

## **CLIENT PROJECT REPORT CPR2416**

### **Monitoring and evaluation of the 55/60mph pilots**

Interim report for the simulator trial of 55 and 60mph through  
roadworks - A follow-on study

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## Table of Contents

Executive summary	1
1 Introduction	3
1.1 Background	3
1.2 Research questions	4
2 Method	5
2.1 Overview	5
2.2 Participant sample	5
2.3 Route layout	7
2.4 Trial procedure	10
2.5 Data collection	11
2.6 Data analysis	15
3 Results	16
3.1 Driver behaviour	16
3.2 Visual behaviour	32
3.3 Perceptions and opinions	36
4 Summary and conclusions	47
4.1 What is the effect of speed limit on driver distraction?	47
4.2 What is the effect of speed limit on driver workload?	47
4.3 What is the effect of speed limit on headway?	48
4.4 What is the effect of speed limit on gap size?	48
4.5 What is the effect of speed limit on drivers' subjective experience?	48
5 Recommendations	50
6 References	51
Appendix A Post-drive questionnaire	52
Appendix B NASA-TLX	54
Appendix C Post-trial interview	55

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## Executive summary

Improving customer satisfaction, particularly through roadworks, is a priority for Highways England. One potential measure to achieve this is raising the speed limit through roadworks from the current 50mph limit to 55 or 60mph.

A speed limit of 55mph is not currently used on the network and thus there is limited evidence regarding how this speed limit might affect driver behaviour, perceptions or performance, in particular in the vicinity of roadworks. A previous simulator trial conducted by TRL investigated driver behaviour in roadworks with a number of different speed limits: 50, 55, 60 and 70mph (Wallbank, Robbins, Tailor, & Chowdhury, 2017). In the 60mph speed limit, driver behaviour was similar to that in the 50mph speed limit. However, there was some evidence to suggest driver behaviour in roadworks differed when the speed limit was 55mph compared to 50mph.

In order to explore possible reasons for any differences and understand the relative safety implications of the 55 and 60mph speed limits, a further driving simulator study was commissioned. The primary aim of this follow-up study was to provide clear evidence as to the suitability of trialling 55mph speed limits on the Strategic Road Network (SRN). This report documents the findings and recommendations from this trial.

Thirty six participants took part in the trial, completing six drives each: one at each speed limit (50, 55 or 60mph) under either 'low' or 'high' traffic conditions. Data on driving behaviour (including speed, headway and lane position) were collected using the TRL 'DigiCar' driving simulator. Participants wore eye-tracking glasses during the drives to capture information on how frequently and for how long they looked at the speedometer. Subjective data on participant perceptions and opinions were also sought using questionnaires and interviews.

The results suggest that the speed limit did have some impact on visual distraction; the 60mph speed limit resulted in substantially fewer (and shorter) fixations on the speedometer than 50 or 55mph. The 55mph speed limit was no more distracting than the 50mph speed limit currently used in roadworks.

Driver workload was measured using a number of metrics: NASA-Task Load Index (TLX), ease/difficulty scores, and variability in driving behaviour. The results suggest that workload was related to the traffic conditions, but not to the speed limit. From the qualitative feedback, some drivers perceived that 55mph was more difficult, but there was no empirical evidence to suggest that this speed limit affected their ability to drive, compared to either 50 or 60mph.

Headway measures the distance between the participant's vehicle and the vehicle travelling in front in the same lane. There was no evidence that the 55mph speed limit resulted in reduced headway and thus increased collision risk compared to 50 or 60mph.

Drivers adjusted their lane changing behaviour depending on the speed limit: more lane changes were made in the 60mph limit and the chosen gap size was larger. There was no difference between the 50 and 55mph drives, suggesting that drivers accepted similar gap sizes at these two speed limits.

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Drivers indicated they were most satisfied with the 60mph limit and least satisfied with the 55mph limit. Reasons for this included the journey time benefits, the familiarity of the speed limit and difficulties in maintaining 55mph (although this latter point was not supported by the eye tracking or speed data). Safety and comfort were rated similarly across the three speed limits.

Based on these results, it is recommended that 55mph is progressed to an on-road trial with a view to validating the findings from the simulator in the real world. This will expand the body of evidence required to understand how drivers react to this novel speed limit.

# 1 Introduction

## 1.1 Background

Safety and customer satisfaction are Key Performance Indicators and critical components of Highways England's vision for the future. As part of this vision, Highways England is committed to improving the customer satisfaction at roadworks, maximising safety (for both road users and road workers) and minimising disruption caused by roadworks schemes.

One potential measure to achieve improvements in customer satisfaction at roadworks is challenging the approach to speed management that is usually applied at major schemes; that is, a 50mph speed limit throughout the entire roadworks scheme. This requires monitoring and evaluation of the safety and customer satisfaction (and operational challenges) associated with raising the speed limit through roadworks to 55 or 60mph.

A speed limit of 55mph is not currently used on the Strategic Road Network (SRN) and so there is limited evidence regarding how this speed limit might affect driver behaviour, perceptions or performance, in particular in the vicinity of roadworks. Similarly, current guidance (Department for Transport, 2009) specifies that the minimum speed limit reduction appropriate at roadworks should be 20mph (leading to a speed limit of 50mph). As a result, 60mph speed limits are relatively uncommon at roadworks.

Driver behaviour at these alternative speed limits (55 and 60mph) was previously evaluated by TRL using the 'DigiCar' driving simulator (Wallbank, Robbins, Tailor, & Chowdhury, 2017). This previous study examined driver behaviour through roadworks with 50, 55, 60 and 70mph speed limits. In the 60mph speed limit, driver behaviour was similar to that in the 50mph speed limit. However, there was some evidence to suggest driver behaviour in roadworks differed when the speed limit was 55mph compared to 50mph.

In order to explore the possible reasons for any differences and understand the relative safety implications of the 55 and 60mph speed limits, a further driving simulator study was commissioned. This report presents the results from this study, the aim of which was to provide clear evidence as to suitability of trialling 55mph speed limits on the SRN. In addition to the objective data collected by the simulator, the study also included a qualitative assessment of road user perceptions of the 55mph speed limit, with a view to understanding the factors affecting customer acceptance of this speed limit.

This simulator study compared driver behaviour between six different drives<sup>1</sup> over the same route; three with 'low' traffic volumes (approx. 600 vehicles per lane per hour) at 50, 55 or 60mph and three at 'high' traffic volumes (approx. 1400 vehicles per lane per hour) at 50, 55 or 60mph. The route consisted of a simulated four-lane all lane running (ALR) Smart Motorway, with major scheme roadworks closing Lane 1 after the first 4.9km of the route. The participants therefore experienced an approach section, a short taper into the roadworks, a 7km drive through roadworks at one of the three speed limits, and a final section of approximately 1km with a 50mph speed limit.

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<sup>1</sup> The term 'drive' in this context refers to driving a single route in the simulator from beginning to end.

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## 1.2 Research questions

The research questions addressed in this study were:

1. What is the effect of speed limit on driver distraction?
2. What is the effect of speed limit on driver workload?
3. What is the effect of speed limit on headway?
4. What is the effect of speed limit on gap size when drivers change lane?
5. What is the effect of speed limit on driver subjective experience?

This report outlines the work undertaken to answer these research questions, presenting the simulator trial methodology (Section 2) and the findings related to driving behaviour (Section 3.1), visual behaviour (Section 3.2), and perceptions and opinions from the questionnaires and interviews (Section 3.3). The final sections of this report present a summary of the results (Section 4), and recommendations for the next steps (Section 5).

## 2 Method

### 2.1 Overview

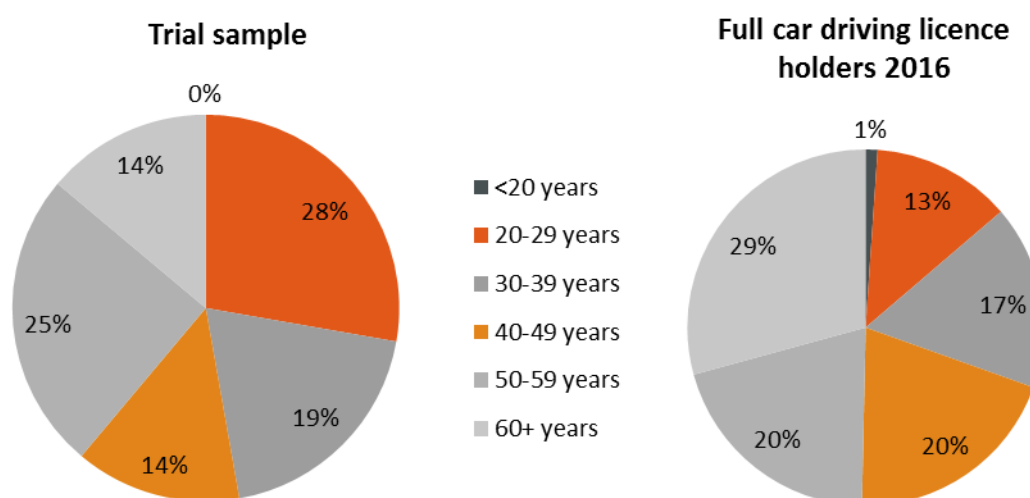
All participants drove six separate drives, one at each speed limit (50, 55 or 60mph) under either low or high traffic conditions, in a repeated measures (or within-participants) design.

Participants wore eye-tracking glasses during each drive to capture their gaze position, and were asked to complete a short questionnaire at the end of each drive to capture their perceptions on the ease of driving, feelings of safety, and levels of satisfaction with each speed limit.

### 2.2 Participant sample

Thirty-eight participants were recruited for the trial. Two participants were removed from the analysis due to issues with the eye-tracking data. Therefore, 36 participants were included in the final analysis.

An equal number of female and male participants were included in the study (18 female, 18 male) across a range of ages. Figure 1 compares the distribution of ages in the trial sample to the population of full car driving licence holders in Great Britain (data from March 2016) (data.gov.uk, 2016).

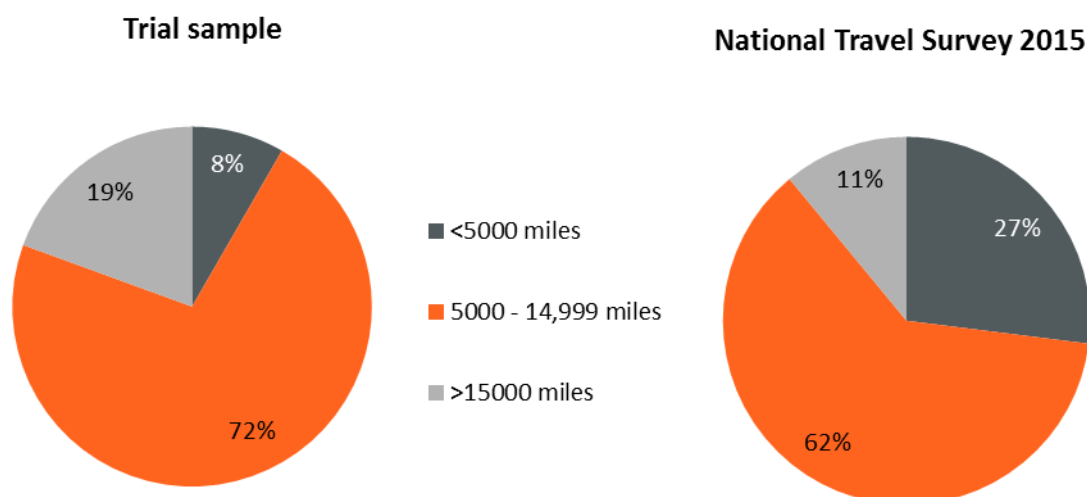


**Figure 1: Comparison of the age distribution of the trial sample and full car driving licence holders in Great Britain 2016**

The percentage of 30-59 years olds was broadly comparable between the trial sample and the population of licence holders in Great Britain. Licence holders aged 20-29 years appear to be overrepresented in the sample, and licence holders aged 60 and over were underrepresented. Older drivers are typically more susceptible to simulator sickness; as such, participants tend not to be recruited from this age category. In addition, older drivers tend not to drive as often as other age groups (GB licence data are not necessarily the most representative source of information relating to types of drivers on the road) and so may be less critical to include in the sample..



The vast majority (over 80%) of participants were experienced drivers with over 10 years' experience. The annual mileages reported by participants are shown in Figure 2; these are compared to the average annual mileage for 4-wheeled cars in England in 2015 (Department for Transport, 2016).

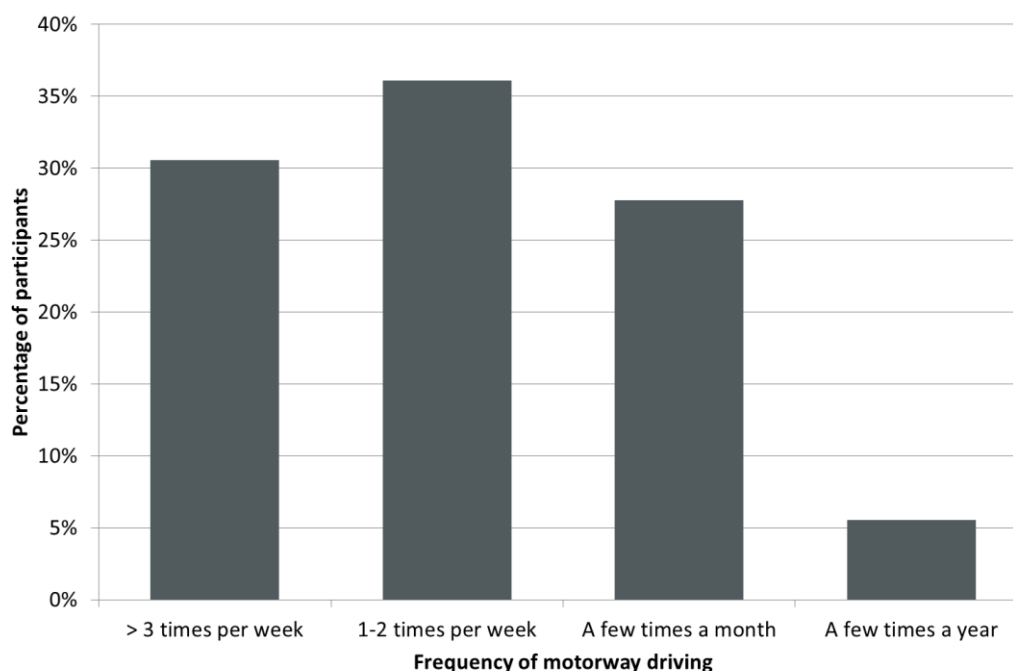


**Figure 2: Comparison of the average annual mileage of the trial sample and the figures reported in the National Travel Survey for England in 2015**

The average annual mileage of the sample is slightly larger than in the population as a whole. As Figure 3 shows, participants reported frequently travelling on motorways<sup>2</sup> and thus are likely to have experience driving through speed restricted roadworks on the SRN. As a result, the final sample can be said to be reflective of the target population for this study.

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<sup>2</sup> The recruitment criteria specified that drivers should drive on motorways at least a few times a month, but two participants reported travelled on motorways less frequently. Nevertheless, it is still possible to be confident that all participants had some experience of driving on motorways.



**Figure 3: Reported frequency of motorway use**

## 2.3 Route layout

All drives utilised the route developed for the previous study (Wallbank, Robbins, Tailor, & Chowdhury, 2017) which examined 55 and 60mph through roadworks on a Smart Motorway ALR environment that was not yet fully operational, but within the 'Operational Regime Testing' phase of development. Temporary traffic management (TTM) was present and the variable signs and signals (VSS) were blank. Speed limits were displayed on ground level fixed-plate signs.

The total length of the route used in this study was 13.1km, consisting of a 3.3km approach section, a 1.6km lead-in to the roadworks, a 7.2km work zone in which the speed limit varied depending on the drive, and a final 1km work zone with a speed limit of 50mph in all drives.



**Figure 4: Route structure**

Each drive took approximately 8-10 minutes, depending on the speed at which participants travelled. The drives all took place under clear and dry daytime conditions.

### 2.3.1 Temporary traffic management

All TTM was configured to comply with TSM Chapter 8 layouts for standard works, as in the previous trial. The simulated TTM involved closure of Lane 1 with three open lanes for traffic.

### 2.3.2 Speed limits

Three different speed limits (50, 55 and 60mph) were tested under low and high traffic conditions. The speed limits in each section, for each of the six drives, can be seen in Table 1. All drives started with a speed limit of 70mph and ended with a speed limit of 50mph. The speed limits varied between 50, 55 and 60mph through the taper lead-in and work zone A according to the drive.

**Table 1: Speed limit (mph) in each section of the six drives**

Drive	Traffic condition	Approach (3.3km)	Taper Lead-in (1.6km)	Work Zone A (7.2km)	Work Zone B (1.0km)
1	Low	70	50	50	50
2	Low	70	55	55	50
3	Low	70	60	60	50
4	High	70	50	50	50
5	High	70	55	55	50
6	High	70	60	60	50

### 2.3.3 Enforcement

The simulated roadworks sections included average speed cameras and the associated signs to simulate speed enforcement. This replicated, to the degree possible within a simulated environment, the conditions typically experienced when driving through long-term roadworks on the Highways England Strategic Road Network.

### 2.3.4 Simulated traffic

Within the simulation, traffic was 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' and programmed using three parameters: traffic volume, speed, and lane merge behaviour. Traffic consisted of a mix of vehicle types, including cars, vans, motorbikes and HGVs.

Two traffic volumes were included; a 'low' traffic volume (approximately 600 vehicles/hour/open lane) to measure participant behaviour during free-flowing conditions when participants can drive at their preferred speed, and a 'high' traffic volume (approximately 1400 vehicles/hour/open lane) to measure participant behaviour during more naturalistic traffic flows.

The traffic was programmed to behave similarly to traffic on real roads with differentials in speeds between vehicles and lanes to ensure naturalistic traffic flow. Vehicles were not permitted to undertake other AI vehicles; therefore average speeds observed in each lane increased from the nearside to the offside lanes. Table 2 shows the maximum speed permitted for AI vehicles in each lane for each section of the route.

**Table 2: AI permitted speeds (mph) by lane for each drive**

Speed limit	Traffic condition	Lane	Approach	Taper	Work zone A	Work zone B
50mph	Low	1	70	50	-	-
		2	70	50	50	50
		3	75	55	55	55
		4	80	57	57	57
55mph	Low	1	70	55	-	-
		2	70	55	55	50
		3	75	60	60	55
		4	80	63	63	57
60mph	Low	1	70	60	-	-
		2	70	60	60	50
		3	75	65	65	55
		4	80	68	68	57
50mph	High	1	70	50	-	-
		2	70	50	50	50
		3	75	55	55	55
		4	80	57	57	57
55mph	High	1	70	55	-	-
		2	70	55	55	50
		3	75	60	60	55
		4	80	63	63	57
60mph	High	1	70	60	-	-
		2	70	60	60	50
		3	75	65	65	55
		4	80	68	68	57

There is anecdotal evidence that with a speed limit of 50mph in roadworks, HGVs tend to travel at or just below the enforcement threshold (57mph), resulting in close following with car drivers who are compliant with the speed limit. Increased speed limits of 55 or 60mph could help to reduce the speed differential between cars and HGVs, thus reducing instances of close following.

However, there is insufficient available evidence of actual HGV behaviour to robustly model it in the simulated environment, with key missing information including the percentage of HGVs that engage in close following behaviour and the actual following distance of HGVs. For these reasons, a research question around close following has not been included in this study. However, some assumptions were made about the behaviour of the HGVs in order to set the parameters used to configure HGV behaviour:

- 15-20% of the traffic was HGVs
- 50% of the HGVs were compliant with posted speed limits
- 50% of the HGVs were non-compliant and passed through either at the enforcement limit (i.e., speed limit + 10% +2) or at a maximum speed of 63mph, depending on which was lower.

HGVs otherwise followed the same behaviours as the other traffic.

Maximum speeds did not apply to the participant's vehicle. Traffic in Lane 4 was programmed to move naturally into Lane 3 if the participant's vehicle approached; this ensured that the participant was free to drive at whatever speed they choose when travelling in Lane 4, and speed choice was not affected by other traffic.

Lane merge behaviour of the AI vehicles at the taper was programmed to be as realistic as possible. The distance from the taper at which vehicles moved out of closed lanes was based on data collected on real roads as part of the on-road trial programme carried out by TRL.

## **2.4 Trial procedure**

The trial lasted approximately two hours for each participant. There were three phases: familiarisation, trial drives, and post-trial interview. Upon arrival at TRL, participants met a TRL researcher who obtained informed consent and briefed them on the trial procedure, including the questionnaires they were required to fill out after every drive.

### **2.4.1 Familiarisation**

Participants were introduced to the simulator and asked to adjust the seat position and mirrors. They were asked to drive in the simulator as they would normally. The simulator was set up for a familiarisation drive on a motorway route with no other traffic, to allow participants to become comfortable with the controls. They drove the route for approximately 5 minutes, and towards the end they were asked to change lanes several times. The simulation was stopped when participants declared themselves comfortable driving in the simulator.

### **2.4.2 Trials**

Participants were asked to wear eye-tracking glasses for the duration of the trial. The eye-tracking equipment was set-up and calibrated after the familiarisation drive. Participants were then asked if they were comfortable and ready to begin the trial drives. The order in which participants completed the scenarios was counterbalanced to control for order

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effects. Eye-tracking and simulation data were recorded for each drive and participants completed a questionnaire (Appendix A) and a workload questionnaire (Appendix B) after each drive.

### **2.4.3**      *Post-trial interview*

After completion of the six trial drives, participants took part in a post-trial interview (see Appendix C).

## **2.5**      **Data collection**

Three types of data were collected during the study:

1.      Simulator data on participant driving behaviour
2.      Eye-tracking data on participant visual behaviour
3.      Questionnaire and interview data on participant perceptions and opinions

The specific types of data collected during the study are shown in Table 3.

**Table 3: Data collection**

Category	Type of data	Metric	Measurement method
Driving performance	Speed	Mean speed and standard deviation in speed Proportion of time above speed limit Proportion of time above enforcement limit	Simulator
	Headway	Mean headway and standard deviation in headway Minimum headway	
	Close following	Number of close following events Mean time spent close following	
	Lane changes	Proportion of time in each lane Number of lane changes Gap size when changing lanes (headway and sternway relative to vehicles in the target lane)	
	Lateral lane position	Mean lateral lane position and standard deviation in lateral lane position	
	Collisions and near-misses	Number of collisions Near-misses reported by participants	
	Response to the change in speed limit	Distance to adjust to the new speed limit in work zone B	
Visual behaviour	Fixations on speedometer	Mean number of fixations on speedometer Mean length of fixations on speedometer Proportion of time spent fixating on speedometer Number of fixations on speedometer greater than 1 second	Eye-tracking
Subjective data	Workload	Scores on mental, physical, temporal, performance, effort and frustration subscales Total workload score	NASA-TLX
	Ease/difficulty of travel	Scores on ease/difficulty of travel and reasons for these Ease/difficulty of maintaining constant speed with digital vs. analogue speedometer	Questionnaire Interview
	Satisfaction	Scores on satisfaction Scores on journey time Preferred speed limits and reasons for these	Questionnaire Interview
	Safety	Scores on feelings of safety	Questionnaire
	Comfort	Scores on feelings of comfort towards other cars and HGVs	Questionnaire Interview
	Perceived speed	Perceived speed travelled relative to the speed limit	Questionnaire

### 2.5.1 *DigiCar simulator*

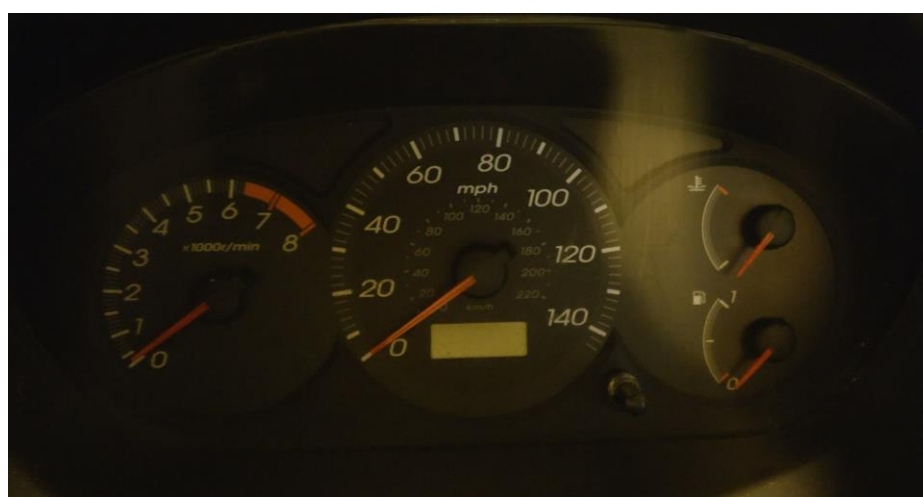
The DigiCar simulator logs data at 20Hz (i.e., 20 times per second). DigiCar provides a highly immersive and realistic driving experience to users fully duplicating the operation of a real vehicle. Previous studies have demonstrated the validity of DigiCar as an environment where driver performance and behaviour very closely follows that observed on real roads (Diels, Robbins, & Reed, 2012).

Superior quality audio and visual systems with detailed graphics contribute to making the experience as real as possible. The simulator also benefits from a sophisticated motion system providing the driver with an impression of the acceleration forces and vibrations that would be experienced when driving a real vehicle. All control interfaces have a realistic feel and the manual gearbox can be used in the normal manner (automatic gears can be simulated).

Surrounding the simulator vehicle is a large forward display screen giving the driver a 210° horizontal forward field of view at a pixel resolution of up to 6114×1536. A dedicated rear screen provides a 60° rearward field of view, thus enabling normal use of all mirrors. A stereo sound system with speakers inside and outside the vehicle generates realistic engine, road, and traffic sounds to complete the representation of the driving environment. Validation studies of DigiCar have shown it provides a highly realistic driving experience within which a driver's behaviour and vehicle control very closely mirrors their performance on real roads.

The raw 20Hz simulator data were aggregated across each section (approach, taper, work zone A and work zone B) of each of the six drives for all 36 participants. The variables recorded align with those presented in Table 3.

Figure 5 shows the speedometer of the DigiCar simulator. 60mph is clearly marked, and a white notch indicates 50mph, but note that there is no marking for 55mph.



**Figure 5: DigiCar speedometer**



### 2.5.2 *Eye-tracking glasses*

SMI Natural Gaze eye-tracking glasses (ETG) were used to capture participants' natural eye glance and fixation behaviours<sup>3</sup>. These glasses feature parallax-free parallel eye-tracking at 60Hz with a tracking distance from 40cm to infinity and gaze accuracy of 0.5 degrees over all distances. A High Definition (HD) camera recorded images at a resolution of 1280 x 960. The glasses weighed 75g. Data were collected via the glasses using SMI iView software.

The gaze fixations captured by the ETG were automatically mapped to reference images using SMI's Automated Semantic Gaze Mapping (ASGM) software. This software logged each recorded fixation with the speedometer during the study and mapped it to a location on a reference image. These fixations were then analysed in SMI's 'BeGaze' software to generate the required information time spent looking at the speedometer.

### 2.5.3 *Subjective data*

#### 2.5.3.1 *Post-drive questionnaire*

Participants completed a short questionnaire after each of the six drives. The questionnaire (see Appendix A) collected data on participants' opinions of the ease, safety, comfort and satisfaction associated with each drive. The questionnaire also asked whether they experienced any near-misses or collisions in each drive.

#### 2.5.3.2 *NASA-TLX*

The National Aeronautics and Space Administration (NASA) Task Load Index (TLX) is a "multi-dimensional scale designed to obtain workload estimates from one or more operators while they are performing a task or immediately afterwards" (Hart, NASA-Task Load Index (NASA-TLX): 20 Years Later, 2006). The NASA-TLX contains six subscales related to workload: mental demand, physical demand, temporal demand, frustration, effort, and performance. A score for each subscale is obtained using a scale of 1-20. The performance subscale is reverse rated (i.e. a high score indicates low workload), so the scores for this subscale are reversed when calculating its contribution to workload. The full NASA-TLX also includes a participant weighting of the subscales to determine the overall workload; in this case the NASA 'Raw' TLX was used, which omits this step (Hart & Staveland, 1988). As such, an overall workload score was calculated from the sum of the scores of the six subscales.

NASA-TLX scores were obtained at the end of each drive. The purpose of the questionnaire was to understand the subjective workload associated with each drive. An example NASA-TLX questionnaire is provided in Appendix B.

#### 2.5.3.3 *Post-trial interview*

The trial concluded for each participant with a structured interview. Participants first provided their demographic information, and then were interviewed by the researcher to gather more information on their most and least preferred speeds, their perception of the

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<sup>3</sup> Due to restrictions with the eye-tracking equipment, participants were only eligible for the trial if they did not require glasses or contact lenses for driving purposes.

relative difficulty of travelling at 55mph, their experiences of differences between the drives, and the details of any near-misses or collisions experienced during the drives. The interview structure can be found in Appendix C.

## 2.6 Data analysis

### 2.6.1 *Statistical comparisons*

Statistical tests were carried out to determine whether the differences observed or reported between the different speed limits (50, 55 and 60mph) and between the different traffic conditions (low and high traffic) were significant.

The type of test used varied depending on the data:

- Two-way repeated measures<sup>4</sup> analysis of variance (ANOVA) is a technique used to test for significant differences in mean responses in the three speed limits and two traffic conditions, and the interaction between speed limit and traffic. Post-hoc tests<sup>5</sup> were used to examine differences between specific speed limits.
- Chi-squared tests are a technique used to test for significant relationships between two count variables.

The assumptions required for each test were checked prior to commencing the analysis and, where necessary, non-parametric<sup>6</sup> techniques were used instead.

Results were considered significant if the p-value<sup>7</sup> was less than 0.05, a typical standard in the behavioural sciences.

### 2.6.2 *Qualitative data*

Qualitative data were analysed to establish key themes; responses were grouped according to these themes in order to identify clear patterns.

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<sup>4</sup> A 'repeated measures' or 'within participants' design was required since participants completed all six drives.

<sup>5</sup> These tests examined differences between each pairwise combination (e.g. between 50 and 55mph, between 55 and 60mph and between 50 and 60mph). The Bonferroni correction was applied to control for the effect of multiple comparisons.

<sup>6</sup> Unlikely parametric techniques (such as ANOVA), non-parametric techniques make no assumptions about the probability distribution of the variables being tested. These tests are less powerful than their parametric alternatives.

<sup>7</sup> A p-value less than 0.05 indicates that there is a 95% chance that the comparison being made has arisen due to the variable under investigation, and not simply due to random fluctuations ('noise') in the data.

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## 3 Results

Throughout this section, mean (or total) values across all 36 participants are presented in the tables and charts to illustrate the findings. In many of the charts, the standard deviation is also presented using error bars; this measure indicates how variable the data are across participants. For example, for the questionnaire data, smaller error bars indicate that participants' responses were fairly similar to each other, whilst larger bars indicate that the results were more variable.

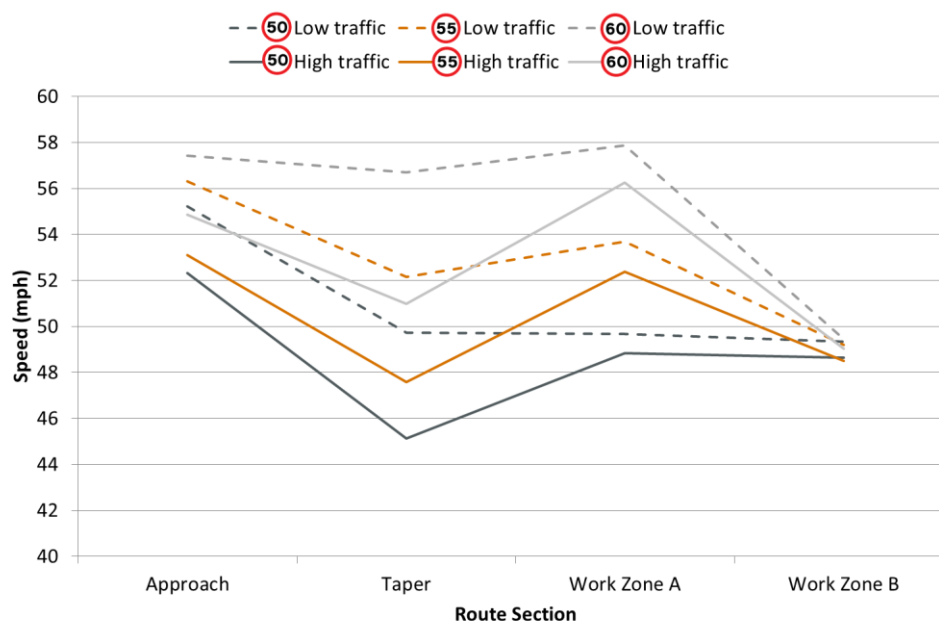
The simulator data also enables the variability (standard deviation) within each drive to be estimated. The mean of this value represents the average variability across participants. Smaller values of this measure suggest that participants' behaviour was fairly consistent across the length of the drive, whilst larger values suggest there was more variability in this measure. Highly variable data might suggest that participants' are finding it hard to maintain a particular behaviour (e.g. speed).

### 3.1 Driver behaviour

This section presents the results of the analysis of data collected using TRL's driving simulator. Section 3.1.1 presents a summary of the speeds for the whole drive; whilst the other subsections (excluding Section 3.1.8) present only the findings from work zone A (where the speed limit varied between drives).

#### 3.1.1 *Speeds throughout the drive*

The mean speeds for each participant, in each section of the route, were calculated from the simulator data (Figure 6). Each participant started in the approach section (with the national speed limit). Within this section, participants accelerated up to full speed before being introduced to the advance sign zone for the works and a reduction to the speed limit. The taper was a short section during which Lane 1 was gradually coned off. Work zone A was the area in which the speed limit varied according to the condition, and the main area of analysis for this report, and work zone B had a 50mph speed limit in all conditions.

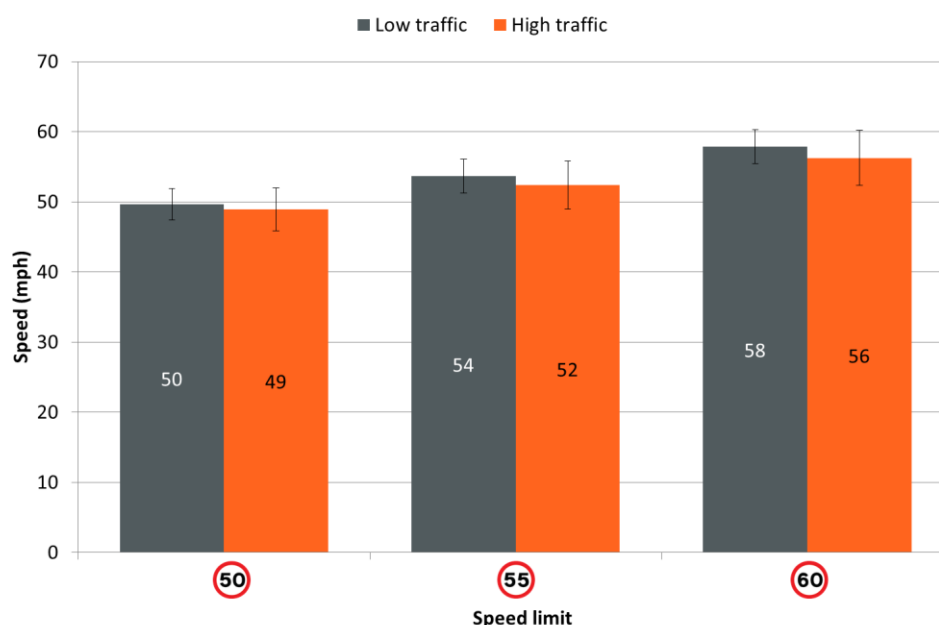


**Figure 6: Mean speeds through each section of the route**

Through the approach, taper and work zone A, Participants generally travelled faster in the lower level of traffic compared to the corresponding high traffic condition for each speed limit. In work zone B (where the speed limit was 50mph in all drives), participants travelled at an average of approximately 49mph in all drives.

### 3.1.2 Speed

Figure 7 shows the mean speed within each of the six drives through work zone A.

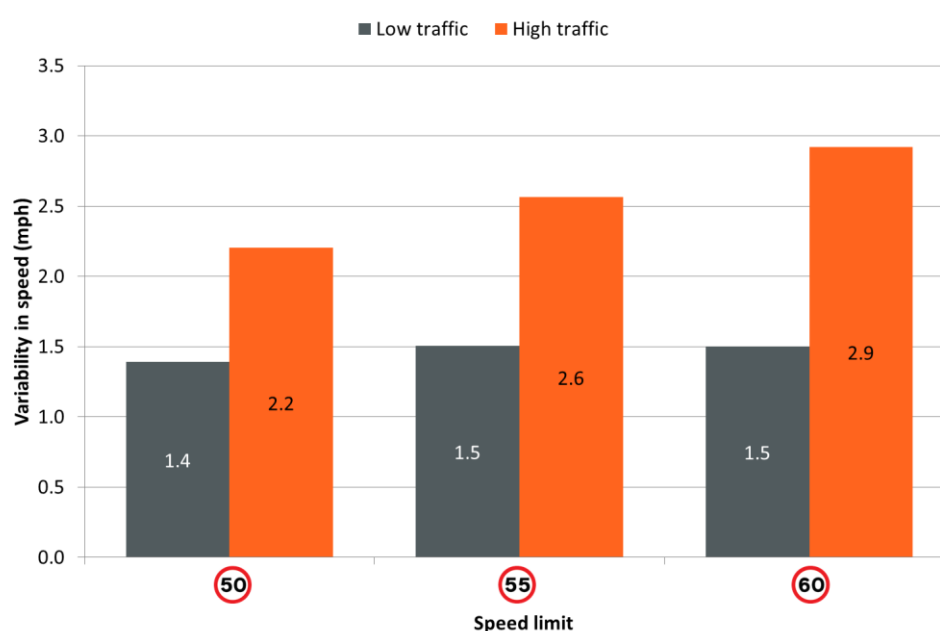


**Figure 7: Mean speed through work zone A**

Average speeds were typically slightly higher in the low traffic condition than the high traffic condition, but were below the speed limit in all six drives.

A two-way repeated measures ANOVA was conducted to test whether there were significant differences in average speed across the two traffic conditions (high and low) and three speed limits (50mph, 55mph, 60mph). The analysis showed that average speeds were significantly different between the high and low traffic conditions ( $p < 0.01$ ) and differed significantly across the different speed limits ( $p < 0.01$ ). However, the interaction between traffic and speed limit was not significant ( $p = 0.09$ ), suggesting that the change in average speed between the three speed limits was not dependent on the traffic level. Partial eta-squared values (a measure of the variability explained by each variable) suggested that the speed limit explained the majority of the variation in average speeds.

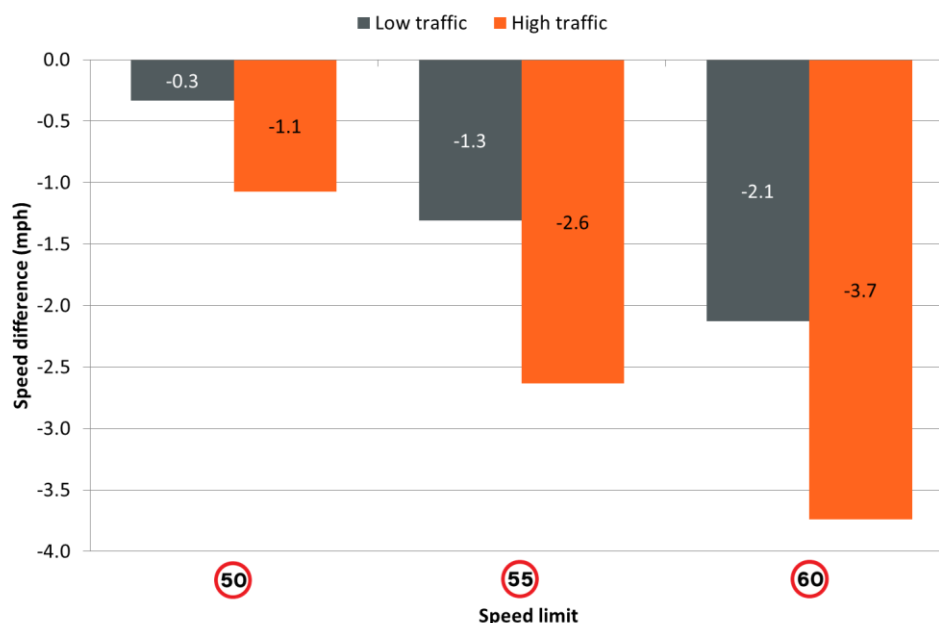
Figure 8 shows the average variability (standard deviation) in speed across work zone A.



**Figure 8: Average standard deviation in speed through work zone A**

The variability in speeds was greater in the high traffic conditions than the low traffic conditions, probably due to the larger number of AI vehicles influencing the participants speed choice. However, there was little difference between the three speed limits. If a speed limit of 55mph was more difficult for drivers to maintain, we would expect to see more variability at this speed limit; the absence of this finding suggests that participants were, on average, able to maintain their preferred speed in all three speed limits.

Figure 9 shows the difference between the mean speed and the speed limit in work zone A for each drive.

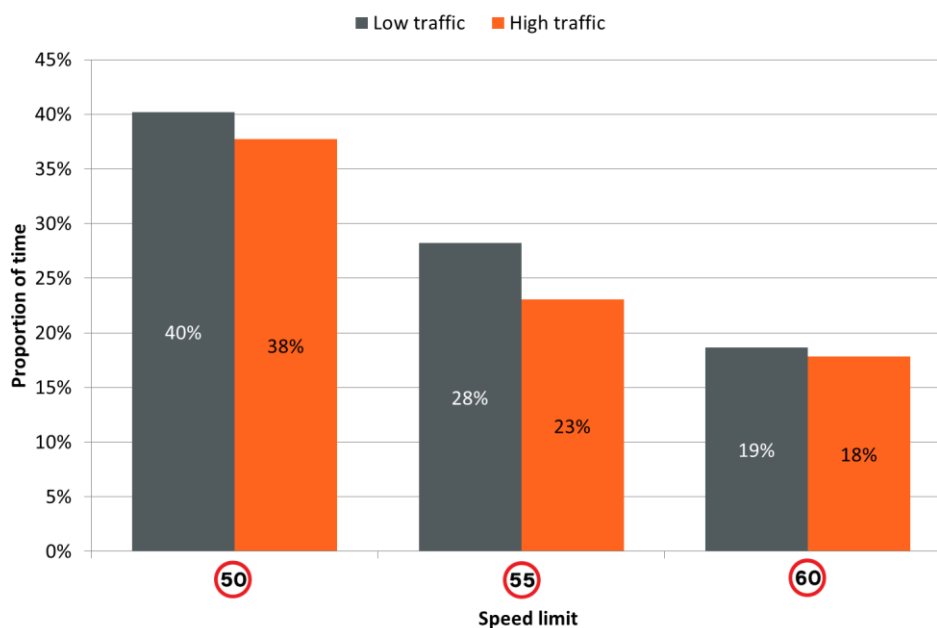


**Figure 9: Difference between speed limit and mean speed through work zone A**

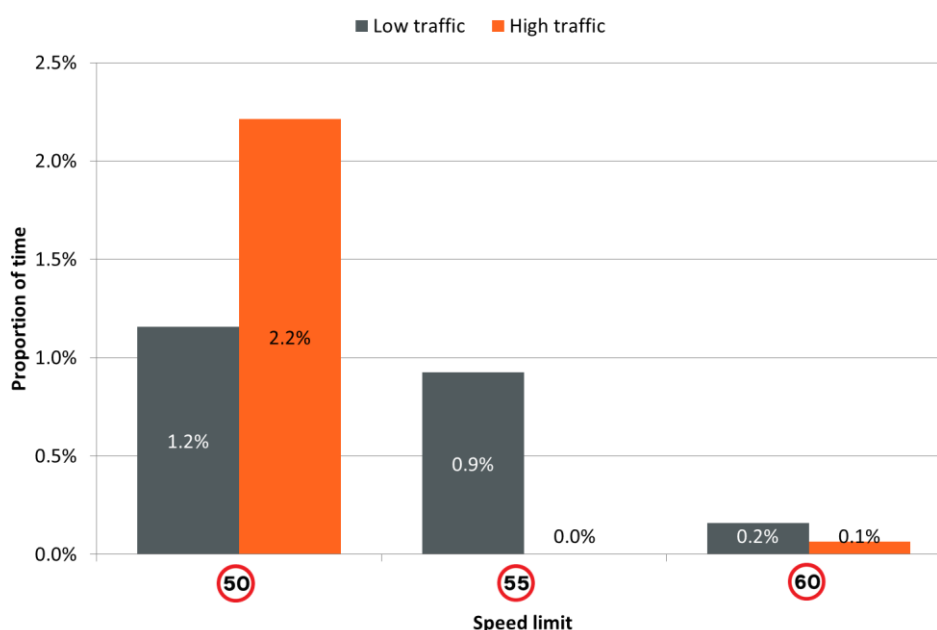
On average, bigger differences in speed were observed in the high traffic conditions and in the 55mph and 60mph speed limits compared with the 50mph speed limit. Statistical tests showed there were significant differences between speed limits ( $p < 0.01$ ) and traffic conditions ( $p < 0.01$ ). However, the interaction was not significant ( $p = 0.09$ ).

Figure 10 shows the mean proportion of time spent travelling above the speed limit in each drive and Figure 11 shows the corresponding proportion for speeds above the enforcement threshold<sup>8</sup> (speed limit + 10% + 2mph).

<sup>8</sup> This is based on the Association of Chief Police Officers (ACPO) Speed Enforcement Policy Guidelines 2011-2015 (ACPO, 2013) which suggest that a Fixed Penalty or speed awareness education may be appropriate when the speed is 10% +2mph above the speed limit (see paragraph 9.6). These are only guidelines and a police officer/ force can decide to enforce at a speed lower than this limit assuming they have considered the tolerance of the measurement equipment (paragraph 9.7).



**Figure 10: Mean proportion of time spent above the speed limit through work zone A**






**Figure 11: Mean proportion of time spent above the enforcement limit through work zone A**

Participants spent more time on average travelling above the speed limit and the enforcement limit in the 50mph drives than the other speed limits.

Whilst speeding was generally less prevalent in the high traffic condition compared to the low traffic condition, the proportion of time above the enforcement limit was inflated in the 50mph speed limit with high traffic (2.2% compared to 1.2% in Figure 11); this was impacted by one driver who spent over half of this drive exceeding the enforcement threshold.

Table 4 describes the number of participants (out of 36) who exceeded the speed or enforcement limit in work zone A.

**Table 4: Number (proportion) of participants exceeding the speed and enforcement limit through work zone A**

Speed limit	Traffic condition	Number of participants who exceeded the speed limit	Number of participants who exceeded the enforcement limit
	Low	33 (92%)	5 (14%)
	High	32 (89%)	4 (11%)
	Low	30 (83%)	3 (8%)
	High	27 (75%)	0 (0%)
	Low	25 (69%)	1 (3%)
	High	25 (69%)	1 (3%)

In general, the number of individuals speeding decreased as the speed limit increased. Very few people (five or fewer) exceeded the enforcement threshold for any period of time in any of the six drives.

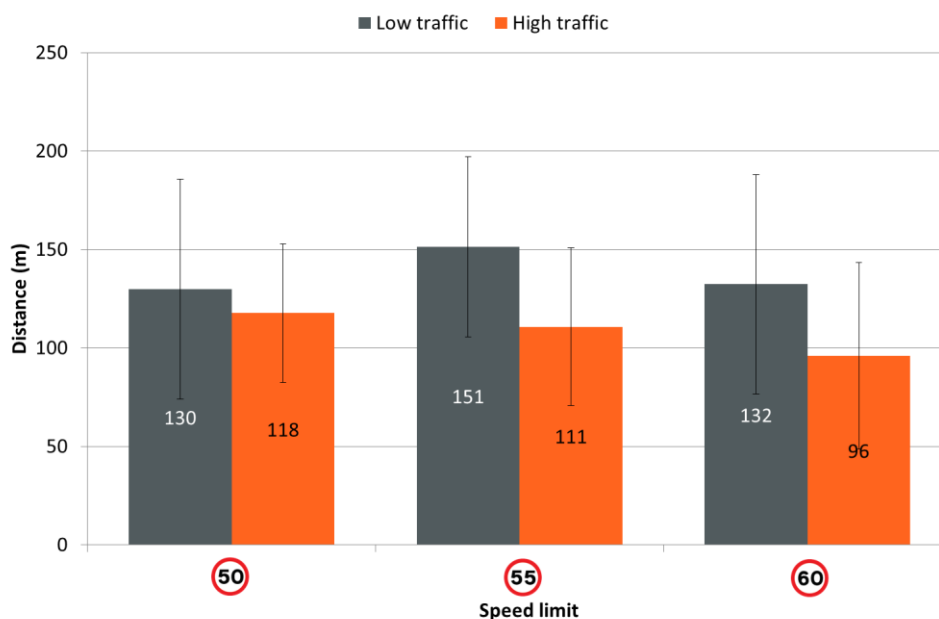
### 3.1.3 Headway

Headway measures the distance between the participant's vehicle and the AI vehicle travelling in front in the same lane. The maximum headway recorded by the simulator is 250m; distances beyond this are recorded as null.

To ensure the data presented are comparable, participants with null headway in at least one of the drives have been excluded from the analysis. As a result, the results in this section are based on 22 participants (of the 36 who took part in the study).

The mean headway across participants for each drive is shown in Figure 12.



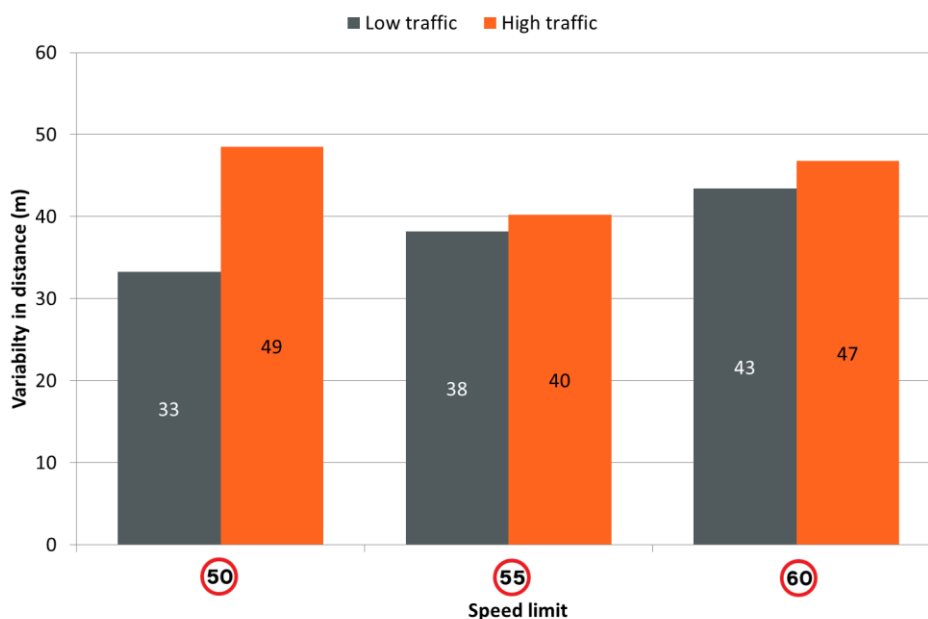


**Figure 12: Mean headway through work zone A (N = 22)**

The results indicate that headway was, on average, significantly longer in the low traffic drives compared to the high traffic drives ( $p = 0.01$ ). In the previous trial (Wallbank, Robbins, Tailor, & Chowdhury, 2017), headway typically increased as the speed limit increased but this result was not as clear for this trial. Comparing the three low traffic conditions, 55mph had the longest average headway with 50 and 60mph being fairly similar. In the high traffic condition, the headway decreased slightly as the speed limit increased, contradicting the result seen previously. However, there was substantial variability in average headway across participants (as shown by the large error bars). Statistical tests (repeated measures ANOVA) showed that the differences between speed limits was not significant ( $p = 0.25$ ) and neither was the change in average headway across speed limits by traffic condition ( $p = 0.22$ ).

The mean headway in each drive vastly exceed the recommended stopping distances presented in the Highway Code (53m at 50mph and 73m at 60mph), suggesting that drivers were, on average, allowing enough distance between them and the vehicle in front to pull up safely in an emergency.

Figure 13 shows the average variability (standard deviation) in headway across work zone A.

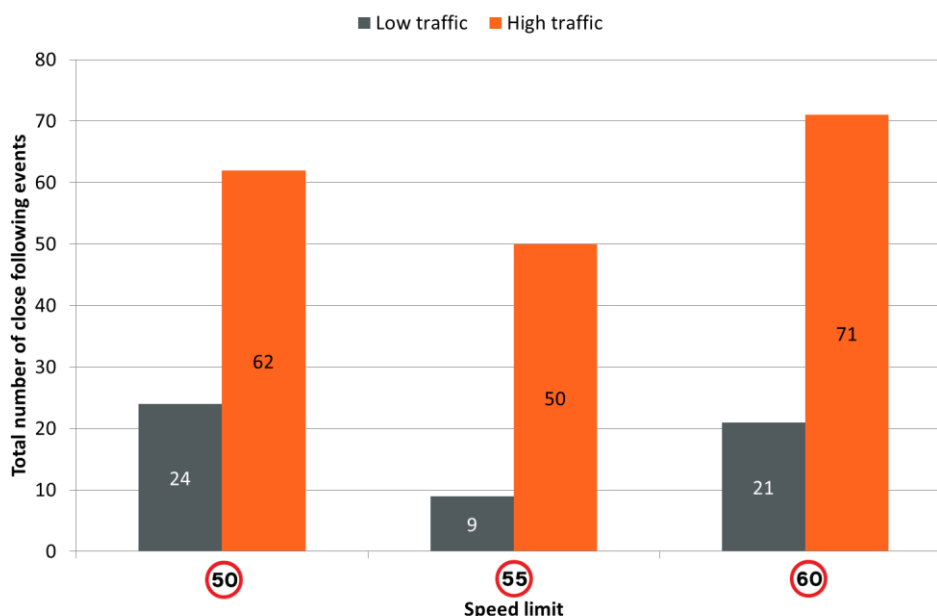


**Figure 13: Average standard deviation in headway through work zone A**

Variability in headway was greater for the high traffic drives (in particular for the 50mph speed limit), suggesting that participants found it harder to maintain a constant headway when there were more vehicles. The magnitude of the variability in headway between the three speed limits was similar. If a speed limit of 55mph was more difficult for drivers to maintain, we would expect to see more variability in headway.

### 3.1.4 Close following

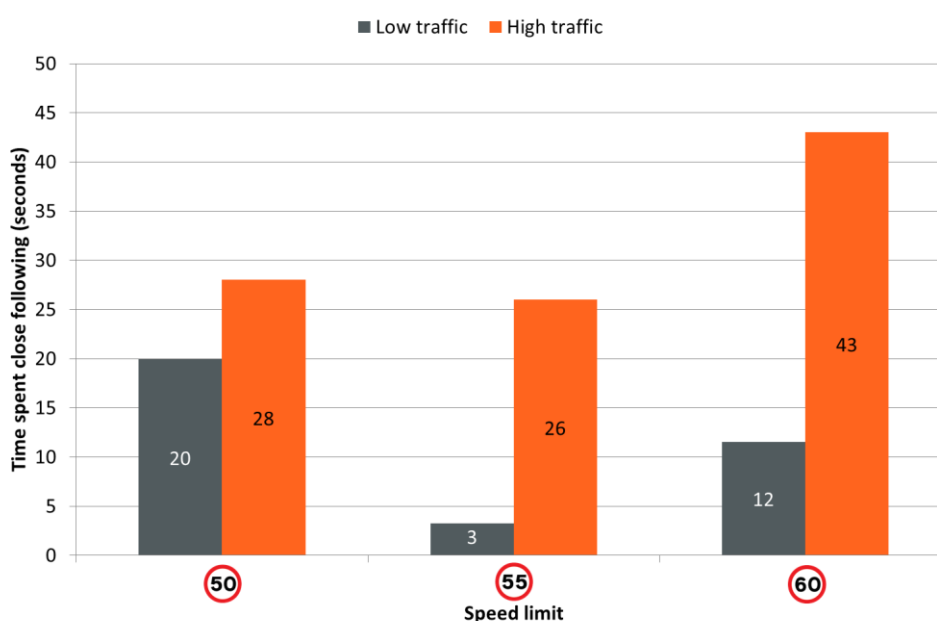
Data from the simulator was used to investigate the amount of close following by participants in each of the drives. 'Close following' was defined as any incidence in which the headway to the vehicle in front was less than 2 seconds. For the purposes of this analysis, 'close following events' have been defined points in the drive when this timeframe to the vehicle in front was maintained for over three seconds. Figure 14 shows the total number of close following events recorded in work zone A in each drive.



**Figure 14: Total number of close following events through work zone A**

In total across all participants, there were more close following events in the 60mph speed limit than 50 or 55mph (which had the lowest figures). There were more events in the high traffic condition, probably related to the higher number of vehicles present. A chi-square test was conducted to test whether there was a relationship between the number of close following instances across speed limit and traffic conditions. This was not significant ( $p = 0.20$ ); showing that the change in the number of close following events between the 50, 55 and 60mph speed limits was similar for the low and high traffic conditions.

The time spent close following was also recorded for each participant; Figure 15 shows the mean time spent close following.



**Figure 15: Mean time spent close following through work zone A**

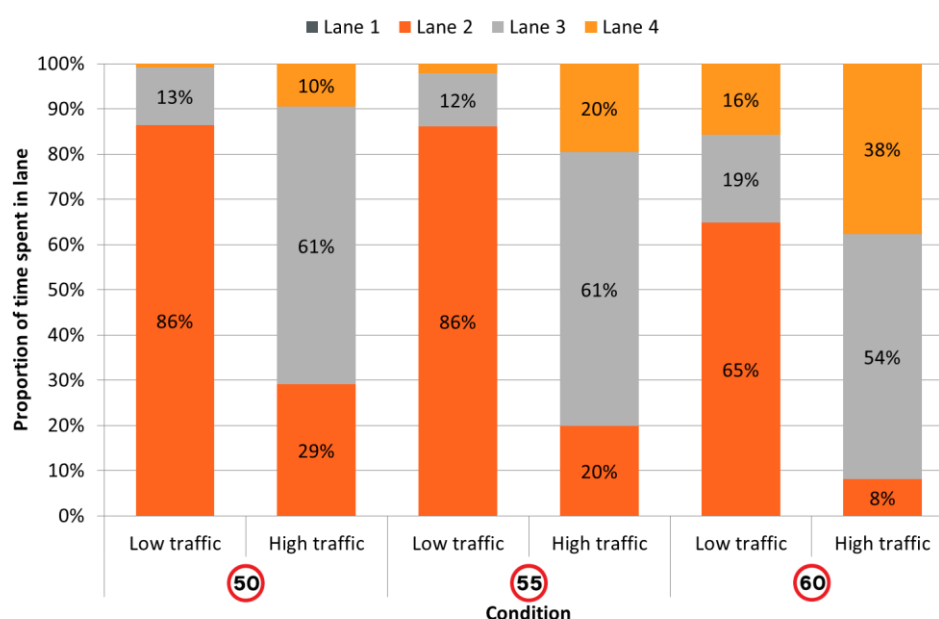
In both the low and high traffic conditions the average time spent close following was lower in the 55mph speed limit than either 50 or 60mph; however, the difference between speed limits (particularly between 50 and 55mph) was much smaller for the high traffic condition.

Statistical tests (repeated measures ANOVA) showed there were significant differences across traffic conditions ( $p < 0.01$ ) and speed limits ( $p < 0.01$ ). However, the interaction was not significant ( $p = 0.26$ ). Post-hoc tests show that the time spent close following was significantly different between the 55 and 60mph speed limits. The 50mph speed limit was not significantly different from either the 55 or 60mph results.

These results suggest that a speed limit of 55mph resulted in less close following than 60mph, but comparable levels to that seen at 50mph.

### 3.1.5 Lane changes

Once within the roadworks, participants were able to choose between travelling in Lane 2, 3 and 4. Lane 1 was closed to traffic by a line of traffic cones; traffic reported in Lane 1 represents incursions into the works. The proportion of time spent in each lane is presented in Figure 16.

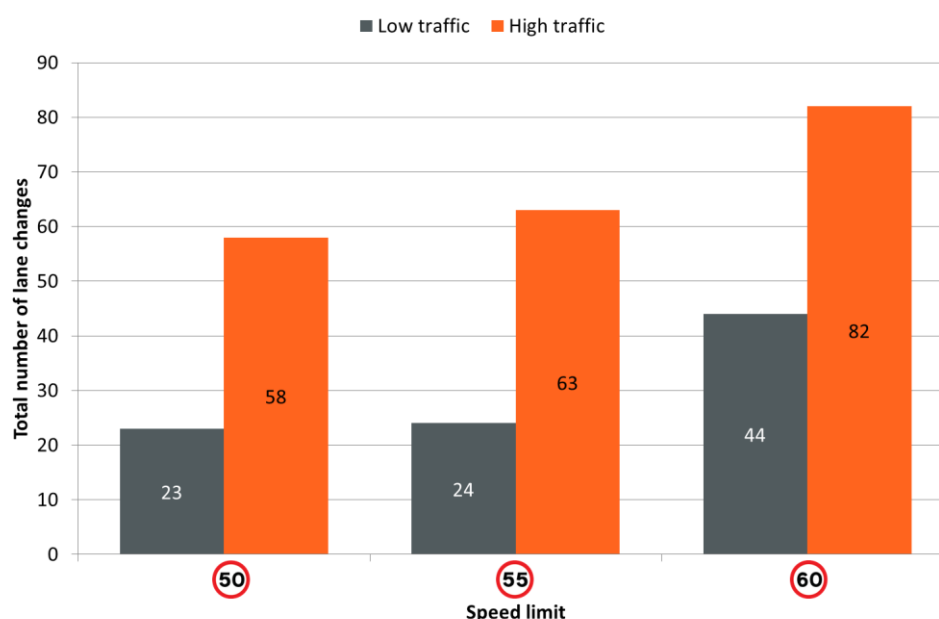


**Figure 16: Proportion of time in each lane through work zone A**

During the low traffic conditions, participants tended to prefer Lane 2, whilst in the high traffic conditions Lane 3 was more commonly used, suggesting that there was more overtaking in the high traffic conditions. Comparing across speed limits, the proportion of time spent in Lane 2 tended to decrease as the speed limit increased from 50mph to 60mph. In contrast, the proportion of time spent in Lane 4 increased with the highest mean value (38%) recorded in the 60mph limit with a high level of traffic.

Figure 17 shows the total number of lane changes carried out in work zone A in each drive. About 30-50% of all lane changes occurred in this section; the majority of lane changes occurred in the approach and taper sections as participants responded to the signing

instructions that Lane 1 was going to be closed and negotiated the AI vehicles that were also changing lanes.

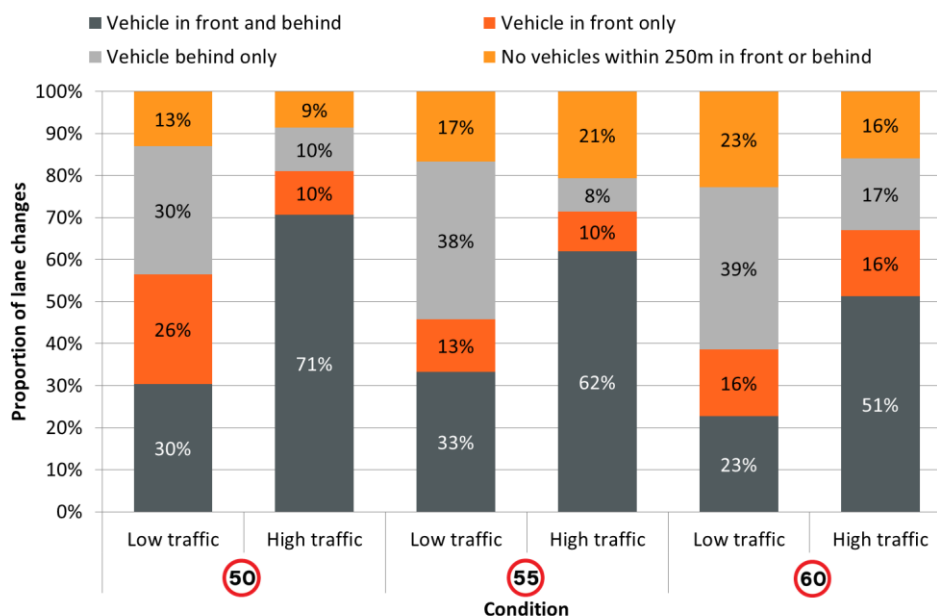


**Figure 17: Total number of lane changes through work zone A**

There were more lane changes in the high traffic condition than the low traffic, where there were fewer AI vehicles to negotiate. The number of lane changes was highest in the 60mph speed limit.

A chi-square test showed that there was no significant relationship between the number of lane changes and the speed limit and traffic conditions ( $p = 0.44$ ); the change in the number of lane changes between the 50, 55 and 60mph speed limits was similar for the low and high traffic conditions.

The headway and sternway (i.e. the distance from the rear of the participant's vehicle to the vehicle in the same lane behind – up to a maximum of 250m) were recorded for each lane change. This enabled classification of the lane changes according to the presence of surrounding vehicles; results of this are shown in Figure 18.

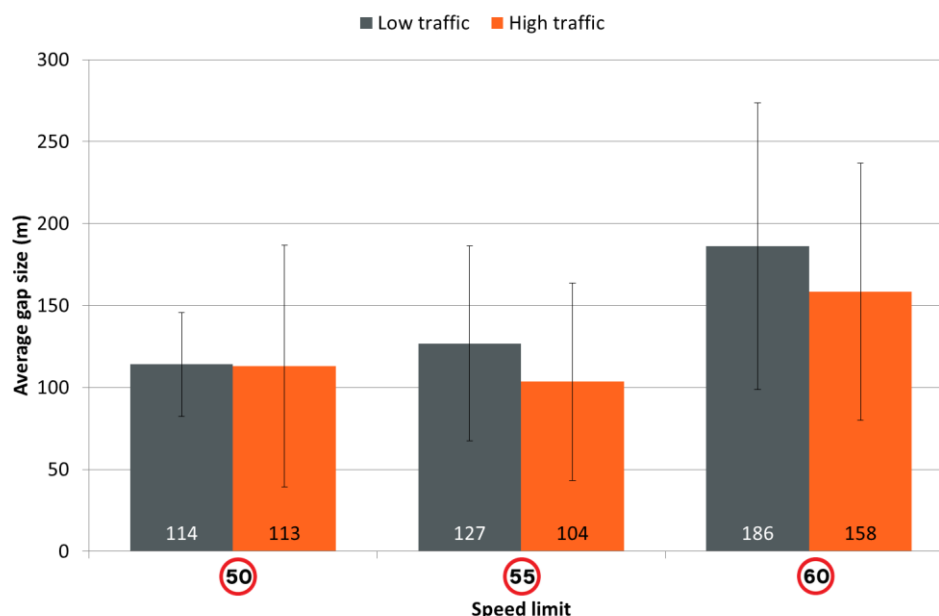


**Figure 18: Type of lane change through work zone A**

In the high traffic condition, more than half of lane changes involved the participant moving into a gap between two vehicles (i.e. a vehicle was recorded both in front and behind). Less than a third of the lane changes in the low traffic condition were of this type. This confirms the differences in high and low traffic density which were employed in the study.

As speed limit increased, drivers tended to select a gap with no vehicles in front or behind more often; this might suggest that they were adjusting their driving style to compensate for the increased speed.

For the lane changes where the participant moved into a gap between two vehicles, the measures of headway and sternway were used to calculate the 'gap size' which was accepted by participants (see Figure 19).



**Figure 19: Mean gap size accepted for lane changes in work zone A (lane changes with a vehicle in front and behind of the participant's vehicle, N = 155)**

Statistical tests show there was a significant difference in average gap size across the three speed limits ( $p < 0.01$ ), suggesting that drivers adjusted the size of the gap when changing lanes to compensate for the increased speeds. There was a non-significant difference between traffic conditions ( $p = 0.05$ ) and a non-significant interaction ( $p = 0.99$ ).

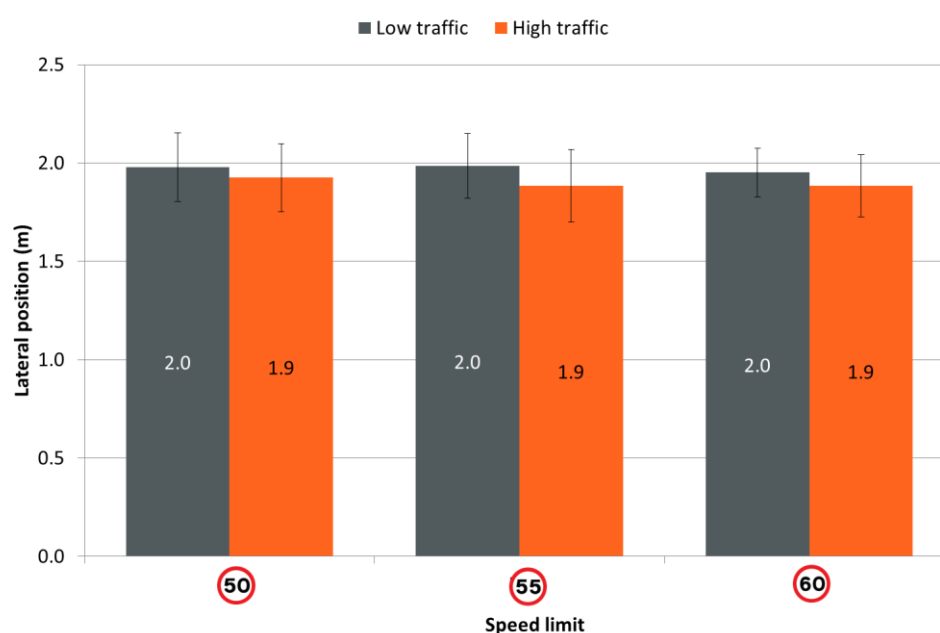
Post hoc tests show that the average gap size for the 60mph drive was significantly higher than the 50 and 55mph drives, but there was no difference between the 50 and 55mph results. This suggests that in the 55mph speed limit, drivers accepted gap sizes comparable to those accepted at 50mph. Since the average speed was 3-4mph quicker in the 55mph speed limit (see Figure 7), this might suggest that there was an element of increased risk during the 55mph lane changes; faster speeds with the same distance between vehicles implies less time to react to an emergency. However, since participants typically selected a point in the middle of the gap, the average distance to the vehicle in front at these speed limits was over 50m, close to the recommended minimum stopping distance from the Highway Code (53m at 50mph). This indicates that most drivers were allowing adequate distance between them and the vehicle in front to pull up safely if it suddenly slowed down or stopped.

The large error bars in Figure 19 indicate that the gap size varied substantially across drives; there was less variability in the 50mph speed limit with low traffic, perhaps because drivers found it easier to negotiate lane changes in this drive.

### 3.1.6 Lateral lane position

Lateral lane position measures the position of the participants' vehicle within the lane<sup>9</sup>. The mean lateral lane positions were between 0m and 3.6m; where values close to 0 indicate that, on average, the participant drove mainly on the left side of the lane; values close to 1.8m indicate the participant drove mainly in the centre of the lane; and values close to 3.6m indicate that the participant drove mainly on the right side of the lane.

Figure 20 shows the mean lateral lane position for each drive.



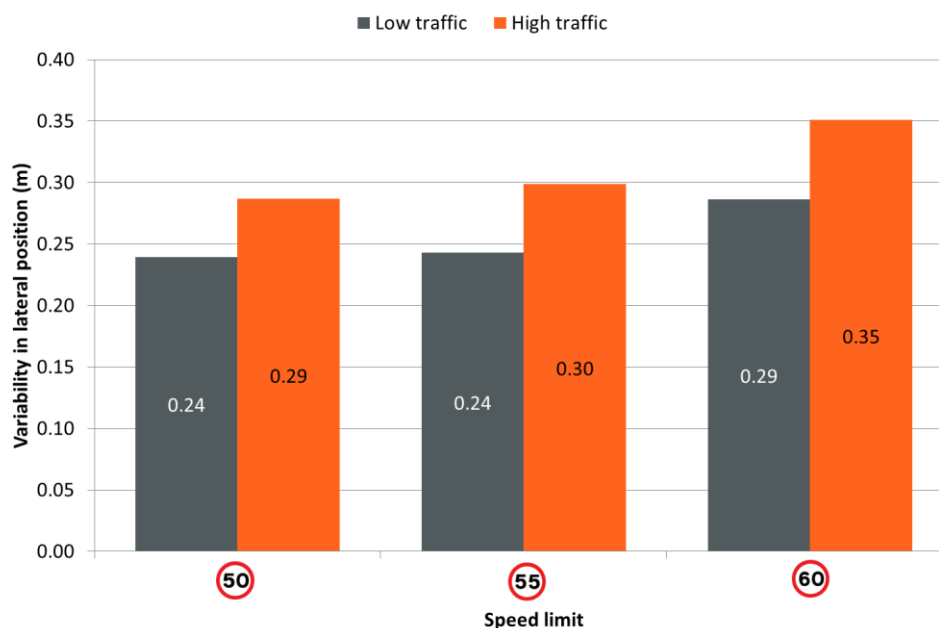
**Figure 20: Mean lateral lane position through work zone A**

Overall, the average lateral lane position remained fairly consistent across all drive. Two-way repeated measures ANOVA shows that average lateral lane position was significantly different across traffic conditions ( $p < 0.01$ ). But speed limit was not significant ( $p = 0.06$ ) and neither was the interaction between traffic and speed limit ( $p = 0.08$ ). This suggests that drivers tended to drive in the same position within the lane, irrespective of the speed limit.

Figure 21 shows the average variability (standard deviation) in lateral lane position across work zone A.

<sup>9</sup> To account for differences in the number of lane changes between drives, a three second period before and after each lane change was removed from the data prior to calculating the mean and standard deviation.





**Figure 21: Average standard deviation in lateral lane position through work zone A**

The variation in lane position suggests that, on average, participants' amount of movement within lane was similar across all drives (but slightly higher in the high traffic drives). This suggests that the speed limit did not influence the amount that drivers moved within the lane. If 55mph was causing a distraction to drivers from the need to look at their speedometer more than at 50 or 60mph, we might expect more variability in this measure.

### 3.1.7 Collisions and near-misses





There were no collisions recorded in any of the six drives.

Participants were asked about whether they had any near misses after they finished each drive and these were investigated further in the post-trial interview. Near-misses were reported by participants in 38 of the 216 drives and were more common in the high traffic condition. In all cases, participants reported that these were due to sudden or unexpected manoeuvres by the AI vehicles which forced the participant to respond by slowing their vehicle or changing lane.

### 3.1.8 Response to the change in speed limit

In the four drives with a 55 or 60mph speed limit in work zone A, there was a step-down in speed limit to 50mph in work zone B. In order to understand how long it took drivers to notice the speed limit change and adjust their behaviour accordingly, the distance after the change in speed limit at which the speed of the participant first reached the new average speed was recorded. The results are presented in Table 5.

**Table 5: Distance (in metres) where the speed changed after encountering speed limit**

Speed limit in work zone A	Speed limit in work zone B	Traffic condition	Minimum distance (number of participants)	Maximum distance	Mean distance
		Low	0 (14)	973	141
		High	0 (12)	946	185
		Low	0 (7)	926	187
		High	0 (6)	916	275

On average, it took participants around 140 - 275m to adjust their speed following the step down, with longer distances observed in the high traffic conditions (possibly related to a higher cognitive load due to the higher number of AI vehicles) and longer distances when the step down in speed was 10mph (60mph to 50mph) compared to 5mph (55mph to 50mph).

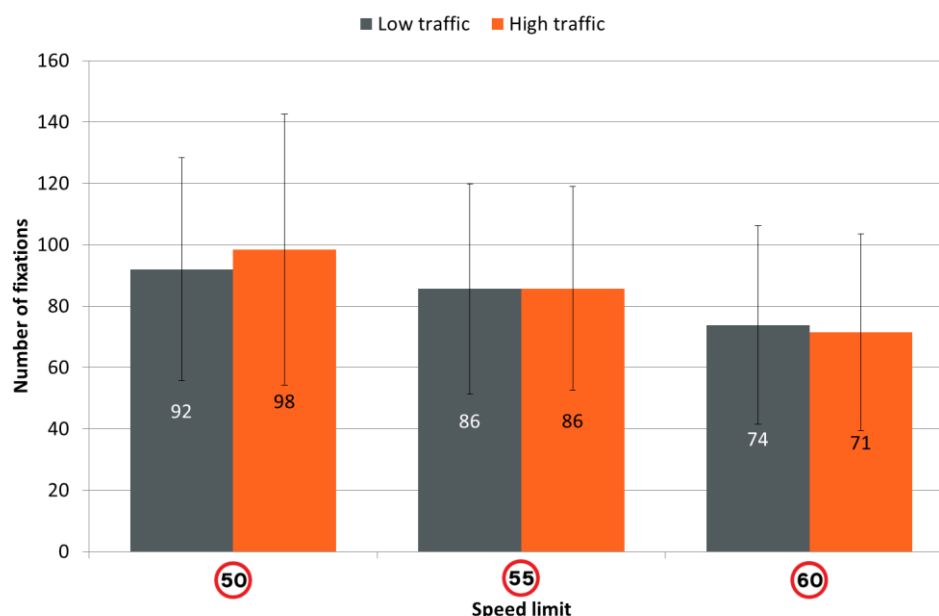
Some participants adjusted their speed before the change in speed limit (the 'minimum distance' column shows the number of participants for which this was the case). Since it is possible to see the new speed limit signs a few hundred metres upstream of the actual gateway, these individuals started decelerating before they reached this point.

Other participants took much longer to notice the change in speed limit (almost 1km), suggesting that they did not see the speed limit change at the initial gateways signs.

### 3.2 Visual behaviour

This section presents the eye-tracking data collected in work zone A. The primary aim of this analysis was to identify the extent to which the speed limit impacted on the amount of time drivers spent looking at the speedometer.

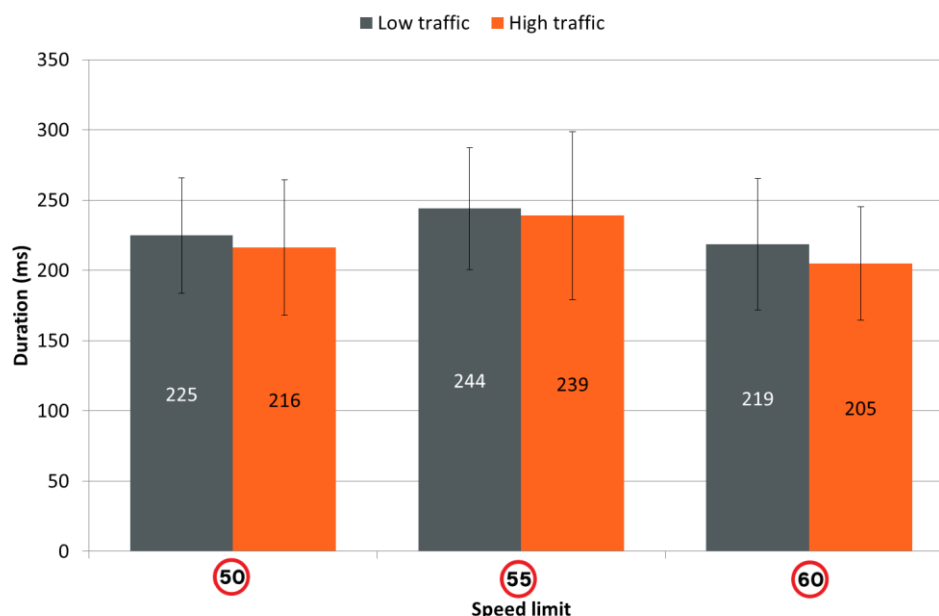
Figure 22 shows the mean number of fixations on the speedometer for each of the six drives.



**Figure 22: Mean number of fixations on speedometer**

There was little difference in the average number of fixations on the speedometer between the two traffic conditions (repeated measures ANOVA shows this was not significant ( $p = 0.73$ )). However, there was a significant difference across the three speed limits ( $p < 0.01$ ), with fixations reducing as the speed limit increased. Post-hoc tests showed that the average number of fixations differed significantly for all three pairwise comparisons (i.e. 50 and 55mph differ, 50 and 60mph differ and 55 and 60mph differ). The interaction between speed limit and traffic condition was not significant ( $p = 0.36$ ).

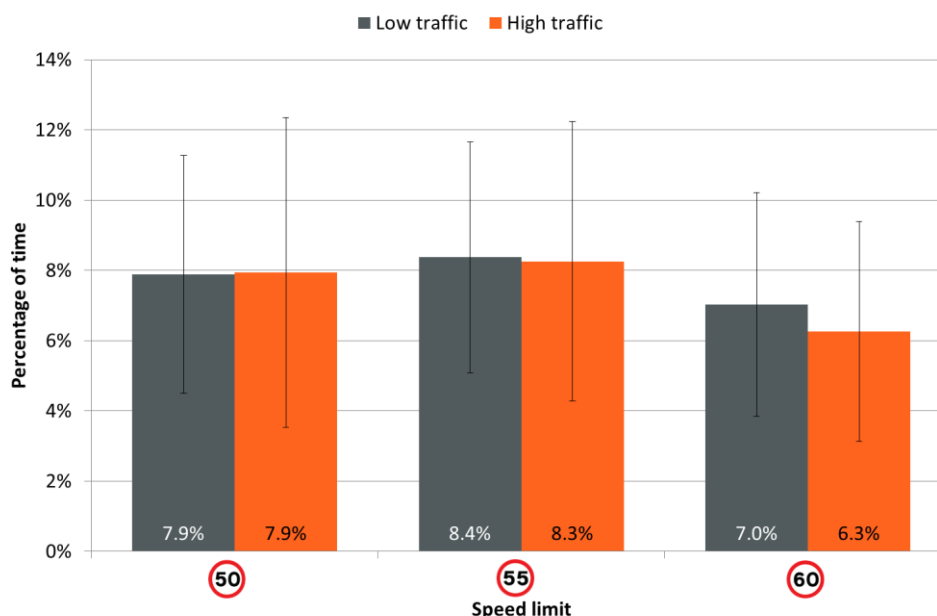
Figure 23 shows the mean fixation length (ms) on the speedometer in each of the six drives.



**Figure 23: Mean duration of fixations on the speedometer**

The average fixation on the speedometer was longer in the low traffic condition than the high traffic condition. Two-way repeated measures ANOVA showed this difference was significant ( $p < 0.01$ ). The results also show that average fixation was significantly longer in the 55mph limit, compared to both the 50 and 60mph limits. There was no significant difference between the 50 and 60mph limits. The interaction between traffic and speed limit was not significant ( $p = 0.70$ ), suggesting that the effect of the speed limit on average fixation was similar across the two traffic conditions.

Figure 24 combines the information on number of fixations with the speedometer (Figure 22) and mean duration of each fixation (Figure 23) to estimate the proportion of overall time spent looking at the speedometer in each of the six drives.



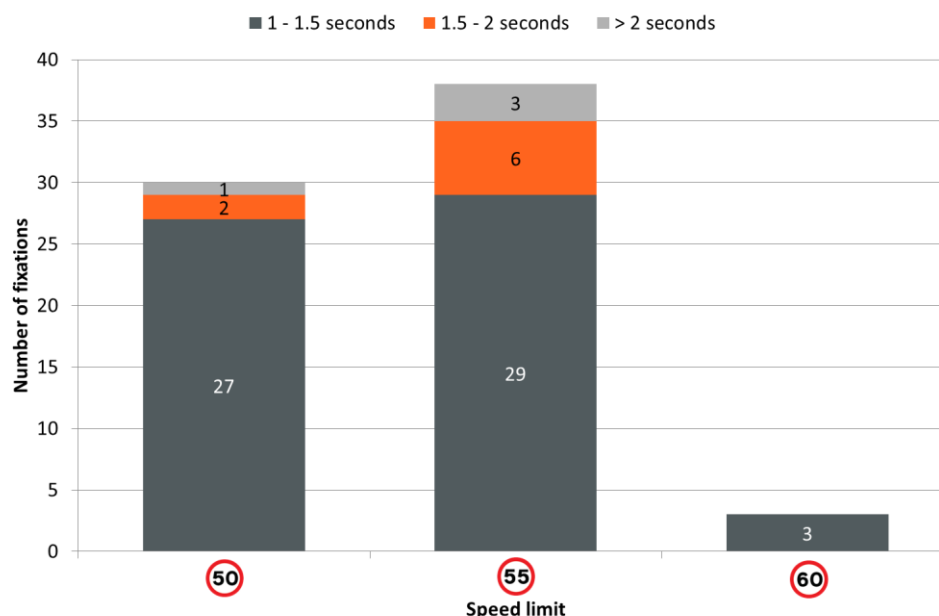
**Figure 24: Mean proportion of time spent fixating on speedometer**

On average, participants spent around 6-9% of the drive in work zone A looking at the speedometer. This appears high, but no baseline data is available for comparison with typical on-road conditions. However, since the only differences between drives were the speed limits and traffic conditions, there is no reason to expect that the relative differences in on-road conditions would be different from those seen here.

Overall, the 55mph speed limit was associated with the largest proportion of time spent looking at the speedometer, and the 60mph speed limit was associated with the lowest. The difference between speed limits was significant ( $p < 0.01$ ). Pairwise comparisons show that the amount of time spent looking at the speedometer when the speed limit was 60mph was significantly lower than both 50 and 55mph; however, there was no significant difference between 50 and 55mph. This suggests that the level of distraction with 55mph was comparable to the current 50mph speed limit.

There was no significant difference in the proportion of time spent looking at the speedometer between the two traffic conditions ( $p = 0.29$ ) and the interaction was not significant ( $p = 0.48$ ).

Whilst short periods of time spent looking at the speedometer might not increase collision risk substantially, long duration fixations are likely to pose a greater risk. Figure 25 shows the total number of fixations of over 1, 1.5 and 2 seconds in each of the three speed limits tested. Note, only fixations over 2 seconds are considered distracting in the literature but fixations of over 1 and 1.5 seconds are also included here for comparison.



**Figure 25: Total number of fixations of over 1, 1.5 and 2 seconds**

Only three fixations of over 1 second occurred in the 60mph speed limit, and all these were between 1 second and 1.5 seconds in duration. Both 50 and 55mph had considerably more ‘long’ fixations, with 55mph featuring the most. 55mph also had more fixations of greater than 1.5 and 2 seconds.

The National Highway Traffic Safety Administration’s “Visual-Manual NHTSA Driver Distraction Guidelines” define quantifiable criteria for evaluating the extent of in-vehicle distractions, based on eye glance behaviour. The NHTSA guidelines are specific to secondary (i.e. non driving) related tasks, and therefore do not apply directly to this study. However, they provide a useful benchmark with which to define high levels of distraction.

A number of criteria for eye glance testing using a driving simulator are specified. Two of these criteria were used to test the level of distraction associated with looking at the speedometer when driving through the works:

- “For at least 21 of the 24 test participants, no more than 15 percent (rounded up) of the total number of eye glances away from the forward road scene should have durations of greater than 2.0 seconds while performing the secondary task, and
- For at least 21 of the 24 test participants, the mean duration of all eye glances away from the forward road scene should be less than 2.0 seconds while performing the secondary task” (NHTSA, 2010)

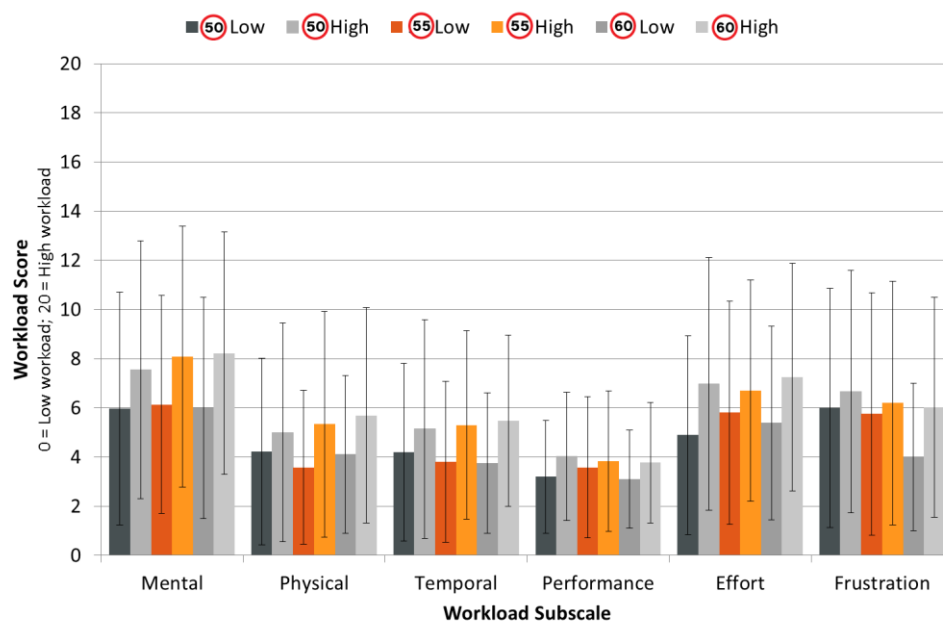
Within this study, although there were some fixations over 2 seconds in duration (see Figure 25); none of the participants in any of the drives had a mean fixation duration on the speedometer of over 2 seconds. In addition, none of the participants in any drive had more than 15% of their fixations over 2 seconds. As a result, the level of distraction observed in this study was compliant with the NHTSA evaluation criteria and is not considered unsafe.

### 3.3 Perceptions and opinions

This section presents the results of the analysis of data collected using the post-trial questionnaire (including the NASA-TLX workload measures) and the post-trial interviews.

#### 3.3.1 Workload

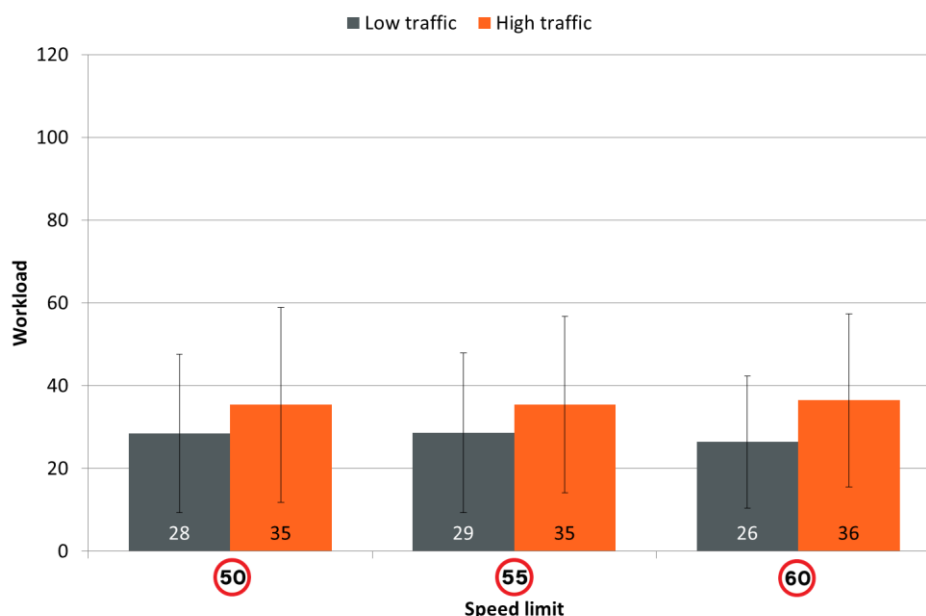
After each drive participants were asked to complete the NASA Task Load Index which provides a workload rating on each of six subscales (mental demand, physical demand, temporal demand, frustration, effort, and performance). The mean rating of each of the six subscales is shown in Figure 26. The performance subscale has been reversed to align with the other subscales, i.e. a low score indicates a low contribution to overall workload and a high score indicates a high contribution to overall workload.



**Figure 26: Mean workload subscale ratings**

The main differences between the drives are between the low and high traffic, rather than the different speed limits. Repeated measures ANOVA for each of the subscales shows that the average workload score was significantly different for the two traffic conditions ( $p < 0.01$  for all six scales). However, there was no significant difference between speed limits and the interaction between speed limit and traffic was also non-significant ( $p > 0.05$  in all cases).

The subscales were combined to estimate total workload (see Figure 27).



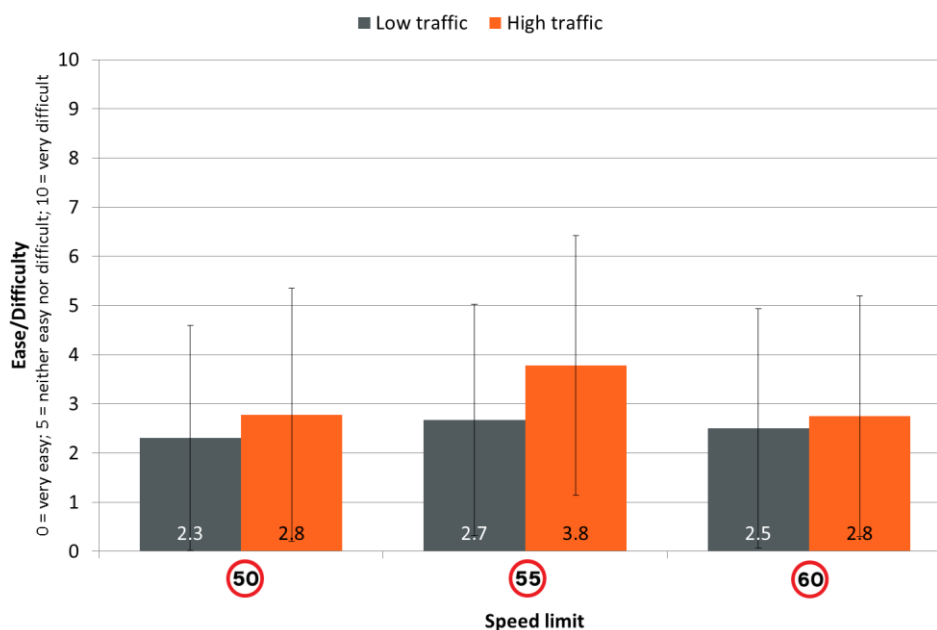
**Figure 27: Average total workload**

As seen for each of the subscales, the low traffic conditions had lower ratings than the high traffic conditions (repeated measures ANOVA shows this difference was significant ( $p < 0.01$ )). However, there was no significant difference across the three speed limits ( $p = 0.92$ ) and the interaction between traffic and speed limit was not significant ( $p = 0.41$ ). This suggests participants' workload was related to the traffic conditions and not the changing speed limit.

### 3.3.2 *Ease/difficulty of travel*

In addition to the workload measures, participants were asked to rate the ease/difficulty of travelling through the roadworks at the different speed limits (Figure 28).





**Figure 28: Mean responses to survey question: 'How easy or difficult did you find it to travel at the speed limit through the roadworks?'**

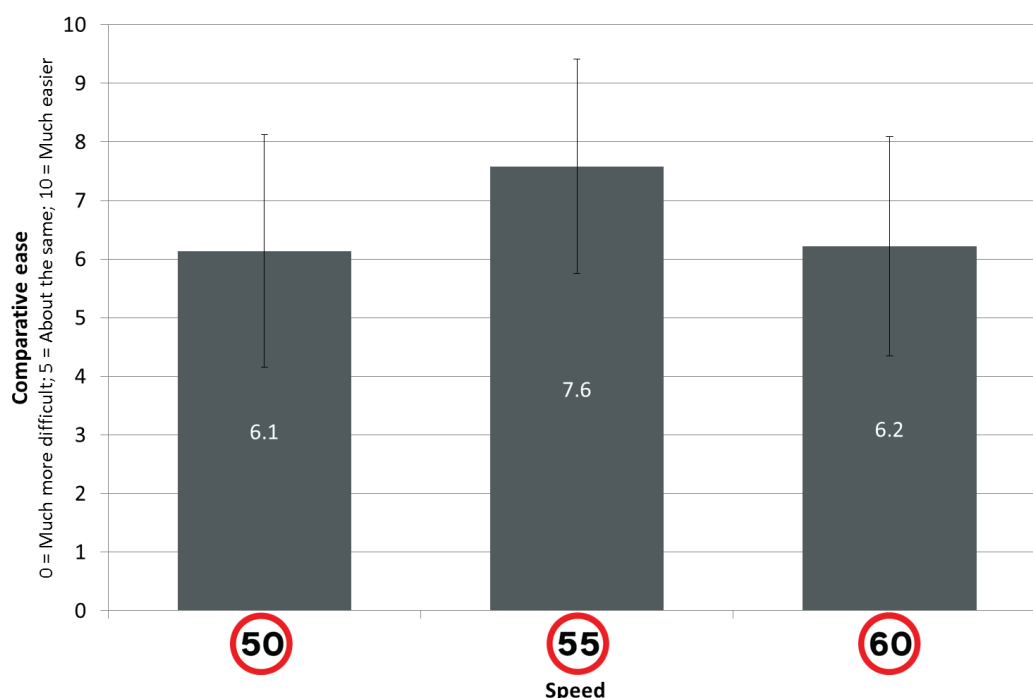
The highest reported difficulty was 55mph in the high traffic condition (3.8), although this was still at the 'easy' end of the scale. The 55mph was also the highest rating of the three low traffic conditions (2.7).

The mean rating was significantly different ( $p < 0.01$ ) between the two traffic conditions, with greater difficulty of travel in high traffic conditions. However, there was no significant difference between the three speed limits ( $p = 0.07$ ) and the interaction between traffic and speed limit was not significant ( $p = 0.57$ ).

In the final questionnaire after all six drives, participants were also asked to rate how easy or difficult they found it to travel at 55mph compared to 50 and 60mph. The scale ranged from 0 (much easier) to 10 (much more difficult), with 5 indicating 'about the same'. The mean score was 6.3, indicating that, in general, participants found it slightly more difficult to travel at 55mph. A one-sample t-test was used to test if this value was statistically different from 5. The result was significant ( $p < 0.01$ ), suggesting that, on average, participants found it more difficult to travel at 55mph compared to 50 and 60mph.

Four participants marked the 55mph speed limit as easier while eight marked it as about the same, leaving 24 participants who marked it as more difficult. The predominant reason given for the difficulty was identifying the speed on the speedometer and a perception of spending more time looking at the speedometer to maintain an appropriate speed. A secondary reason was lack of familiarity with the 55 speed.

The final questionnaire also asked participants to rate whether they felt a digital speedometer would make it easier or more difficult to maintain a constant speed, compared with an analogue speedometer, such as that used in this trial. The results are shown in Figure 29.



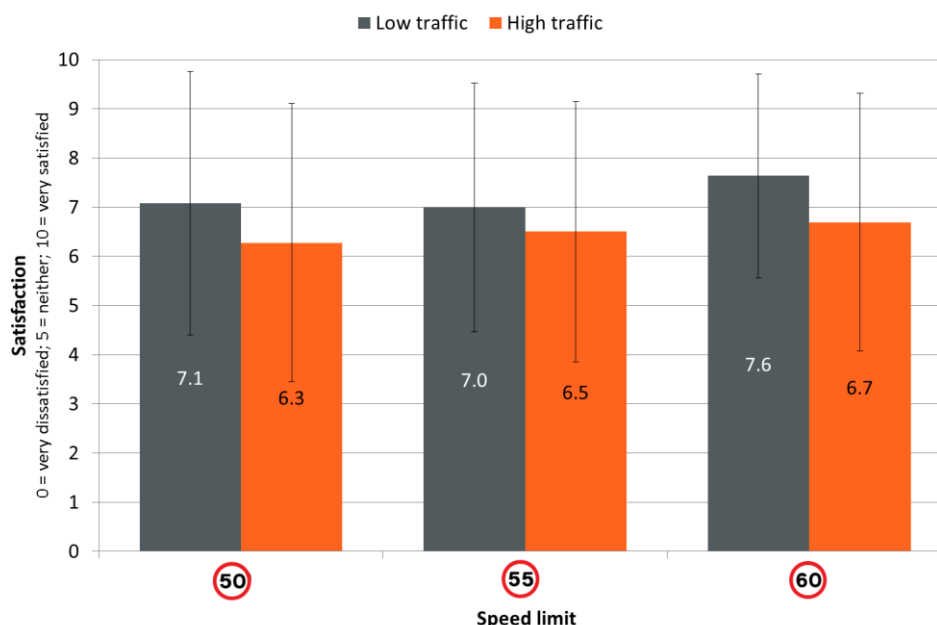
**Figure 29: Mean responses to survey question: ‘In your opinion, how easy or difficult would it be to use a digital compared with an analogue speedometer to maintain a constant speed?’**

The results show that participants believed all three speeds would be more easily maintained with a digital speedometer (i.e. the means are all greater than 5 = about the same). Statistical tests (Friedman’s test) show there was a statistically significant difference in this rating across the three speed limits ( $p < 0.01$ ).

In particular, participants thought that 55mph would be easier to maintain with a digital speedometer (mean rating of 7.6) and post-hoc tests show that this rating was significantly different from 50mph ( $p < 0.01$ ) and 60mph ( $p < 0.01$ ). However, 50mph was not significantly different from 60mph ( $p = 0.32$ ).

### 3.3.3 Satisfaction

A number of questions were asked to gauge participants’ satisfaction with the speed limits and drives experienced. Reported satisfaction (from 0 = very dissatisfied to 10 = very satisfied) with each of the six drives is shown in Figure 30.

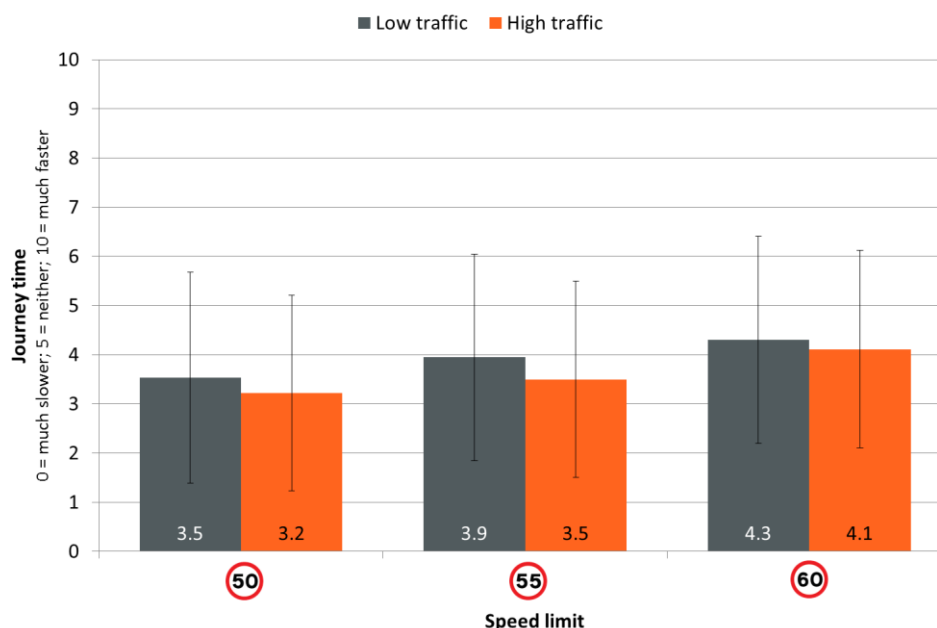


**Figure 30: Mean responses to survey question: ‘Thinking about your typical motorway journey, how satisfied or dissatisfied would you feel driving through roadworks such as these?’**

The results show that overall participants were satisfied with all three speed limits in both the high and low traffic conditions (mean scores were all above 5). The highest satisfaction ratings were for 60mph in both the high and low traffic conditions.

A two-way repeated measures ANOVA showed average level of satisfaction was significantly different between the two traffic conditions ( $p < 0.01$ ) but no significant differences were found between the three speed limits ( $p = 0.17$ ) or the interaction between traffic and speed limit ( $p = 0.64$ ).

Figure 31 describes participants’ expectations of the impact of each speed limit on their journey times.

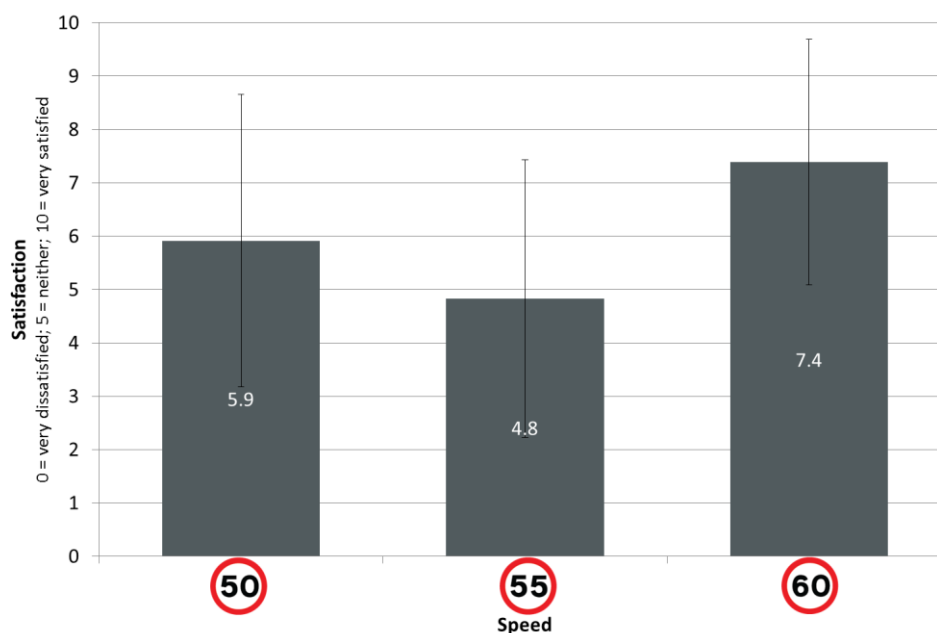


**Figure 31: Mean responses to survey question: ‘How do you think driving through roadworks such as these would affect your journey time (compared to driving the same route with no roadworks)?’**

The results show that participants expected their journey to be most affected by the 50mph speed limit and least affected by the 60mph speed limit.

A two-way repeated measures ANOVA showed significant differences in average journey time across the three speed limits ( $p < 0.01$ ). The differences were not significant across traffic conditions ( $p = 0.07$ ) and the interaction between speed limit and traffic was also non-significant ( $p = 0.73$ ). Pairwise comparisons suggest that participants rated the journey times as significantly faster in the 60mph speed limit compared to 50mph, but neither 50 or 60mph were significantly different from 55mph.

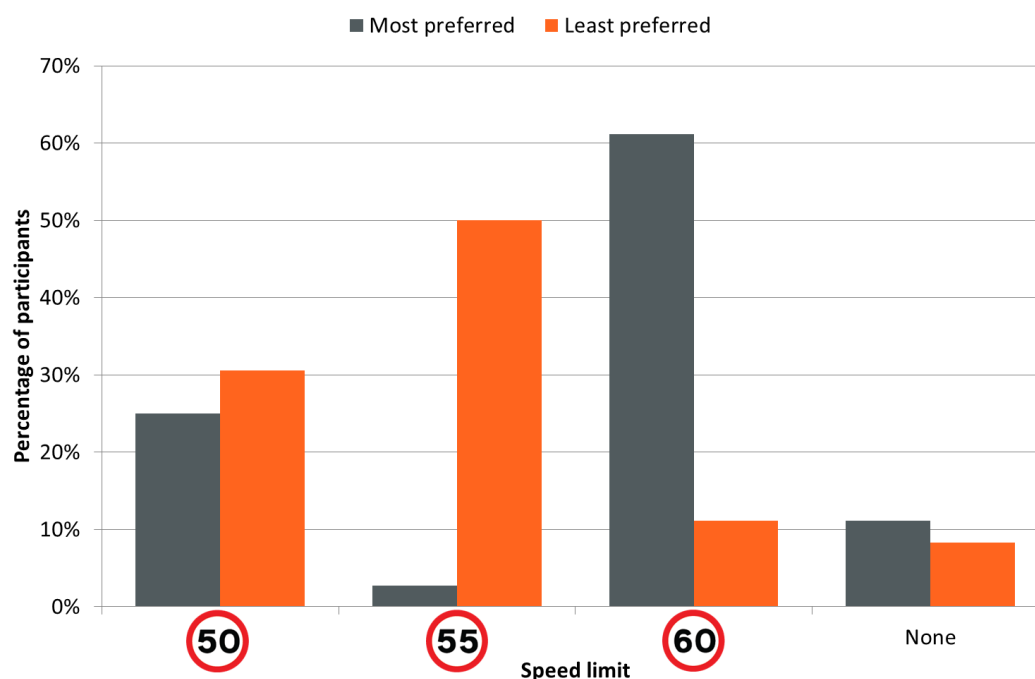
In addition to the questions around satisfaction asked immediately after each drive (Figure 30 and Figure 31), participants were also asked to rate their overall satisfaction with each speed limit at the end of the trial (Figure 32).



**Figure 32: Mean responses to survey question: 'In these trials, please mark your satisfaction with each speed limit when travelling through roadworks'**

The 60mph speed limit was given the highest rating of satisfaction and 55mph was given the lowest rating. Friedman test shows there was a statistically significant difference in the satisfaction rating depending on the speed limit in the work zone ( $p < 0.01$ ). Post hoc analysis showed there were significant differences in level of satisfaction between all three pairwise combinations of speed limits (50 and 55mph, 50 and 60mph, and 55 and 60mph).

Using the ratings given for each speed limit, the most and least preferred speeds among participants were analysed (Figure 33).



**Figure 33: Most and least preferred speeds**

This clearly shows 60mph as the most preferred speed limit and 55mph as the least preferred. Three participants chose all three speeds as equally preferred, and one chose 60mph and 55mph as equally preferred above 50mph. Only one participant indicated 55mph as their preferred speed.

The reasons given by participants who chose 60mph as their preferred speed were:

- Felt like a more normal and comfortable speed for the motorway (14 participants)
- Faster (5 participants)
- Easier to overtake HGVs (5 participants)
- Kept traffic moving (3 participants)
- Higher concentration (1 participant)

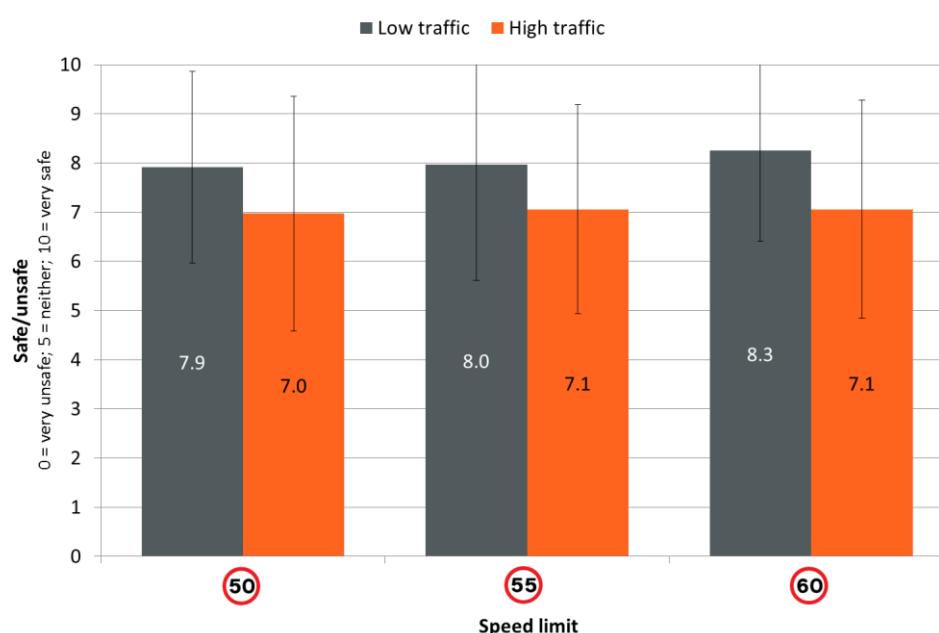
Participants who choose 50mph as their preferred speed typically thought it was safer. Finally, four participants rated 50 and 60mph equally, and reported they did so because they felt it was easier to maintain on the speedometer. Only one participant rated 55mph as their preferred speed saying s/he found it quite comfortable to travel at this speed. Another rated 55mph and 60mph equally, but this was due to difficulty by that particular participant in maintaining foot position at 50mph due to the participants' height.

Reasons for choosing 55mph as the least preferred speed were predominantly related to difficulty in maintaining that speed when it is more difficult to see on the speedometer. Two participants also mentioned lack of familiarity with the speed. With regard to 50mph as the least preferred speed, participants felt that it was too slow and not sufficiently engaging or that it would be safer to go faster. Those participants who chose 60mph as their least preferred speed all did so due to safety concerns.

Participants were also asked if they could identify any disadvantages to their preferred speed. Of the 23 participants who chose 60mph as their preferred speed, only 10 identified a potential disadvantage. Nine of these reasons related to safety; five to reduced reaction times, one reported it being generally less safe and three identified an increased risk to road worker safety. The final identified disadvantage was reduced time to read signs. Three of the participants who had a preferred speed other than 60mph identified disadvantages relating to slower travel and risk of speeding.

### 3.3.4 Safety

Figure 34 describes the feeling of safety participants had in each drive.



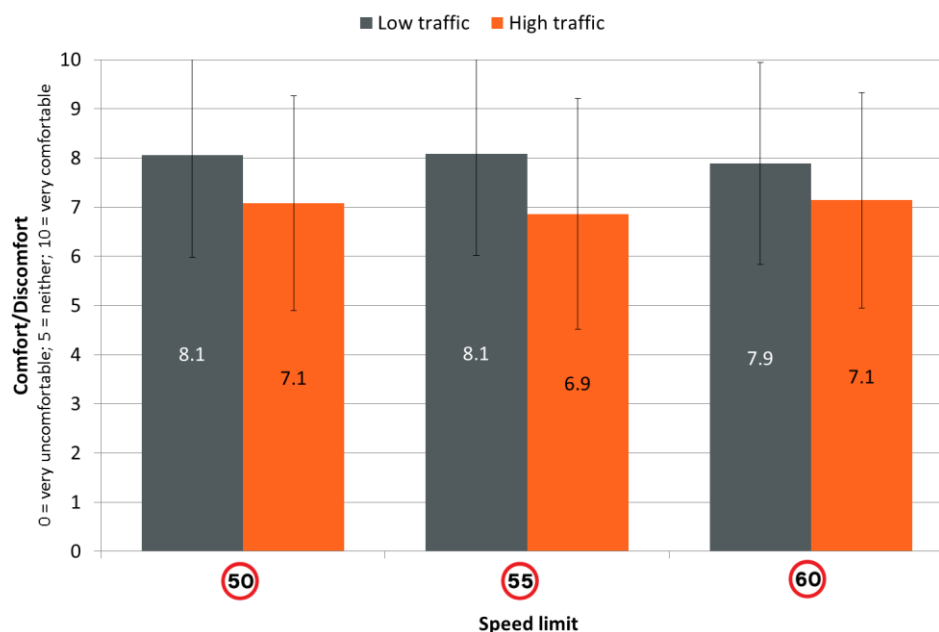
**Figure 34: Mean responses to survey question: ‘How safe or unsafe did you feel when driving through the roadworks in this drive?’**

The results show that participants felt safe in all drives (all means were above 5), and more safe in the low traffic conditions.

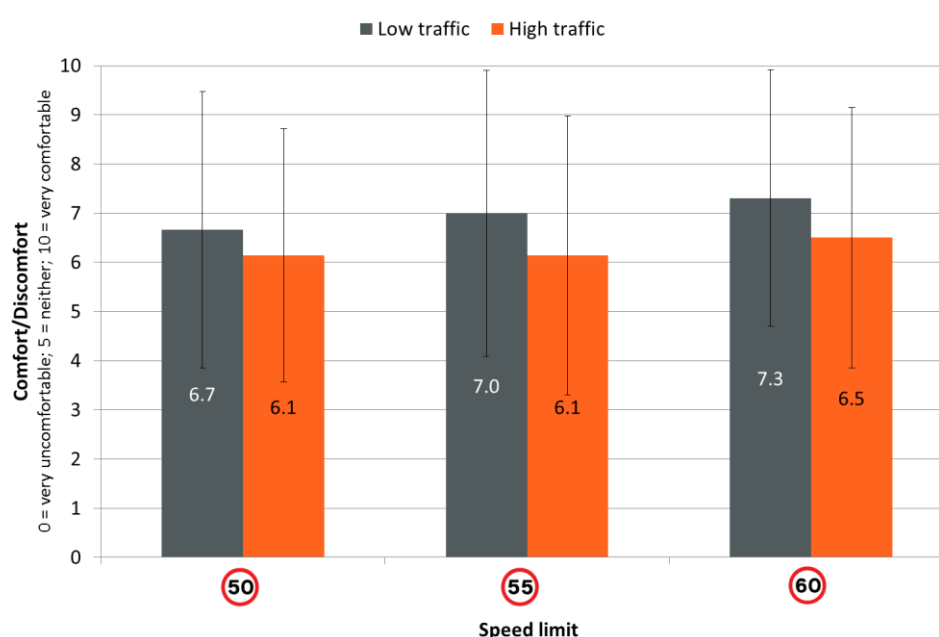
A two-way repeated measures ANOVA shows that average levels of safety were significantly different for the two traffic conditions ( $p < 0.01$ ). However, the average level of safety was not significantly different across speed limits ( $p = 0.73$ ) and the interaction between traffic and speed limit was also non-significant ( $p = 0.85$ ).

### 3.3.5 Comfort

Figure 35 and Figure 36 describes participants’ feelings of comfort towards cars and HGVs in each drive.



**Figure 35: Mean responses to survey question: 'How comfortable or uncomfortable did you feel about the presence of other cars when travelling through the roadworks in this drive?'**



**Figure 36: Mean responses to survey question: 'How comfortable or uncomfortable did you feel about the presence of HGVs when travelling through the roadworks in this drive?'**

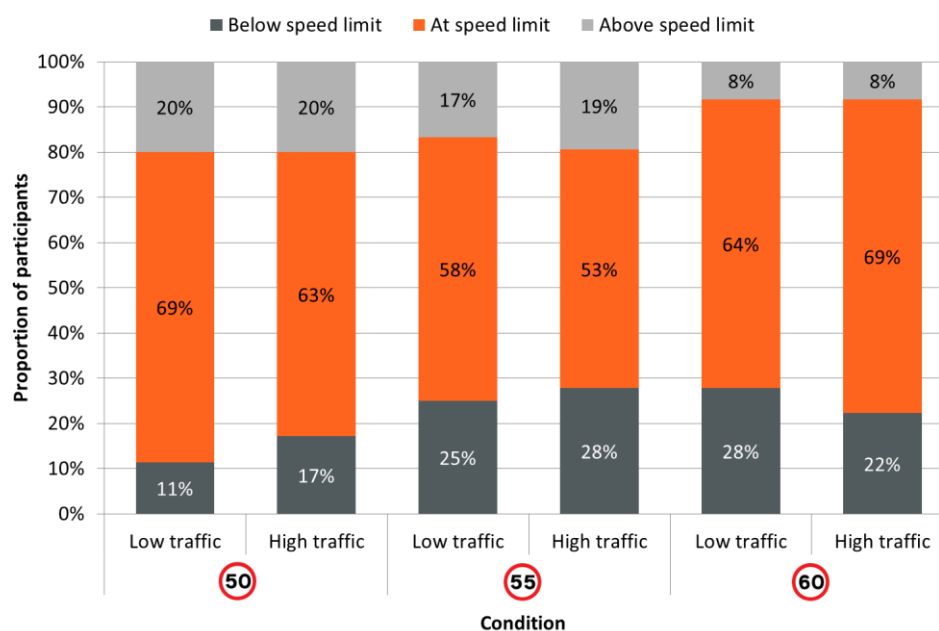
The results show that participants felt comfortable around cars and HGVs in all drives (all means are above 5). In general, participants rated their comfort around cars higher than their comfort around HGVs, and gave higher ratings of comfort in the low traffic conditions than the high traffic condition. The comfort around HGVs tends to increase slightly as the speed increases, while car comfort is more stable.



Statistical tests (repeated measures ANOVA) showed that the average level of comfort regarding both the presence of cars and of HGVs was significantly different for the two traffic conditions ( $p < 0.01$  and  $p = 0.02$  respectively). However, there was no significant difference between speed limits ( $p = 0.91$  and  $p = 0.17$ ) and the interaction of speed limit and traffic condition was non-significant ( $p = 0.59$  and  $p = 0.77$ ).

### 3.3.6 Perceived speed

After each drive, participants were asked whether they drove below, at or above the speed limit. Figure 37 describes the perceived speed adherence.



**Figure 37: Responses to survey question: ‘In general, at what speed did you drive through the roadworks in this drive?’**

In general, participants reported that they drove at the speed limit in all drives. This was lowest in the 55mph speed limit. The proportion of participants reporting driving above the speed limit decreased as the speed limit increased.

These results broadly align with the data from the simulator which suggest that average speeds were typically at or below the limit (Figure 9), but speeding was more common at the lower speed limits (Figure 10 and Figure 11).

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## 4 Summary and conclusions

### 4.1 What is the effect of speed limit on driver distraction?

The results suggested that the speed limit had some impact on the level of visual distraction exhibited by drivers. The lower speed limits (50 and 55mph) resulted in more fixations on the speedometer than the 60mph speed limit. The mean duration of fixations on the speedometer was significantly higher in the 55mph speed limit than either 50 or 60mph (in the low traffic condition). On average, the total time spent looking at the speedometer was significantly lower in the 60mph speed limit than in either 50 or 55mph; there was no difference between 50 and 55mph. Speed limits of 50 and 55mph also resulted in more long duration fixations on the speedometer than 60mph.

Taken together these results suggest that the novel 55mph speed limit was no more distracting than the 50mph speed limit currently used in roadworks on the SRN. Overall, the 60mph speed limit was the least distracting.

### 4.2 What is the effect of speed limit on driver workload?

The NASA Task Load Index was used to measure workload on a variety of scales (mental demand, physical demand, temporal demand, frustration, effort, and performance). There were significant differences in each scale between the two traffic conditions (with workload rated significantly higher in the high traffic condition), but there were no significant differences between the speed limits.

When asked about the ease/difficulty of each speed limit, the 55mph speed limit was rated as more difficult to travel at than either 50 or 60mph. The predominant reasons given for this included identification of the speed on the speedometer, a perception of spending more time looking at the speedometer, and the lack of familiarity with this speed. These reasons align with those given by participants in the previous trial (Wallbank, Robbins, Tailor, & Chowdhury, 2017) and suggest that some drivers perceived there to be an effect on driver distraction (at least in terms of monitoring the speedometer). However, as discussed in Section 4.1, these subjective reports are not supported by the eye tracking data collected in this study.

Drivers thought that a constant speed would be easier to maintain with a digital speedometer compared to an analogue one, particularly when the speed was 55mph. This driving simulator trial used an analogue speedometer only, and so behavioural data to support or refute this perception is not available.

Whilst not a direct measure of workload, the variability in speed and lateral lane position is an objective measure of performance, which can be related to workload (i.e. reduced performance may be correlated with higher workload). In this case, high variability in speed and lateral position might indicate a high task demand. Speeds were more variable in the high traffic condition compared to the low traffic condition, but there was little difference in the variability in speed (or lateral lane position) between the three speed limits.

The results therefore suggest that workload was not greatly impacted by the speed limit. From the qualitative feedback, some drivers perceived that 55mph was more difficult, but

there was no empirical evidence to suggest that this speed limit actually affected their ability to drive, compared to either 50 or 60mph.

### **4.3 What is the effect of speed limit on headway?**

Mean headway was not significantly different between the three speed limits. This measure exceeded the recommended stopping distances provided in the Highway Code, suggesting that drivers typically allowed a sufficiently safe distance between them and the vehicle in front.

Analysis of close following revealed that there was less close following when the speed limit was 55mph compared to 60mph; however the 55mph was different to the 50mph speed limit currently used in roadworks on the SRN.

Variability in headway was greater for the high traffic drives, suggesting that participants found it harder to maintain a constant headway when there were more vehicles. There was no indication that headways were more variable in the 55mph speed limit than the other two speed limits.

There were no collisions in any of the drives but participants did report a number of near misses which were caused by the AI vehicles pulling in close to the participants' vehicle.

Based on these results, there was no evidence that the 55mph speed limit resulted in reduced headway and thus increased collision risk compared to 50 or 60mph.

### **4.4 What is the effect of speed limit on gap size?**

Evidence suggested that drivers adjusted their lane changing behaviour according to the speed limit. Specifically, the results showed that the total number of lane changes was similar in the 50 and 55mph speed limits, but higher in the 60mph limit. In addition, when the speed limit was faster, drivers more frequently chose to change lanes when there were no vehicles in the close vicinity (+/- 250m).

For lane changes where there was an AI vehicle both in front and behind, the mean gap size selected by participants varied across speed limits; typically, larger gaps were chosen at 60mph compared to the lower speed limits. There was no difference between the 50 and 55mph results, suggesting that drivers accepted similar gap sizes.

These results indicated that when faced with a novel 55mph speed limit, drivers' lane changing behaviour was similar to that in a 50mph speed limit. Since average speeds were typically faster in the 55mph limit, a similar gap size might suggest an increased collision risk. However, suitable stopping distances (in line with the Highway Code) were maintained, in all speed limits, suggesting that drivers would have had sufficient time to react to an emergency if required to do so.

### **4.5 What is the effect of speed limit on drivers' subjective experience?**

The level of satisfaction differed significantly between the three speed limits: satisfaction was highest with the 60mph limit and lowest with the 55mph limit. There were a number of reasons given for these ratings including journey times (participants rated the journey times

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as significantly faster in the 60mph speed limit compared to 50mph), the familiarity of the speed limit (specifically, the lack of familiarity with 55mph), the movement of traffic (which was reported as being better in 60mph) and difficulties in maintaining 55mph on the speedometer.

From the interview data, there was some qualitative evidence that perceived safety (both to road users and road workers) reduced as the speed limit increased. However, safety ratings provided in the post-trial survey showed no significant differences between the speed limits.

Participants rated higher levels of comfort when travelling in proximity to cars compared with when travelling close to HGVs. Significantly higher ratings of comfort were also given in the low traffic than the high traffic condition. There was no significant difference in reported comfort between speed limits for either vehicle type.

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## 5 Recommendations

Results from this driving simulator study provide no evidence of increased risk associated with a speed limit of 55mph in roadworks; there were no safety concerns identified relating to the level of visual distraction, driver workload, or the ability of a driver to maintain safe headways between vehicles.

On the basis of these findings it is recommended that a 55mph speed limit can be progressed to an on-road trial on the SRN. On-road trials are important for validating the findings from the simulator in the real world, and broadening the body of evidence required to understand how drivers react to this novel speed limit.

As far as possible, traffic in the simulator was modelled so as to be representative of the real world. However, due to a lack of previous data on real-world HGV behaviour, it is not possible to comment on the representativeness of the AI HGV behaviour in the simulator. Further, since this study investigated the behaviour and performance of car drivers (in the simulated environment), it cannot be used to draw conclusions about the impact of a 55mph speed limit on HGV behaviour, including the extent to which HGV drivers close follow in different speed limits. On-road trials of the 55mph should seek to collect robust data on HGV behaviour in order to investigate this area.

It is also recommended that driver perceptions and opinions are sought as part of future on-road trials; there was some evidence from this simulator study to suggest drivers may be less satisfied with a 55mph speed limit than other speed limits. A larger sample of drivers who travel through roadworks on the SRN is required in order to be able to generalise this finding to the general population. Possibly, dissatisfaction observed in this study may have been related to the lack of familiarity with the 55mph speed limit; future work should be undertaken to understand how satisfaction changes as new speed limits become more commonplace.

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## Appendix A Post-drive questionnaire

Drive X										
1. How <b>easy or difficult</b> did you find it to travel at the speed limit through the roadworks?										
Very easy			Neither easy nor difficult					Very difficult		
0	1	2	3	4	5	6	7	8	9	10
2. In general, at what speed did you drive through the roadworks during this drive?										
Below the speed limit			At the speed limit			Above the speed limit				
3. Thinking about <b>your typical motorway journey</b> , how likely or unlikely are you to travel at such a speed limit through roadworks?										
Very unlikely			Neither likely nor unlikely					Very likely		
0	1	2	3	4	5	6	7	8	9	10
4. How <b>safe or unsafe</b> did you feel when driving through the roadworks in this drive?										
Very unsafe			Neither safe nor unsafe					Very safe		
0	1	2	3	4	5	6	7	8	9	10
5. How <b>comfortable or uncomfortable</b> did you feel about the presence of <b>other cars</b> when travelling through the roadworks in this drive?										
Very uncomfortable			Neither comfortable nor uncomfortable					Very comfortable		
0	1	2	3	4	5	6	7	8	9	10
6. How <b>comfortable or uncomfortable</b> did you feel about the presence of <b>HGVs</b> when travelling through the roadworks in this drive?										
Very uncomfortable			Neither comfortable nor uncomfortable					Very comfortable		
0	1	2	3	4	5	6	7	8	9	10

7. Thinking about your typical motorway journey, how <b>satisfied or dissatisfied</b> would you feel driving through roadworks such as these?										
Very dissatisfied			Neither dissatisfied nor satisfied					Very satisfied		
0	1	2	3	4	5	6	7	8	9	10
8. How do you think driving through roadworks such as these would affect your <b>journey time</b> (compared to driving the same route with no roadworks)?										
My journeys would be much <b>slower</b>				Would have no effect on my journey time			My journeys would be much <b>faster</b>			
0	1	2	3	4	5	6	7	8	9	10
9. Did you have any collisions in this drive?								Yes	No	
10. Did you have any near-misses in this drive?								Yes	No	



## Appendix B NASA-TLX

## Your experience of Drive X

## NASA TLX

For the following questions please think about your last drive and place an "X" along each scale at the point that best indicates your experience.

If you are unsure about the meaning of any of the questions, please ask the researcher to explain.

1 **Mental Demand:** How mentally demanding was the task?

Low | | | | | | | | | | | | | | | | | | High

2 **Physical demand:** How physically demanding was the task?

Low | | | | | | | | | | | | | | | | | | High

3 **Temporal demand:** How hurried or rushed was the pace of the task?

Low | | | | | | | | | | | | | | | | | | High

4 **Performance:** How successful were you in accomplishing what you were asked to do?

Low | | | | | | | | | | | | | | | | | | High

5 **Effort:** How hard did you have to work to accomplish your level of performance?

Low | | | | | | | | | | | | | | | | | | High

6 **Frustration:** How insecure, discouraged, stressed, irritated, and annoyed were you?

Low | | | | | | | | | | | | | | | | | | High

## Appendix C Post-trial interview

Background information				
1. What was your age at your last birthday?				
2. Are you male or female? (please tick)				Male      Female
3. For how many years have you held a driver's licence?				
4. Approximately how many miles do you drive per year?				
5. Please estimate how often, on average, you drive on motorways, based on the last 12 months? Please tick a box.				
More than 3 times a week	Once or twice a week	A few times a month	A few times a year	Never
6. Does your current primary vehicle (i.e. the vehicle you drive most often) have a digital or analogue speedometer? (please tick)			Digital	Analogue
			Both	Don't know

Post-trial Interview											
1. In these trials, please mark your <b>satisfaction with each speed limit</b> when travelling through roadworks on the scale											
	Very dissatisfied			Neither satisfied nor dissatisfied						Very satisfied	
	0	1	2	3	4	5	6	7	8	9	10
50mph											
55mph											
60mph											
Why did you choose your most preferred speed?											

Are there any disadvantages to your most preferred speed?

Why did you choose your least preferred speed?

Are there any advantages to your least preferred speed?

(If all speeds were rated the same) Why did you rate all speeds the same?

2. How **easy or difficult** did you find it to travel at the 55mph speed compared to the 50 and 60mph speed?

Much easier					About the same				Much more difficult	
0	1	2	3	4	5	6	7	8	9	10

What made it easier/more difficult? (check if they generally drove near the speed limit)

3. In your opinion, how **easy or difficult** would it be to use a digital compared with an analogue speedometer to maintain a constant speed?

	Much more difficult with a digital speedometer			No difference				Much easier With a digital speedometer			
	0	1	2	3	4	5	6	7	8	9	10
50mph											
55mph											
60mph											

4. Did you have any collisions in any of your drives? If so, which one(s) and what happened? (as much detail as possible)

5. Did you have any near-misses in any of your drives? If so, which one(s) and what happened? (as much detail as possible)

6. To what extent did your experience differ between the drives? Please describe.

7. Did you notice any differences regarding HGVs between any of the drives? Please describe.

# Monitoring and evaluation of the 55/60mph pilots



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