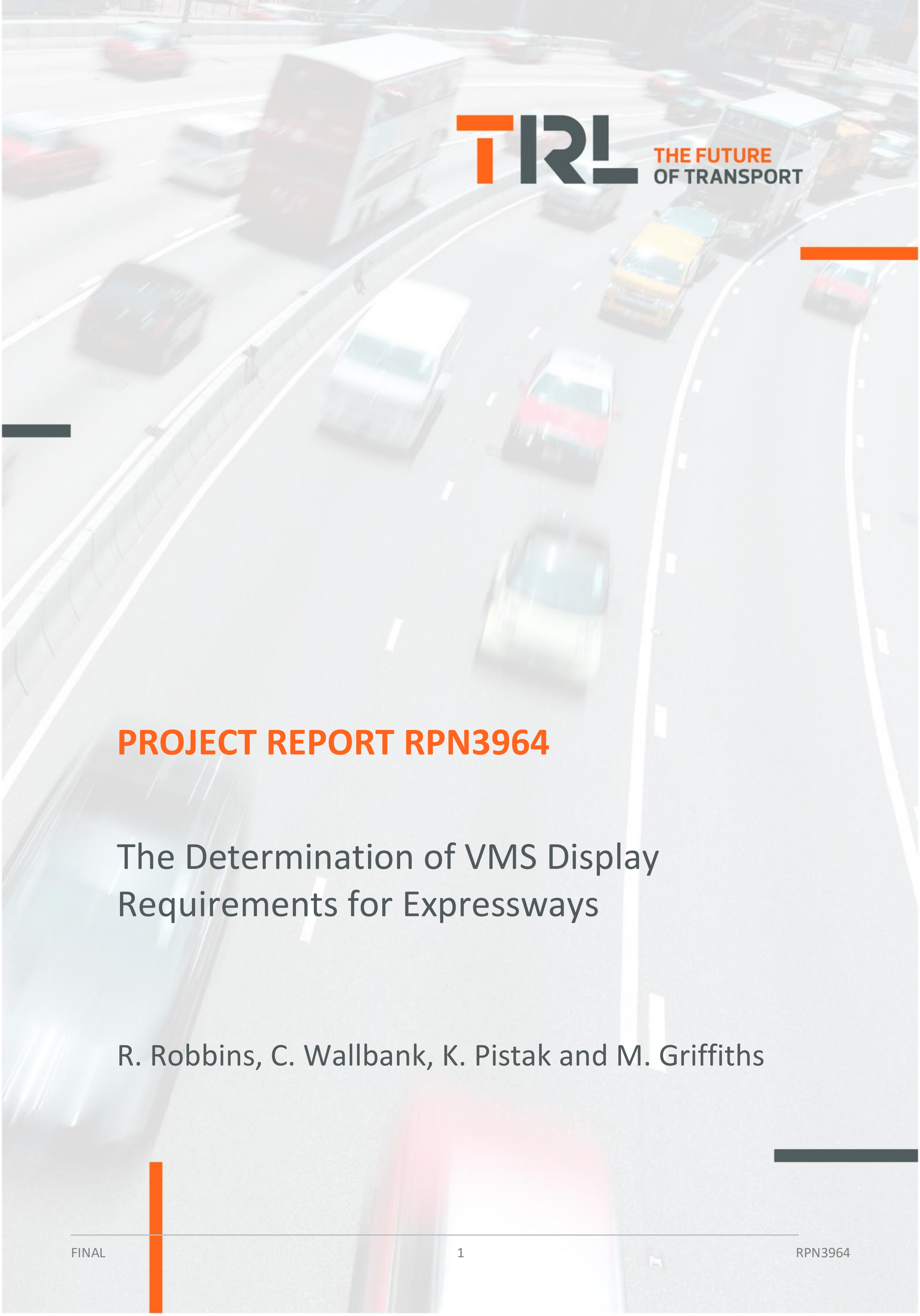

PROJECT REPORT RPN3964

The Determination of VMS Display Requirements for Expressways

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Report details

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This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
Draft 1	16/05/2017	Introduction and method for client review	RR	SH
Draft 2	26/05/2017	Final draft for client review	RR	SH
Final	12/07/2017	Final version	RR	SH

Table of Contents

1 Executive summary

A driving simulator study was conducted at TRL to investigate the impacts on driver performance and subjective impressions of varying three characteristics of variable message signs (VMS). These were the size of the display area, the number of text lines displayed, and the placement of the VMS.

Six different VMS Options were designed and a simulated expressway environment was built broadly reflective of the current draft IAN describing their design. This route was naturalistic in appearance and comprised two and three lane dual carriageways.

Forty-three participants completed six drives of the route in a partially counterbalanced order, with each drive displaying a single VMS Option. Each drive included two typical scenarios which may be encountered on an expressway; these were a “queue ahead” scenario in which the VMS displayed warnings and speed restrictions, and an “incident” scenario in which warnings, speed restrictions and lane closures were present.

Statistical analysis of the performance data recorded by the driving simulator showed no differences in performance where the information displayed in the VMS was materially identical. Some differences were found between Option 6 (verge mounted VMS) and the other Options, they were likely due to the different information displayed (Option 6 was only displayed on the two lane sections of road, therefore, there were cases where its information was different from that displayed on Options 1 to 5 when they were on a three lane road). In summary, our evidence showed that varying the size of the aspects, varying the number of text lines and varying the size of the VMS in comparison to Option 1 (currently authorised) did not meaningfully impact on driver performance.

Participant subjective impressions of the Options showed lower ratings of ease of identification, understanding and satisfaction with information provision for Options 5 and 6 than for the other Options.

Based on driver performance our results support the consideration of any of the six Options tested for future use. However, the subjective data analysed suggests Options 1 to 4 would be preferred by Highways England’s customers.

2 Introduction

This report describes a driving simulator research study undertaken by TRL for Highways England. The purpose of this research was to help determine the variable message sign (VMS) display requirements for use on expressway schemes. Forty-three drivers viewed six different VMS Options in a simulated naturalistic expressway environment and differences in driving performance and subjective opinions between the Options were analysed.

2.1 Background

Highways England is meeting the challenge of maximising network performance and user satisfaction by developing a highly innovative approach to the upgrade of the design of its busiest A-roads. This future design approach is called an Expressway.

As described in the Road Investment Strategy (RIS) (December, 2014) expressways shall be "A-roads that can be relied upon to be as well-designed as motorways and which are able to offer the same standard of journey to users".

Highways England Strategic Business Plan (SBP) 2015-2020 (December, 2014) elaborates on the requirements for expressways stating they will offer three main improvements over standard A-roads:

- *Encourage more free-flowing traffic by modernising junctions*
- *Provide emergency refuge and maintenance areas*
- *Use advanced technology to detect and help clear incidents more quickly and get traffic moving again.*

It is the third of these improvements, the use of advanced technology to detect and clear incidents, which is the principle focus of this research study.

2.2 Project objectives

The purpose of this project is to deliver robust evidence which will provide an opportunity to optimise and inform the content of a future expressway Requirements and Advice Document (RAD) which describes the concept of operations and design requirements for expressways.

The portions of the RAD which are to be potentially optimised following this project are those which describe variable message signs (VMS). Specifically, the project assessed how varying three characteristics of VMS displays affected driver behaviour and opinions on an expressway. These three characteristics are the size of the VMS, the supporting text on the VMS, and placement of VMS. These aspects were combined into six different VMS configurations (Options) for the purposed of this research.

The trial compared alternative dimensions of VMS displays and the number/spacing of text lines they display in order to optimise technology provision on expressways – particularly those routes that have a maximum of two lanes in each direction and/or lower flows.

This project delivers against three overall objectives:

- Objective 1: Evidence the impact of altering VMS aspect sizes, making comparison with current approved aspects used on IAN 161 schemes
- Objective 2: Evidence the impact of altering the number of lines of text displayed on VMS, making comparison with current authorised messages
- Objective 3: Evidence the impact of varying the site of the VMS (overhead or verge)

An additional research objective was proposed after project commencement. Highways England wishes to understand the impact of reduced size VMS spacing on driver situation awareness. A parallel research trial was undertaken using a video based methodology and described separately.[1]

2.3 Research questions

Five specific questions were tested. These were:

H1 – Does VMS Option 2 produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?

H2 – Does VMS Option 3 produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?

H3 – Does VMS Option 4 produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?

H4 – Does VMS Option 5 produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?

H5 – Does VMS Option 6 produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?

See Section 4.1 for specifications of all Options tested.

[1] Balfe, N., Pistak, K., Robbins, R., & Griffiths, M. (2016). Evaluation of VMS Spacing on Expressways. Draft Report RPN 3961. Crowthorne: TRL

3 Method

3.1 Summary of procedure

This research assessed how six different VMS configurations (Options) affected driver performance. These Options differed by the size of VMS, the supporting text on VMS, and placement of VMS.

A medium-fidelity[2] driving simulator was used to collect data. A total of 43 participants completed a 2.5 hour trial session (including familiarisation and breaks).

Participants completed a total of six drives, one for each Option. All Options were presented in almost identical virtual environments; i.e. all drives were completed under the same route geometry. Each drive only varied by the Options presented, and in the case of the incident scenario, the number of lanes present (three lanes were present during Options 1 to 5 and two lanes were present at Option 6). For a fuller description of the different conditions present at each Option see Section 4.2.

In order to ensure maximum statistical robustness, each participant drove all conditions in a partially counterbalanced order. Whilst this approach required participants to drive for 1.5 to 2 hours, the increased statistical robustness of a within participants design supported this approach.

Behavioural data were collected from the simulator, impressions of the drive were collected during each drive, and subjective opinions were also collected from a brief questionnaire administered at the end of the driven component of the trial.

3.2 Trial conditions

The six drives completed by each participant varied according to the Option presented. See Section 4.1 for a full description of the VMS presented.

3.3 Procedure

The trial session began with a rigorous familiarisation phase to acclimatise participants to the virtual environment, maximising the chance that their behaviour reverted to that seen in normal driving before data collection began.

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[2] MiniDigiSim can be described as a medium fidelity driving simulator as it has a high resolution, wide-angle field of view, a realistic force-feedback steering wheel, gear shifter and weighted pedals, and is placed on a fixed base. In contrast, a low fidelity simulator may simply be a single, lower resolution screen and a basic control interface. A high fidelity simulator, such as TRL's DigiCar, would most likely consist of an entire vehicle on a motion system surrounded by high quality visuals producing the most immersive driving experience.

Participants then completed six ~15 minute drives. At two points during each drive (between the first and second halves of the drive and at the end of the drive) participants were asked about their subjective experiences of the section they had just completed.

After all six drives were completed a short questionnaire was administered.

Total trial length was approximately 2 to 2.5 hours. The procedure timeline can be seen in Figure 1.

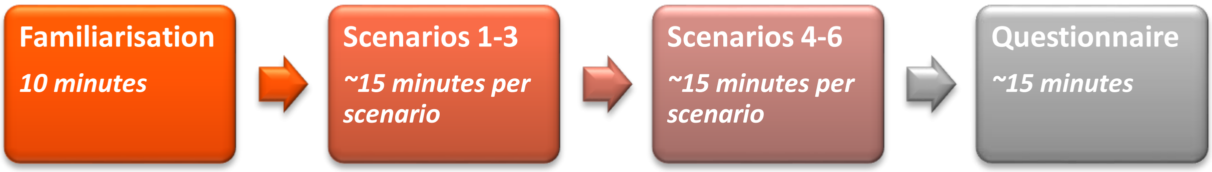


Figure 1. Procedure timeline

The order in which these drives were encountered was partly counterbalanced between participants, using a Latin Square method.

3.4 Participants

A total of 47 participants were recruited (43 of whom successfully completed the trial and were included in the analysis, see Section 5.2 for further information). The sample was intended to be representative of typical drivers on the strategic road network (as can be seen in Section 5.2, the sample was broadly representative by gender split, age and annual mileage).

The participant sample was drawn from TRL's participant database. The TRL participant database includes over 2,500 drivers throughout Berkshire, Surrey and Hampshire. A randomly selected sample of drivers from the database who matched the recruitment criteria were invited to take part in the trial.

3.4.1 Sample recruitment criteria

The demographics of the sample recruited were controlled across several factors:

- A range of ages in line with the UK driving population
- A mean annual mileage across all participants in line with the UK driving population
    - A minimum annual mileage of 2000 was required
- All participants had at least 2 years' driving experience
- All participants drive on a major A road at least once or twice a month

3.4.2 Participant instructions

Participants were asked to "drive as they normally would during their commute or when on their way to a similar, regular appointment". This instruction was carefully worded to encourage participants to drive naturally.

It was also clearly stated that the purpose of the research was to understand how people really drive, not to make any sort of judgement about the quality of their driving.

4 Test route

This section of the report describes the features of the 3D model produced for the trial, including the design of VMS and the road environment.

4.1 VMS specification

Participants saw a total of 13 VMS during each of their six drives. For Options 1 to 5 five of the VMS were blank and eight displayed information. For Option 6 six of the VMS were blank and seven displayed information. Within each drive all VMS were of the same Option; in other words, the VMS only varied by the information displayed, otherwise they were the same specification/dimensions.

The VMS differed by the type of structure, and the dimensions/design (but not meaning) of their contents between drives. The sequence of displays shown in both scenarios can be seen in Table 2.

4.1.1 VMS spacing

All VMS were 1500m apart.

4.1.2 VMS messages

Each Option used a different display area. The specifications of the Options tested in each condition can be seen in Table 1.

Table 1. Specifications of VMS displays tested

Option	Currently authorised?*	Display size (height x width, mm)	Aspect height	Text	Location	Example VMS (to scale)
1	Yes	2560 x 3840	1500mm	2 lines	Cantilever	
2	No	2080 x 3840	1500mm	1 line	Cantilever	
3	No	1500 x 3840	1500mm	No text	Cantilever	
4	No	2260 x 3840	1200mm	2 lines	Cantilever	
5	No	1200 x 2720	1200mm	No text	Cantilever	
6	No	2520 x 1360	1200mm	No text	Verge	

* As used on Highways England IAN 161 schemes

4.1.3 VMS structures

Three types of VMS structures were used, referred to as: *standalone*, *collocated* and *verge mounted* (see Figure 2). The standalone VMS were always presented in isolation of other road features, the collocated signs were always placed at emergency refuge areas (ERAs), and verge mounted VMS were collocated both in isolation and at ERAs. In Options 1 to 5 ten of the VMS were of the standalone type and three were of the collocated type. In Option 6 all VMS were the same (verge mounted).

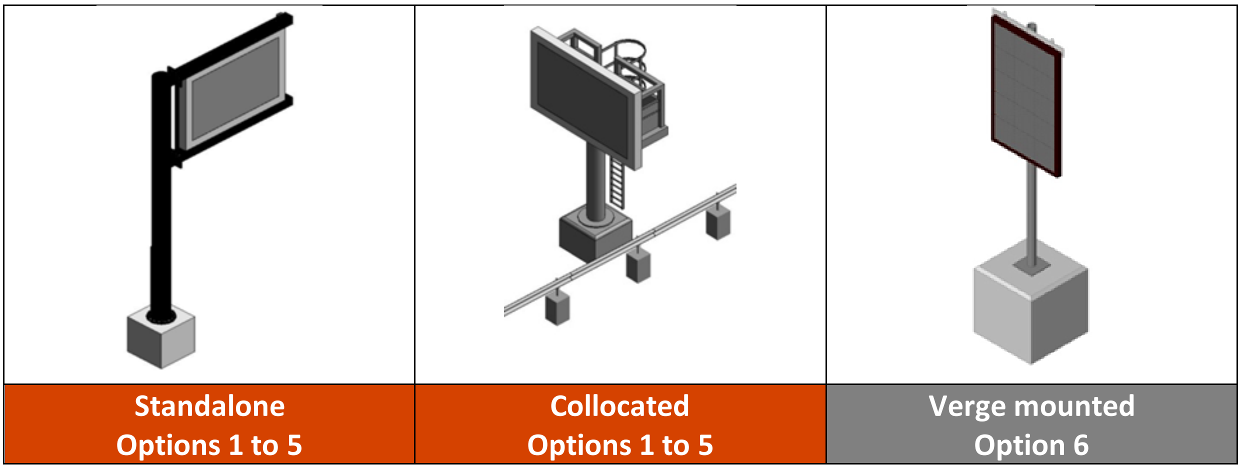


Figure 2. Design of VMS

4.2 Sequence of VMS messages

Two VMS scenarios were included for testing: queue protection and lane closure incident.

4.2.1 Queue protection

This scenario was selected for testing as typically queue protection has a pronounced reduction in speed over a short distance and so typically provides more onerous trial conditions than for example controlled motorway settings. This scenario started 6km after the beginning of the route. The sequence of VMS encountered by drivers can be seen in Figure 3.

Figure 3. Sequence of signs in queue prevention scenario

4.2.2 Incident (Options 1 to 5)

A nearside lane closure (two lanes out of three) was included as it is likely to be one of the most frequent closure combinations on three lane routes and also provides more onerous trial conditions than a single lane closure. Also it achieved the aim of requiring participants to change lanes, something which they may not otherwise have done given the volume of traffic present (1,000 vehicles per hour, per lane). This scenario started 15km after the beginning of the route.

Figure 4. Sequence of signs in incident scenario

4.2.3 Incident (Option 6)

Option 6 differs from the above as it is verge mounted and has not been applied to a three lane environment within the simulator. Therefore, in the case of Option 6 the incident scenario took place on a two lane road and the nearside lane closure only applied to one lane.

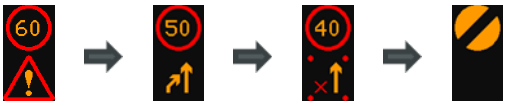


Figure 5. Sequence of signs in lane closure scenario (Option 6 only)

The sequence of VMS encountered by drivers for all six VMS Options can be seen in Table 2.

Table 2. VMS sequence plan

	ERA locations	VMS ID and Distance	Option 1 (Current authorised)	Option 2	Option 3	Option 4	Option 5	Option 6
Options 1 to 5: 3 LANES Option 6 : 2 LANES		26k end						
	21km	13. - 21km (collocated with ERA)						
	18.5km	12. - 19.5km	40 Incident	40 Incident	40	40 Incident	40	40
		11. - 18km	50 Incident	50 Incident	50	50 Incident	50	50
	16km	10. - 16.5km	50 Incident	50 Incident	50	50 Incident	50	60
		9. - 15km	60 Lane closure ahead	60 Closure ahead	60	60 Lane closure ahead	60	
	13.5km	8. - 13.5km (collocated with ERA)						
	11km	7. - 12km						
All Options 2 LANES		6. - 10.5km						
	8.5km	5. - 9km						
		4. - 7.5km	40 Caution	40 Caution	40	40 Caution	40	40
	6km	3. - 6km (collocated with ERA)	60 Queue ahead	60 Queue ahead	60	60 Queue ahead	60	60
	3.5km	2. - 4.5km						
		1. - 3km						
		0km start						

4.3 Incident at lane closure section

Approximately 20km into the route an incident was present. This incident took the form of two vehicles stopped in Lane 1, arranged as if they recently collided. No temporary traffic management (e.g. cones, emergency response vehicles etc.) was present. This event replicates an incident in Lane 1 where emergency response was yet to attend. The incident was located approximately 500m after VMS number 12 (see Figure 6 for an example of VMS 12, Option 1).

Figure 6. Example of lane closure VMS (VMS ID12, Option 1)

4.4 Route specification

A 23km long section of generic A-road was modelled. The route consisted of several gradual curves and short straights. No junctions or bridges were present. The route met the geometric requirements described in TD 9/93 *Highway Link Design* for a dual two lane all-purpose trunk road (D2AP) and a dual three lane all-purpose trunk road (D3AP).

4.4.1 Rationale for including/omitting certain route features

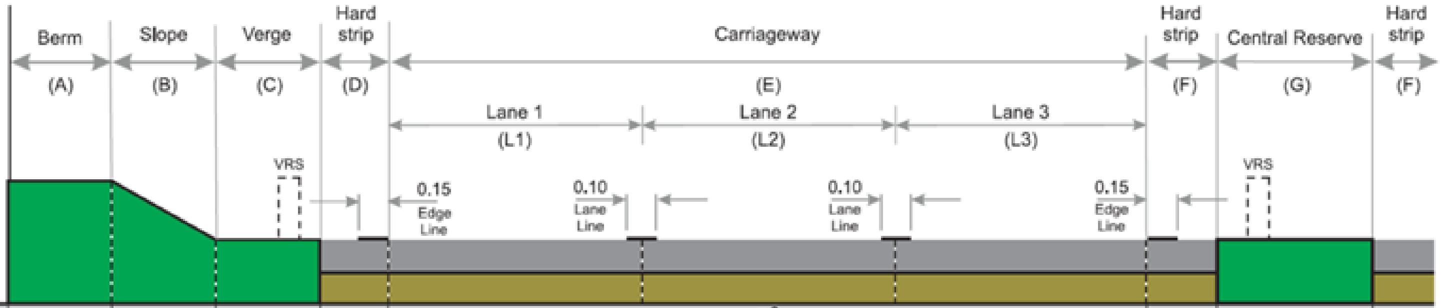
The purpose of this study was to establish the effects of VMS displays on driver behaviour and not the effects of any other significant route features (e.g. junctions), therefore, a simplified route was modelled where unnecessary and potentially confounding features were excluded. Therefore, no junctions were present. By adopting this approach we maximise the probability that any observed differences are due to the presence of the VMS and not due to other road features. Although an uninterrupted stretch of this length is unlikely to occur in reality, we are confident that this approach increased the reliability of our data without compromising its validity.

4.4.2 Horizontal and vertical alignment

The road was flat with no crossfall. Large radius Curves were present to ensure requirements for VMS sightlines were met while retaining the appearance of a real road environment.

4.4.3 Cross section

The route cross section conformed to standard TD27/05, as per Figure 7 below. Hard strips of 1m were provided throughout.



Road Type	A	B	C[2]	D[3, 11]	E[3] L1	E[3] L2	E[3] L3	F[5]	G[2]	
Dual 2 Lane (D2AP)	Varies	Varies	2.50	1.00	7.30		N/A	1.00	2.50	
					3.65	3.65[9]				
Dual 3 Lane (D3AP)	Varies	Varies	2.50	1.00	11.00			1.00	2.50	
					3.65	3.70	3.65			

Dual Carriageway

Figure 7. Road surface cross section (TD27/05)

4.4.4 Road Restraint Systems (VRS)

The model provided VRS in the verge at the ERA sites; barriers at these sites were compliant with TD19/06 Requirements for Road Restraint Systems.

In accordance with the Expressways RAD the model depicted a Rigid Concrete Barrier (RCB) in the Central Reserve without gaps.

VRS was not present at any other location. Although in reality it would be present at other locations such as at standalone VMS, we are confident that this non provision does not impact the study objectives or compromise the data validity.

4.4.5 Stopping Sight Distance

Visibility to the VMS met a minimum of 350m in all cases.

4.4.6 Emergency Refuge Area

ERA sites containing all appropriate infrastructures including collocated VMS were placed in the route at 2.5km spacing. The first ERA was located 500m into the expressway (3.5km after the start of the road). Therefore, three ERAs were collocated with VMS (the 3rd, 8th and 13th VMS).

ERA's met the following criteria: entry Taper 25m; design Length 30m, exit Taper 45m; ERT at the midpoint of the ERA. An example of the appearance of an ERA can be seen in Figure 8.

Figure 8. Example ERA as it appeared to drivers

4.4.7 Road markings and signage

4.4.7.1 Speed camera signs

A speed camera sign advising of variable speed limit enforcement was included 250m in advance of the first VMS in the nearside verge. Repeater speed camera signs were displayed at every VMS site and were located where practical on the signalling superstructure. See Figure 9 for examples of these signs.

Figure 9. Variable speed limit sign (left), speed camera repeaters (right)

4.4.7.2 Road markings

Nearside and Offside edge lines were present and compliant with diagram 1012.3. Other road markings were in accordance with those required for a D2AP or a D3AP.

4.4.7.3 Permanent lane gain section

Permanent mid link lane gains within links on the SRN are unusual. Little detail on the correct configuration of these lane gain sections is present in DMRB or TSM Ch8. Their use for climbing lanes is however described in in TD9/93 (Road Geometry - Links), where clause 5.34 states between a 1 in 30 and 1 in 40 taper length is specified. Therefore, with 3.65m wide lanes the total length should be 146m (3.65m lane width x 1/40). A screenshot showing an overhead view of the lane gain section can be seen in Figure 10.

Figure 10. Lane gain section

Our study did not include VMS at the point of the lane gain. Given how rare such lane gains are on the SRN it was considered to be more efficient to direct resources in the other portions of the drive. We removed the influence of the lane gain section on driver performance by excluding data collected during it and shortly after.

4.4.8 Lighting

The drives took place in daylight conditions. No lighting was present in the route.

4.5 Simulated traffic

Traffic was present and designed to behave in a realistic manner to ensure that the behaviours observed in the driving simulator could be generalised to real roads. The vehicles within the simulator are controlled by an Artificial Intelligence (AI) 'engine' which was carefully programmed using three parameters: traffic composition, traffic density, and speed.

4.5.1 Traffic composition

Traffic consisted of a mix of vehicle types, including cars, vans, and motorbikes. High-sided vehicles such as HGVs and busses were excluded from the traffic in order to prevent them from obscuring sightlines to the VMS. Obscuration of VMS is out with the scope of this study.

4.5.2 Traffic density

This traffic was at a density of 1,000 vehicles per lane/hour. This level was selected for two reasons. Firstly, it was sufficient to give a visual representation of naturalistic driving conditions. Secondly, it was not so high as to be a larger source of influence on driver behaviour than the VMS to be tested; high density traffic could result in 'follow the leader' behaviour by participants where their lane and speed choice is constrained by the volume of traffic. Note, traffic was not queueing at the location of the queue signed by the VMS, although it was observing the posted speed limit.

4.5.3 Observance of speed limits

The simulated traffic observed the posted speed limit. In order to allow drivers to speed if they so wished, any vehicle in the rightmost lane changed lanes when the driver approached so the driver was free to choose to speed if they wished whilst still having the visual appearance of being in natural traffic. TRL has used this approach successfully in numerous simulator studies to balance the need for the appearance of realistic traffic levels with the need to observe drivers' unconstrained speed choice.

Exceptions to this were the queue prevention and lane closure sections. In the queue prevention section the simulated traffic did not move out of the way for the participant to keep the scenario similar to the real world. In the lane closure section it was not be possible for the simulated traffic to move out of a participants' way. Once clear of the incident the traffic resumed normal lane use. Participants were free to use any lane.

5 Results

Three main analyses were completed, each of which are described in the remainder of this report section:

- an analysis of drivers' impressions of their drive during the drive
- an analysis of drivers' impressions of the Options after the drive
- an analysis of drivers' performance as recorded by the driving simulator.

The data recorded by the driving simulator was divided into two parts for the purpose of analysis; the first part was the queue ahead scenario which included data captured from the first VMS to the fifth. The second part was the incident scenario; this included the data collected from the eighth to the thirteenth VMS. VMS IDs 7 and 8 were excluded from the analysis as these covered the portion of the drive where the lane gain was present and where participants were asked for their subjective impressions of the previous half of the route. Given these factors were likely to influence performance they were excluded from the scenarios.

5.1 Statistical testing methods

The statistical tests performed on the simulator data included the two-way parametric ANOVA, the Kruskal-Wallis one-way non-parametric ANOVA (with Box-Cox transformations of the dependent variable where necessary). The pairwise-comparisons tests were performed using least-square adjusted means which is appropriate for both balanced and unbalanced data. These statistical analyses were performed using the R[3] platform. Cochran's Q tests were performed on the lane use data (as this was repeated measures categorical data) using SPSS 24.

The within-drive subjective impressions data and the questionnaire data were both analysed using a one-way repeated measures AVOVA. In all cases these data violated assumptions of sphericity, therefore, a Greenhouse-Geisser correction were applied to all results. These data were conducted using the statistical analysis software SPSS 24.

In all cases a statistical significance level of 0.05 was used.

5.2 Sample demographics

Data for 43 participants successfully collected by the trial were included in the main analysis. A total of 47 participants were recruited, however one chose to withdraw from the

[3] R Core Team (2013). R: A language and environment for statistical computing

trial and technical errors resulted in partial data for a further three participants which rendered their data unsuitable for inclusion in main analysis.

The sample comprised 24 males and 19 females (ratio of males to females = 1:0.86), this was similar to the ratio of male to female drivers in the UK (1:0.79), as described in *Driving licence holding and vehicle availability* (NTS02) (DfT, 2013).

A broad range of participant ages was included in the sample. Figure 11 shows the number of participants in each age category as well as the number of participants we would expect to see if our data was precisely the same as the UK driving population (Driving licence holding and vehicle availability (NTS02), DfT, 2013). As can be seen our sample was reasonably similar to the general driving population.

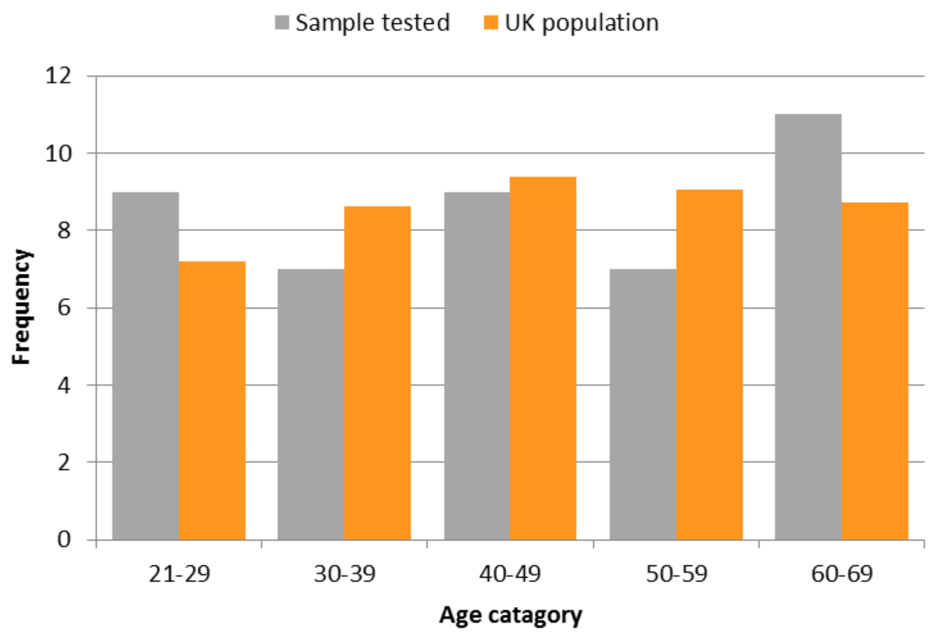


Figure 11. Distribution of participant ages

According to the National Travel Survey (England 2014) the average mileage across all drivers (regardless of road type) was 7,900 miles in 2014. Our sample's median annual mileage was in line with this (8,500), with the lowest annual mileage reported as 1,000 (two cases) and the highest as 20,000 (two cases). The two participants who reported an annual mileage of 1,000 had stated at recruitment that they drove at least 2,000 miles a year.

Our sample was also asked how often they used dual carriageways and motorways. As can be seen in Figure 12, our entire sample used either a dual carriageway or a motorway at least "a few times a year". Unfortunately, national data of dual carriageway and motorway use was not available for comparison.

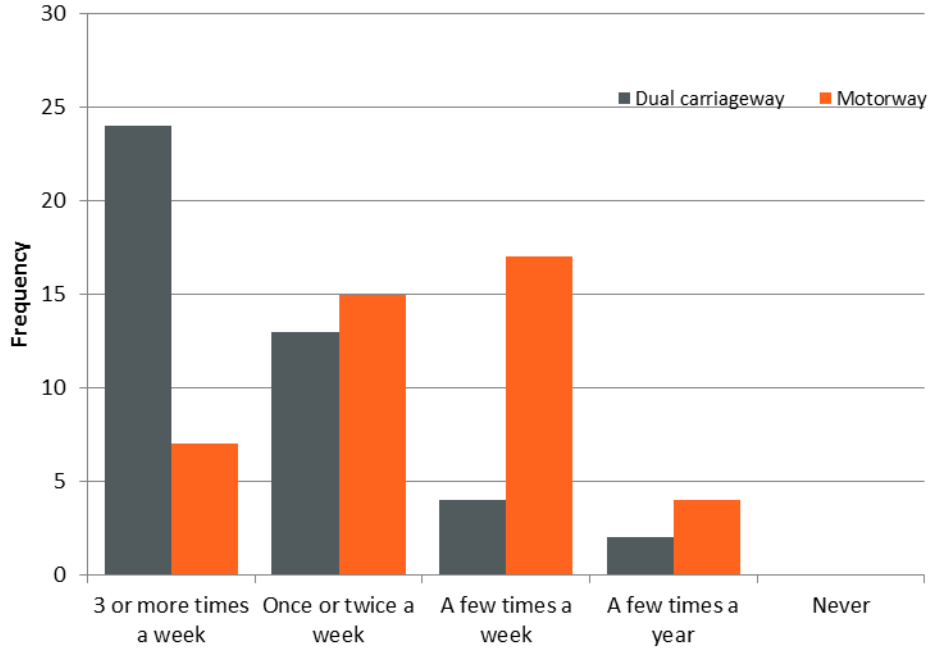


Figure 12. Frequency of use of dual carriageways and motorways

Analysis of the demographics of our sample showed it to be similar to the general driving population.

5.3 Within-drive subjective impressions

Participants were asked to rate their perceptions of safety and satisfaction during each drive, once after the first scenario and once after the second. They were asked to choose a rating from 0 to 10, with 10 extremely safe or satisfying and 0 being not at all safe or satisfying. Participant mean ratings can be seen in Figure 13 and Figure 14, respectively.

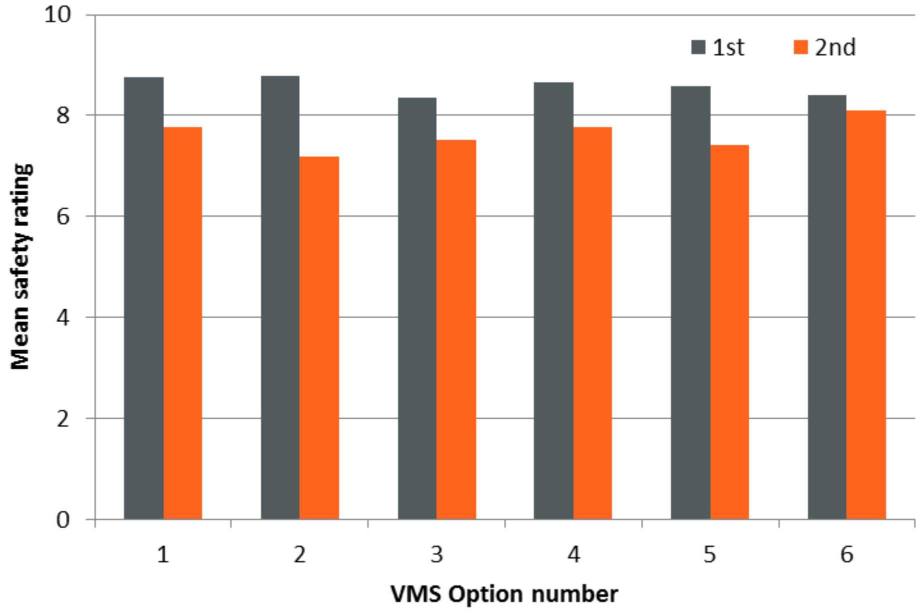


Figure 13. Mean safety of rating during drive

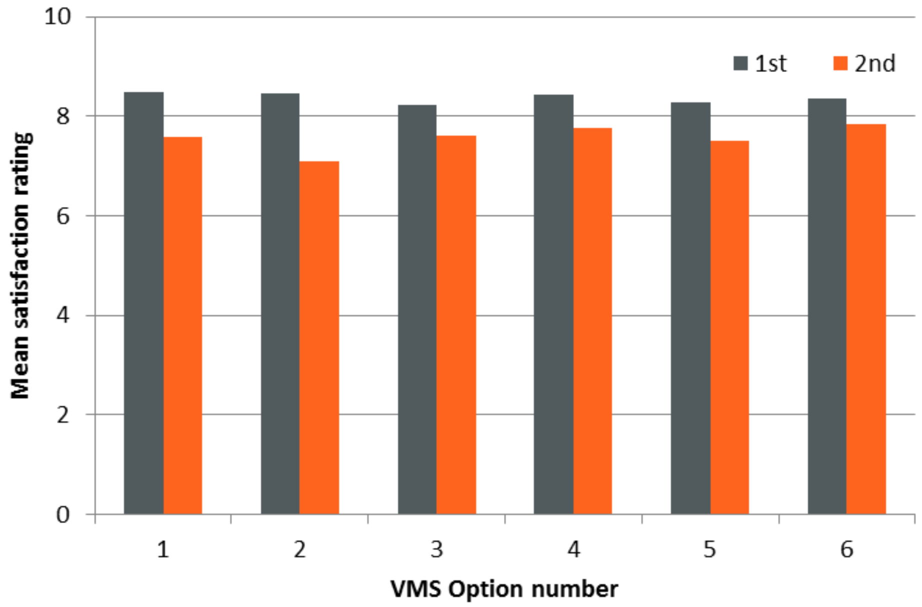


Figure 14. Mean rating of satisfaction during drive

A repeated measures ANOVA was performed on the data for each scenario. No statistically significant differences ($p > .05$ in all cases) were identified between any of the Options for either safety of satisfaction in either the first of second half of the drive.

VMS Option did not affect participant feelings of safety or satisfaction whilst they were driving.

5.4 Questionnaire results

After all six drives had been completed participants were asked to rate each VMS Option against three criteria in a post-trial questionnaire. These criteria were:

- How difficult/easy was it to identify the different pieces of information on the sign (identification)
- How difficult/easy was it to understand the meaning of the sign (meaning)
- How satisfied were they with the provision of information on the sign (satisfaction)

Mean ratings for each of these questions can be seen in Figure 15.

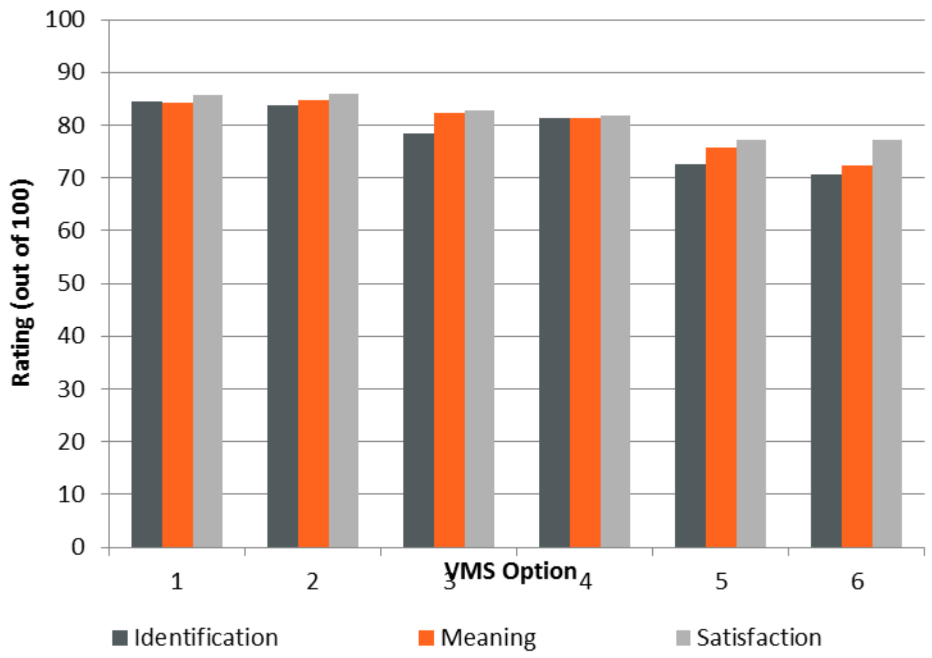


Figure 15. Mean ratings of identification, meaning and satisfaction for all VMS Options

A repeated measures ANOVA was performed on the data for each rating. Results showed no statistically significant differences between Option1 and Options 2, 3 or 4 ($p > .05$). However, there was a significant difference between Option1 and Options 5 and 6 for all three questions (see Table 3).

Table 3. Results of comparing VMS Option 1 with VMS Options 5 and 6

	VMS Op1 vs.	df	Mean Square	F	Sig.
Identify	VMS Op5	1	2992.9	6.22	.017
	VMS Op6	1	5808.1	9.08	.005
Meaning	VMS Op5	1	3108.51	8.30	.006
	VMS Op6	1	2987.81	8.43	.006
Satisfaction	VMS Op5	1	5736.03	11.17	.001
	VMS Op6	1	7784.10	15.17	.001

These results demonstrate that participant evaluations of VMS Options 1 to 4 did not differ, therefore all were equally easy to identify, equally easy to interpret, and equally satisfying in their information provision. VMS Options 5 and 6 were rated lower than the other VMS Options for all questions.

5.5 Simulator data results

The analysis of the simulator data was divided into the first scenario (queue ahead) and the second scenario (incident). The queue ahead scenario included VMS IDs 1 to 5 and the incident scenario included VMS IDs 8 to 13.

For the majority of analyses (excluding surfing data) a zone of interest was identified in proximity of each VMS. The zones were 400m before and after each VMS. This approach was adopted to focus the analysis on how behaviour might have been affected by the VMS.

A total of ten dependent variables[4] were measured. Of these, seven were subjected to statistical testing. The data collected for the remaining three (“surfing”, lane occupancy and time spent at very high risk headway) were not suitable for statistical testing, but were visually inspected for evidence of trends in the data. The dependent variables recorded were:

- **Speed**

  Mean speed was calculated across each zone of interest.

- **Standard deviation of speed (smoothness of speed)**

  Standard deviation of speed was calculated for each zone of interest. The standard deviation is a measure of how much variability is in a set of data, a low value suggests most values are close to the mean.

- **Changes in speed in proximity of VMS (“surfing” between VMS)**

  Mean speed was calculated for each 30m block of the drive. These means were then plotted for evidence of variation in speed between VMS, also known a surfing. This is the phenomenon when drivers slow down when they see a VMS and then speed up once past it. Not subjected to statistical testing.

- **Lane position (mean lateral shift)**

  Mean lateral shift was calculated within each zone of interest. This was drawn from the exact position of the midpoint between the vehicle’s two front wheels and was expressed as meters from the nearside side of the lane. The point furthest to the offside was 0m and the point furthest to the nearside was 3.5m

[4] Dependent variables are the outcomes which a trial measures. The extent to which their values ‘depend’ on the things being manipulated (in this case VMS type) is assessed..

- **Standard deviation of lateral shift (smoothness of lane positioning)**

  Standard deviation of lateral shift was calculated for each zone of interest.

- **Lane occupancy**

  The percentage of lane occupancy when passing each VMS was recorded. Not subjected to statistical testing.

- **Mean headway distance**

  Mean headway was calculated for each zone of interest. This was the distance from the midpoint of the vehicle's front wheels to the nearest vehicle ahead in the same lane as the participant's vehicle.

- **Standard deviation of headway distance (smoothness of headway distance)**

  Standard deviation of headway distance was calculated for each zone of interest.

- **Time spent at high risk headway (< 2 seconds)**

  The proportion of time each driver was within 2 seconds of the first vehicle ahead was calculated.

- **Time spent at very high risk headway (<250 ms)**

  The proportion of time each driver was within 250 milliseconds of the first vehicle ahead was calculated. Not subjected to statistical testing.

In the result sections below where a Figure is displayed the x axis also shows an image of what each VMS was displaying for ease of reference. Option 1 is shown throughout for the queue ahead scenario and Options 1 and 6 are shown for the incident scenario; the information displayed on all other Options can be seen in Table 2.

5.5.1 Queue ahead scenario

No statistically significant differences between VMS Options were found for any of the dependent variables which were subjected to statistical testing. Any dependent variables which were not subjected to statistical testing have an explanation of why this was the case included in their descriptions below. In all other cases statistical testing was performed.

Despite there being no statistically significant differences in the queue ahead scenario, plots were produced of each dependent variable for clarity. In all plots Option 1 VMS displays are shown as examples of available information: for a full list of the different Options presented at each VMS ID please see Table 2.

5.5.1.1 Mean speed – queue ahead

Figure 16 shows the mean speed for each Option at VMS IDs 1 to 5.

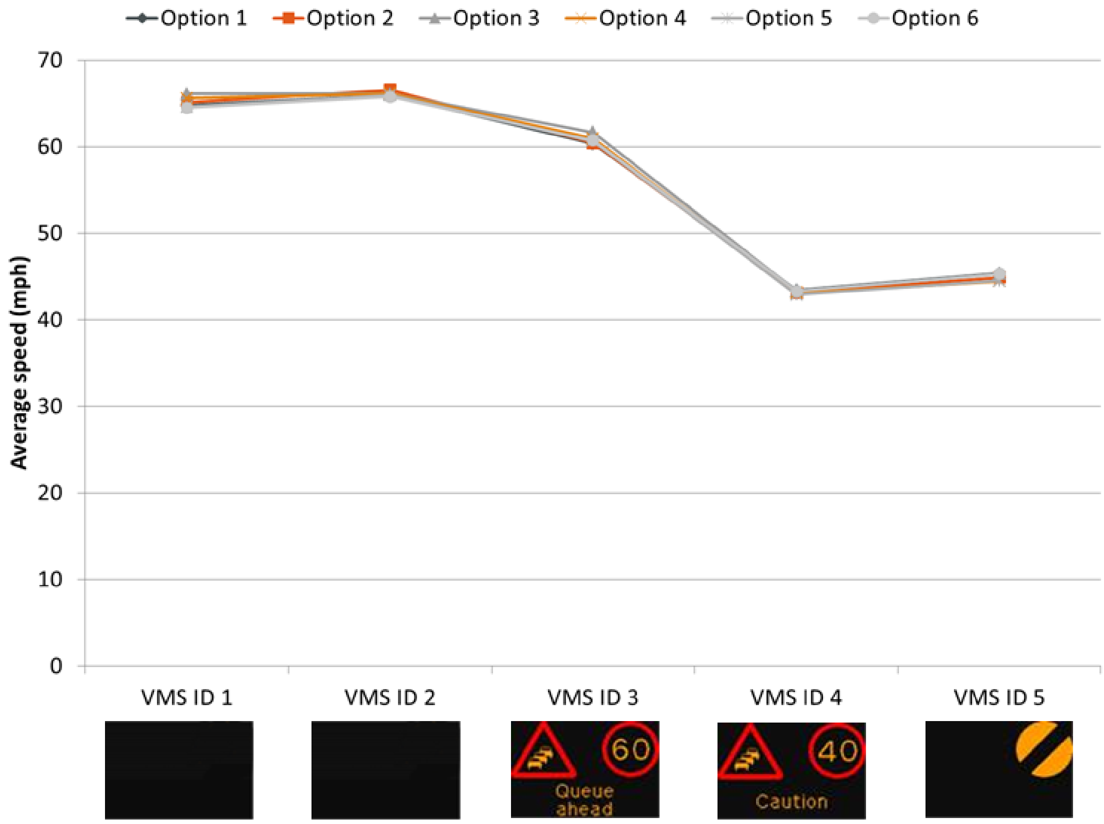


Figure 16. Mean speed during queue ahead scenario

5.5.1.2 Standard deviation of speed – queue ahead

Figure 17 shows the variability in speed for each Option at VMS IDs 1 to 5.

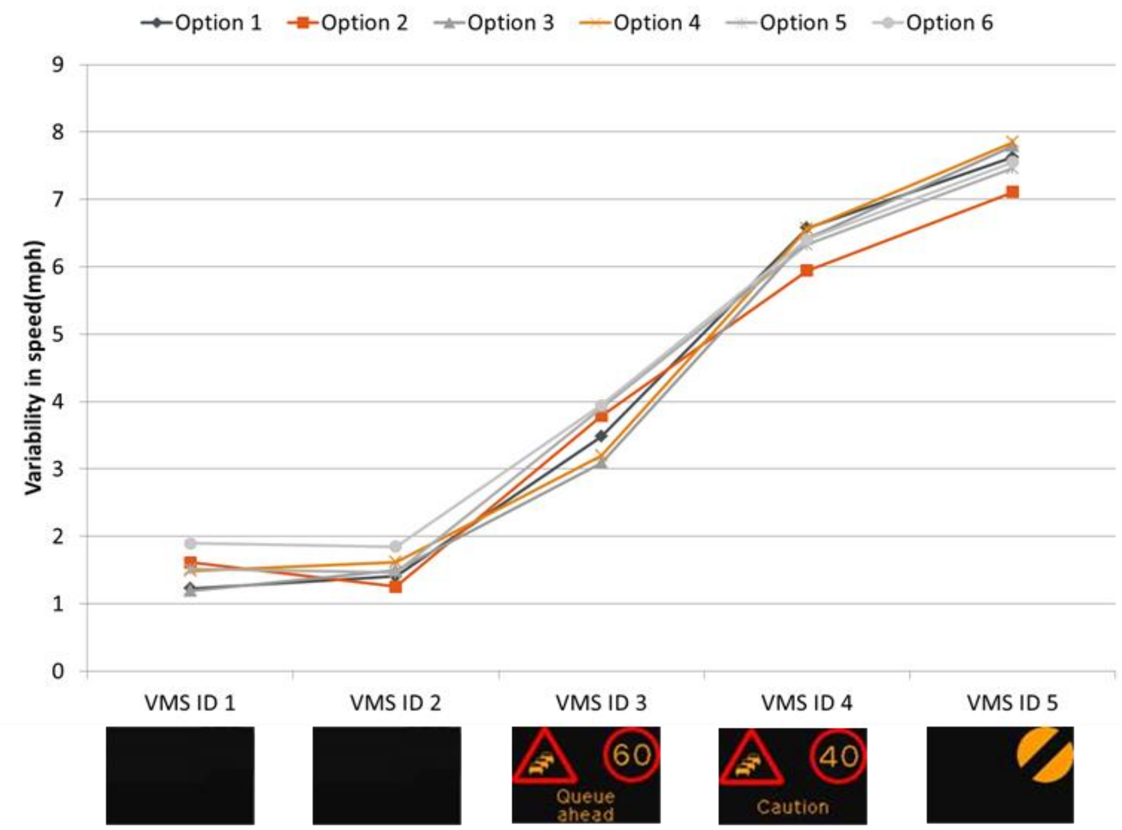


Figure 17. Variability of speed during queue ahead scenario

5.5.1.3 Changes in speed in proximity of VMS ("surfing" between VMS) – queue ahead scenario

In order to identify the presence of any surfing between VMS, Figure 18 was drawn. This Figure shows mean speeds for all Options during the queue ahead scenario. These data suggest drivers did not surf between VMS.

Statistical testing of this data would be extremely complex and given the lack of observable differences in Figure 18 it was decided to not proceed with any analysis.

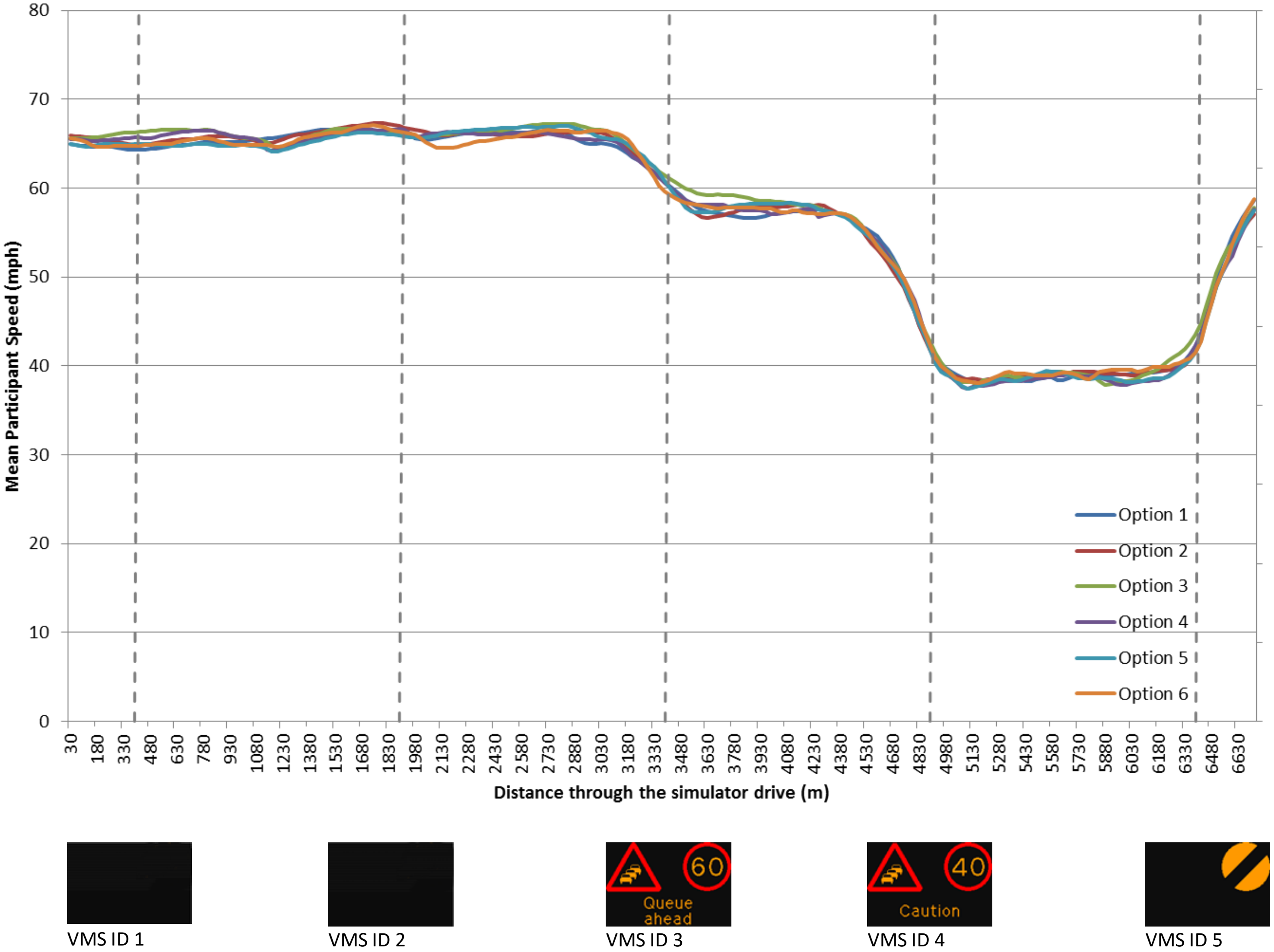


Figure 18. Mean speed throughout queue ahead scenario (surfing)

5.5.1.4 *Lane position – queue ahead scenario*

Participants drove slightly offset from the middle of the lane which is represented by the dotted line in Figure 19.

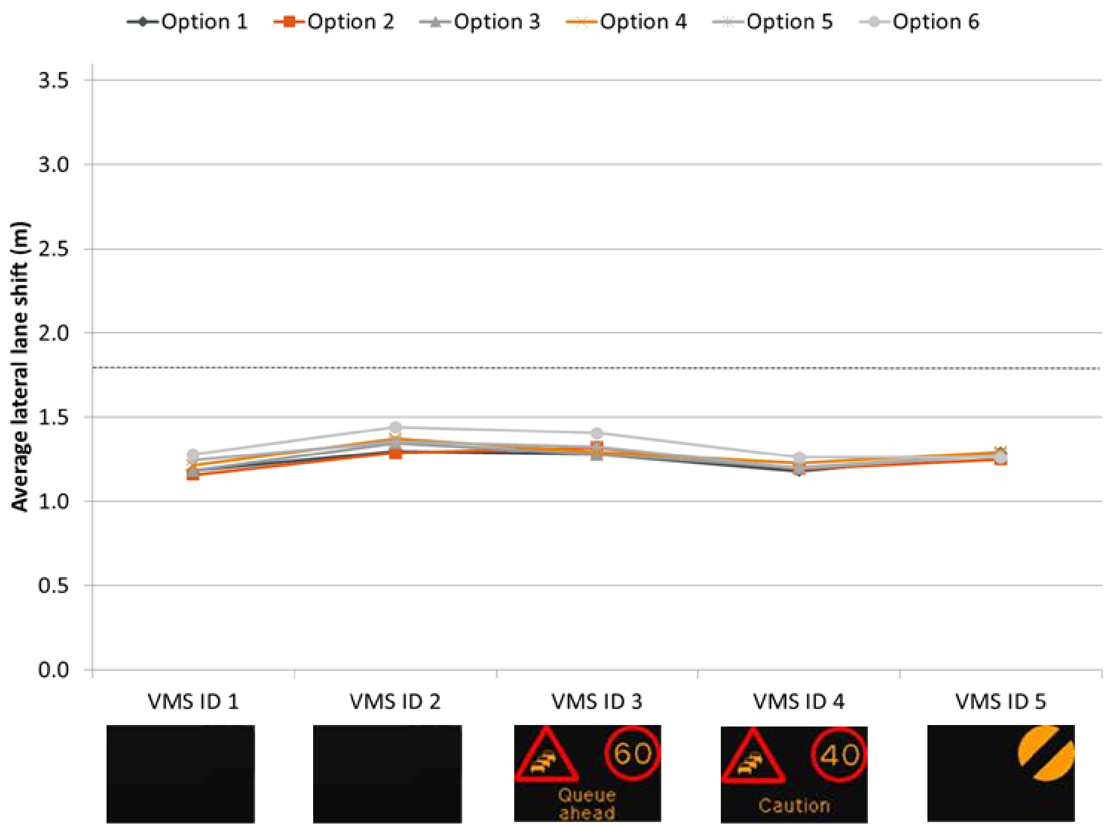


Figure 19. Mean lane position during queue ahead scenario

5.5.1.5 Standard deviation of lateral shift – queue ahead

Figure 20 shows the standard deviation of lateral shift (lane position) for each Option at VMS IDs 1 to 5.

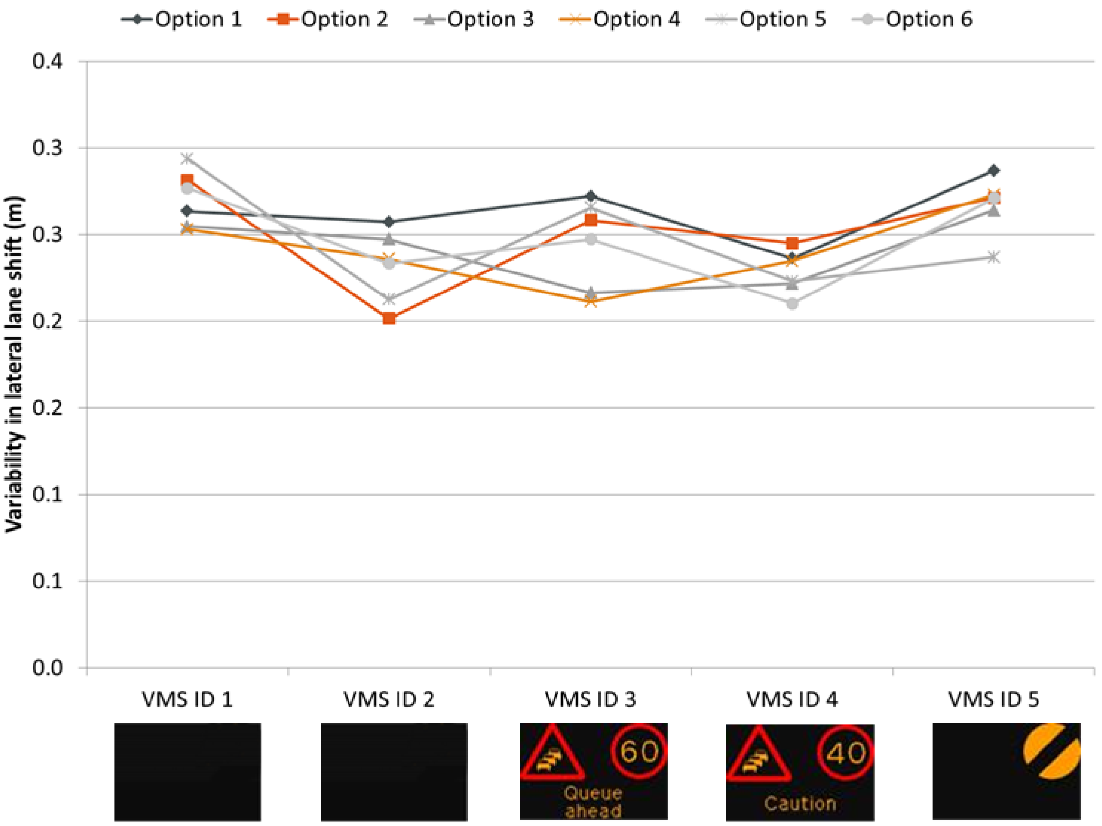


Figure 20. Variability in lateral shift of lane positioning during queue ahead scenario

5.5.1.6 *Lane occupancy – queue ahead scenario*

The lane number of each participant was recorded at the moment they passed each VMS. The percentage of drivers in each lane for each VMS ID number can be seen in Figure 21 to Figure 25. Statistical tests were not performed on the lane occupancy data.

Participants were more often in Lane 1 than Lane 2 when passing all VMS in all Options. Little difference was observed between the Options within the data for each VMS ID.

The data collected at each VMS ID were subjected to a Cochran's Q test. No significant differences between the VMS Options were revealed at any VMS ID.

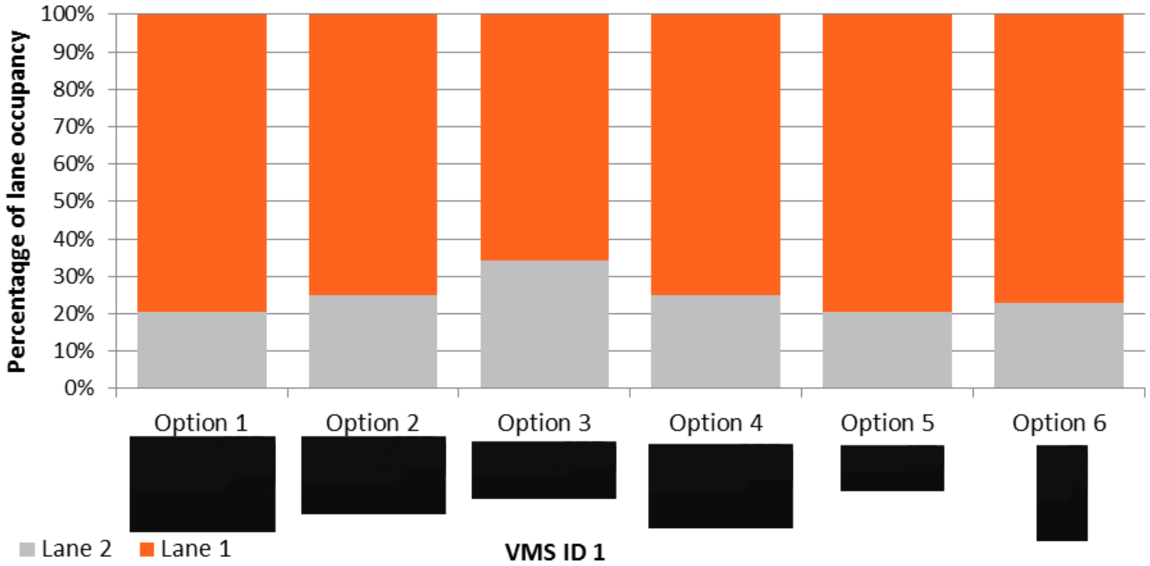


Figure 21. Percentage of lane occupancy at VMS ID 1 during queue ahead scenario

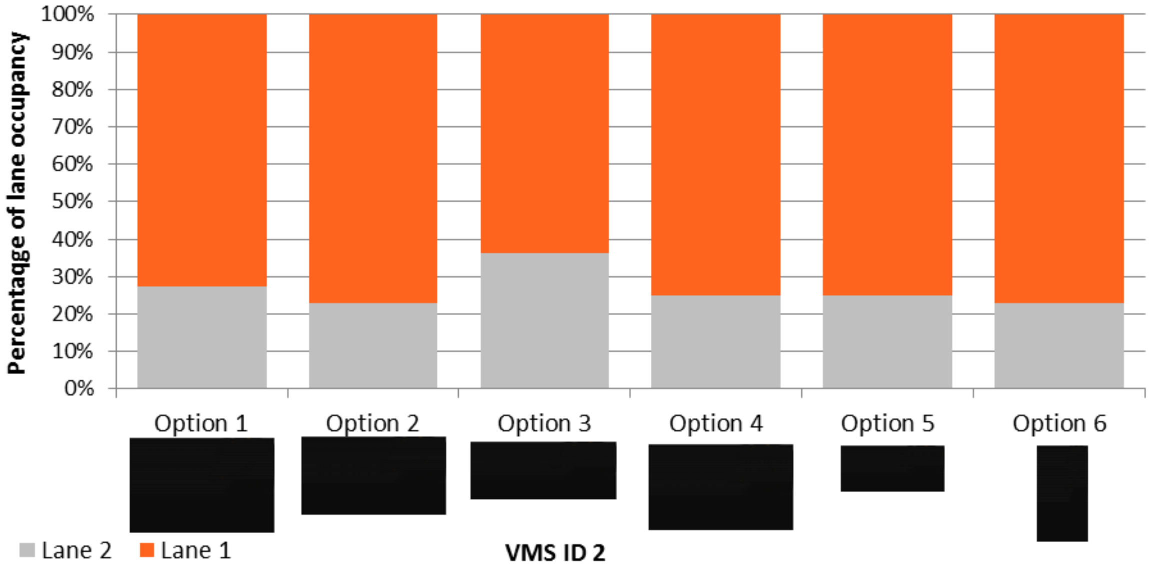


Figure 22. Percentage of lane occupancy at VMS ID 2 during queue ahead scenario

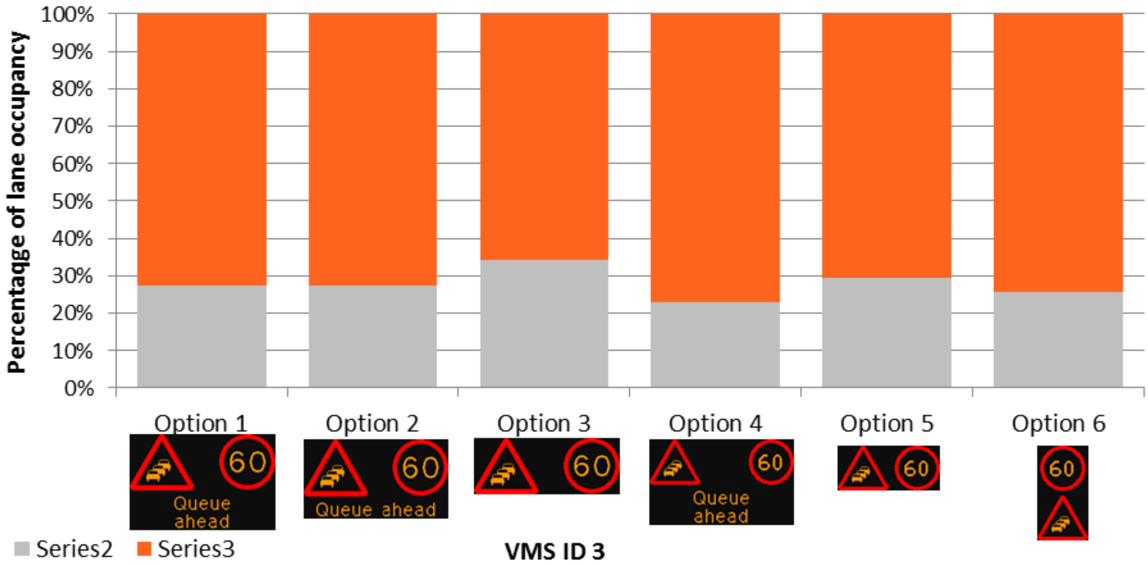


Figure 23. Percentage of lane occupancy at VMS ID 3 during queue ahead scenario

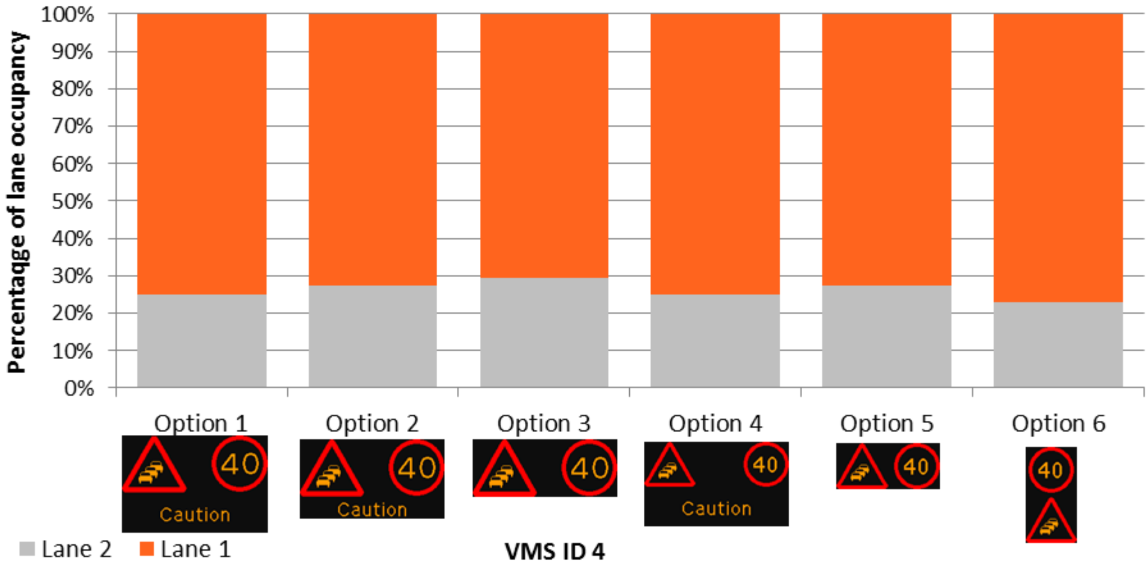


Figure 24. Percentage of lane occupancy at VMS ID 4 during queue ahead scenario

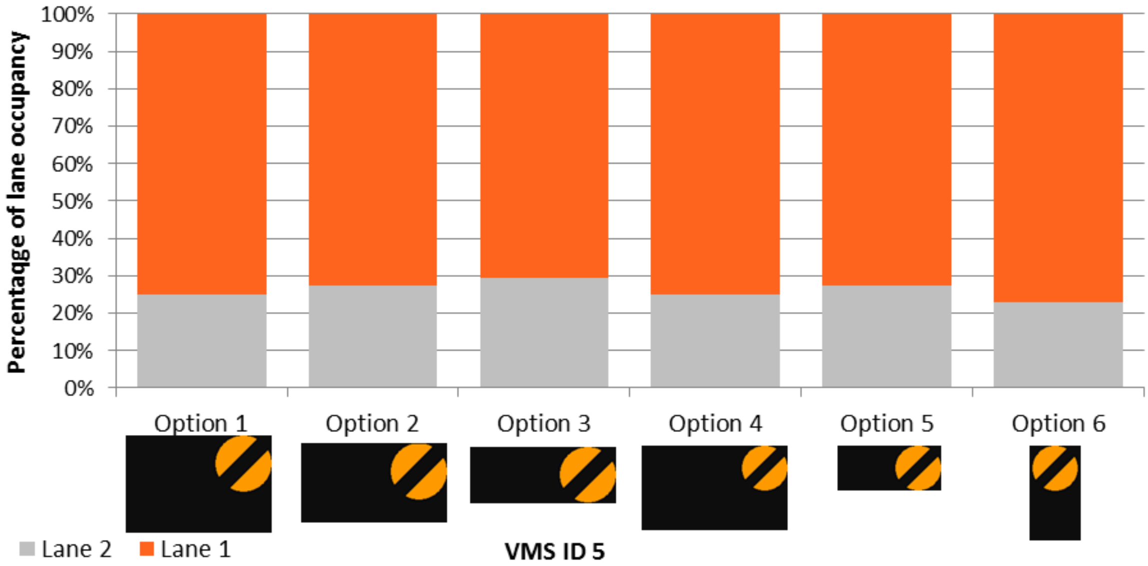


Figure 25. Percentage of lane occupancy at VMS ID 4 during queue ahead scenario

5.5.1.7 Mean headway distance – queue ahead

Figure 26 shows the mean headway for each Option at VMS IDs 1 to 5.

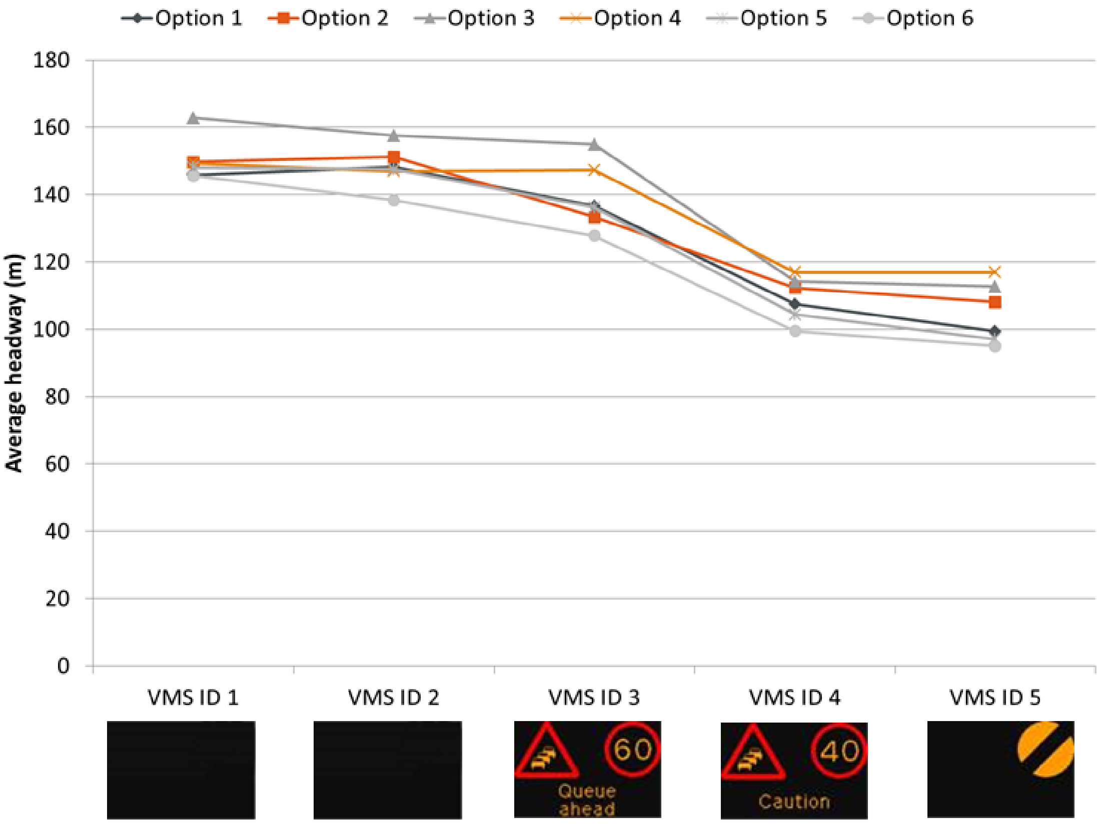


Figure 26. Average headway during queue ahead scenario

5.5.1.8 *Standard deviation of headway distance – queue ahead*

Figure 27 shows standard deviation (smoothness) of headway distance for each Option at VMS IDs 1 to 5.

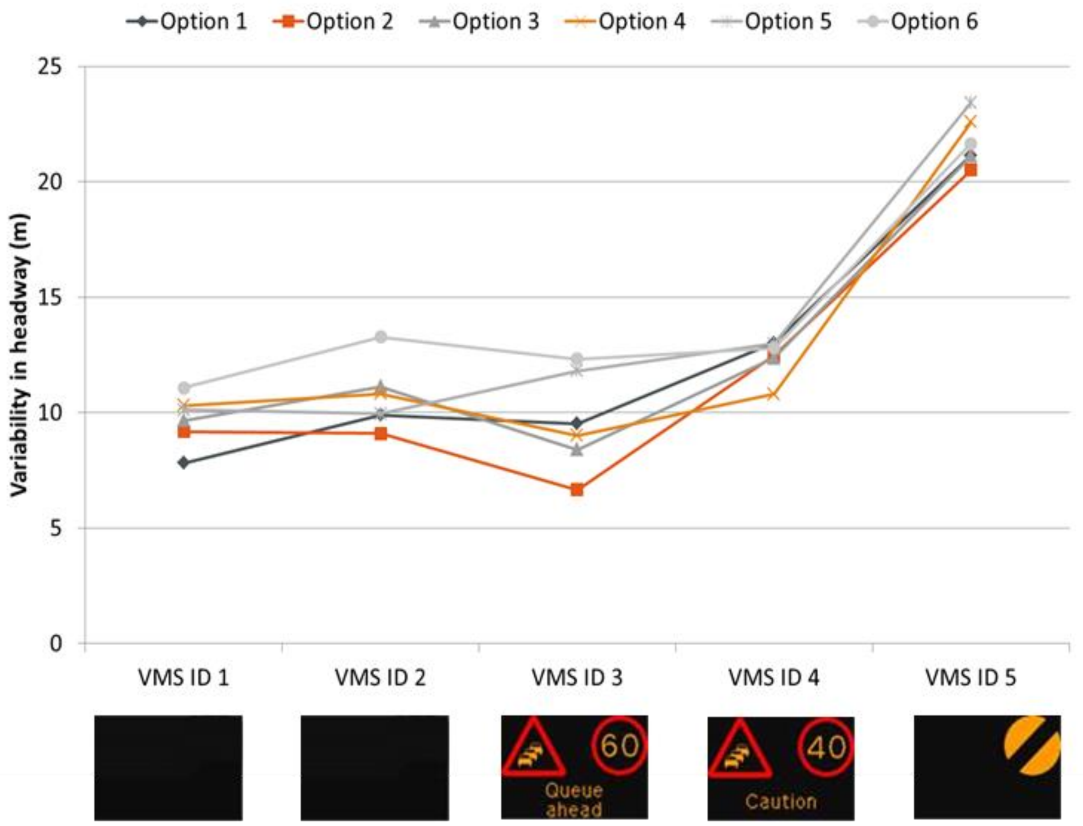


Figure 27. Smoothness of headway distance during queue ahead scenario

5.5.1.9 Time spent at high risk – queue ahead

Figure 28 shows that in most cases participants spent very little time at high risk (within 2 seconds of the vehicle ahead).

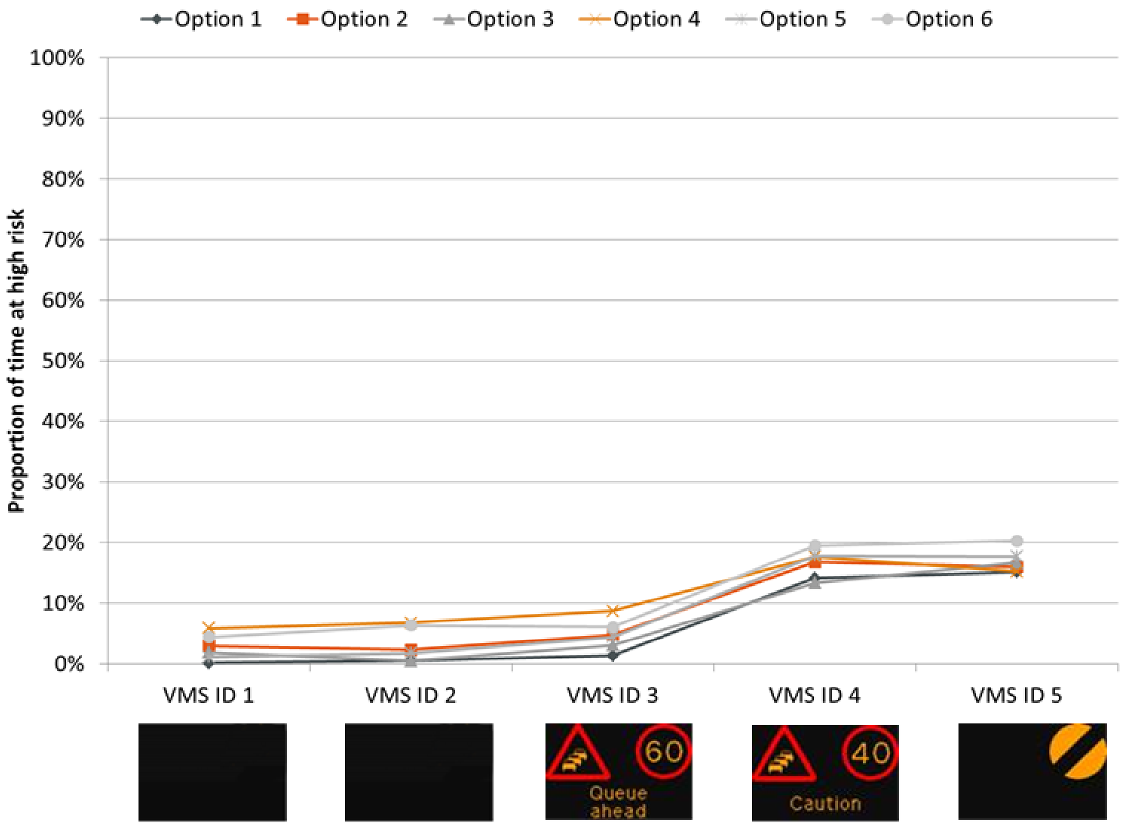


Figure 28. Proportion of time at high risk during queue ahead scenario

5.5.1.10 *Time spent at very high risk – queue ahead*

There were very few incidents of very high risk events. These were calculated as the proportion of time spent where the driver was so close to another vehicle that they would have virtually no time to react. This value was set at 250ms. The prevalence of such events was so low it was not possible to analyse.

5.5.2 *Incident scenario*

The data collected during the incident scenario showed few statistical differences between Options 1 to 5. However, some differences were evident between Option 6 and the other Options, these are described in detail in the remainder of this section.

When considering the data for the incident scenario the reader should appreciate that the messages displayed on Options 1 to 5 were very similar for each VMS ID. However, the messages on Option 6 were usually somewhat different; therefore this should be considered when interpreting the results. These differences can be seen in Table 4.

Table 4. The different information visible to participants during incident scenario

	ERA locations	VMS ID and Distance	Option 1 (Current authorised)	Option 2	Option 3	Option 4	Option 5	Option 6
Options 1 to 5: 3 LANES Option 6 : 2 LANES All Options 2 LANES	21km	13. - 21km (collocated with ERA)						
	18.5km	12. - 19.5km						
		11. - 18km						
	16km	10. - 16.5km						
		9. - 15km						

5.5.2.1 *Mean speed – incident scenario*

The mean speed for the incident scenario was plotted and can be seen in Figure 29. This figure suggests that there was very little difference in mean speed between the Options in the incident scenario, apart from Option 6 which shows higher speeds from VMS ID 9 onwards.

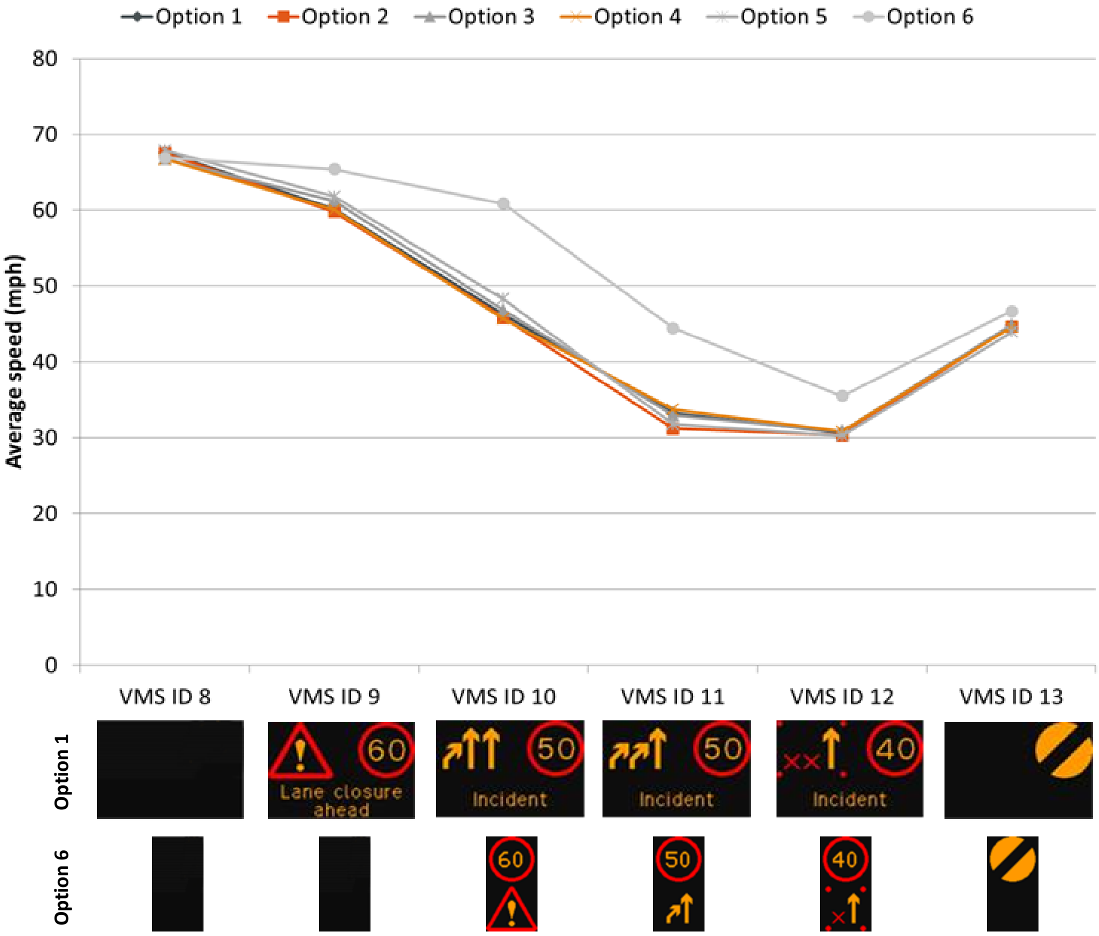


Figure 29. Mean speed during incident scenario

Statistical analysis of these data revealed a significant difference between VMS Options, and the analysis showed that the interaction between VMS Option and VMS ID was also significant ($p<0.001$).

Further investigation using pairwise comparisons showed that the effect of VMS Option was significant for the following VMS IDs:

- VMS ID 9: VMS Option 6 differed from VMS Options 1 ($p=0.0089$), 2 ($p=0.0028$), and 4 ($p=0.0060$).

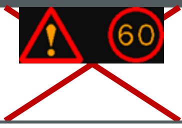
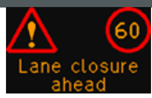
  Note, VMS ID 9 Option 6 was blank, all other Options showed a lane closure ahead.

- VMS ID 10, 11 and 12: Option 6 differed from all other VMS Options for each of these VMS IDs (p<0.001 in all cases)

  Note, at VMS ID 10 Option 6 only showed a speed limit reduction to 60mph, unlike the other Options which showed a reduction to 50mph and a Lane 1 kick over.
- VMS ID 11 for all pairwise combinations with Option 6 were significant (p<0.001). The same pattern was also observed for VMS ID 12.

Table 5 shows mean speeds and which VMS IDs were statistically different from Option 6. The table includes scaled images of the information on display for ease of reference.

Table 5. Statistically significant differences in mean speed between VMS Option 6 and the remaining VMS Options

VMS ID	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
9						
Mean speed	60	60	61	60	62	65
10						
Mean speed	46	46	47	46	48	61
11						
Mean speed	33	31	33	34	32	44
12						
Mean speed	31	30	31	31	30	36

All differences from Option 6 significant to the p = .001 level, except those crossed in red which were not significant.

There were no differences in mean speed between Options 1 to 5. Option 6 was different (higher) from the other Options in almost all cases, but given Option 6 displayed different restrictions and took place on 2 lanes, this was as expected.

5.5.2.2 *Standard deviation of speed – incident scenario*

The standard deviation of speed was calculated for the incident scenario and was plotted in Figure 30. This figure suggests that Options 1 to 5 produces a very similar pattern of behaviour, and Option 6 was different. Given the information displayed on Option 6 was substantially different (see Table 2), this was as expected.

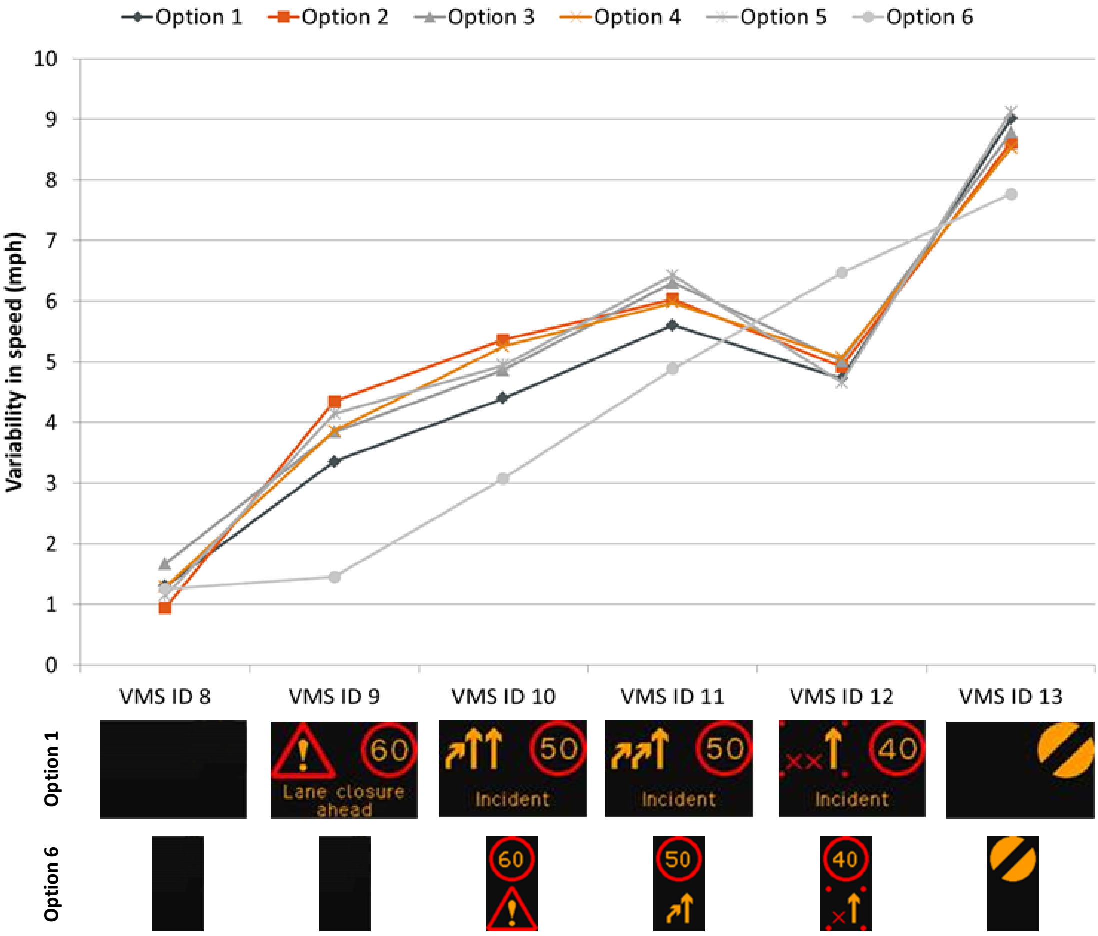
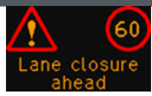


Figure 30. Standard deviation of speed during incident scenario

Statistical analysis of these data showed speed standard deviation showed a significant difference between VMS Options, and the analysis showed that the interaction between VMS Option and VMS ID was also significant ($p<0.001$).

Speed standard deviation only showed significant differences for VMS ID 9 and 10, again predominantly between the pairwise comparisons involving VMS Option 6, with p-values <0.001 (see Table 6).

Table 6. Statistically significant differences in speed standard deviation between VMS Option 6 and the remaining VMS Options

VMS ID	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
9						
StDev of speed	4.4	6.1	5.4	4.9	4.0	6.4
10						
StDev of speed	6.8	7.5	7.6	8.5	7.5	4.4

All differences from Option 6 significant to the p = .001 level, except those crossed in red which were not significant.

There were no differences in standard deviation of speed between Options 1 to 5. Option 6 was different to Options 1, 2, 4 and 5 at VMS ID9, and different to Options 2 to 5 at VMS ID10. There were no other significant differences.

5.5.2.3 *Changes in speed in proximity of VMS ("surfing" between VMS) - incident scenario*

Figure 31 shows mean participant speed throughout the incident scenario. This Figure was drawn to identify any surfing behaviour. As can be seen, there was no suggestion of surfing behaviour for Options 1 to 5.

However, there was some indication that participant speeds dipped in the presence of VMS ID 9 by 2 or 3 miles per hour before returning to the previous speed. Note, during Option 6 VMS ID 9 was blank.

Statistical testing of this data would be extremely complex and given the lack of observable differences in Figure 31 (other than Option 6, which we expect to be different) it was decided to not proceed with any analysis.

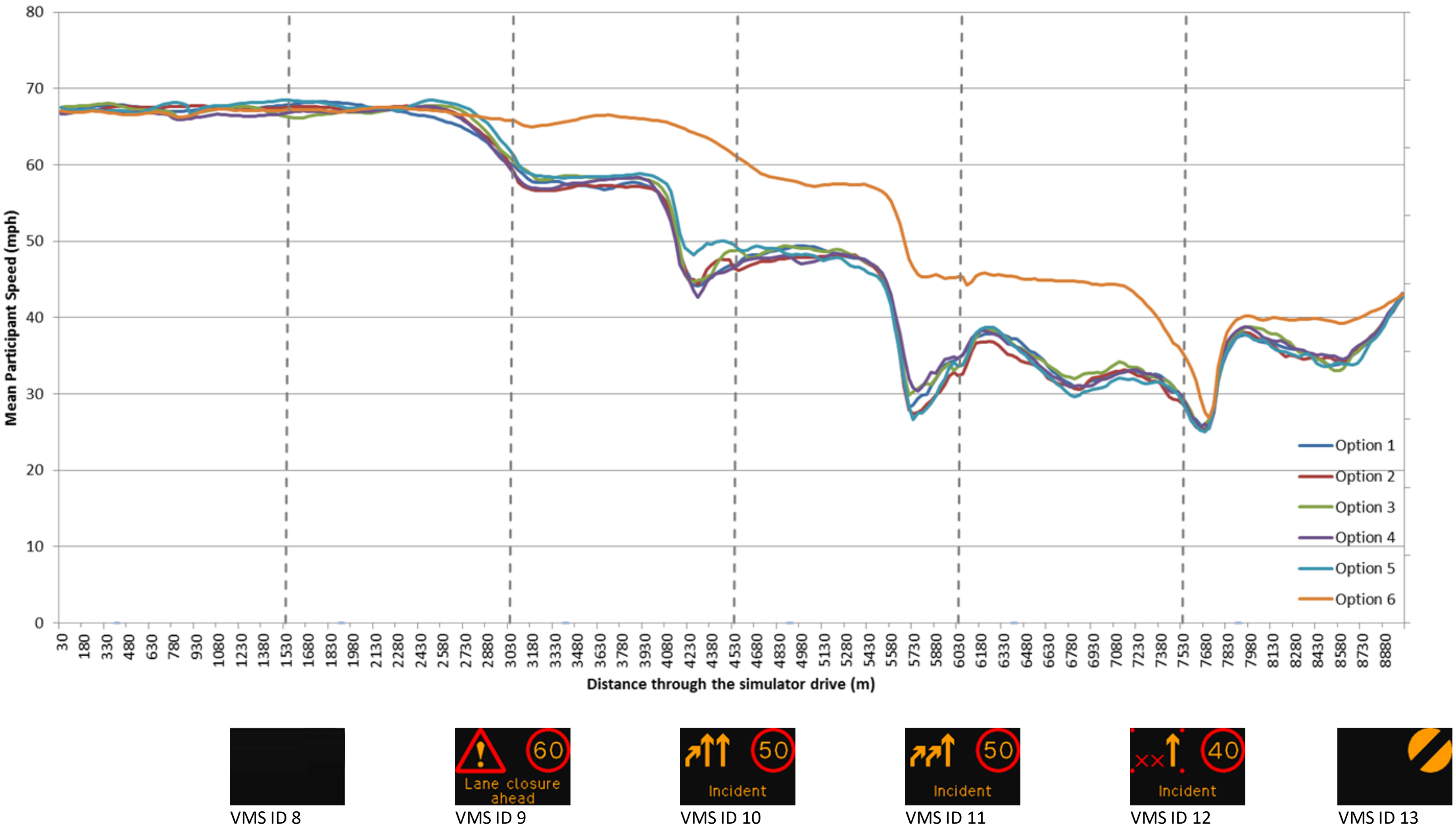


Figure 31. Mean speed throughout incident scenario (surfing)

5.5.2.4 Lane position – incident scenario

There was little apparent difference in lane position between the six Options (Figure 32).

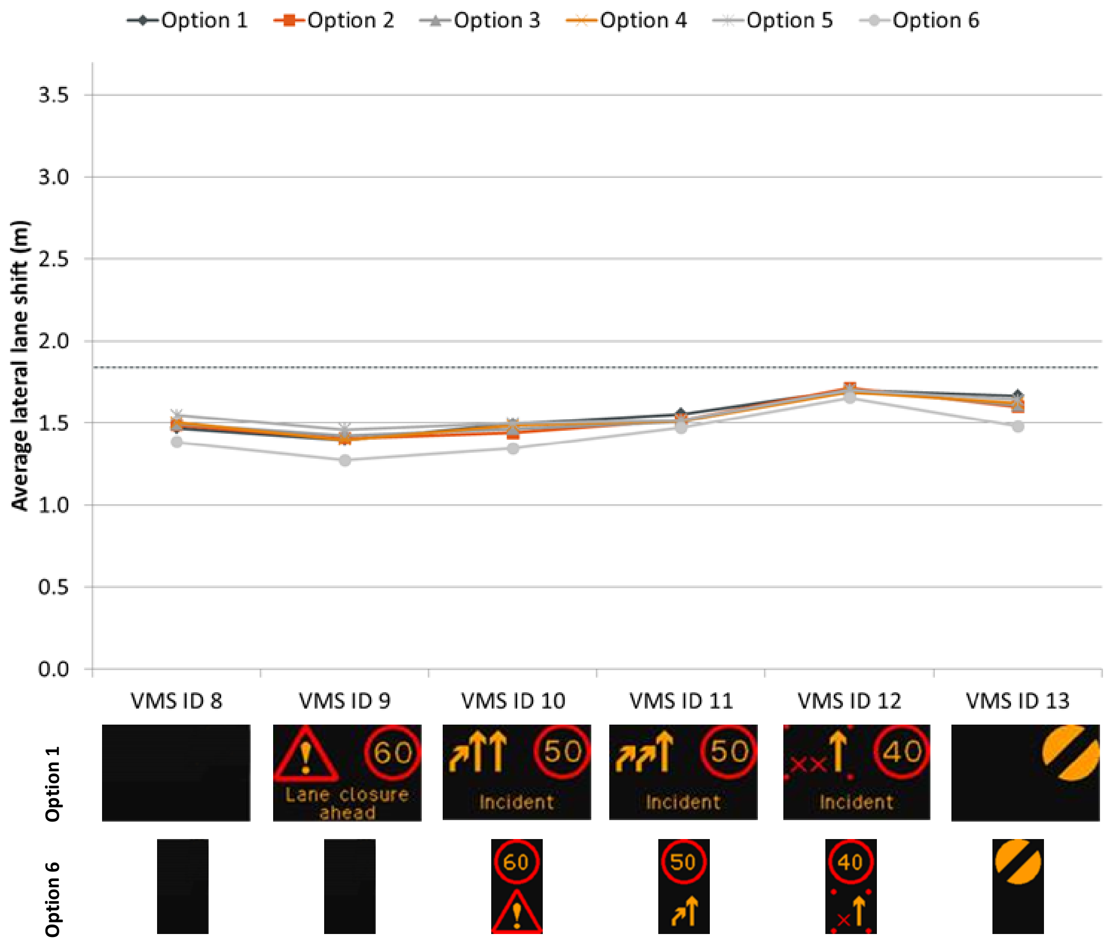


Figure 32. Mean lane position during incident scenario

Statistical analysis revealed no significant differences between Options for mean lateral shift.

Position within lane did not differ between Options.

5.5.2.5 *Standard deviation of lateral shift – incident scenario*

Inspection of shows there was little different in standard deviation of lateral shift at VMS IDs 8, 11, 12 and 13. However, there appears to be more difference between the Options at VMS 9 and 10.

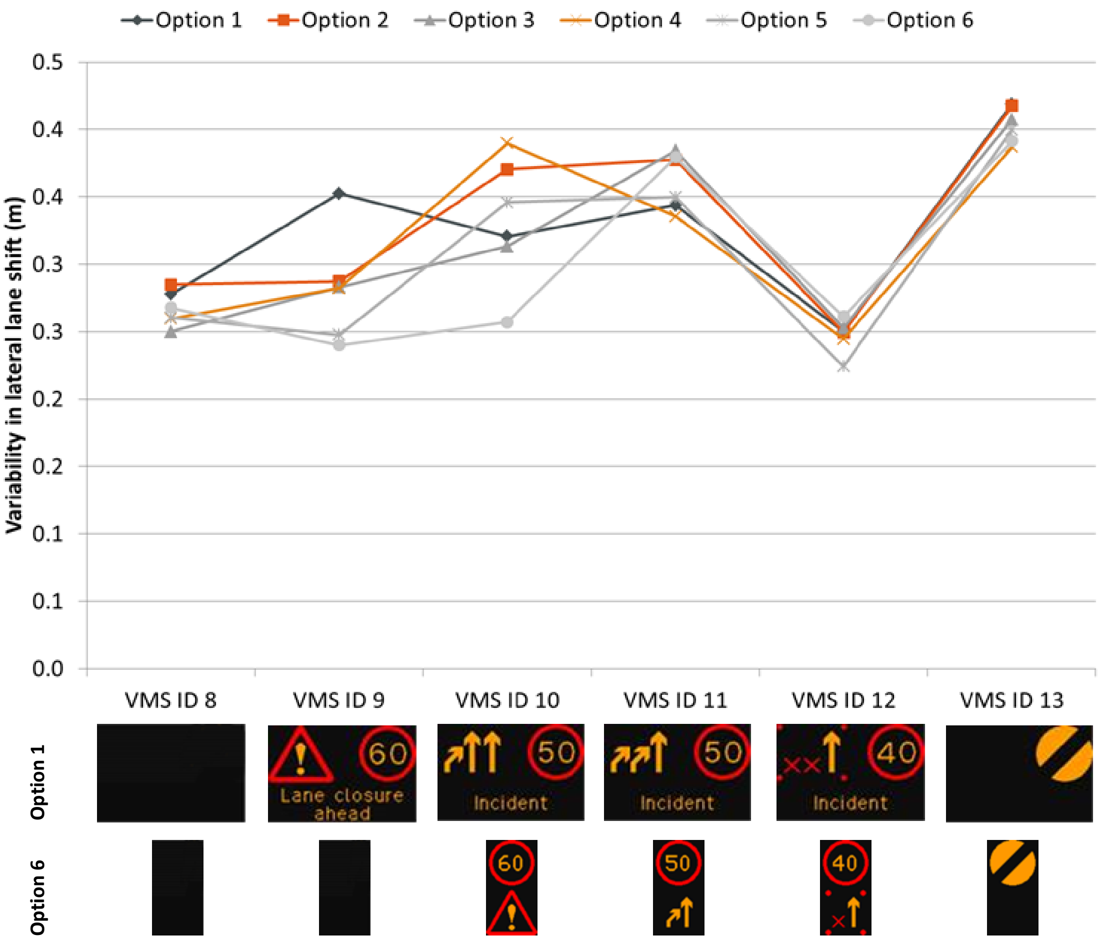
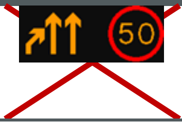
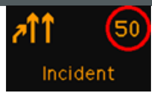


Figure 33. Standard deviation of lane positioning during incident scenario

Statistical comparison of standard deviation of lane position (see Table 7) showed that for VMS ID 10 VMS Option 6 differed from VMS Options 2 and 4 with p-values <0.05 for each comparison. The apparent differences in VMS ID 9 were not significant.

Table 7. Statistically significant differences in variation of lane positioning between VMS Option 6 and the remaining VMS Options

VMS ID	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
10						
SDLP	0.32	0.37	0.31	0.39	0.35	0.26

All differences from Option 6 significant to the p = .05 level, except those crossed in red which were not significant.

Standard deviation of lateral shift did not differ between Options 1 to 5. However, Option 6 was lower than Options 2 and 4 at VMS ID10.

5.5.2.6 Lane occupancy – incident scenario

The percentage of drivers who were in each of the lanes at the moment they passed each VMS ID was recoded.

Note, during the incident scenario three lanes were present for Options 1 to 5 and two lanes for Option 6. A separate figure was drawn for each VMS ID number. In all cases direct comparison between Option 6 and the other Options is problematic due to the different number of lanes available. The data for Option 6 has been included for completeness, however, the reader is advised to exercise caution when making comparisons with this Option.

Comparisons between the frequency of use of Lane 3 (the only lane open throughout the incident scenario) and combined use of Lanes 1 and 2 at each VMS ID were conducted using a Cochran's Q test. No significant differences were found.

VMS ID 8 – There was little difference in the lane chosen by participants when they passed VMS ID 8.

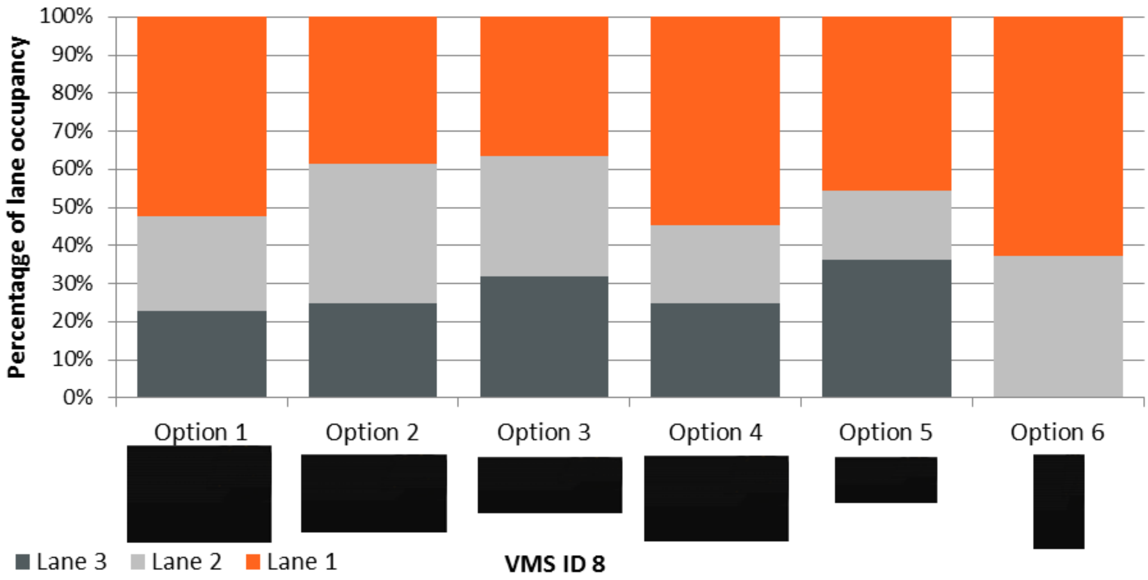


Figure 34. Percentage of lane occupancy at VMS ID 8 during incident scenario

VMS ID 9 – The lane use percentages at VMS ID 9 were very similar to those for VMS ID 8. There was little difference between Options at this VMS ID.

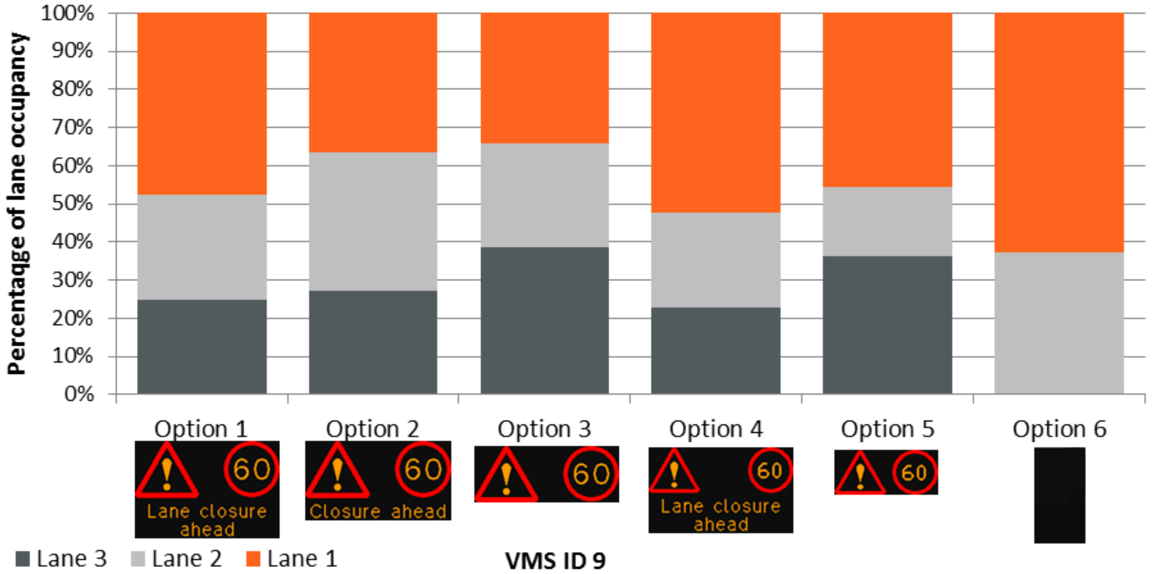


Figure 35. Percentage of lane occupancy at VMS ID 9 during incident scenario

VMS ID 10 – There was little difference between Options 1 to 4 at VMS ID 10. However, more participants were in Lane 1 when passing this VMS ID during Option 5 than during Options 1 to 4.

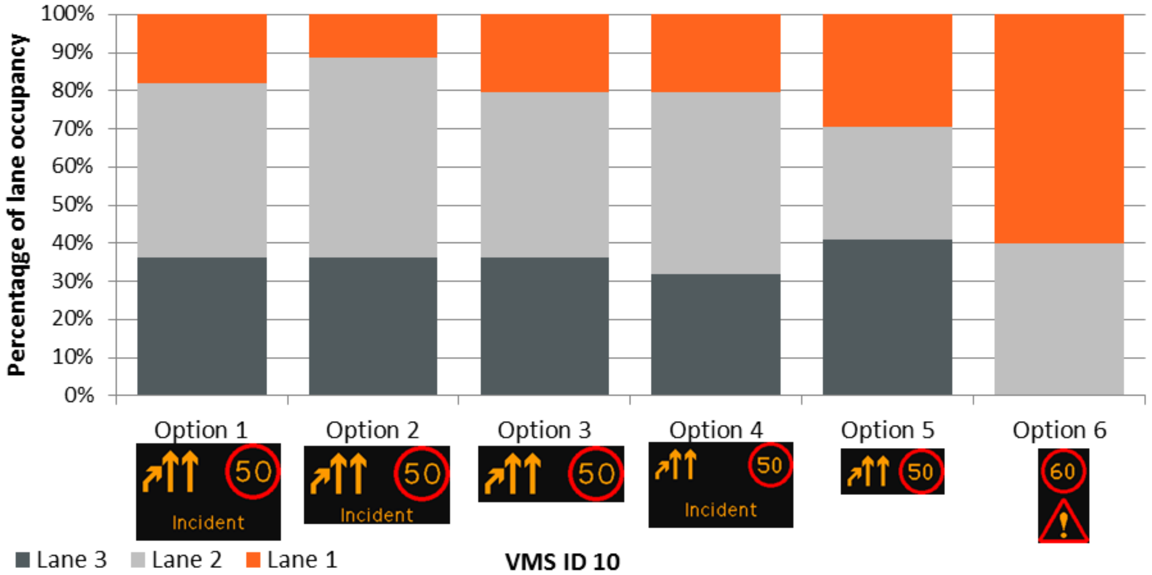


Figure 36. Percentage of lane occupancy at VMS ID 10 during incident scenario

VMS ID 11 – A very large majority of drivers had exited Lane 1 at VMS ID 11. A minority of participants passed it in Lane 2, with most passing in Lane 3. More participants appear to use Lane 3 in Options 1 and 2 than in Options 3, 4 and 5.

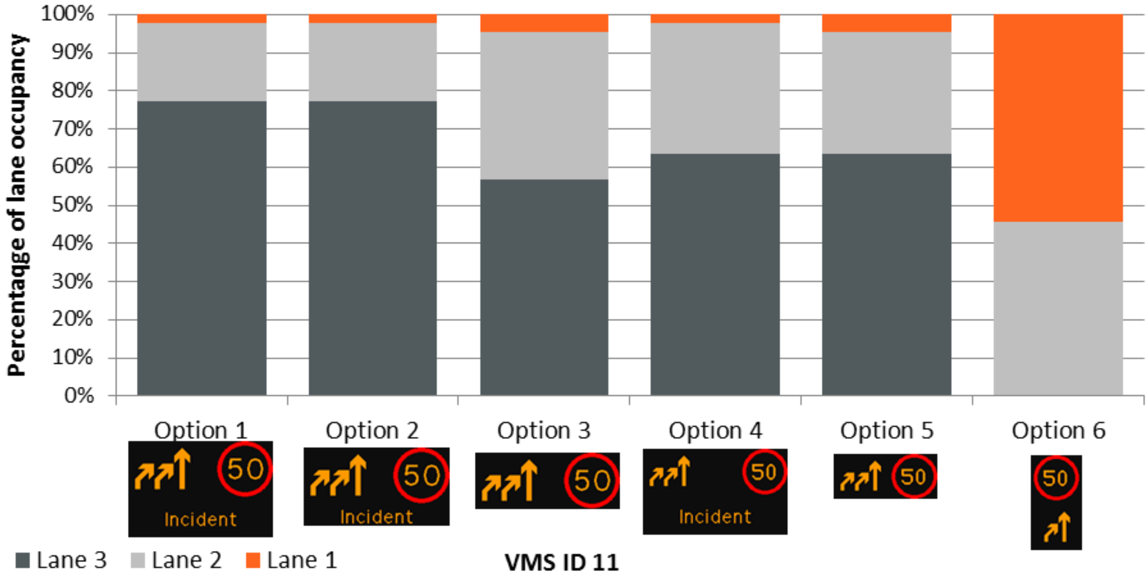


Figure 37. Percentage of lane occupancy at VMS ID 11 during incident scenario

VMS ID 12 **– When passing VMS ID 12 nearly all participants were in Lane 3 across Options 1 to 5. There was only one instance of a participant being in Lane 1 when passing this VMS and this occurred during Option 4.**

Just under 90% of participants were in Lane 2 at this VMS during Option 6.

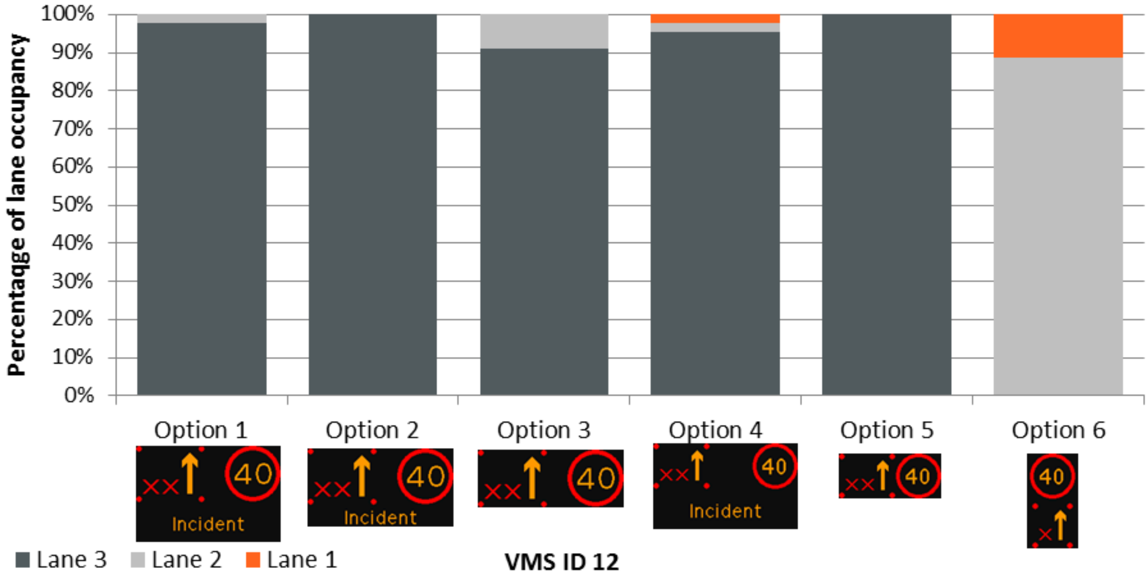


Figure 38. Percentage of lane occupancy at VMS ID 12) during incident scenario

VMS ID 13 – There was little difference in lane use between the Options at VMS ID 13.

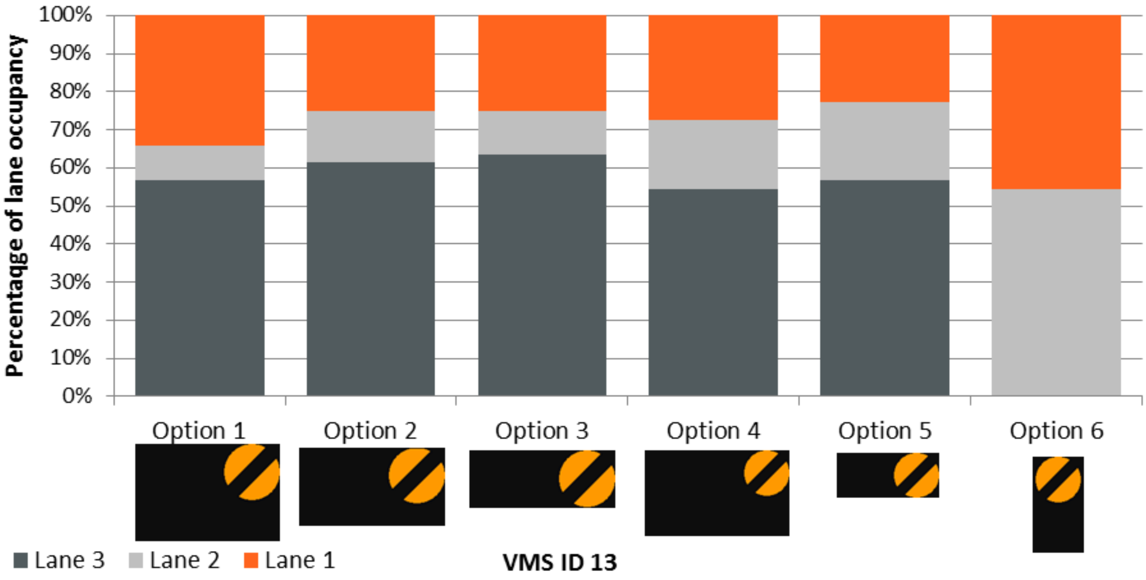


Figure 39. Percentage of lane occupancy at VMS ID 13 during incident scenario

5.5.2.7 *Mean headway – incident scenario*

The pattern of performance observed in Figure 40 shows that there was little difference between Options 1 to 5. Option 6 produced different average headways at VMS IDs 9 and 10, again, given the different information displayed on Option 6, this is in line with expectations.

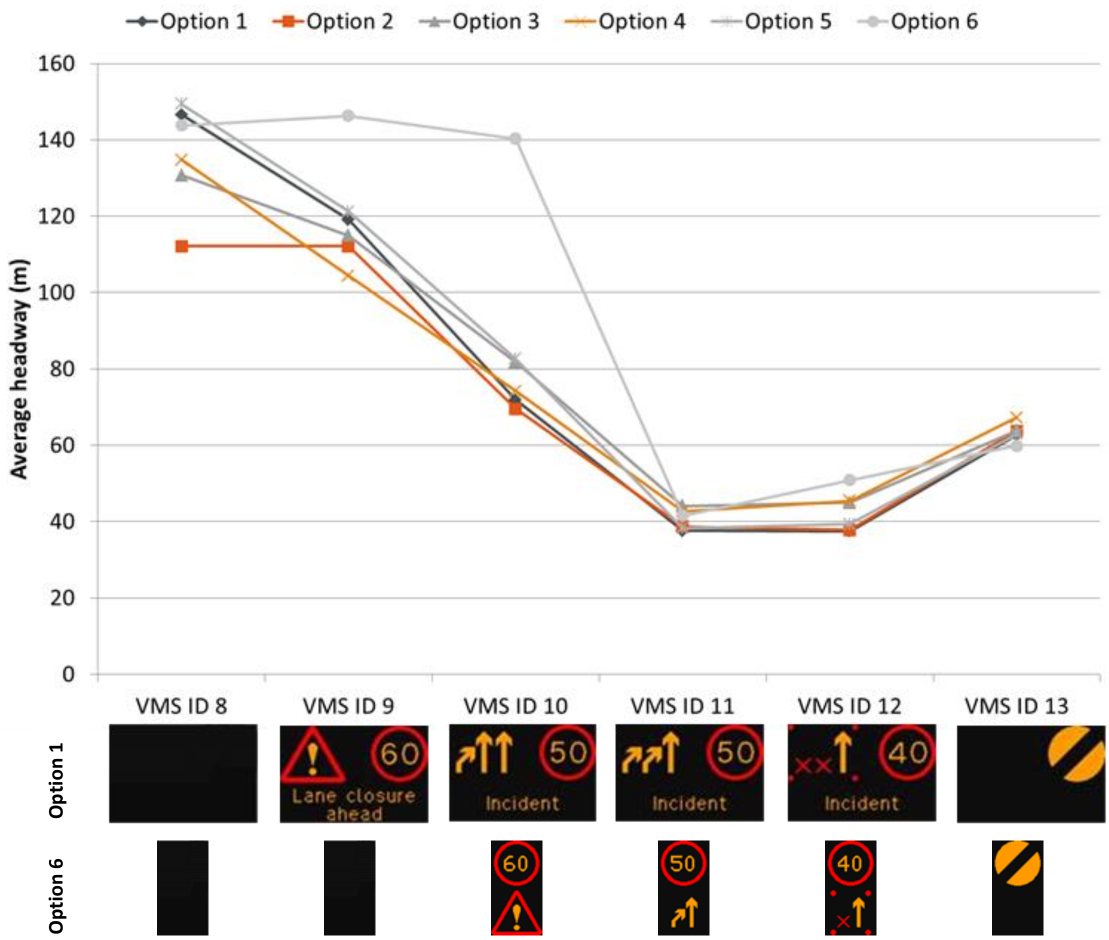
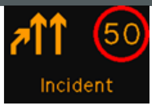
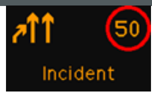


Figure 40. Average headway during incident scenario

Statistical analysis showed some of these apparent differences were significant (see Table 8). At VMS ID 10 Option 6 showed significant differences between all pairwise comparisons (p-values <0.001). There were no differences at VMS ID 9.

Table 8. Statistically significant differences in average headway between VMS Option 6 and the remaining VMS Options

VMS ID	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
10						
Headway	72	69	82	74	83	140

All differences from Option 6 significant to the p = .001 level, except those crossed in red which were not significant.

Average headway did not differ between Options 1 to 5. However, Option 6 was higher than Options 1 to 5 at VMS ID10.

5.5.2.8 *Standard deviation of headway distance – incident scenario*

Figure 41 shows a similar pattern of performance for Options 1 to 5, with Option 6 somewhat different.

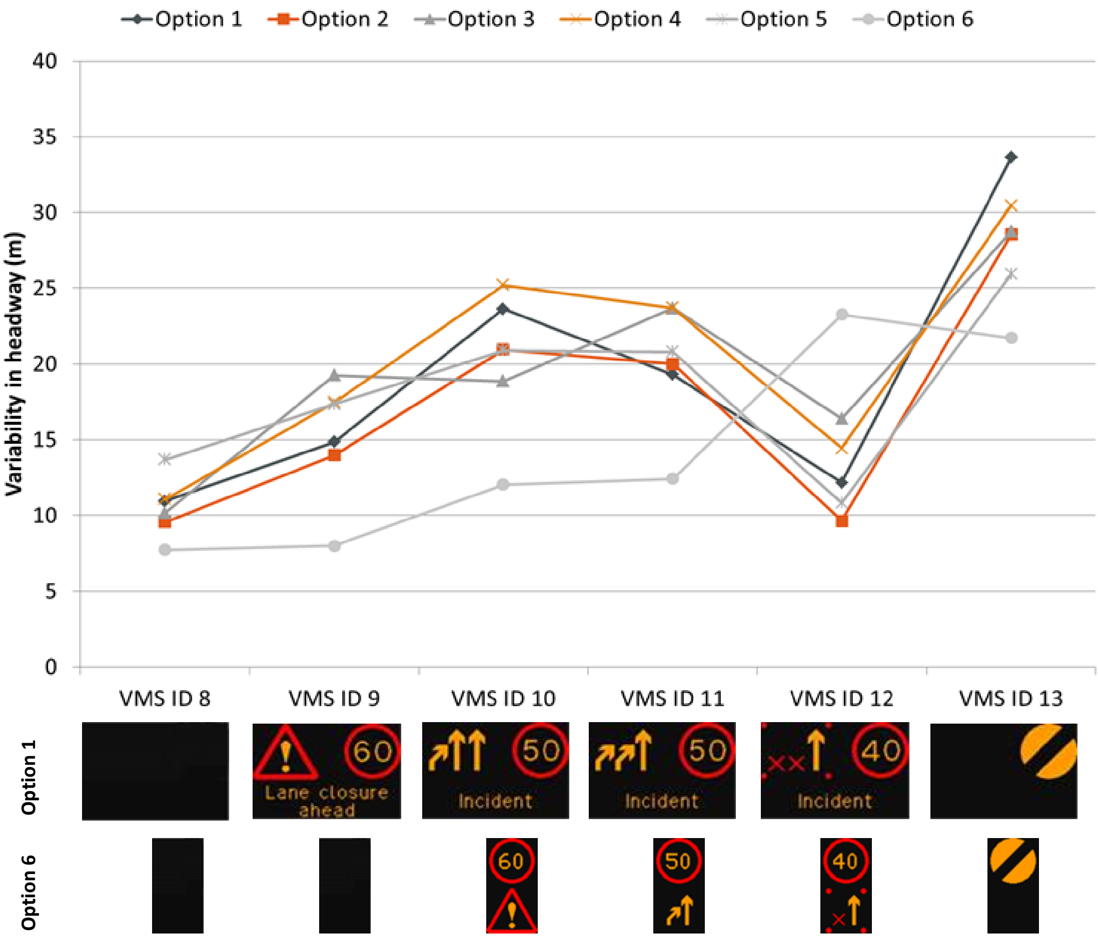


Figure 41. Variation of headway distance during incident scenario

Headway standard deviation did not show any statistically significant differences between any of the VMS Options.

There was no difference in Variation of headway between any of the Options.

5.5.2.9 *Time spent at high risk – incident scenario*

There appeared to be little difference in time spent at high risk (<2 seconds from vehicle in front) between the six Options (see Figure 42).

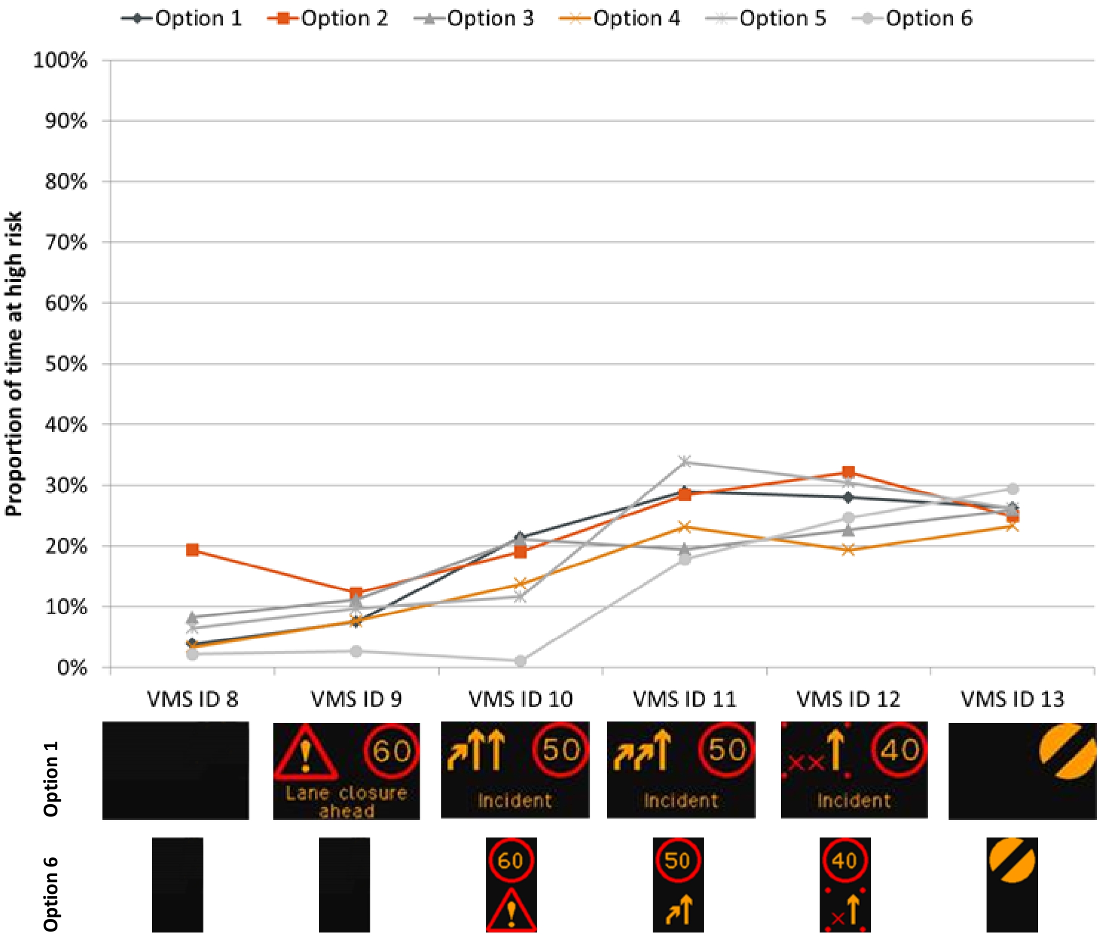


Figure 42. Proportion of time at high risk during incident scenario

Statistical investigation of the time spent at high risk headway showed no significant differences at the 95% level of confidence.

There was no difference in proportion of time at high risk (<2s) between any of the Options.

5.5.2.10 Time spent at very high risk – queue ahead

The proportion of time spent at very high risk (within 250ms of another vehicle) was very low in all cases, and no statistically significant differences were identified.

There was no difference in time spent at very high risk (<250ms) between any of the Options.

5.6 Summary of results

A sample of the general driving population was recruited and analysis of their demographics showed a spread of ages and experience of driving on roads which share similarities to expressways (dual carriageways and motorways). Slightly more males completed the trail than females (24 and 19), a proportion which is similar to the proportion of male to female driving licence holders in the UK.

Three sets of analyses were completed: participants' subjective impressions during their drive, participants' subjective impressions following the drive, and their performance data captured from their six drives in TRL's driving simulator. The results can be summarised as:

- The sample we tested was similar to the wider driving population in terms of gender split, age rage and annual mileage.
- VMS Option did not affect participant feelings of safety or satisfaction while they were driving.
- VMS Options 1 to 4 were judged to be equally easy to identify, to interpret in terms of their meaning, and equally satisfying in their information provision.
- VMS Options 5 and 6 were rated as less easy to identify, less easy to understand and less satisfying in information provision than the other VMS Options.
- Analysis of participant performance during the queue ahead scenario showed no difference between the six Options.
- Analysis of participant performance during the incident scenario showed no differences between VMS Options 1 to 5.
- Analysis of participant performance during the incident scenario showed several differences between Option 6 and the other Options.
    - Participants drove more quickly in Option 6 from VMS IDs 9 to 12.
    - There was more variation in participant speed in Option 6 at VMS ID9 and 10.
    - There was less variation in how smoothly participants kept to their lane in Option 6 than in Options 2 and 4 at VMS ID10.
    - There was no observable trend of surfing between VMS IDs.
    - There were no significant differences in lane use between the Options.
    - Participants had a larger headway during Option 6 than any of the other Options at VMS ID10.
    - There was no difference in the variation of headway between all Options.
    - There was no difference in the time spent at risk between all Options.

It is important to be aware that the information displayed on Option 6 was different at all VMS IDs and this is likely to account for the differences observed.

Furthermore, there were some differences in density of traffic between Options 1 to 5 and Option 6 in the incident scenario. Traffic was set at 1000 vehicles per lane, per hour in all open lanes, in all Option conditions. When Options 1 to 5 were presented in the incident scenario (which takes place on a three lane road) this resulted in a total traffic density of 3000 vehicles per lane, per hour in the one remaining open lane once the traffic merged across from Lanes 1 and 2. In comparison, the total traffic present at the lane closure for Option 6 was only 2000 vehicles per lane, per hour as it occurred on a two lane road, requiring two lanes of traffic to merge, not three. This may account for some of the variation observed between Option 6 and the remaining Options.

5.7 Evidence to support hypotheses

Five specific questions were tested:

- **H1** – Does smaller VMS type A (Option 2) produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?
  Results – No differences were observed.
- **H2** – Does smaller VMS type B (Option 3) produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?
  Result – No differences were observed
- **H3** – Does VMS with one line of text (Option 4) produce performance, behaviour or subjective impression than current authorised VMS (Option 1)?#
  Result – No differences were observed
- **H4** – Does VMS with no text (Option 5) produce different driver performance, behaviour or subjective impression than current authorised VMS (Option 1)?
  Result – No differences in performance were observed. Option 5 was rated as subjectively less easy to identify, less easy to understand and less satisfying in information provision.
- **H5** – Does the placement of VMS (overhead (Option 6) vs. low-level verge mounted (Option 1)) influence driver performance, behaviour or subjective impression?
  Result – Whilst several differences were observed in performance during the incident scenario, no differences were observed in the queue ahead scenario. The information shown on Option 6 was very similar to the other Options in the queue ahead scenario but quite different in the incident scenario. Therefore, where road conditions and displayed information are similar, Option 6 was not different from Option 1. Option 6 was rated as subjectively less easy to identify, less easy to understand and less satisfying in information provision.

6 Discussion

This research was designed to deliver against three objectives:

- Objective 1: Evidence the impact of altering VMS aspect sizes, making comparison with current approved aspects used on IAN 161 schemes
- Objective 2: Evidence the impact of altering the number of lines of text displayed on VMS, making comparison with current authorised messages
- Objective 3: Evidence the impact of varying the site of the VMS (overhead or verge)

Our evidence showed that varying the size of the aspects, varying the number of text lines and varying the site of the VMS in comparison with Option 1 (currently authorised) did not have a meaningful impact on driver performance.

In the cases where statistically significant differences were observed, these were between Option 6 and the other Options, and were located where the road conditions (2 lanes in Option 6 vs. 3 lanes in all other Options) and the information displayed on Option 6 was different from the other Options. Therefore, the differences we observed are highly likely to be due to the informational content and not the format in which it was delivered. Where the information was essentially the same (queue ahead scenario) there was no difference between Option 6 and the other Options.

Subjectively, participants did not rate Options 2, 3 or 4 as different from Option 1 (current authorised). However, they did rate Options 5 and 6 as less easy to identify, less easy to interpret, and less satisfying in their information provision than Option 1. The ratings of the Options collected during the drive (of safety and satisfaction) showed no differences. These data suggest drivers may have a preference for the larger, more information-rich VMS used in Options 1 to 4.

7 Conclusion

The data collected by this research suggests there is little, if any, difference in how drivers respond to the six VMS Options tested. Therefore, factors other than driving performance could take priority when deciding which of the Options to take forward for further testing, such as operational factors, obscuration, flexibility to display a range of information which may be required at a later date, installation/maintenance issues, value and customer experience.

Given the indication of a subjective preference for Options 1 to 4 and the importance of the customer experience one of those Options may be best suited for further consideration. That said, the degree to which driver opinions may change over time as they become accustomed to Options 5 and 6 is unknown.

The Determination of VMS Display Requirements for Expressways

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