THE FUTURE OF TRANSPORT

CLIENT PROJECT REPORT CPR2538

Narrow Lanes Simulations

55 mph and 60 mph

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Report details

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Executive Summary

In order to implement enhancements aimed at improving their customers' experience through road works, Highways England commissioned TRL to investigate the use of both 55 mph and 60 mph speed limits within road works with narrow lane widths.

As part of this project, three individual work areas were investigated: simulation trials of speed limits within road works with narrow lanes, a standard's and guidance review, and a risk assessment for a potential future on road pilot of both speed limits.

The trials simulated a narrow lanes road works environment using TRL's Mini-Digi Simulator to investigate three individual speed limit scenarios: a 50 mph, a 55 mph and a 60 mph speed limit. Using two separate participant samples, car drivers and HGV drivers, participants completed each scenario. Data was collected through the simulator's input devices along with post-drive questionnaires in order to understand the effects of the posted speed limit on vehicle positioning, cognitive resources and subjective experience.

The route layout and temporary traffic management used was designed to align with best practice approaches used on road. The length of the simulated route was selected to allow for optimal data collection and time for participants behaviours to normalise prior to the works zone.

The width of the narrowed lanes was chosen for the study after consultation with the layouts used within schemes involved with the previous 55 mph and 60 mph on road piloting. The widths were fixed across the three scenarios; lane 1 = 3.25 m, lane 2 = 3.00 m, lane 3 = 2.85 m. To add further realism, and ensure confidence in the behaviours observed, the simulated traffic was controlled by Artificial Intelligence. Depending on their class and compliance levels, these vehicles were subject to different behaviours. These behaviours were informed from on road data of both vehicle distributions and compliance levels seen previously at the two speed limits within road works.

Findings from the trial indicated that the posted speed limit had very little impact on the positioning of a participant's vehicle within the simulated environment. Overall, participants felt safe across all three scenarios, with feelings of comfort remaining similar across all three speed limits.

Other factors such as the individual lane width and proximity to other vehicles did impact on participants' vehicle positioning and feelings of comfort, unlike the changes in posted speed limit.

Participants positioned their vehicle consistently within the lane, on average marginally left of centre. Participants typically repositioned their vehicles when passing other vehicles which were on the left hand side of their vehicle, moving right, away from the adjacent car or HGV. Participants moved slightly further away from HGVs where possible when compared to cars.

The standards review sought to provide a summary of the impacts and practicalities of any identified potential changes to documentation required to implement either of the new speed limits in roadworks. An extensive search for applicable guidance resulted in detailed analysis being undertaken on 20 individual documents. A total of 31 individual excerpts were found to be requiring changes with a range of impacts.

Several key themes were identified, with the majority of these directly relating to guidance on the implementation and usage of speed restrictions in road works. No change in guidance would be required to be able to implement either a 55 mph or 60 mph pilot on road. However, in order to encourage further adoption of either speed limit in the future, sections of guidance relating directly to the application of speed limits within roadworks would benefit from updates.

Both scenarios were then investigated within risk reviews; building an evidence base from relevant literature and discussions with technical experts, the use of both the 55 mph and 60 mph scenarios were considered within comprehensive risk assessments. The assessments looked to outline whether any resulting risks were tolerable and what controls and monitoring would need to be in place as part of any future on road pilot.

The review concluded that, if specific extra monitoring was in place to monitor compliance at other 50 mph speed limited road works, along with other key mitigations and monitoring, use of the 60 mph speed limit within road works with narrow lanes could be piloted on road.

Extra monitoring of compliance could be implemented at a corporate level. The project board would need to communicate the details of any pilots of 60 mph nationally, ensuring other schemes using the common speed restriction of 50 mph implement clear monitoring of compliance. It is important that a clear abort process and feedback loop is implemented to ensure the risks caused by potential reduced compliance at 50 mph schemes are reduced.

There are also currently unknown changes in risks around distraction levels relating to the 55 mph speed limit within narrow lanes; further research would be required in this area to inform the risk and tolerability discussion prior to any on road piloting. Although no real change in performance or workload was observed within the simulation study, these findings in themselves do not provide detailed understanding into the risk of distraction when a 55 mph speed limit is in operation: the use of an analogue speedometer within narrow lanes was not trialled in this project as the speedometer used was digital.

1 Introduction

Highways England has five specific strategic outcomes, each with supporting enablers, within its business plan, delivery plan, and road investment strategy. An area of major interest for the Customer Service Division is enhancements aimed at improving the customer experience through road works.

In order to contribute to this, TRL has been commissioned to further investigate the use of both 55 mph and 60 mph speed limits within roadworks. This report outlines the investigation into the use of increased speed limits within road works where narrow lanes widths are in use.

1.1 Background

Previous work in this area has already been undertaken; this sought to investigate and pilot the use of increased speed limits on road where appropriate. Focusing on using increased speed limits in sections of road works with a limited number of traffic management features, the work was used to challenge the perceived normal approach of 50 mph speed limits for speed management on major motorway road works schemes.

The use of both 55 mph and 60 mph speed limits were trialled through simulation studies, on road trials, along with customer and stakeholder engagement studies. This increased understanding of the potential benefits of an increased speed limit for customers and of the practical application and management of risks when applying increased speed limits to sections of roadworks where full width lanes and a minimal work force are present.

1.2 Project breakdown

1.2.1 Risk review and assessment for potential on road pilot

To facilitate an appropriate on road pilot of either of the scenarios investigated within the simulation study, a safety case was developed and risk assessments were undertaken. An evidence base was formed from a review of relevant literature, previous research, and discussions with technical experts. Risk discussions together with mitigating measures are outlined within the assessment along with risk tolerances and recommendations for future on road use.

1.2.2 Narrow lanes simulation trials

In order for more of Highways England's customers to be able to gain the benefits of increased speed limits through road works, the use of 55 mph and 60 mph speed limits within a wider range of traffic management features needs to be investigated.

This report presents the study comparing the effects on driver behaviour from increased speed limits within a simulated narrow lanes road works environment.

1.2.3 Standards and guidance review

The future use of increased speed limits through road works within narrow lanes would potentially require relevant standards and guidance to be updated. This initial review provides a summary of the impacts and practicalities of potential changes to existing guidance.

2 Risk assessment

2.1 Scope

2.1.1 Aims and scenarios

The aim of this assessment was to examine the risks of generic roadworks during a trial phase where 55 mph and 60 mph speed limits are used on sections of road works with narrow lanes. This assessment draws conclusions from the available evidence and uses expert opinion to identify whether the resulting risks are tolerable and what controls and monitoring would need to be instated as part of any on road trial.

This section is primarily concerned with safety but other elements are taken into account where appropriate. The core questions addressed here are:

- Is it acceptably safe to trial 55 mph and 60 mph speed limits in sections of temporary traffic management with narrow lanes?
- What risks would arise as part of such a trial and who would they affect?
- What controls and monitoring should be in place before an on road trial proceeds?

There are three scenarios associated with this innovation; the first scenario is 50 mph speed limit at road works with narrow lanes and is used as a base scenario for comparison. The other two scenarios, 55 and 60 mph speed limits at roadworks with narrow lanes, are analysed and compared with the base scenario.

For each of these three scenarios there are variables which will increase or decrease the associated risks; these variables are listed in Table 1. The hazards associated with each scenario will be considered in this assessment.

Table 1: Variables which will affect risk

Scenario ID	Description
A	Road workers present or not present
B	Darkness or daylight
C	Sight stopping distance
D	Overall traffic flow
E	HGV volumes
F	Road marking conspicuity

2.1.2 *Characterisation of decision features*

The decision to trial the 55 and 60 mph speed limit in road works with narrow lanes has been characterised in accordance with the guidance contained in GD04/12. Table 2 provides a framework for assessment of the various decision features and is a reproduction of the table in GD04/12. Cells have been highlighted in Table 2 to indicate the Type (A, B or C) of the various decision features for this trial.

Table 2: Characterising decision features; reproduced from DMRB volume 0 section 2 part 3 – GD04/12

Features	Type A Specialist Technical / Coordinator roles	Type B Professional Safety Advisors	Type C Professional Roles
What is the size of the decision impact? (Geographically and in impact terms: the extent of the network, and the number of 'Users'/'Workers')	Local, low density	Local, high density or national, low density	National, high density
What are the cost implications of the decision for Highways England?	Low	Medium	High
What is the lifetime of the decision? (How long will Highways England be affected by the decision?)	Rest of the day	Months to a few years	Decades
What is the level of safety risk or uncertainty associated with the decision?	Low	Medium	High
What is the policy or stakeholder interest level? (How sensitive is it?)	Low	Medium	High

This results in the following breakdown of decision features for the proposed trials:

- 1 decision feature is of Type A
- 2 decision features are of Type B
- 2 decision features are of Type C

This suggests that an road trial of a 60 mph speed limit within narrow lanes would be Type B/C where there is an equal distribution of classification features.

2.2 Risk assessment methodology

This risk assessment was conducted in line with the Standard for Risk Assessment on the SRN, GD04/12. The risk assessment considers the risk posed to all affected parties, potential causes and necessary controls, and the stage of the lifecycle at which the hazards could be realised.

In the absence of robust collision or frequency data, a quantitative risk assessment cannot be conducted to calculate actual risk levels. Therefore, a risk comparison has been undertaken to compare the potential risks associated with a speed limit of 55 mph or 60 mph in road works with narrow lane restrictions with those associated with a speed limit of 50 mph. Risk and tolerability were assessed by risk specialists at TRL informed by technical experts. Where uncertainty still exists around certain risks or hazardous events, recommendations for further study and trial monitoring have been made.

2.3 Identified risks and benefits

2.3.1 At risk populations

For the purpose of this risk assessment the populations are defined as 'workers' and 'users'. However, given that the location of any live trials is yet to be decided it cannot be assumed that third parties will not also be impacted. A site specific risk assessment must be carried out for each trial location to accurately capture the at risk populations.

The population of road workers would be expected to contain the following groups:

- Road workers (installation and removal or TM)
- Construction workers (operatives working within the closure)
- Traffic officers
- Recovery workers (free recovery areas)

The population of road users would be expected to include:

- Drivers
- Emergency services
- Privately contracted vehicle recovery and repair providers

2.3.2 Proposed benefits

The benefits of the proposed innovation include the following:

- Improved customer satisfaction: research undertaken as part of the 55 and 60 mph Highways England trial (Wallbank *et al.*, 2017) found that the majority of the participants indicated they preferred the higher speed limits, with the notable reason being the ability to safely pass HGVs at these higher speeds. It is important to note that those trials did not involve narrow lanes.

- Reduced close following from HGVs: during previous trials of 60 mph (Wallbank *et al.*, 2017) the proportion of HGVs close following (in this case, defined as vehicles following within 2 seconds), dropped substantially from 65% in the 50 mph section to 50% in the 60 mph section. This was likely related to the difference in speed between vehicle types.

2.4 Risk summary

The key risks most likely to be affected by a change in posted speed limit are:

- Road workers being struck by road users,
- Road user behaviour changing at other road works,
- Collisions with road worker vehicles when accessing and egressing from works site,
- Risk of collision during vehicle recovery,
- Changes in crash barrier type presents a risk to road users and workers,
- Vicinity collisions between road users,
- Road users colliding with infrastructure.

The full outline and discussion of these risks can be found within Appendix J.

The key mitigations recommended for the trials are:

- Enforce posted speed limits,
- Minimise road worker exposure to the 55 mph and 60 mph speed limits,
- Appropriate use of IPVs for the expected speed limit,
- The use of appropriate crash barriers which do not compromise impact protection or user safety,
- Close monitoring of incidents, near misses and road user behaviours throughout the trial.

2.4.1 Monitoring

Before a trial is commenced the follow factors would need to be reviewed:

- The proposed usage of remotely-controlled signage to change speed limit,
- Vehicle recovery plans: these would need to use appropriate controls and measures for the expected speed limit,
- The proposed safety barriers used must maintain suitable containment levels along working width class and impact severity,
- The site layout/traffic management plan: this would need to ensure that, if working space is reduced due to the barrier type or the positioning for the higher speed limits, then appropriate risk assessments are in place.

Live on-going monitoring will be required for the following factors:

- Incident reports including near misses and non-injury accidents,
- Traffic speeds and compliance with speed limits,
- Road user behaviour at other road works with a different speed limit, and
- Vehicle positioning within lane.

Monitoring for review at major trial milestones during the lifetime of the trial would consist of:

- General incident reports,
- Public complaints,
- Flow patterns, and
- Patterns of lane occupancy.

2.4.2 Abort process

The detailed abort process would be written as part of the monitoring plan for a specific trial. The abort criteria used would include:

- Full sight stopping distance,
- Visibility,
- Gantries,
- No road workers present,
- Vehicle flow, and
- Percentage of HGVs.

2.5 Risk evaluation

During this risk review two key risks have not yet been assigned a level of tolerability. In both cases there is currently insufficient previous research available to inform the tolerability assessment. The impact on other roadworks with lower speed limits is currently unknown: as a minimum, it is recommended that monitoring of speed compliance at a selection of these other schemes would need to be implemented in order gather information around this potential behaviour. This monitoring would need to feed back into the general abort process.

If all of the monitoring previously suggested was adopted, the use of 60 mph speed limits within roadworks with narrow lanes could be progressed to on road pilots on the SRN.

The final risk yet to be considered tolerable is the unknown change in risks around maintaining 55 mph within narrow lanes (with potential driver distraction from the unique challenges around 55 mph on analogue speedometers). Once further research into the effects of the unique distractions of 55 mph using analogue speedometers specifically within narrow lanes has been undertaken, this can be used to inform the risk discussion around this specific hazardous event, and the tolerability of changes in this risk can be made.

All the other risks and hazardous events identified and discussed within this risk assessment have been assessed as being tolerable as long as the appropriate controls and monitoring is implemented.

3 Method of approach for simulations

3.1 Overview

The study used a simulated motorway environment in TRL's Mini-Digi Simulator (MDS) to test three different scenarios:

1. A 50 mph speed limit in roadworks with narrow lane widths
2. A 55 mph speed limit in roadworks with narrow lane widths
3. A 60 mph speed limit in roadworks with narrow lane widths

All participants involved in the study drove all three separate scenarios, taking around 10-20 minutes per scenario. After completing each scenario, participants completed a short questionnaire in order to gain insight into how their feelings of safety and levels of workload were affected by the scenario in question.

3.2 Participant sample

The study investigated two separate participants' samples: individuals who regularly drive a car and those who regularly drive a heavy goods vehicle (HGV). As the individuals in each sample were unique to either group no comparisons in the results are possible between the two vehicle types.

3.2.1 Car drivers sample

A participant driver sample was recruited for the study from TRL's participant database. Those individuals whose place of residence was within a 30 km radius of TRL's Crowthorne office were contacted and invited to participate in an initial online survey.

The survey sought to establish each participant's availability for the trials, along with information to categorise them against Highways England's customer segmentation. The information was used for a targeted recruitment process, recruiting a total of 36 individuals to take part in the study. A breakdown of the participant's segmentation can be seen in Appendix A.

During the trial a single participant was removed from the analysis due to issues with the collection of simulation data. The individual was replaced by another fitting the same recruitment characteristics; therefore 36 participants were included in the final analysis of the car drive sample.

3.2.2 HGV drivers sample

Traditionally, professional HGV drivers as a demographic have been difficult to recruit in large enough numbers to take part in trials based away from their location of work. The participant driver sample used for this study was recruited from a distribution centre based locally to TRL's Crowthorne office.

No targeted recruitment was undertaken, unlike with the car participants; instead only the participant's availability to undertake all three drives across the trialling period was sought. A similar pre-drive segmentation survey was administered to participants on the day of trialling. A total of 51 individuals took part in the study; however, due to time restraints and availability, only 32 participants completed all three scenarios. The breakdown of those 32 HGV drivers can be seen in Appendix A.

3.3 Research questions

For each of the two separate samples (car and HGV) the main research questions for the study were:

1. Does the posted speed limit influence the participants' vehicle positioning, i.e. does the increased speed limit affect the participants' lateral lane position?
2. Does the posted speed limit influence the participants' cognitive resources, i.e. does the increased speed limit affect the mental workload of participants?
3. Does the posted speed limit influence the participants' subjective experience whilst in the roadworks, i.e. does the increased speed limit affect participants' emotional state?

3.4 Scenario design

3.4.1 Route design

Each of the three scenarios used within the study utilised the same route layout and were implemented in a three lane environment on a standard motorway which was being upgraded to a Smart Motorway (All Lane Running) section. Using the same layout for each scenario limited the effect of factors such as topography, road geometry and environmental distractions on the results of the study.

Speed limits were displayed on ground level fixed-plate hard signs and the temporary traffic management (TTM) layout was designed to align with best practice approaches used on road in real major scheme road works. Detailed plans of the TTM layout used can be seen in Appendix B. Traffic was moved towards the off side of the carriageway by the TTM in order to create sufficient work space on the near side. All variable signs and signals within the simulation were blank, representing a partially incomplete scheme where the infrastructure and technology are present on the carriageway but had not been activated as work had not been completed.

The total length of the route was 13.5 miles, as shown in Figure 1, comprising a one mile standard section, a three mile 'approach' zone, a small 'lead-in' zone (marking the section between the initial roadworks advanced warning traffic signs and the start of the narrow lane section), followed by a seven mile works zone, concluding with a two mile 'end' section after the roadworks.

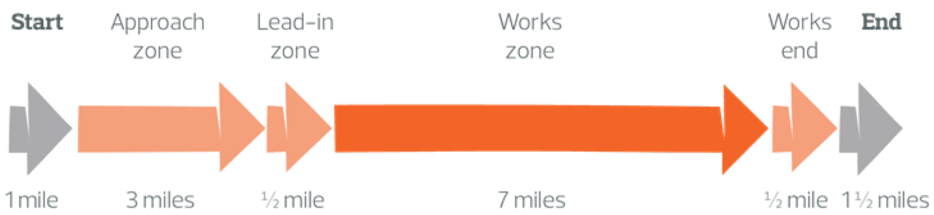

Figure 1: Diagram of route layout

The purpose of the four miles prior to the start of the road works was to allow sufficient time for a participant's behaviour within the simulator to normalise before encountering the narrow lanes section, ensuring their behaviour would be as representative as possible of their on road behaviour.

3.4.2 Lane widths

The narrowed lane widths used within the study were chosen to give the simulation the feel and characteristics of a typical set of major scheme works encountered by road users on the SRN. These widths were fixed across all three scenarios, controlling for the effect of the lane width on participants' behaviours.

The lane widths used were as follows: lane 1 = 3.25 m, lane 2 = 3.00 m, lane 3 = 2.85 m.

These widths were chosen for the study after consultation with the layouts used within schemes involved in the on road piloting of 55 mph and 60 mph.

3.4.3 Barrier set-back

Along with realistic TTM and narrowed lanes, the barrier design and set-back were chosen to give a realistic experience. Fixing the set-back distance within all three scenarios helps control for the effect of road users travelling adjacent to hazards. On road these distances would be selected to both maximise the carriageway space and maintain sufficient working area within the closure.

Figure 2 below outlines both the lane widths used in the simulation and the barrier set-backs incorporated into the TTM design.

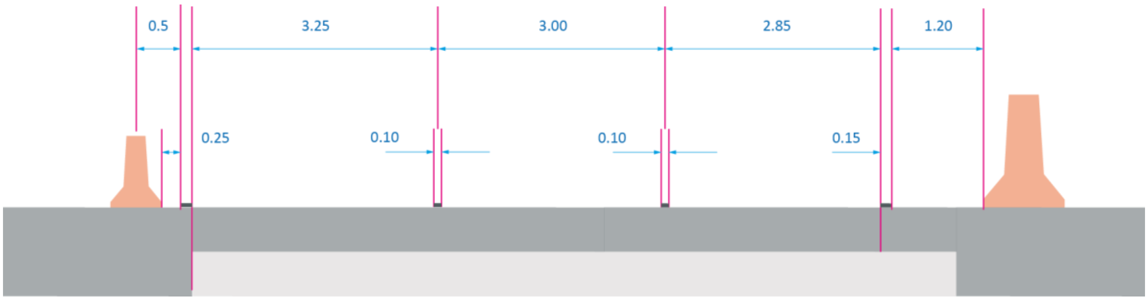

Figure 2: Barrier set-back distance

3.4.4 Enforcement

The infrastructure for average speed cameras and the associated signs were included within the simulated scenario layout and TTM.

The inclusion of average speed cameras within the study, as far as possible, replicates the conditions typically experienced by road users when driving through similar road works. The cameras and signs were included within all three scenarios.

3.4.5 *Simulated traffic*

In order to ensure further confidence in the behaviours observed within the trial during each scenario, participants would encounter and interact with simulated traffic. This traffic was controlled by Artificial Intelligence (AI) in order to provide a realistic pattern of behaviour. The AI vehicles were subject to different behaviours depending on their class and compliance level. The assumptions shown in Figure 3 were made in order to configure the AI vehicles, which populate the simulated environment and formed a 'swarm' around the participant's vehicle.

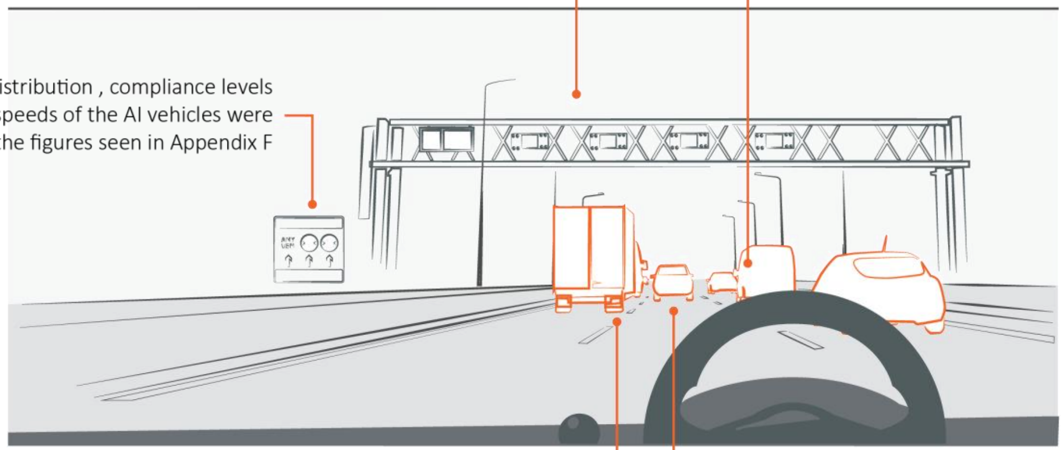

Figure 3: AI vehicle configuration

Individual vehicle data collected via road side monitoring equipment provided both the vehicle distribution and compliance levels used within the study. These values were fixed across all three scenarios within the swarm, ensuring these factors did not affect the driver behaviour seen within the study.

Simulated vehicle speed, however, was not fixed as this factor needed to change realistically between each scenario. Similar data gathered from road side systems provided average speeds seen during the piloting of 55 mph and 60 mph on road, along with data from 50 mph sections of road works. Each of these averages was then used to determine the maximum speed of both compliance and non-compliant AI vehicles, with the averages weighted so that the combined values reflected the average speed seen on road.

Speed generally increased from near side to off side lanes along with vehicle class and compliance level. These parameters were then piloted and refined prior to the trial commencing. A full list of the finalised parameters for the swarm of vehicles can be seen within Appendix C.

3.5 Trial procedure

3.5.1 Car drivers

Overall, the trial lasted around 1-1½ hours for each participant. There were three distinct phases: familiarisation, trial drives and post-drive questionnaires. During recruitment each participant received a copy of the Participant Information Letter, see Appendix D, along with confirmation of the trial booking via email. The information letter outlined the key information to the participant concerning the purpose of the study and what could be expected. Upon arrival at TRL, the participant was met by a researcher who briefed them on the trial procedure and obtained informed consent.

Once happy with the overall trial procedure, participants completed a pre-drive questionnaire (seen in Appendix E) confirming their recruitment characteristics, participants were then introduced to TRL's MDS and encouraged to adjust the seating position and peddles to ensure comfort.

A standardised familiarisation drive was loaded containing a simple rural road with no traffic; participants were instructed to drive as they would normally and were given the opportunity to become familiar with the vehicle's controls and characteristics. The route was driven for approximately five minutes, after which it was only stopped once the participant declared that they were comfortable with the simulation set up.

The order in which each participant completed the three separate scenarios was counterbalanced to reduce any effect on their behaviour from the order of presentation. Each individual drive lasted around 10-15 minutes, followed by a post-drive questionnaire (seen in Appendix F) administered in order to collect the participant's workload and perceptions data.

3.5.2 HGV drivers

As outlined earlier in this report, the HGV participant sample could not be pre-recruited for the study so a modified trial procedure was used. Overall the trial lasted around an hour for each participant; however, each 15-20 minute drive was not necessarily undertaken directly after the last as had been the case with the car participants. The trials followed the same three distinct phases of: familiarisation, trial drives and post-drive questionnaires.

Participants received a modified copy of the Participant Information Letter and a researcher obtained informed consent after briefing them on the trial procedure. A pre-drive questionnaire was then administered, gaining recruitment characteristics, prior to the first scenario.

After being introduced to the MDS, participants were again encouraged to adjust the input devices and their seating position prior to the start of the drive. To reduce the overall run time of the trial, familiarisation was carried out during the first mile at the start of each scenario. Participants were asked to drive as they would normally and were given the opportunity to become familiar with the vehicle's controls. Once the first mile was complete and if participants stated that they were comfortable to continue, the drive continued into the road works section. If participants required more time the drive was stopped prior to the road works and reloaded.

A post-drive questionnaire was administered after each drive, collecting information on the participant's workload and perceptions. The order in which the three scenarios were presented to each participant was not counterbalanced for the HGV sample given the limited time available to participants. Instead, and in order to aid with the collection of the most meaningful data, drivers were presented with both the 50 mph and 60 mph scenarios prior to the introduction of the final 55 mph scenario. This decision was taken during the trialling period in order to reduce the risk of gaining incomplete datasets with no control scenario (50 mph).

3.6 Data collection

3.6.1 Performance

The MDS collected both driver behaviour and performance data in the form of digital outputs. The data extracted during each scenario were as follows:

- The lane in which the participant's vehicle was travelling in,
- The lateral position of the participant's vehicle within the lane of travel (i.e. the distance from the centre of the participant's vehicle to the centre of the lane),
- The type of AI vehicle travelling within adjacent lanes to the participant,
- The speed of the participant's vehicle, and
- Any collisions or near-misses between the participant's vehicle and any AI traffic.

This information was outputted at a frequency of 20 Hz and was limited to within the road works zone. Data from the initial approach were not used allowing for a participant's driving pattern and behaviour to have settled prior to their data being collected. Figure 4 below outlines the overall set up of the MDS system used within the study.

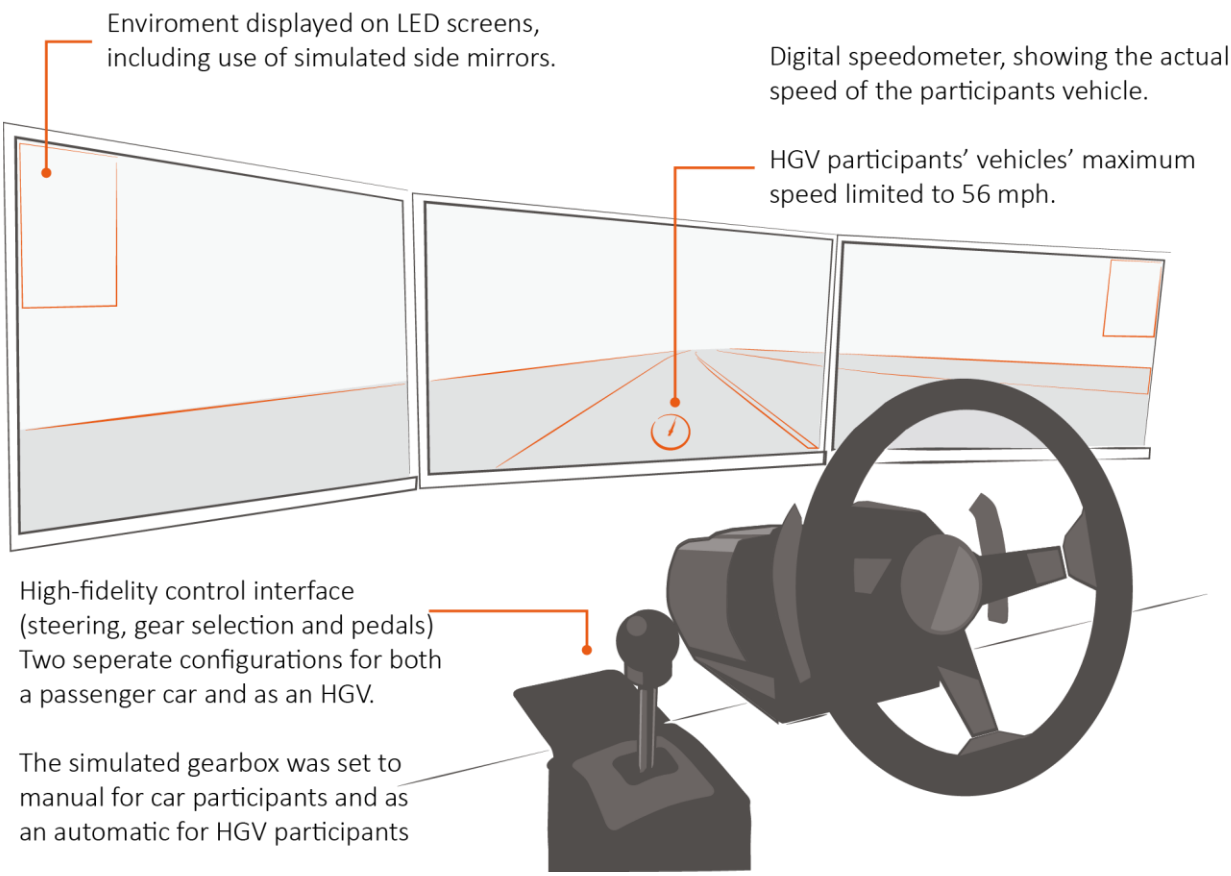

Figure 4: MDS set up

3.6.2 Workload

During the study, data was collected to measure the mental demands associated with driving under each of the three scenarios within a narrow lanes environment. The post-drive questionnaire included an industry standard mental workload measure. The National Aeronautics and Space Administration Task Load Index (NASA-TLX) has been designed to obtain estimates of workload from a participant performing a task, either during or immediately after the task.

In the case of this study, the NASA 'Raw' TLX was used; this variant omitted any participant weighting of subscales normally associated with a full assessment. This method was previously used in workload assessments undertaken as part of simulation studies investigating the impact of 55 mph and 60 mph speed limits on road users in roadworks (Wallbank *et al.*, 2017).

3.6.3 Perceptions

Alongside the workload data, each participant provided subjective data on their feelings of safety, comfort and levels of difficulty experienced within each scenario. The questions used to collect these data mirrored several of those used in the aforementioned simulation studies investigating increased speed limits through road works.

Finally, participants were asked to indicate if they had experienced either a collision or a near miss within the drive.

3.7 Data analysis and statistical comparisons

Statistical tests were used throughout this report to test whether differences observed or reported between the different scenarios were significant. Statistical significance was determined using the probability value (or p – value) in a hypothesis test.

If the probability of obtaining the value of the test statistic by chance was less than 0.05 (5%), the null hypothesis (i.e. the assertion that the two groups score the same on some measure) is rejected. Classifying $p < 0.05$ as 'statistically significant' is commonly used within scientific analysis. If the probability of obtaining the value of the test statistic by chance was greater than 0.05, the null hypothesis cannot be rejected, i.e. it cannot be concluded that the two groups scored differently.

Depending on the data available, two types of test were used:

- Generalised Estimating Equations (GEE): a technique used to test for significant differences in mean responses for a dependent sample (i.e. the same participant completed all three drives). It provides a semi-parametric approach to longitudinal analysis of a continuous or categorical response, implying that the dependent variables need not be normally distributed.
- Friedman test: a non-parametric statistical test for significant differences between speed limits when the dependent variable being measured is ordinal.

4 Results from simulations

This section presents the results of the analysis of driver performance, workload and perceptions data collected during the trial. The following charts and tables illustrate the findings obtained from the two separate participant samples, based on the 36 car participants and 32 HGV participants.

Within some of the charts, the standard deviation of the value is shown using error bars; these bars indicate the variability in the data across the participant sample. Smaller error bars indicate that participants' responses or behaviours were fairly similar to each other, whilst larger bars indicate that the responses were more variable.

Performance data collected from the MDS also enables the variability (standard deviation) within each individual drive to be estimated. The mean of this value represents the average variability across participants within a given measure. Smaller values of a measure suggest that participants' behaviour was fairly consistent across the length of a drive; larger values suggest there was more variability in the measure.

Highly variable data might indicate that participants found it harder to maintain a particular behaviour. For instance, in data on the mean variability of lateral lane position within a lane, smaller values would indicate that participants' movement within a lane was fairly small; whilst larger values indicate greater movement within the lane.

4.1 Effect on vehicle positioning

Analysis of the performance data is presented within this section, measuring the participants' ability to position their vehicle within the narrow lane whilst navigating the roadworks within different speed limits.

4.1.1 Lateral lane position

A mean lateral lane position for each participant reflects the average position of the centre of the participant's vehicle within a given lane. As described earlier, each individual lane within the simulation varied in width, meaning the lateral lane position range necessarily depends on the participant's lane choice.

In order to account for the effect of lane changes on this measure, the data within a five second period before and after each lane change was removed from the data prior to calculating the mean lateral lane position.

Within the charts presented within this section, values closer to zero indicate that, on average, the participant drove closer to the left hand side of the lane. Values closer to the maximum width of the lane (3.25 m, 3.00 m and 2.85 m for lanes 1, 2 and 3 respectively) indicate that, on average, the participant drove mainly on the right hand side of the lane. The maximum lane width and centre of each lane has been marked with solid and dashed lines respectively in the graphs presented in the following sub-sections.

4.1.1.1 Car participants

Figure 5 shows the mean lateral lane position of the centre of the participants' vehicle within lane 1. The average lane position of cars in lane 1 was very similar across all three scenarios, with participants driving slightly to the left of the centre of the lane with all three speed limits.

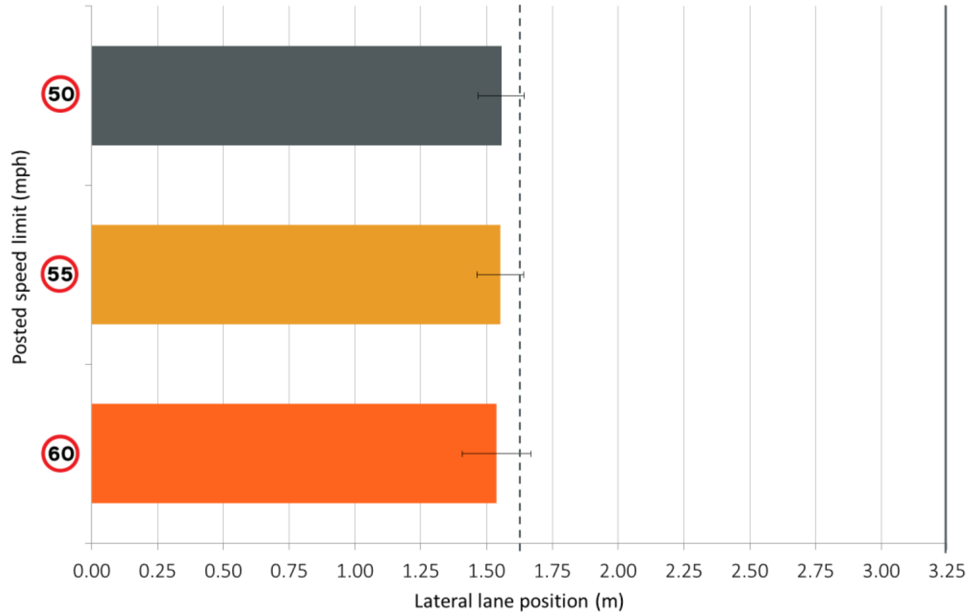

Figure 5: Mean lateral lane position of cars in lane 1

Figure 6 shows the average of the variability (standard deviation) in the measure of lateral lane position within the participant's sample, giving an indication of the average amount of vehicle movement within the lane.

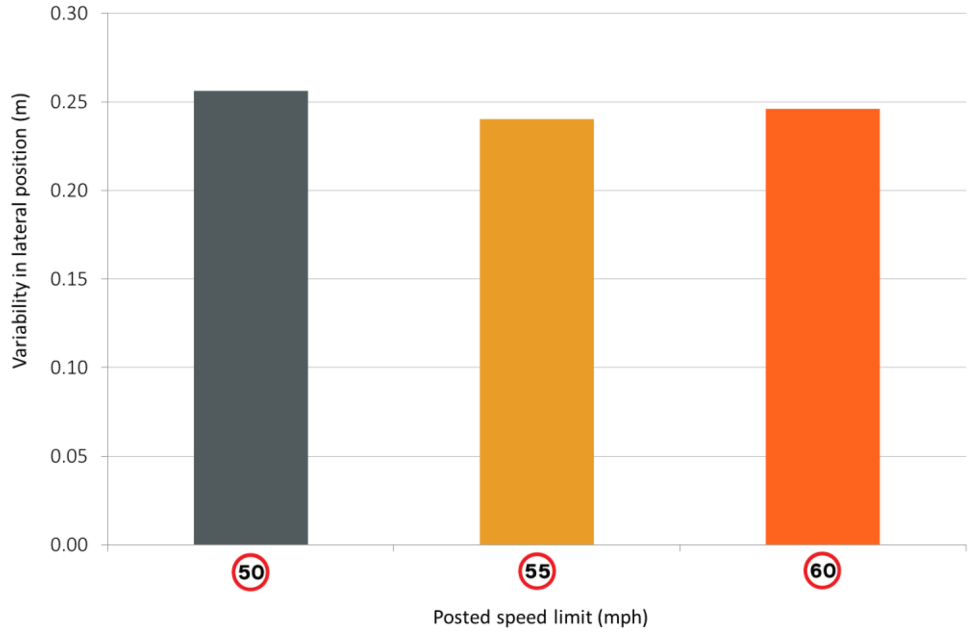

Figure 6: Average standard deviation of lateral lane position of cars in lane 1

The variation in lane position indicates that car participants' movement within lane 1 was similar across all scenarios. A GEE model was used to examine whether the average variability was significantly different across the three speed limits. Analysis showed that the speed limit had no significant effect on variability (p = 0.547).

This finding suggests that the amount of movement that drivers exhibit within lane 1 is independent of the speed limit, with participants comfortably keeping their vehicle within the limits of the lane.

Figure 7 below shows the mean lateral lane position within lane 2. As with the behaviour within lane 1 (Figure 5), the average lateral lane position within lane 2 was consistent across all three speed limits, positioned slightly to the left of the centre of the lane.

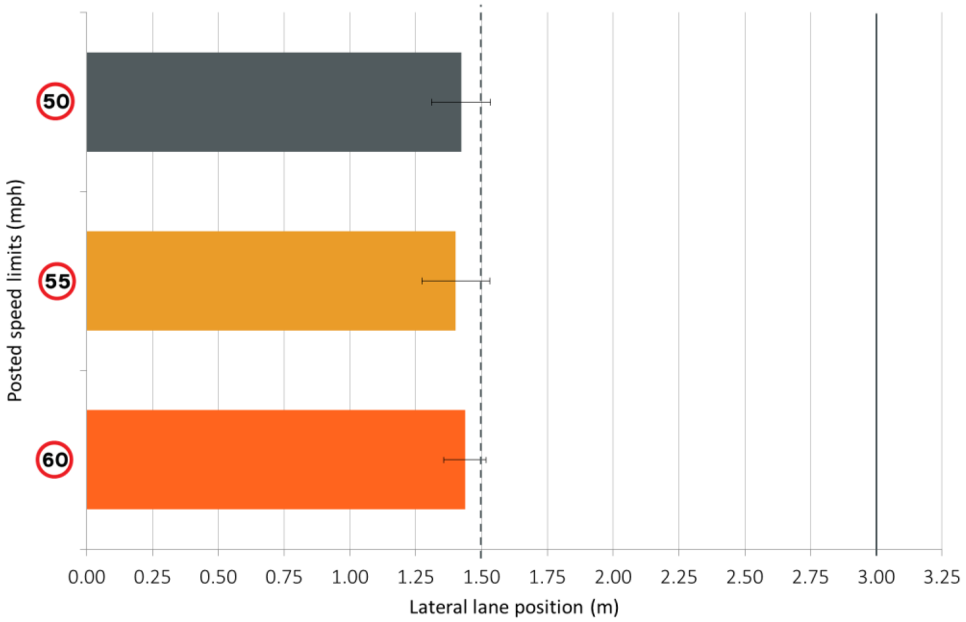

Figure 7: Mean lateral lane position of cars in lane 2

Figure 8 presents the average variability in the lateral lane position of cars within lane 2.

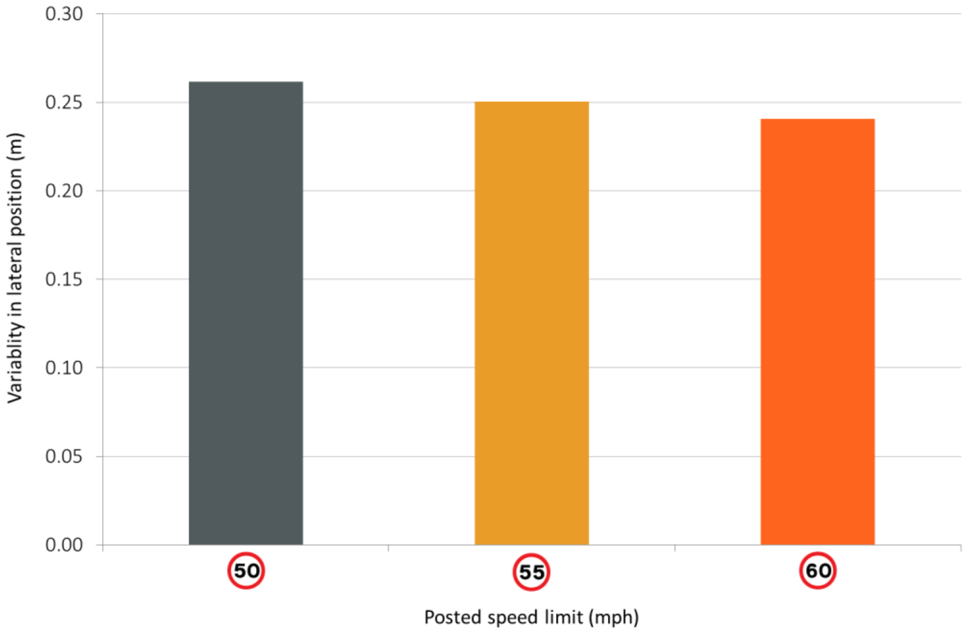

Figure 8: Average standard deviation of lateral lane position of cars in lane 2

As with the same measure in lane 1 (Figure 6), the variability in lateral lane position was similar across all three posted speed limits. There appears to be a slight reduction in movement within the lane as speed limit increases. However, statistical tests on the data using GEE shows no significant difference in average variability in lane 2 across all three scenarios (p = 0.385). These results again suggest that car participants appear to maintain similar lane positions and movement within lane 2 in all three speed limits.

Figure 9 presents the mean lateral lane position of cars in lane 3. These mean values again are similar across the three different scenarios, with drivers tending to drive with the centre of their vehicle slightly to the left of the centre, as observed in the other two lanes.

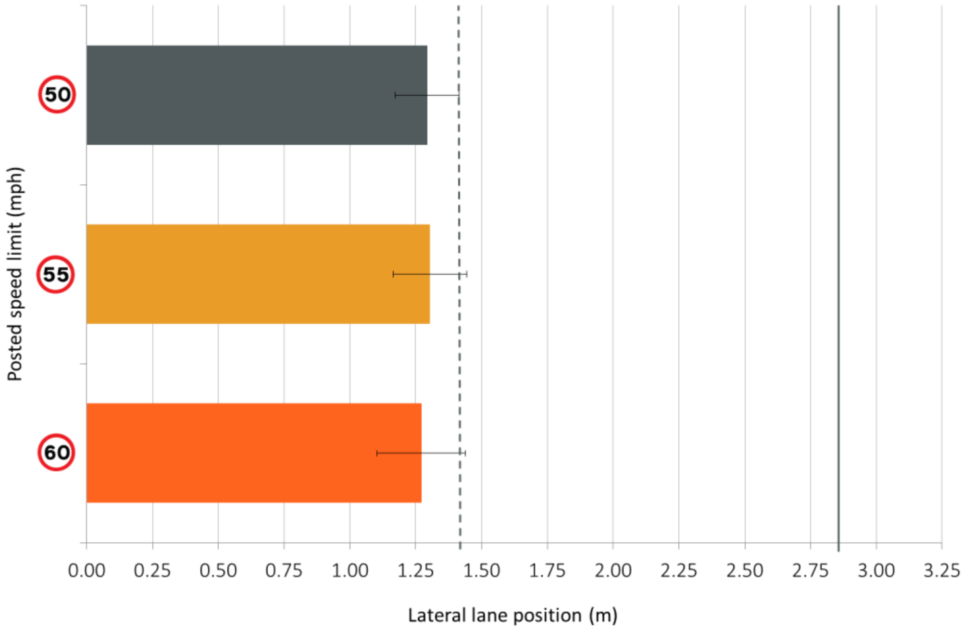

Figure 9: Mean lateral lane position of cars in lane 3

Finally, Figure 10 shows the average variability in lateral lane position within the same lane.

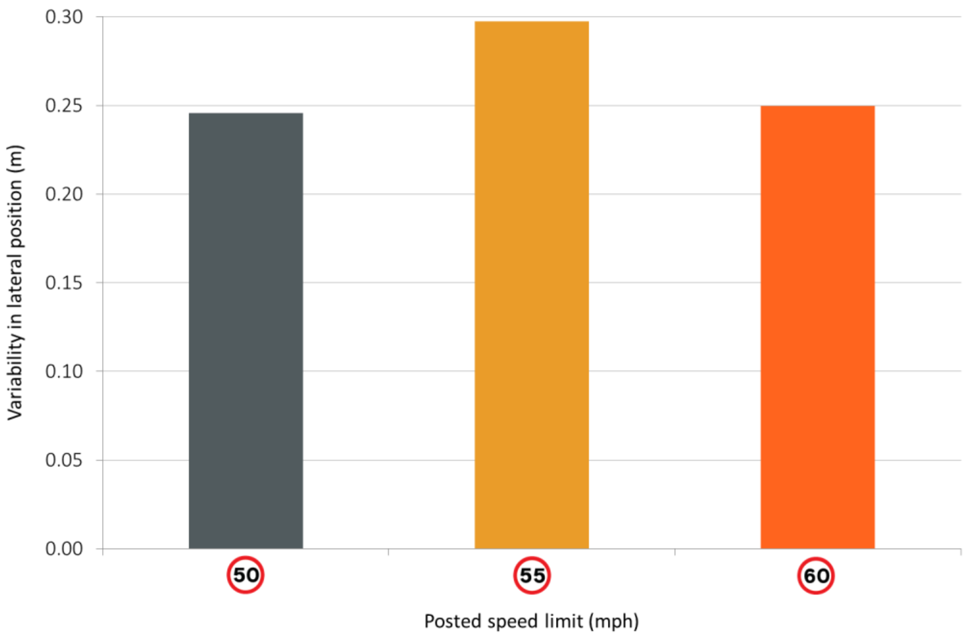

Figure 10: Average standard deviation of lateral lane position of cars in lane 3

Variability within lane position in lane 3 was higher in the 55 mph scenario than in both the 50 mph and 60 mph drives, by around 5 cm. This might suggest that car participants were less consistent in their lane position within lane 3 in the 55 mph scenario than in the same lane in the other speed limit scenarios, with more movement within the right hand lane. However, a statistical test using GEE showed there was no significant difference in average variability in lane position in lane 3 (p = 0.998).

4.1.1.2 HGV participants

During the study, the majority of HGV participants drove in lane 1 (4.4.2). As few participants travelled in lanes 2 and 3, the sample of data cannot be used to draw reliable conclusions. Hence, only analysis of the lateral lane position of HGVs in lane 1 is presented below.

Figure 11 shows the mean lateral lane position of HGVs travelling within lane 1 across all three scenarios.

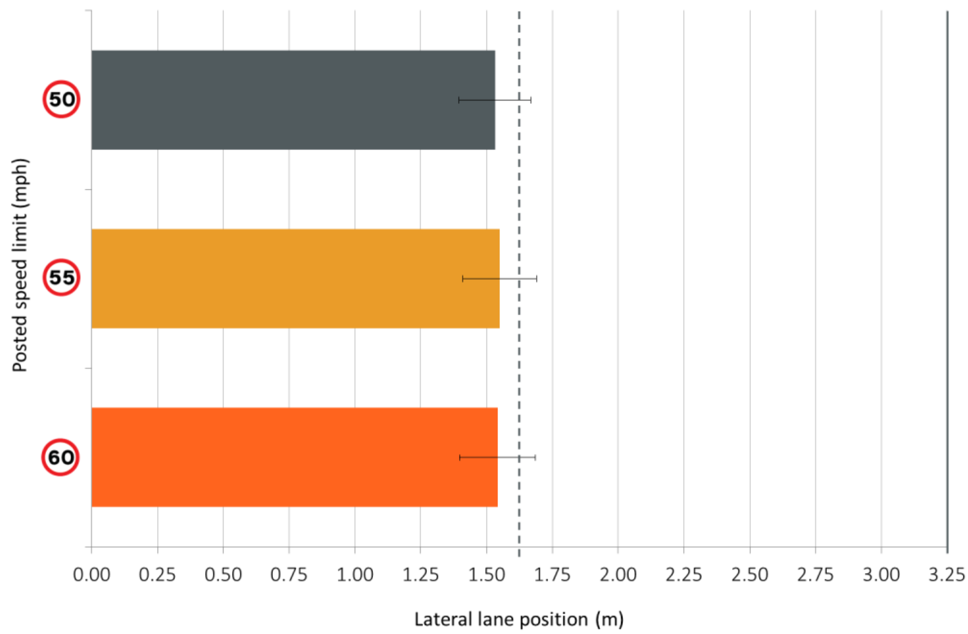

Figure 11: Mean lateral lane position of HGVs in lane 1

The positions within lane 1 were very similar with negligible differences across the three posted speed limits. As with the separate car driver sample, HGV drivers tended to drive with the centre of their vehicle slightly to the left of the centre of the lane.

Figure 12 presents the average variability (standard deviation) in lateral lane position across lane 1 for HGV participants; again this measure indicates the average amount of 'weaving' within the lane.

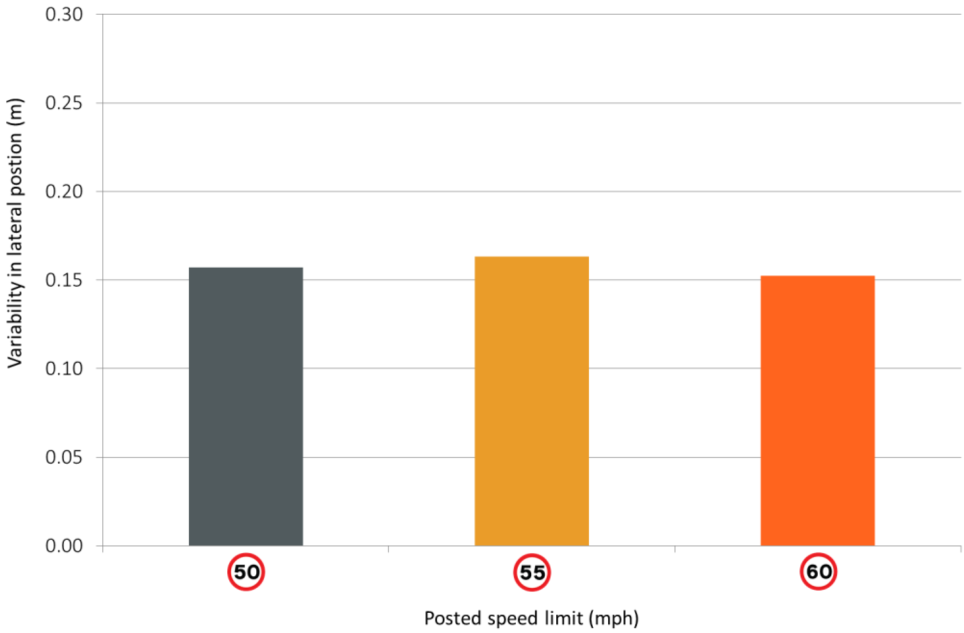

Figure 12: Average standard deviation of lateral lane position of HGVs in lane 1

Statistical tests (using GEE) showed no significant difference in the average variability in lane 1 across the three scenarios ($p = 0.69$) reflected by the negligible differences in the values presented. This suggests that HGV participants' movement within lane 1 was minimal (around 15 cm) and was less than those figures seen within the separate car participant sample (Figure 6), though caution must be used when comparing results from the HGV sample to those of the car sample as they used completely different participants.

4.1.2 Lateral lane position when overtaking other vehicles

The lateral lane positions of participants' vehicles were also measured when the participant was in the process of overtaking an AI vehicle (car or HGV) within the scenario. This measure gives insight into the behaviour of participants changing their position within a given lane when adjacent to other vehicles on the left hand side; this measure was not collected when adjacent to vehicles on the right hand side of the participant during this study.

4.1.2.1 Car participants

The mean lateral lane position of participants' vehicles in lane 2 when overtaking an AI car in the adjacent left hand lane is presented in Figure 13 below. The average position was similar across the three posted speed limits. Compared to the results shown in Figure 7, participants' average position was nearer the centre of the lane rather than slightly nearer to the left hand side.

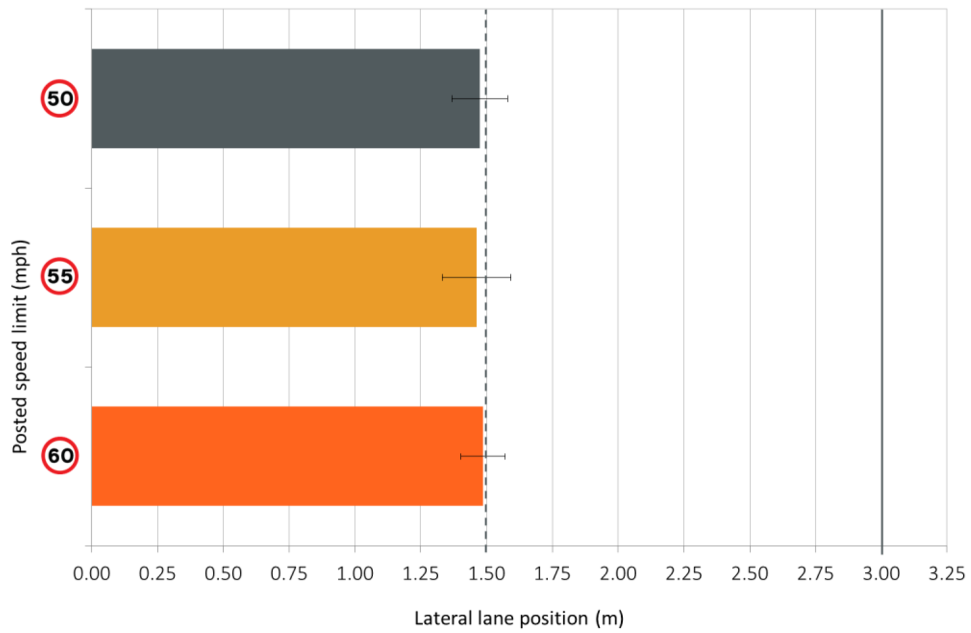

Figure 13: Mean lateral lane position of cars when overtaking AI cars in lane 1

Looking at the movement within the lane whilst passing another vehicle in adjacent lanes, Figure 14 indicates that there was a reduction in the movement of the participant's vehicle as the posted speed limit increases. The difference was less than 5 cm and the GEE tests showed there was no significant difference across the three speeds (p = 0.10).

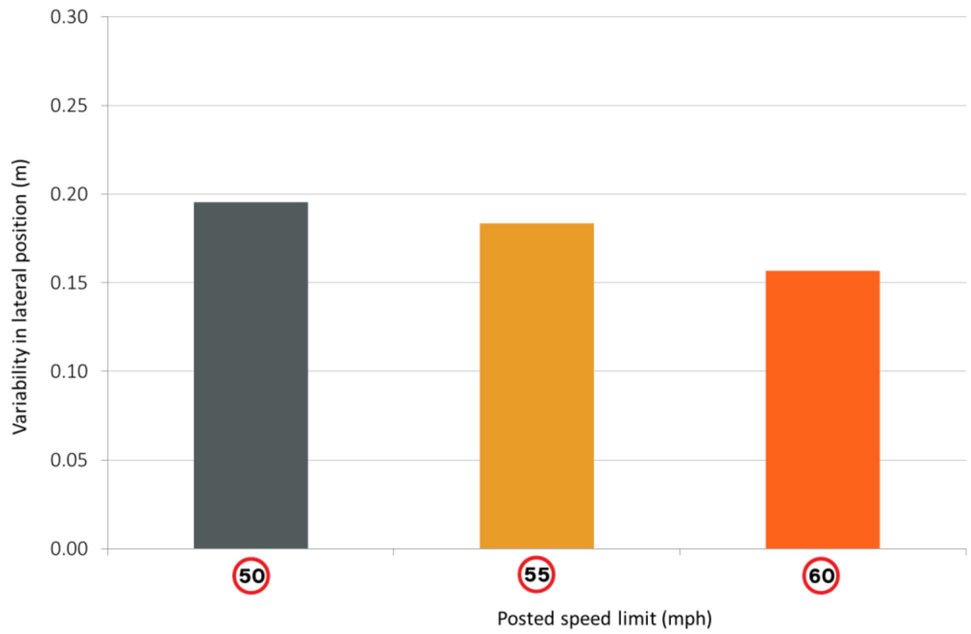

Figure 14: Average standard deviation of lateral lane position of cars in lane 2 when overtaking AI cars in lane 1

Participants showed a similar pattern of behaviour when overtaking AI HGVs in lane 1. Figure 15 shows that, on average, participants positioned their vehicles in the centre of the lane for both the 50 mph and 55 mph speed limit scenarios. During the 60 mph speed limit scenarios, participants drove further towards the right hand side of the lane, with the centre of their vehicles positioned slightly to the right of centre. The error bars, however, indicate more variability within the mean positions in the 60 mph speed limit scenario.

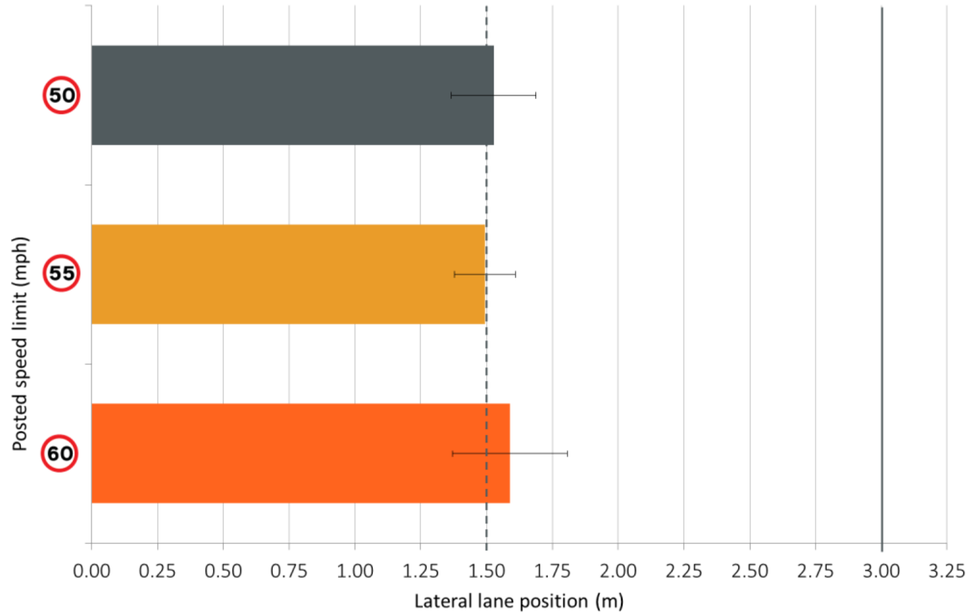

Figure 15: Mean lateral lane position of cars when in lane 2 when overtaking AI HGVs in lane 1

Figure 16 shows the average variability in lane position of participants in lane 2 when overtaking HGVs which were in lane 1; again, overall the mean variability is similar across all three scenarios. A GEE test showed no significant difference in average variability (p = 0.58) meaning that the movement of participants while overtaking HGVs in lane 1 was not affected by the posted speed limit.

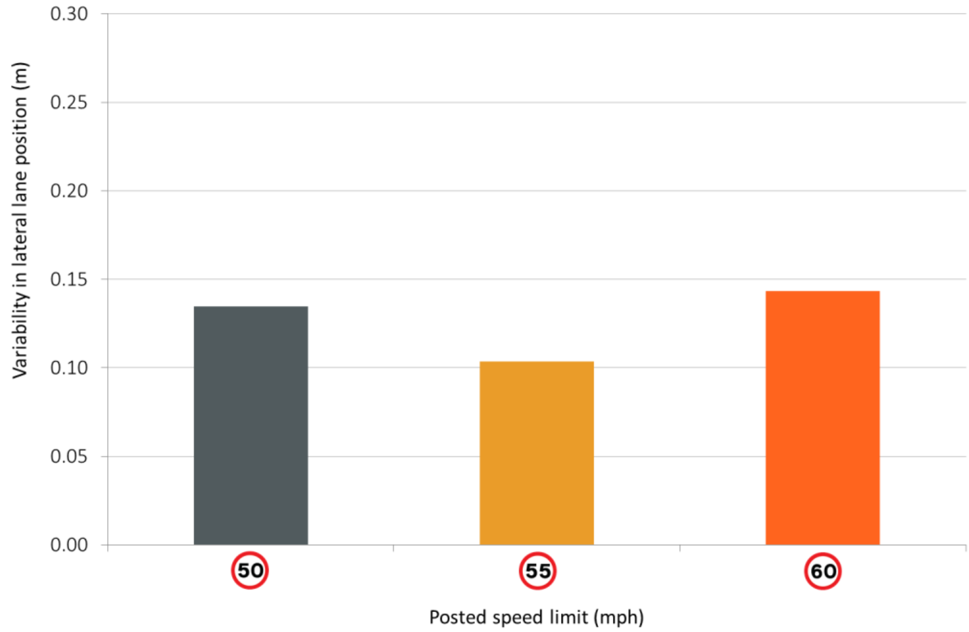

Figure 16: Average standard deviation of lateral lane position of cars in lane 2 when overtaking AI HGVs in lane 1

Comparing Figure 14 and Figure 16, the overall variability appears to be lower when participants were passing HGVs than when passing cars.

Again the mean positions of participants' vehicles in lane 3 whilst passing AI cars on the left hand side of the participant's vehicle appear consistent across the three scenarios as shown in Figure 17. Unlike in lane 2, there does not appear to be a substantial difference in the participants' average position between general lateral lane position (Figure 9) and the position participants adopted whilst overtaking (Figure 17).

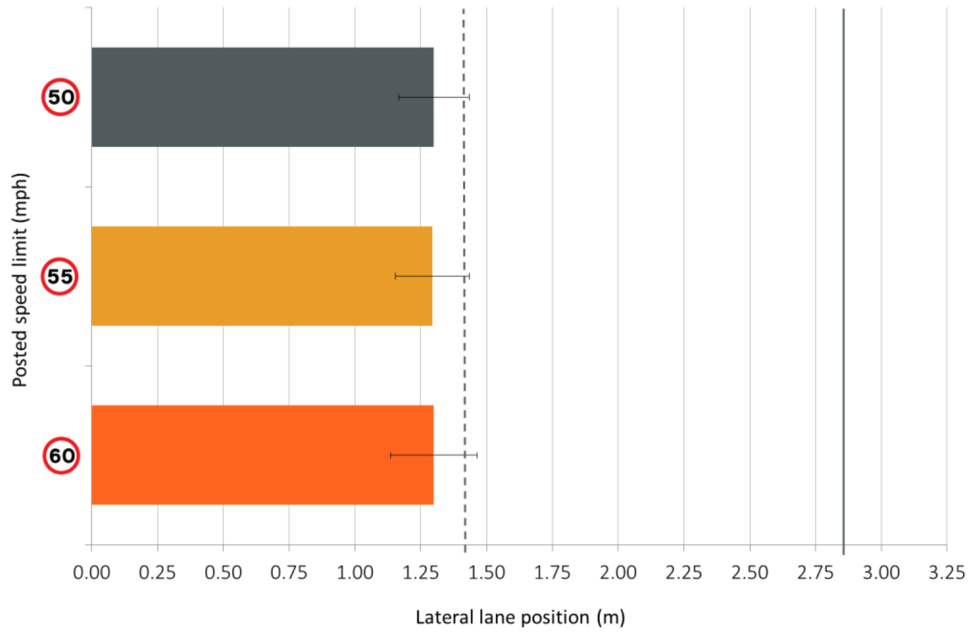

Figure 17: Mean lateral lane position of cars in lane 3 when overtaking AI cars in lane 2

This lack of change in position when overtaking in lane 3 may be a reflection of participants having a limited amount of space within this narrowest lane.

The pattern of reduced movement within a lane as posted speed limit increases did, however, appear to continue within the values for variability of overtaking participants in lane 3. A GEE test showed no significant difference ($p = 0.24$) in this measure, meaning that, although there was a reduction in movement as the posted speed increased, it cannot be concluded that the amount of movement differed because of the change in the speed limit.

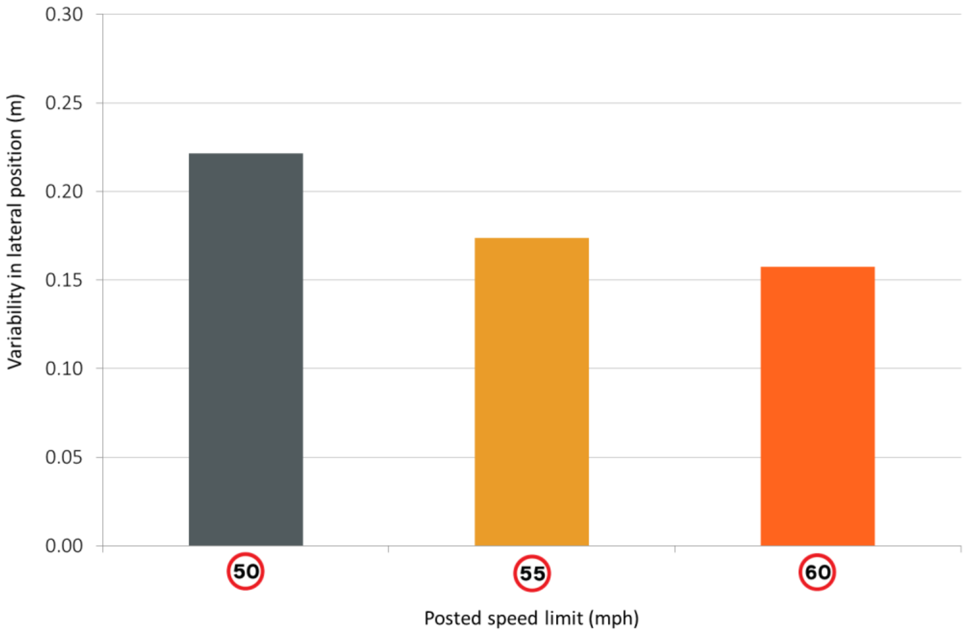

Figure 18: Average standard deviation of lateral lane position of cars in lane 3 when overtaking AI cars in lane 2

Figure 19 presents the average lane position of car participants' vehicles in lane 3 when overtaking an AI HGV in the lane adjacent on the left hand side of the participant.

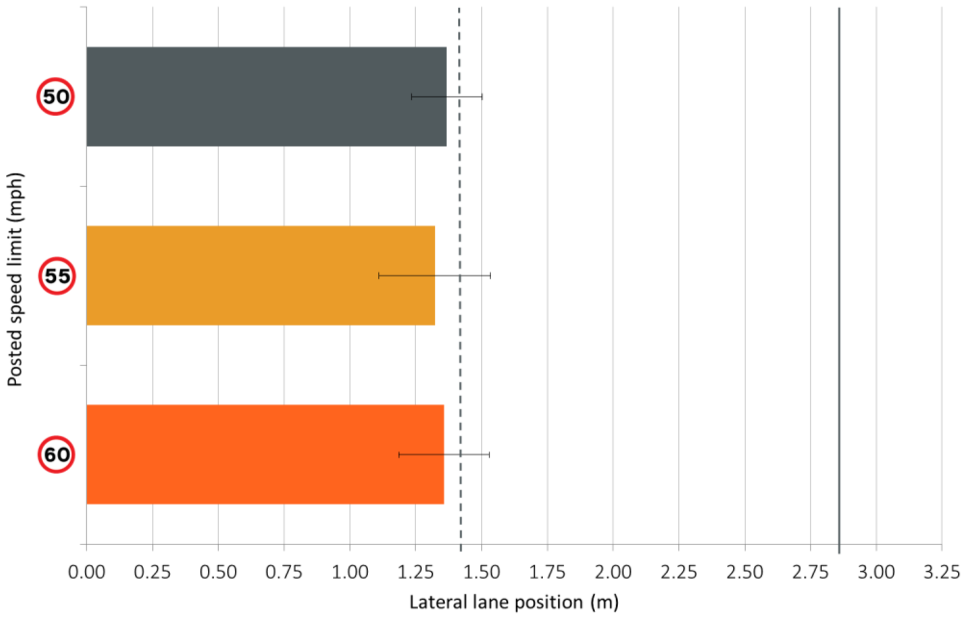

Figure 19: Mean lateral lane position of cars in lane 3 when overtaking AI HGVs in lane 2

The mean lateral lane position was consistent across all three scenarios, with participants placing the centre of their vehicles close to the middle of the lane. When compared to Figure 9 (mean position in lane 3 overall), there was a slight shift towards the right hand side of the lane, as seen previously in respect of overtaking. However, when compared to the position when over taking AI cars (Figure 17), the differences were minimal. The position of participants' vehicles in lane 3 appeared to be more consistent, most likely due to the reduced lane width.

Finally, the average variability in lane position is shown in Figure 20. This decreased slightly as posted speed limit increased. Again, statistical tests (GEE) showed that the difference was not significantly different (p = 0.098). However, the overall pattern of reducing amounts of movement as speed limit increased aligned with patterns seen when overtaking cars in the same lane (Figure 18), albeit that the amount of movement was reduced when overtaking HGVs when compared to cars.

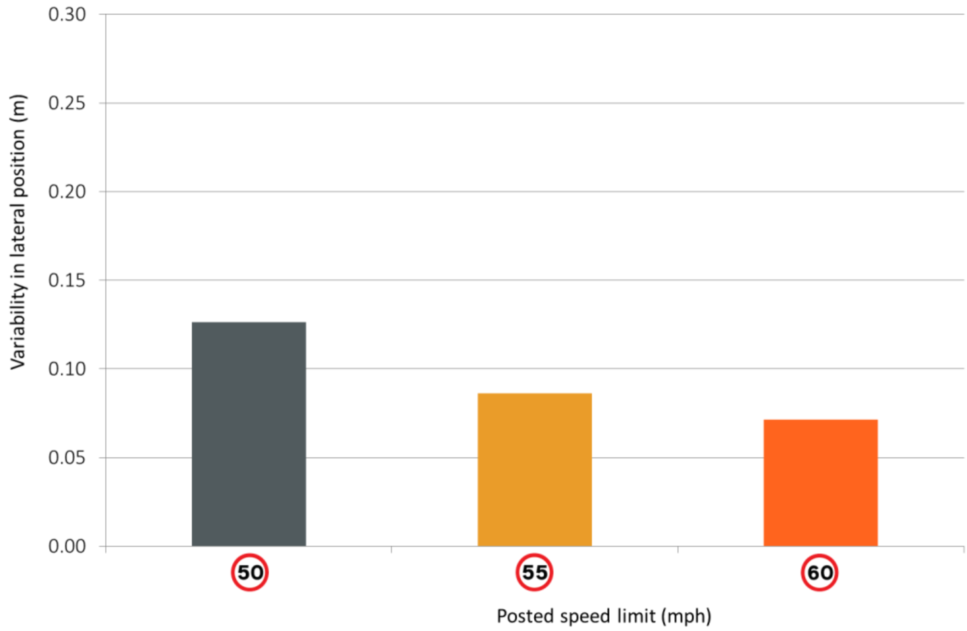

Figure 20: Average standard deviation of lateral lane position of cars in lane 3 when overtaking AI HGVs in lane 2

4.1.2.2 HGV Participants

As with the previous analysis of general lateral lane position, due to the small number of HGV participants negotiating the simulated road works in lanes 2 and 3, no analysis of lateral lane position while overtaking other vehicles in the environment could be undertaken.

4.2 Effects on cognitive resources

This section presents the analysis of workload data which indicated the effects on the participant's cognitive resource of undertaking the task of navigating the vehicle through narrow lane road works with varying posted speed limits.

4.2.1 NASA-TLX

Workload data from both participant samples (cars and HGVs) were collected after each drive. The task load index provides workload ratings for six subscales: mental demand, physical demand, temporal demand, frustration, effort, and performance. These can then be combined to provide the total workload demand for the drive. A low score indicates a low contribution to the overall workload and a high score indicates a high contribution to the overall workload.

4.2.1.1 Car participants

Figure 21 shows the mean ratings of each of the individual six subscales used within the NASA-TLX.

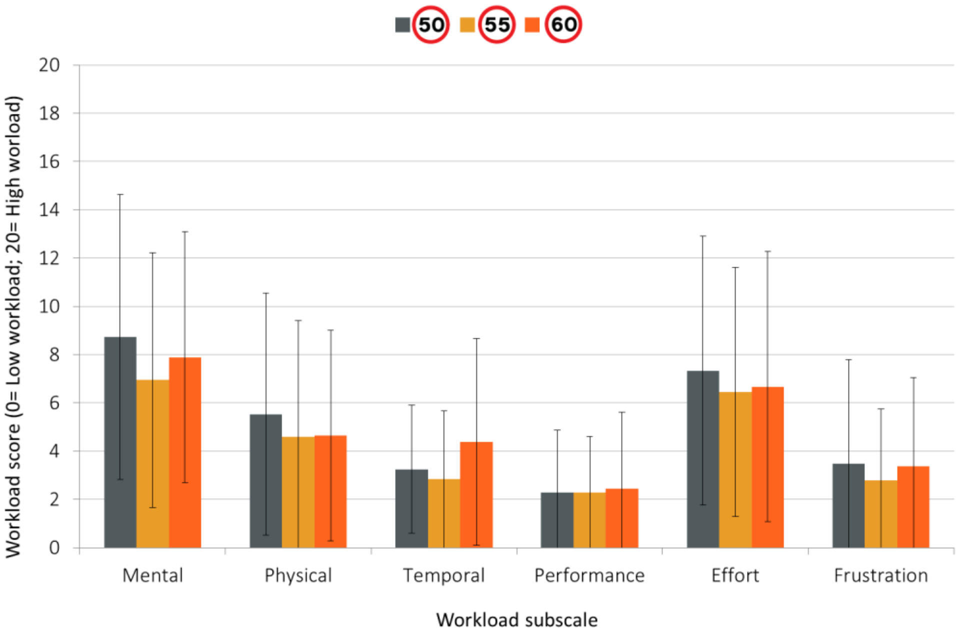

Figure 21: Mean workload subscale ratings for car participants

Each of the individual subscales indicated a relatively low workload score, on average less than 10, with relatively little difference in individual's scores between different posted speed limits. Both mental demand and effort scored, on average, slightly higher than the other subscales. This pattern across all six different subscales has been exhibited in previous studies investigating similar activities of participants negotiating simulated road works within the MDS (Wallbank *et al.*, 2017).

Friedman tests for each of the subscales showed that in all but one of the subscales there was no significant difference ($p > 0.05$ in all cases) between the three different scenarios. The exception to this was in the temporal demand subscale where a significant difference ($p = 0.04$) between the three speed limits was detected: the temporal demand subscale for the 55 mph drive was significantly lower than that of the 60 mph drive ($p = 0.038$). Although a difference between the temporal subscale average scores with the 55 mph and 60 mph scenarios was detected, neither scenario was found to be different relative to the 50 mph speed limit control scenario.

Figure 22 presents the combined scores. As seen with the individual subscales the total workload scores are low with little change between scenarios. A Friedman test showed that the total workloads across the three speed limits were not significantly different from each other ($p = 0.25$).

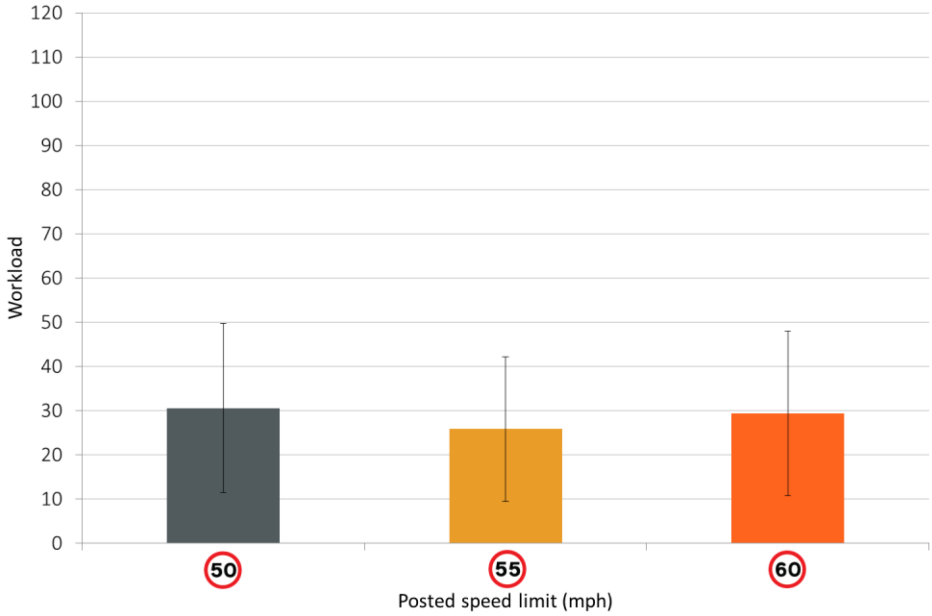

Figure 22: Average total workload for car participants

4.2.1.2 HGV Participants

As with the results from the car participants, the HGV participant results are presented as both the individual subscales (Figure 23) and a combined total workload (Figure 24).

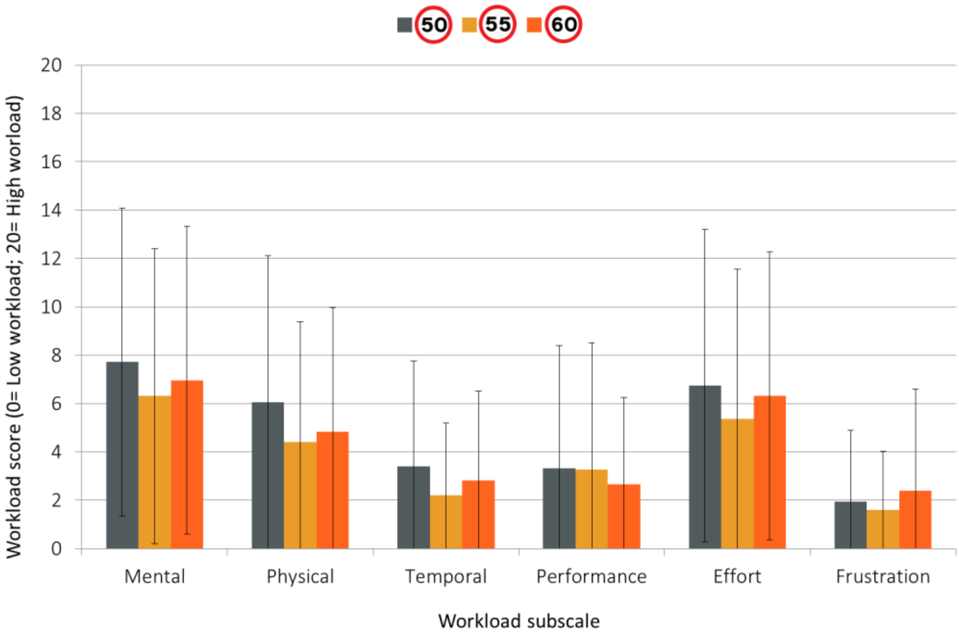

Figure 23: Mean workload subscale ratings for HGV participants

A Friedman test for each of the subscales showed no significant difference between the workload scores at the three posted speed limits ($p > 0.05$ in all cases). The average individual subscales scores were again at the lower end of the scale and consistent, indicating that participants did not find any scenario significantly more demanding than any other.

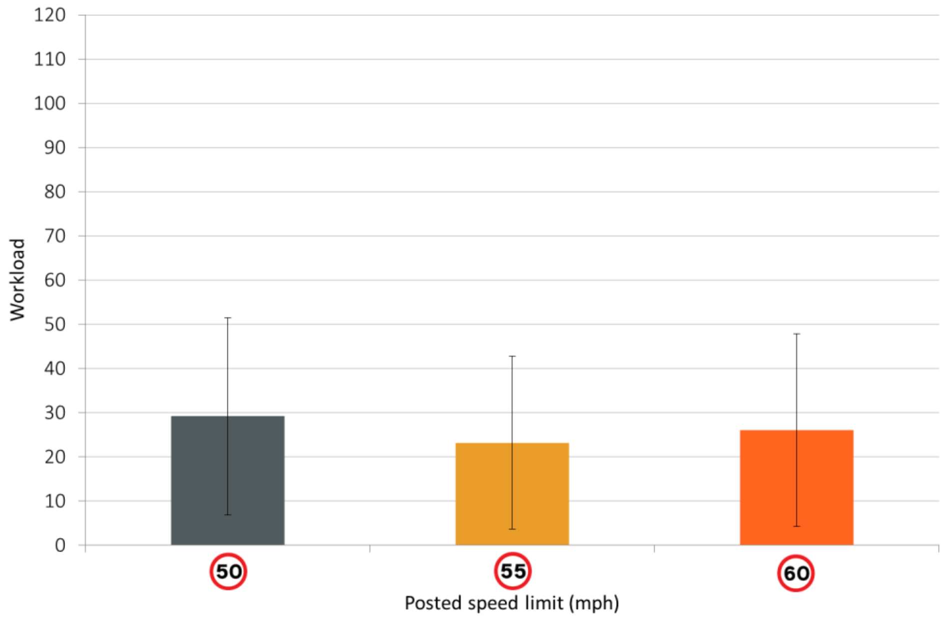

Figure 24: Average total workload for HGV participants

Undertaking a Friedman test showed that the total workloads across the three speed limits were not significantly different for HGV participants ($p = 0.35$). The large variability in responses, seen in the error bars within Figure 23, does suggest that there may have been some difference in individual responses (as seen within car participants).

4.2.2 Participants' perceptions of difficulty

In the post-drive questionnaire, participants were asked to rate the ease/difficulty of travelling through the road works at the different speed limits.

4.2.2.1 Car participants

The responses to the survey question *'How easy or difficult did you find it to travel at the speed limit through the road works?'* are presented below in Figure 25.

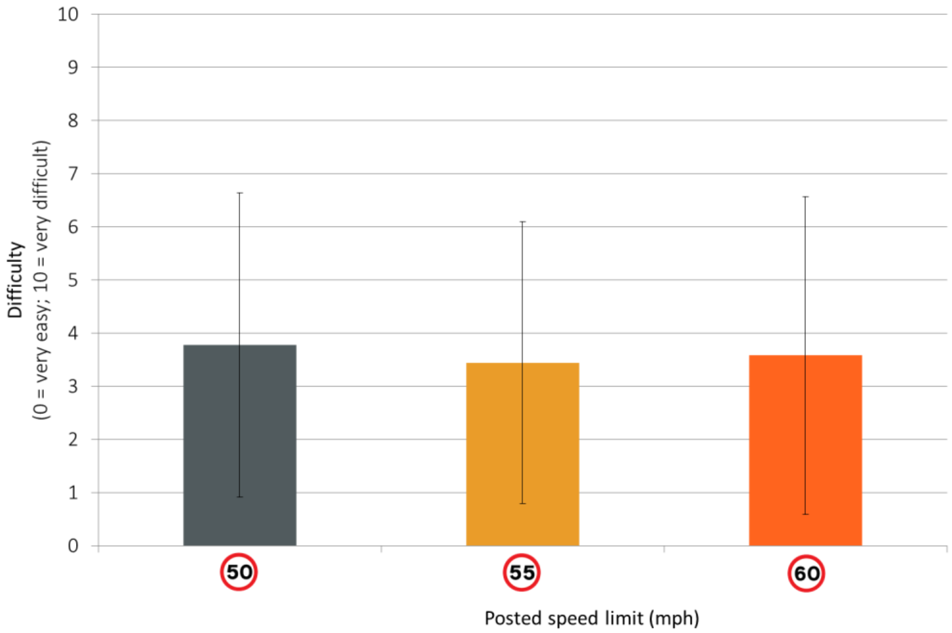

Figure 25: Mean responses to difficulty question car participants

Due to the subjective nature of the question, the variability in responses was quite high, indicated in the large error bars. However, there was little difference between the mean responses at different posted speed limits. The highest average reported difficulty was in the 50 mph speed limit scenario (3.8), although this is still towards the ‘easy’ end of the scale.

Statistical analysis (Friedman tests) showed no significant differences between the mean ratings in the different posted speed limit scenarios (p = 0.99).

4.2.2.2 HGV Participants

The responses to the survey question *‘How easy or difficult did you find it to travel at the speed limit through the road works?’* are presented below in Figure 26.

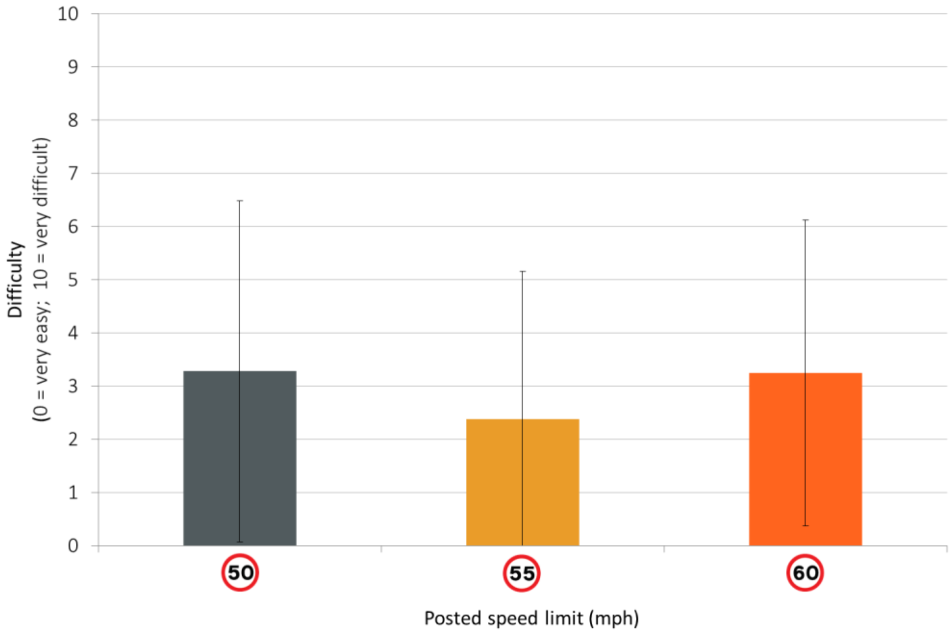

Figure 26: Mean responses to difficulty question HGV participants

Due to the subjective nature of the question the variability in responses was quite high, indicated by the large error bars. The highest average reported difficulty was in both the 50 mph and 60 mph speed limits (3.3), although this is still towards the ‘easy’ end of the scale.

Statistical analysis (Friedman tests) showed that there were significant differences in mean responses for HGV participants between the three speed limits ($p = 0.05$). Post-hoc tests showed that responses to the 55 mph speed limit scenario was rated significantly ‘easier’ than both the 50 mph speed limit control scenario ($p = 0.05$) and the 60 mph speed limit scenario.

4.3 Effects on subjective experience

4.3.1 Participants feelings of safety

Within the post-drive questionnaire, participants were also asked to indicate how safe they felt in each of the three speed limit scenarios.

4.3.1.1 Car participants

The responses to the survey question ‘*How safe or unsafe did you feel when driving through the road works in this drive?*’ are presented below in Figure 27.

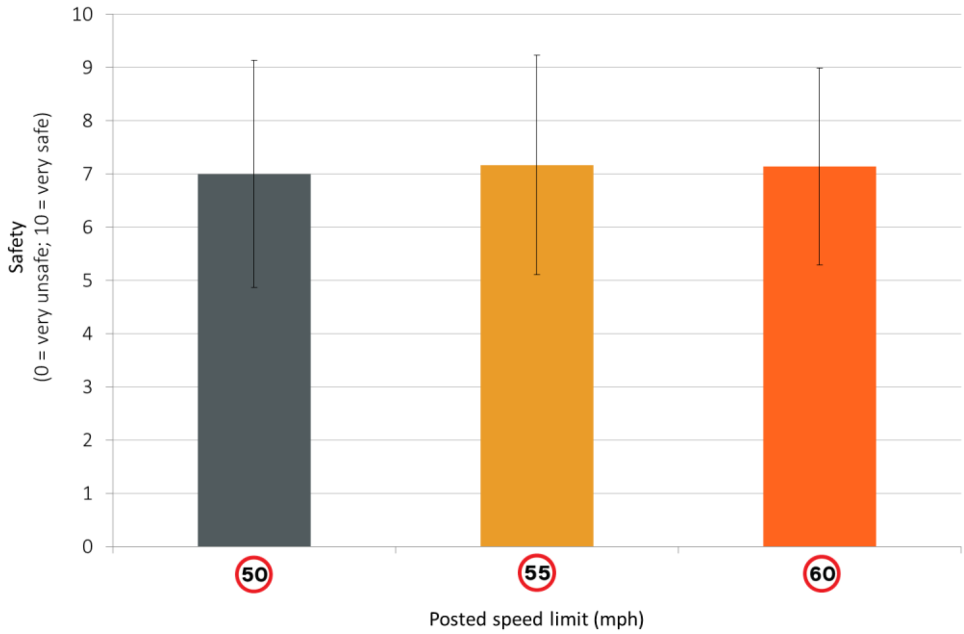

Figure 27: Mean response to safety survey question car participants

On average, all participants felt quite safe in all drives with the mean scores being above a score of 7. Friedman tests showed that the average feeling of safety was not significantly different between the three different scenarios ($p = 0.87$).

4.3.1.2 HGV participants

The responses to the survey question ‘*How safe or unsafe did you feel when driving through the road works in this drive?’* are presented below in Figure 28.

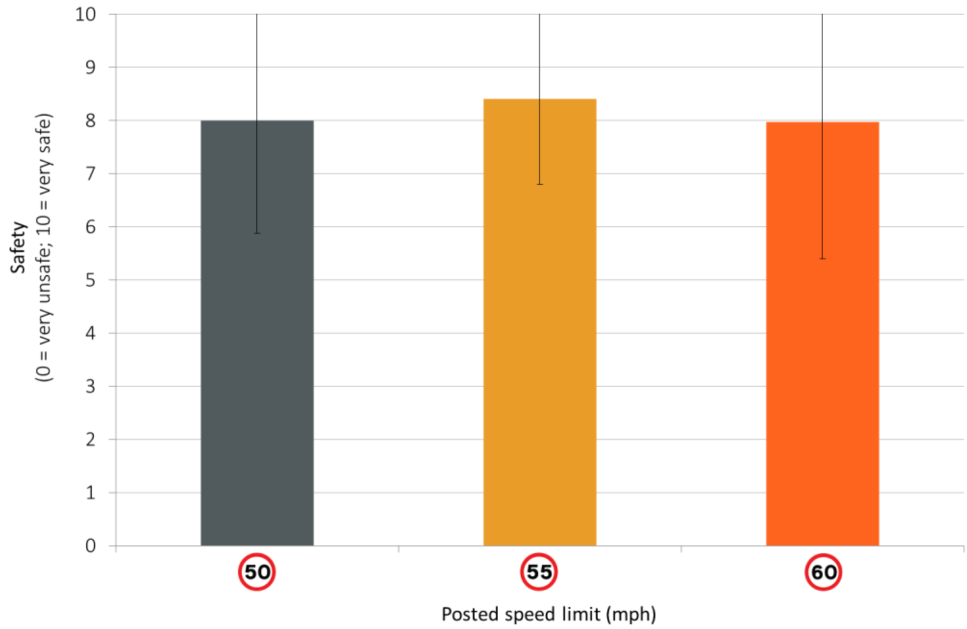

Figure 28: Mean response to safety survey question HGV participants

Again, on average, all participants in this sample felt quite safe in all scenarios with the mean scores being above a score of 8. Friedman tests showed that the average feeling of safety was not significantly different between the three different scenarios (p = 0.629).

4.3.2 Participants' feelings of comfort

Lastly in the post-drive questionnaire, participants were also asked to indicate how comfortable they felt in each of the three different speed limit scenarios in the presence of different vehicle classes.

4.3.2.1 Car participants

The responses to the survey question '*How comfortable or uncomfortable did you feel about the presence of other car/HGVs when travelling through the road works in this drive?*' are presented below in both Figure 29 and Figure 30.

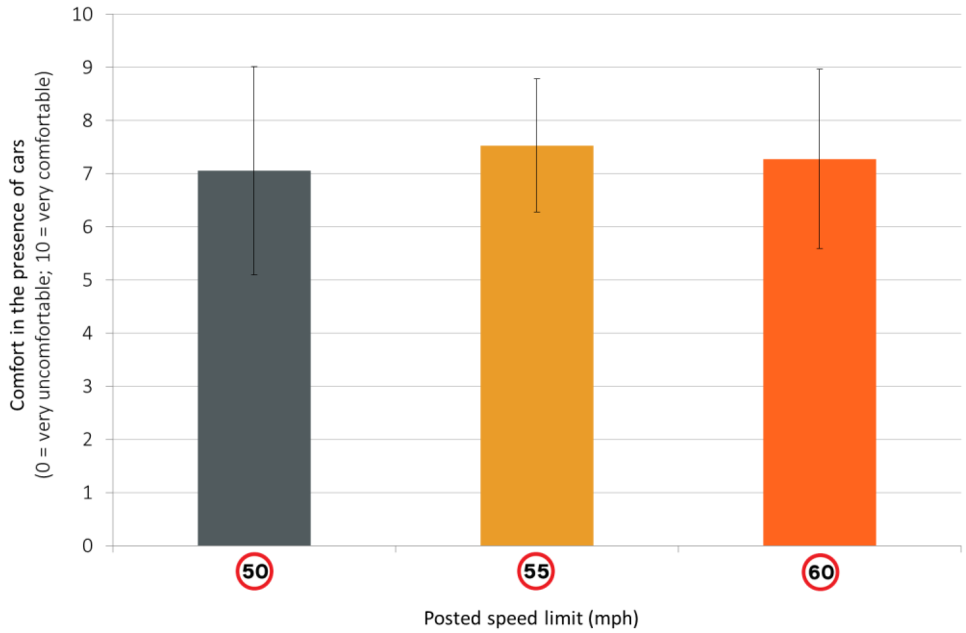

Figure 29: Mean response to comfort survey question in the presence of cars for car participants

The results show that, on average, participants felt comfortable around other cars in all three scenarios, with all mean scores being above 7. There were minimal differences between the three speed limit scenarios with statistical tests (Friedman) showing no significant difference in the average ratings of comfort between the three speed limit scenarios (p = 0.68).

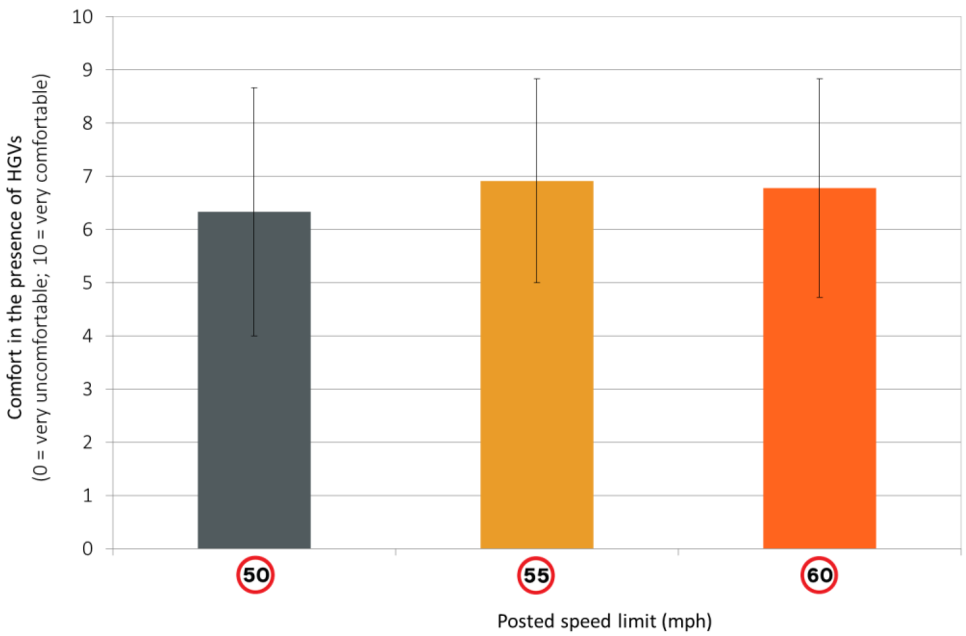

Figure 30: Mean response to comfort survey question in the presence of HGVs for car participants

Again the results showed that, on average, participants also felt comfortable around HGVs in all three scenarios, with all mean scores being above 7. There were minimal differences between the three speed limit scenarios with statistical tests (Friedman) indicating that the differences between the three speed limit scenarios were not significant (p = 0.35).

Participants indicated that, on average, they felt marginally more comfortable around cars (Figure 29) than around HGVs (Figure 30).

4.3.2.2 HGV participants

The responses to the survey question '*How comfortable or uncomfortable did you feel about the presence of other car/HGVs when travelling through the road works in this drive?*' are presented below in both Figure 31 and Figure 32.

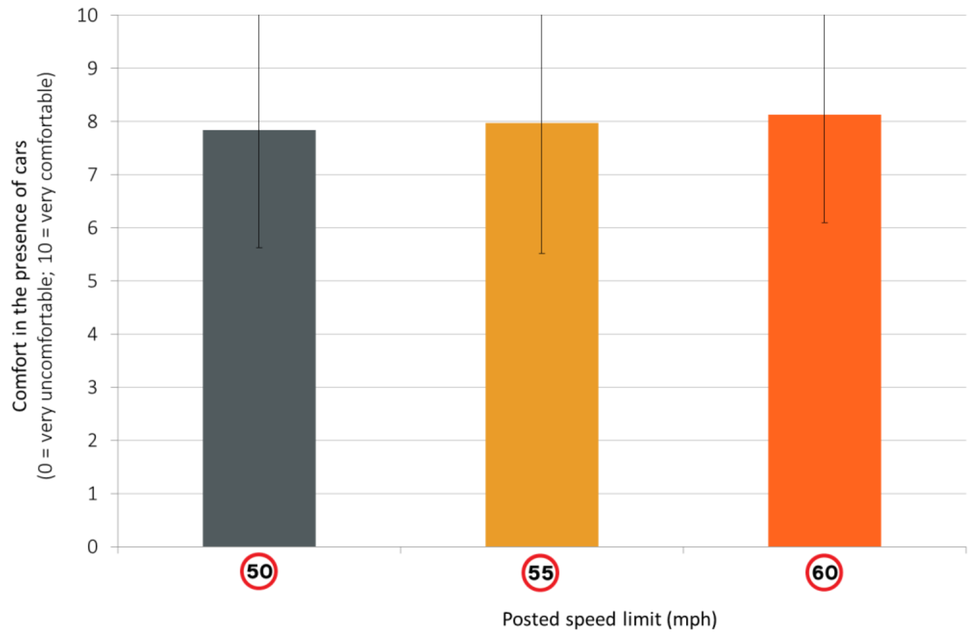

Figure 31: Mean response to comfort survey question in the presence of cars for HGV participants

The results show that, on average, participants felt comfortable around other cars in all three scenarios, with all mean scores being above 7. There were minimal differences between the three speed limit scenarios with statistical tests (Friedman) showing no significant difference in the average ratings of comfort between the three speed limit scenarios (p = 0.88).

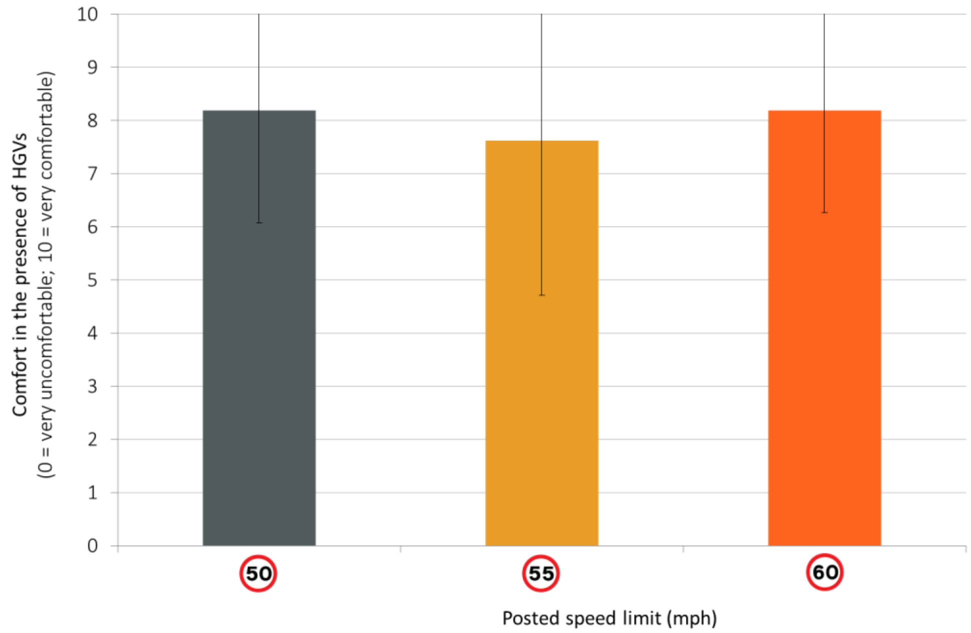

Figure 32: Mean response to comfort survey question in the presence of HGVs for HGV participants

Finally the results show that, on average, participants also felt comfortable around HGVs in all three scenarios, with all mean scores being above 7. There were minimal differences between the three speed limit scenarios with statistical tests (Friedman) indicating that the differences across the three speed limit scenarios were not significant (p = 0.98).

On the whole participants indicated little difference in their comfort levels around cars (Figure 31) or HGVs (Figure 32).

4.4 Other safety outcomes

4.4.1 Speed

During the study, speed data was collected from within the road works zone. The mean values for both car and HGV participants are presented in Table 3 below.

Table 3: Mean speed through the works zone (standard deviation of mean)

Car Participants			HGV Participants		
50	55	60	50	55	60
48.5 mph	52.4 mph	55.3 mph	44.8 mph	48.3 mph	50.6 mph
(1.70)	(1.97)	(2.37)	(0.36)	(0.75)	(1.15)

As outlined in Figure 4 within Section 3.6, the digital speedometer used in the simulations present the actual speed of the participants vehicle, no 'over reading' was built in as with speedometers on real-world vehicles.

There was a significant difference between the average speeds in the three scenarios; this finding was expected as drivers are known to increase their speed as the posted speed limit increases (see for example, Wallbank *et al.*, 2017).

Average speeds were typically lower than the posted speed limit for all drives and for both car and HGV participant samples. Average speeds were more variable in the 60 mph scenario for both car and HGV participants.

4.4.2 Lane distribution

In each scenario, participants chose which lane to travel in. The proportion of time spent in each lane is presented in Figure 33 and Figure 34 for car and HGV participants respectively.

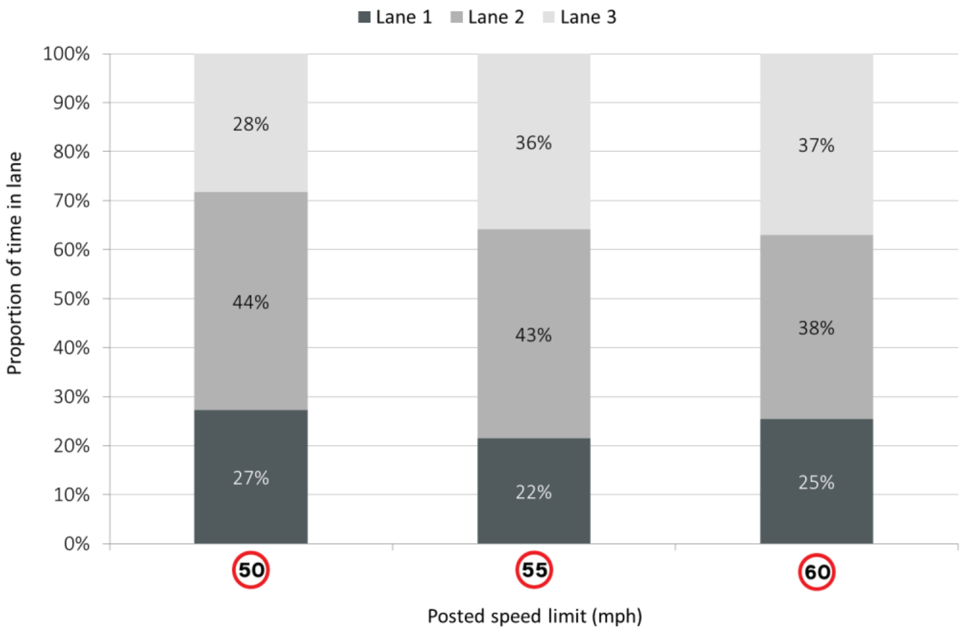

Figure 33: Lane distribution for car participants within the road works zone

Across the three scenarios, there appeared to be a change in distribution of lane choice within car participants. The proportion of time that car participants spent in lane 3 increased from 28% in the 50 mph scenario to 37% in the 60 mph scenario, with a corresponding decrease in lane 2 (from 44% in 50 mph to 38% in 60 mph). The proportion of time that participants spent in lane 2 remained relatively consistent across the three scenarios.

Other factors such as AI vehicle behaviours and road geometry were controlled across the three different scenarios, so the results suggest that participant's lane choice may be influenced by the posted speed limit. However, this is far from conclusive given that there were differences in the programmed speeds of the AI vehicles in each scenario; in particular, the AI vehicles were programmed to go at higher speeds when the higher speed limits were in use, this being an assumption about how drivers would react that could not be validated using real world data. The change in lane distribution of participants may, therefore, be a reflection of these assumptions rather than of reality and further validation on road would be required to gain confidence in this finding.

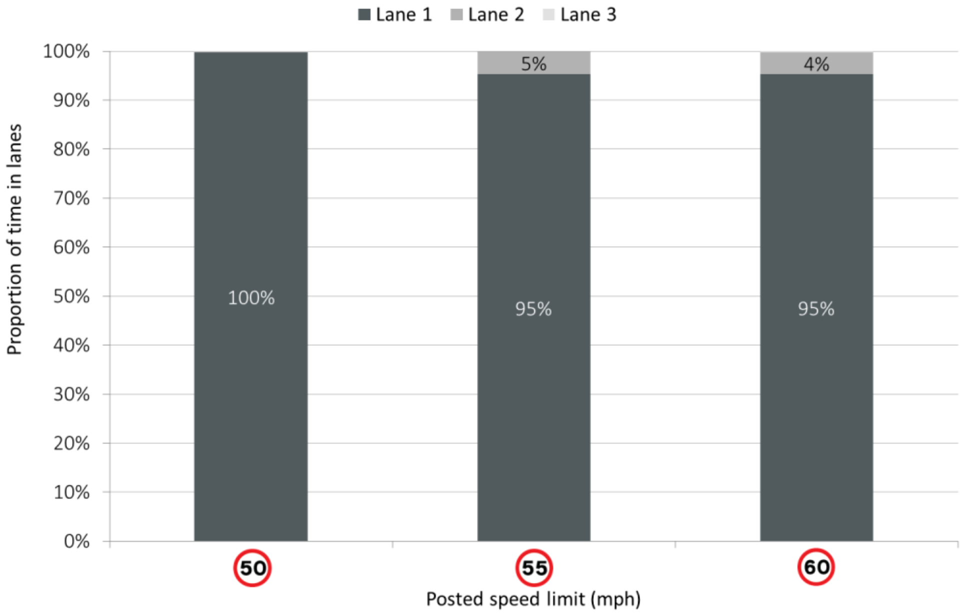

Figure 34: Lane distribution for HGV participants within the road works zone

Unlike the car participants, HGV participants spent the majority of their time travelling within lane 1 during the study (over 95% in all three scenarios). HGV participants did not have as much of a free choice as the car participants given that both the middle and right hand lanes were narrowed significantly.

5 Simulation study discussion and conclusions

5.1 Discussion

What is the effect of the posted speed limit on the participant's vehicle positioning?

The results seen within the previous section suggest that the posted speed limit had very little impact on the positioning of a participant's vehicle within the simulated environment. Both samples of car and HGV participants, on average, drove marginally closer to the left hand side of the lane when the posted speed limit is higher, with this behaviour being apparent across all three lanes (even as the lanes narrowed more to the off side).

Participants on the whole repositioned their vehicles when passing other vehicles which were on the left hand side of the participant's vehicle, typically moving right away from the adjacent vehicle be it car or HGV. This movement was reduced for participants traveling in lane 3 practically due to the reduced width available for the participant. Where possible, participants moved marginally further away from HGVs when compared to cars; throughout the study these behaviours appeared consistent across all three posted speed limits.

As the three lanes within the simulation environment all had different widths, the variability measure for each lane could be used to identify any effect on vehicle positioning and control across the road works at different speeds.

Statistical testing showed that, although there may have been relatively small changes in movement within a lane, any changes seen were not significantly different. This means that any changes seen in both car and HGV participants' mean data could not be attributed to the change in posted speed limit. This pattern continued when tests were undertaken on variability data taken from overtaking periods.

What is the effect of the posted speed limit on the participant's cognitive resource?

Several different measures were used within the study to investigate a potential impact on cognitive resource. Overall, mean total workload and difficulty scores were low, with both samples showing limited differences in responses across the three scenarios.

HGV participants did report a statistically significant lower level of difficulty for the 55 mph scenario than for both the 50 mph and 60 mph scenarios. The lower mean value may be a result of several different factors affecting the participant's experience:

Firstly, the variability in individual responses to the survey question (apparent from the size of the error bars presented in Figure 26) indicates that confidence in the specific mean results is low.

Secondly, in order to facilitate the collection of useable data during the trial period, counterbalancing the presentation order of the three scenarios was not used for all participants. Priority was shifted to ensuring minimum data collection of both a control (50 mph) scenario and the 60 mph experimental scenario. The 55 mph scenario was presented after the other two scenarios around 40% of the time; it is unlikely that the effects of any presentation bias impact the results of difficulty scores only and do not affect other subjective measures such as workload subscales.

Finally, the explanation of an 'easier' mean response may be linked with the speed limiter applied to the HGV simulation vehicle. In order to create a realistic experience for the participants, the HGV vehicles top speed was limited to 56 mph. The survey question asked how easy or difficult was to travel at the speed limit through the works, as the HGV participant's vehicle was limited to 56 mph (showing 55 mph on the digital display); this could have potentially made it easier for the drivers to maintain speed.

Other than this reported 'easier' rating within difficulty for HGV participants, there were small variations in the individual mean scores within the workload subscales for car participants. There was no meaningful difference between the three scenarios across the mean values; however, statistical tests did show a significant difference between scenarios within the temporal demand subscale between the 55 mph and 60 mph speed limit scenarios. However, there was no difference between the mean scores for either of these scenarios when compared to the 50 mph speed limit control scenario.

Despite these two exceptions, the results from the study indicate that the workload of participants was not greatly impacted by the posted speed limit when participants were travelling within narrow lanes.

What is the effect of the posted speed limit on the participant's subjective experience?
Analysis of the data collected in the study indicates that participants mostly felt safe during the trials, with levels of safety remaining consistently low across the three different scenarios. Car participants did express marginally lower levels of comfort when in the presence of HGVs, when compared to cars. Again this was consistent across all there scenarios; however, due to the variability in the survey responses, confidence in this small difference being associated with any particular factor is low.

Overall there was no significant difference in responses across the three speed limits, so the participant's subjective experience appears to be, on average, similar across the three different scenarios investigated within the study.

5.2 Simulation study conclusions

From the results and discussions contained within this report the following conclusions can be drawn, with relatively high confidence, in response to the original research questions posed in Section 3.3:

1. For both car and HGV participants, speed limits of 55 mph and 60 mph appear to have minimal influence on the ability of drivers to safely position and navigate their vehicle within the narrow lanes environment.

   Any variations in the position of their vehicle within the lane appear to be linked with other factors, such as the presence of other vehicles or the width of the lane, rather than being a direct result of a change in posted speed limit.

2. There appears to be little effect on car and HGV participant's cognitive resources when travelling in either 55 mph or 60 mph scenarios when compared to a 50 mph scenario. Both individual workload subscales and total workload were not influenced by the change in posted speed limit.

3. As with the previous two research questions, participants' subjective experiences of both safety and comfort were not impacted by either of the two increased posted speed limits. Small variations in responses cannot be linked with the change in speed limit; rather they appear to be a result of differences in individual's responses.

6 Standards and guidance review

This review investigates applicable standards and guidance documents that were identified via a desk-based exercise. Any future regular use of increasing speed limits through road works in narrow lanes will require relevant documentation to be updated accordingly; this review is aimed at providing an initial summary of the impact and practicalities of the change to existing guidance that would be required.

6.1 Methodology

Guidance and standard documents that provide details on road works were first identified as part of the review via an extensive search for guidance documents in Highways England's Standards for Highways. These documents were then examined, with those relevant to road works with narrow lanes being identified and sourced; the method used can be seen in Appendix G. Within each existing guidance document, all relevant references to other Highways England standards documents, most of which are in DMRB, were also identified and sourced.

These specific documents were then analysed, categorising each relevant section along with assessing the impact and practicalities of any potential changes to enable the regular use of both 55 mph and 60 mph speed limits. In addition to the categorisation procedure listed above, common themes were identified to assist in providing overall insight in areas that may require future effort.

6.2 Results of review

In total, the review identified 20 highway standards and guidance documents which were considered relevant to any potential increase of speed limit within road works with narrow lanes[1]. The complete list of reviewed documents can be found in Appendix H.

Just over half of the documents reviewed would potentially require some kind of change to enable 55 mph and 60 mph speed limits to be used regularly on road within road works with narrow lanes. A total of 146 individual excerpts were identified and categorised; a detailed log of these excerpts can be found in Appendix I.

Within the 146 excerpts, 115 required 'no changes' to be made to enable either 55 mph or 60 mph speed limits to be used regularly within road works with narrow lanes. The remaining 31 had the impact of a potential change scored against the following scale: high, medium or low. Along with these scores, themes were also assigned to each potential change. These themes help to indicate the specific areas that will require targeted input to

[1] Requests had been made to source a copy of the amended version of Chapter 8 Part 3, currently awaiting Department for Transport (DfT) publication. These requests were unsuccessful within the timeframe of the work package so the 2016 online published version of 'Chapter 8 Part 3: Update' was reviewed. Several of the high impact excerpts reviewed may therefore be amended or altered with the imminent re-publication of the document.

enable the regular use of 55 mph or 60 mph speed limits at road works with narrow lane restrictions. An overview of the scores and themes can be seen in Figure 35.

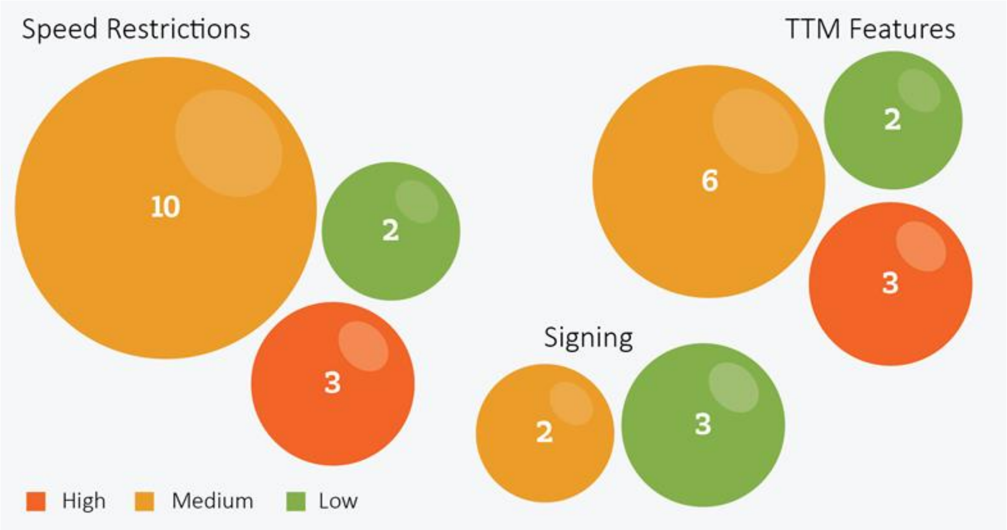

Figure 35: Number of excerpts requiring changes split by theme and impact

6.3 Findings of review

Several key themes and excerpts were identified as requiring a ‘high’ impact change; the majority of these were around elements of guidance and recommendations related directly to the implementation and usage of speed restrictions.

One of the key excerpts within this theme comes from recommendations within the Traffic Signs Manual (TSM) Chapter 8 Part 1: Design. The application of temporary mandatory speed limits on high-speed roads outlines appropriate speed reductions to limit the risk associated with specific traffic management features, narrow lane widths being among them. Table 3.5 in TSM Chapter 8 Part 1 recommends a 20 mph reduction in speed (relative to the permanent speed limit) when narrowing lanes. As this specific document is paramount to traffic management, the implications of this information are noted throughout other related documentation.

Changes to Table 3.5 would impact on many of the other standards and guidance documents listed in the review, as current practice has been formed around the recommended 20 mph reduction in speed. Although the current guidance does not need to be changed in order to allow the use of a 60 mph speed limit when narrow lanes are in use, changes to the wording in the guidance may encourage the more frequent adoption of a 60 mph speed limit in these circumstances (with appropriate additional mitigations in place to ensure that there is no reduction in the level of safety).

7 Recommendations

On the basis of the findings and results of the three individual elements of this project, it is recommended that:

1. The 60 mph speed limit scenario within narrow lanes can be progressed to an on road pilot study on the SRN. On road trials are important in validating the findings from the simulator study in the real world, and broadening the body of evidence required to understand how both drivers and road workers react to the changes in speed reduction.

   Individual scheme specific risk assessments must be undertaken for schemes progressing to on road pilots of 60 mph; these assessments should ensure that the key mitigations and monitoring requirements outlined within this study are applied.

2. The 55 mph speed limit scenario within narrow lanes could only be progressed to on road pilots if further work is carried out to investigate: the unknown impacts of driver distraction at 55 mph in narrow lanes outlined within section 2.2 within this report.

   Once further research has been added to the risk discussion for the use of 55 mph, and the risk of distraction caused at 55 mph is deemed tolerable within narrow lanes, the use of the 55 mph scenario could then be progressed to an on road pilot study.

3. Any potential on road use of either 55 mph and/or 60 mph speed limits in future pilot studies does not require any immediate change to key standards and guidance. However, in order to encourage further adoption, sections of guidance relating directly to the implementation and usage of speed restrictions within road works would need updating (with appropriate additional mitigations in place to ensure no reduction in levels of safety).

4. Specific levels of driver satisfaction and individual opinions were not sought during this study; previous work carried out in the use of 55 mph and 60 mph on road investigated these areas in respect of full width lanes (Wallbank *et al.*, 2017). Any future work should seek to understand how road users' satisfaction changes as the specific use of either a 55 mph or 60 mph speed limit within the narrow lanes environment becomes more commonplace.

Bibliography

Beard G, Tailor A, Wallbank C and Fernandez-Medina K (2017). *Fatigue and road works*. TRL.

British Standard (2010). BS EN 1317-2:2010..

Department for Transport / Highways Agency (2006). *TD 19/06 Requirement for road restraint systems*.

Department for Transport / Highways Agency (2009). *Traffic SIgns Manual Chapter 8 Traffic Safety Measures and Signs for Road Works and Temporary Situations Part 1: Design.*, TSO, London.

Department for Transport / Highways Agency (2009). *Traffic Signs Manual Chapter 8 Traffic Safety Measures and Signs for Road Works and Temporary Situations Part 2: Operations.*, TSO, London.

Department for Transport (2016). *Domestic Road Freight Statistics*.

Department of Transport / Highways England (2016). *Traffic Signs Manual Chapter 8 Traffic Safety Measures and Signs for Road Works and Temporary Situations Part 3: Update.*, TSO, London.

Highways Agency (2006). *Speed Limit Enforcement at Road Works: Guidance and Best Practice*.

Nassrullah Z (2016). *Development of a micro-simulation model for motorway roadworks with the use of narrow lanes and lane closure schemes*. Mancheter.

Tailor A and Hopkin J (2017). *Monitoring and evaluation of the 55/60mph pilots: Results from skaeholder engagement following the on-road trial of 55mph at the M3 J2-4a scheme*.

Tailor A (2017). *Monitoring and evaluation of the 55/60mph pilots: Results from stakeholder engagement following the on-road trial of 60mph at the A1 Leeming to Barton scheme*.

Tailor A (2017). *Monitoring and evaluation of the 55/60mph pilots: Results from stakeholder engagement following the on-road trial of 60mph on the M1 J32-35a scheme*.

Tailor A (2017). *Monitoring and evaluation of the 55/60mph pilots: Results from stakeholder engagement following the on-road trial of 60mph on the M5 J4a-6 scheme*.

Walker G and Calvert M (2015). Driver behaviour at roadworks., *Applied ergonomixs*, pp. 18-29.

Wallbank C, Hammond J, Myers R, Ognissanto F and Durrell L (2017). *Monitoring and evaluation of 55/60mph pilots: Interim report for the on-road trials of 55mph on the M3 Junction 2 to 4a scheme*.

Wallbank C, Hammond J, Myers R and Chowdhury S (2017). *Monitoring and evaluation of the 55/60mph pilots: Interim report for the on-road trials of 60mph on the A1 Leeming to Barton scheme*.

Wallbank C, Palmer M, Hammond J and Myers R (2017). *Monitoring and evaluation of the 55/60mph pilots: Interim report for the on-road trials of 60mph on the M1 J32-35a scheme*.

Wallbank C, Chowdhury S, Fleetwood R and Myers R (2017). *Monitoring and evaluation of the 55/60mph pilots: Interim report for the on-road trials of 60mph on the M5 Junction 4a to 6 scheme*.

Wallbank C, Robbins R, Tailor T and Chowdhury S (2017). *Monitoring and evaluation of the 55/60mph pilots: Interim report for the simulator trial of 55 and 60mph through roadworks*.

Wallbank C, Balfe N and Chowdhury S (2017). *Monitoring and evaluation of the 55/60mph pilots: Interim report for the simulator trials of 55 and 60mph through roadworks - A follow-on study*.

Wallbank C, Hammond J, Myers R, Ognissanto F and Durrell L (2017). *Monitoring and evalution of the 55/60mph pilots, Final report for 60mph trials*.

Yousif S, Nassrullah Z and Norgate S (2017). Narrow lanes and their effect on drivers' behaviour at motorway roadworks., *Transportation Research Part F*, pp. 86-100.

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