Transport Research Laboratory

Emergency refuge area simulation study

by C Diels, N Reed, R Robbins, T Rees, I Summersgill, AM Parkes

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by C Diels, N Reed, R Robbins, T Rees, I Summersgill, AM Parkes (TRL)

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	(Paul Goward)

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Contents

List of Figures 3

List of Tables 5

Executive summary 6

1 Introduction 13

1.1 Emergency Refuge Area 13

1.2 Roof-bar lighting 13

2 Methods 15

2.1 Participants 15

2.2 Experimental design 15

2.3 Trial procedure and instructions 19

2.4 Route design 20

2.5 TRL Driving Simulator – CarSim 22

2.6 Measures of interest 23

3 Results 24

3.1 Driving behaviour results 24

3.1.1 Speed profile 24

3.1.2 ERA approach speed 24

3.1.3 Braking profile 25

3.1.4 Speed upon entering ERA 27

3.1.5 Stopping position 28

3.1.6 Total time spent in ERA 30

3.1.7 Number of exit attempts 31

3.1.8 Rear headway 32

3.1.9 Reversing within ERA 32

3.1.10 Speed upon re-entering motorway 32

3.2 Questionnaire results 33

3.2.1 Ease of locating ERA 33

3.2.2 Clarity of ERA signs 34

3.2.3 Perceptions of safety when entering ERA 35

3.2.4 Sufficiency of stopping distances 35

3.2.5 Impressions of safety when parked in ERA 36

3.2.6 Clarity of indication of parking area within ERA 37

3.2.7 Confidence of having stopped in most appropriate location within ERA 37

3.2.8 Difficulty when rejoining motorway 38

3.2.9 Confidence when rejoining motorway 39

3.2.10 Speed when rejoining motorway 39

3.2.11 Sufficient space to accelerate within ERA 40

3.2.12 Factors which influenced participants stopping position 41

3.2.13 Comments 42

4 Discussion 45

4.1 Safety Interpretation 46

4.2 Network performance interpretation 48

5 Conclusions **49**

Acknowledgements **50**

References **50**

Glossary of terms and abbreviations **51**

Appendix 1 – Low lit ERA lighting details **52**

Appendix 2 – TRL CarSim **53**

Appendix 4 – Speed profiles as a function of ERA location **56**

Appendix 5 – Braking profiles as a function of ERA location **57**

List of Figures

Figure 1: Top: Low lit (left) and Unlit ERA (right); Bottom: Revised (left) and Small ERA (right) 6
Figure 2: The TRL advanced car simulator 7
Figure 3: Breakdown of participant groups 7
Figure 4: Speed (left) and braking (right) profile on approach, entrance and exiting from each ERA 8
Figure 5: Stopping positions in each ERA 9
Figure 6: Breakdown of participant groups 15
Figure 7: Unlit ERA (Top) and Low lit ERA (Bottom) on approach (left) and upon entering (right). Diagram for each ERA design are shown below the screenshots. 16
Figure 8: Revised ERA on approach (top left) and upon entering (top right). Bottom: Diagram of the Revised ERA design. 17
Figure 9: Small ERA on approach (left) and upon entering (right). Bottom: Diagram of the Small ERA design. 18
Figure 10: Standard ERA on approach (left) and upon entering (right). Bottom: Diagram of the Standard ERA design. 19
Figure 11: Schematic plan of the simulator scenario 22
Figure 12: TRL's driving simulator, CarSim. 22
Figure 13: Speed profile on approach to and upon rejoining the motorway from each ERA 24
Figure 14: Average Time-Distance graph on approach and entering of each ERA 25
Figure 15: Brake force applied upon approach and entrance into each ERA. Brake force values range from 0-1 26
Figure 16: Maximum brake force (range = 0-1) within 100m preceding the start of the ERA and entrance to the ERA. Error bars indicate the 95% confidence interval of the mean (95% CI) 26
Figure 17: Frequency distribution of applied maximum brake force as a function of distance from the ERAs 27
Figure 18: Speed (mph) on entering each ERA (95% CI) 28
Figure 19: Stopping positions in each ERA. Stopping positions refer to the position of the rear axle of the simulator vehicle. Distance from the rear axle to the front of the car was 2.45m 29
Figure 20: Mean total amount of time (s) spent in each of the ERAs (95% CI) 31
Figure 21: Average number of times participants stopped within the ERA after first accelerating on exit (95% CI) 31
Figure 22: Speed (mph) upon rejoining the motorway from each ERA (95% CI) 33
Figure 23: Mean ratings for ease of locating the ERA (95% CI) 34
Figure 24: Mean ratings of clarity of signage (95% CI) 34
Figure 25: Mean scores for the safety of entering the ERA (95% CI) 35
Figure 26: Mean scores for sufficient stopping distances when entering the ERA from the motorway (95% CI) 36
Figure 27: Mean ratings of safety for parking in the ERA (95% CI) 36
Figure 28: Mean ratings for whether the correct parking location was clearly indicated in the ERA (95% CI) 37
Figure 29: Mean confidence for stopping in the most appropriate space within the ERA (95% CI) 38
Figure 30: Mean scores for difficulty of rejoining the motorway when exiting the ERA (95% CI) 38
Figure 31: Mean scores for confidence in rejoining the motorway when exiting the ERA (95% CI) 39
Figure 32: Mean scores for whether the motorway was rejoined at sufficient speed (95% CI) 40
Figure 33: Mean ratings of whether there was sufficient space to accelerate (95% CI) 41
Figure 34: Mean scores for the influence that ERA aspects have on stopping position (95% CI) 41

Figure 35: Orus luminaire range (Thorn). 52
Figure 36: TRL driving simulator, CarSim 53
Figure 37: TRL CarSim: Control Room 54

List of Tables

Table 1: Summary of the sections within the ERA simulator trial. 21
Table 2: Measures of interest for an ERA..... 23
Table 3: Mean X and Y coordinates of the stopping positions in the ERA designs 30
Table 4: Percentage of participants parking the correct location within each ERA..... 30
Table 5: Descriptive statistics for the rear headway in metres upon exiting each ERA .. 32

Executive summary

Greater use of the hard shoulder as an active running lane places increased pressure on use of the Emergency Refuge Areas (ERA) as safe havens in the event of a vehicle breakdown. Considering current proposals to extend hard shoulder running within junctions, known as Through Junction Running (TJR), this study investigates drivers' response and subjective evaluation of ERAs positioned both between and within junctions. In particular, TJR is considered to operate at 70mph which may have implications for road safety, in particular drivers' ability to enter the ERA and then safely rejoin the motorway.

The Highways Agency's objective is to create an intra-junction ERA that is less attractive as a non-emergency stopping point while still being safe for emergency use. This is because more than 80% of ERA use is non-legal and non-emergency with a commensurate increase in exposure to risk. In addition there is evidence that stops can occur in the wrong place within ERAs which may have consequences for emergency vehicle access as well as the ability to leave the ERA safely and rejoin the carriageway.

To discourage inappropriate ERA use, as well as to modify the stopping position within ERAs, a number of ERA design considerations have been identified including ERA lighting conditions and ERA designs. The aim of this study was to evaluate the effect on driver behaviour of four ERA design modifications (see Figure 1):

1. Low lit ERA at unlit motorway (night drive)
2. Unlit ERA at fully-lit motorway (night drive)
3. Small ERA format (total length reduced from 100 to 55m)
4. Revised ERA design

Each of the four designs was evaluated compared to a current standard ERA with the ERA located either between or within junctions.

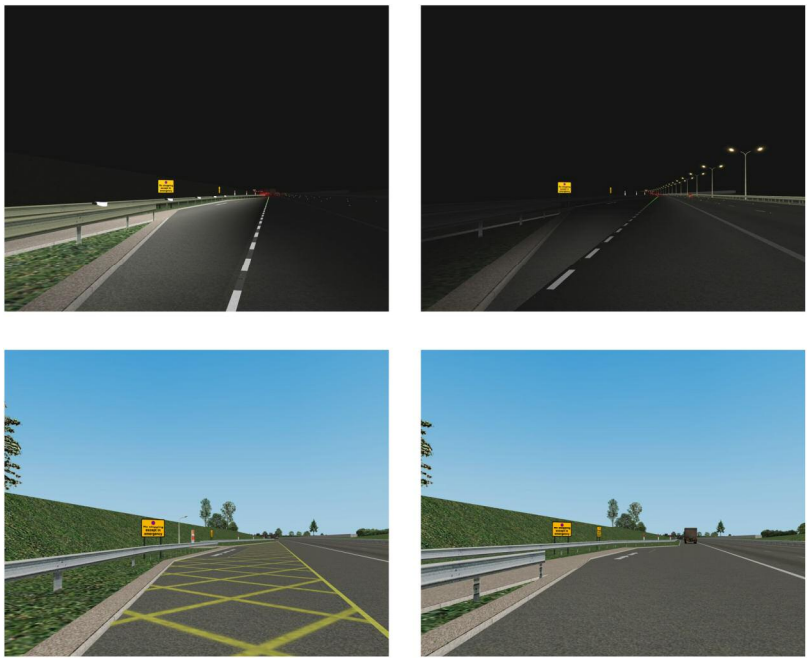

Figure 1: Top: Low lit (left) and Unlit ERA (right); Bottom: Revised (left) and Small ERA (right)

Methods

Investigating drivers' reactions to, and subjective evaluations of the different ERA designs in a real-world setting would be potentially dangerous. Driving simulation provides a safe and efficient alternative method to answer these questions. TRL's advanced driving simulator not only permits the construction of different ERA designs which can be tested in safety, it also replicates the driving environment in high fidelity, in complex traffic conditions (see Figure 2 for a view of TRL's advanced car simulator).

The simulator allows for the capture of broad range of real-time behavioural data; in other words a detailed picture of each driver's performance, moment by moment, can be recorded and analysed in detail. These data are supplemented with a range of custom designed questionnaires which obtain measures of participants' subjective experience of each drive. From these two sources of data a clear picture of how drivers behave and feel during any drive can be painted.

Figure 2: The TRL advanced car simulator

In order to evaluate the different ERA designs, simulated breakdown scenarios were created requiring drivers to stop in an ERA. This allowed for the evaluation of drivers' ability to exit the motorway and drivers' stopping position within the intra-junction ERA. By repairing the simulated fault, drivers were subsequently asked to rejoin the carriageway which in turn allowed for the evaluation of factors such as gap acceptance and speed choice.

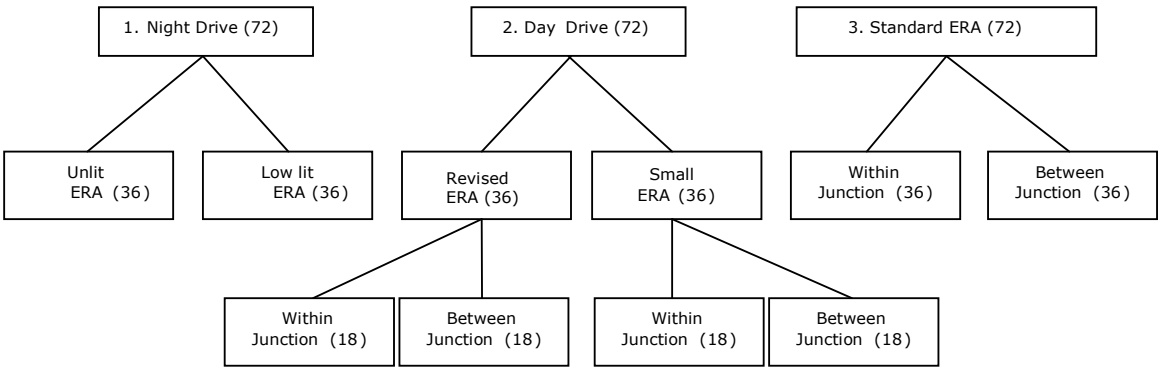

Figure 3: Breakdown of participant groups

In the simulator study, a total of 72 drivers participated. Participants were evenly split into two age groups (Younger=17-44 yrs; Older = 45+ yrs) with an equal number of male and female participants in each group. Figure 3 shows the breakdown of

participants groups. The study design required each participant to undertake three drives in the simulator for a period of around 10 minutes each. In the night drive, participants were asked to stop the vehicle in either the Unlit or Low lit ERA which was always positioned between-junctions. In a second drive, they had to stop in either the Revised or Small ERA, which in turn could be located either within or between a junction. In a third drive, participants had to stop the vehicle in a Standard ERA that was located either within or between a junction.

Results and discussion

The first finding was that the location of the ERA, that is, whether it was located between or within a junction, did not differently affect driving behaviour and participants' subjective evaluation of the ERAs. This suggests that the use of ERAs within junctions is unlikely to introduce driving behavioural concerns beyond those associated with ERA use in general. Hence, in the following, the results will be discussed without further reference to ERA location.

Figure 4 shows the speed and braking profile on approach, entrance, and exit from each ERA design. Note that braking force was measured as a relative value ranging from 0-1. With regard to the speed profile on approach and entrance to the ERAs, it was found that the average approach and entrance speed tended to be lower for the Small and Unlit ERAs. In addition, the braking profile for the Small and Unlit ERAs also showed considerable later and sharper braking levels compared to the Revised, Low lit, and Standard ERA. The highest maximum braking force applied within 100m preceding the start of and entrance to the ERA was observed in the Small and Unlit ERA.

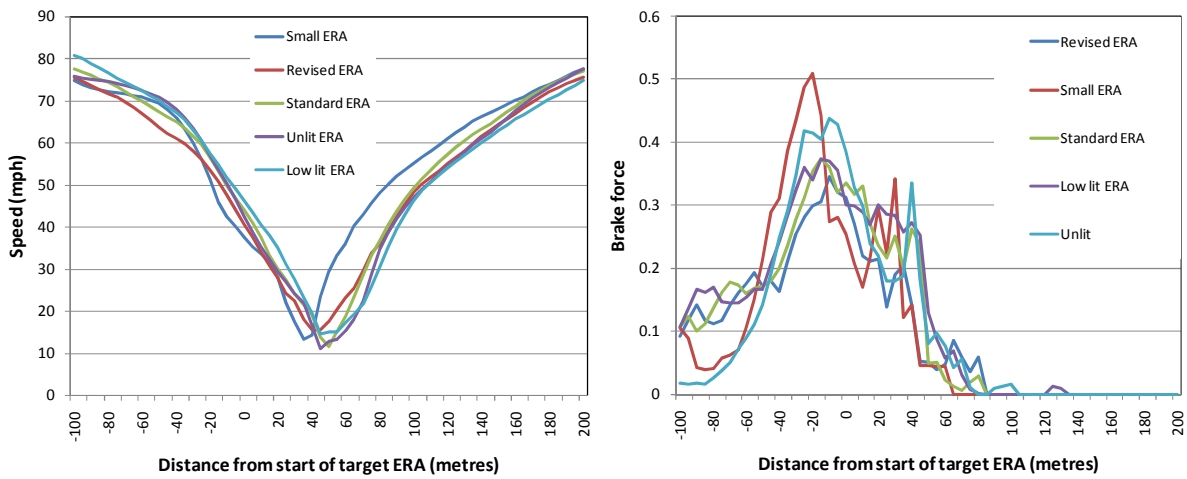

Figure 4: Speed (left) and braking (right) profile on approach, entrance and exiting from each ERA

These results can be interpreted as participants being more cautious when entering the Small and Unlit ERA. With regard to the Unlit ERA this can be understood considering the reduced visibility making it harder for participants to locate the start of the ERA, judge the ERA's dimensions and whether the ERA provided sufficient space to bring the vehicle to a halt. As expected, when asked to indicate the ease of locating the ERAs, participants indicated that it was harder to locate the Unlit ERA compared to the other ERAs.

A similar argument can be put forward for the small ERA whereby the reduced length of the ERA may have instigated participants to lower their travelling speed to ensure they can safely and comfortably bring the vehicle to a halt. Subjective comments provided further support for these interpretations.

Figure 5 shows the stopping positions (X and Y coordinates) of the vehicle in each of the five ERA designs. Note that the stopping position refers to the position of the rear axle of the simulator vehicle. The largest number of participants parking the vehicle in the correct location was observed in the Small (75%) and Unlit ERA (78%). In the other ERA designs, including the Standard ERA, the percentage was lower and hovered around 60% of the participants.

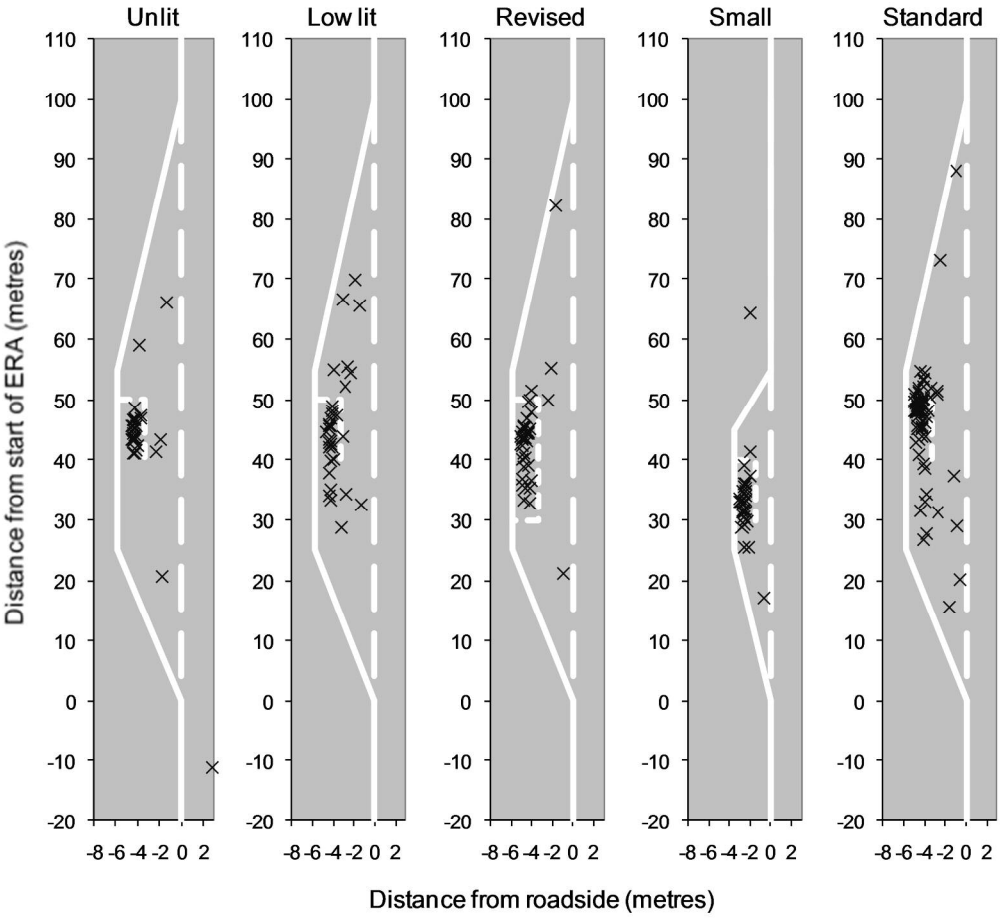

Figure 5: Stopping positions in each ERA

The hatched road markings in the Revised ERA had the intended effect of discouraging participants from parking in the hatched area. However, the arrows signalling participants to park towards the front of the parking bay were not as effective. From this it can be concluded that hatchings effectively discourage participants from parking on them, more so than the arrows that precede the delineated bay.

Parking at the beginning of the ERA in particular is considered to endanger the parked motorist and hinder emergency vehicle access. When comparing the stopping positions across the ERAs, the Standard ERA performed worst in that a larger proportion of participants parked not only at the beginning of the ERA, but also closer to the road side. From a road safety perspective, alternative ERA designs would therefore be preferable. The Revised ERA appears to be the most robust design ensuring correct parking positions under daytime conditions. Future research might benefit from evaluating the Revised ERA under night-time conditions.

Regarding the Unlit ERA, a high percentage (78%) of participants parked the vehicle in the correct location. However, the ERA design appeared to have a significant shortcoming in that 4 out of 36 participants (11%) failed to stop in the dedicated ERA

altogether despite being instructed to bring the vehicle to a halt in the upcoming ERA. Based on the assumption that the failure to use the ERA could be ascribed to reduced ERA visibility, the use of completely unlit ERAs therefore appears not to be advisable. Failure to use the ERA might lead to motorists having to park on LBS1 (i.e. hard shoulder) thereby compromising road safety and network performance.

As a consequence of the limited acceleration space available in the Small ERA, driving speed upon re-entering the motorway was found to be significantly lower when leaving the Small ERA in comparison to the other ERA designs. This, in turn, may negatively affect road safety and network performance in the light of the higher speed differential.

Subjective comments indicated that problems re-entering the motorway were not unique to the Small ERA. Overall, participants expressed great concern about re-entering the motorway. They indicated the ERAs in general to be too small to pick up speed and safely rejoin the traffic at the motorway.

Finally, a large number of participants indicated the advanced warning signs indicating the presence of the ERAs to be positioned too close to the ERAs. Participants expressed a preference for signs further in advance of the ERA.

Safety interpretation

The study of ERA use has revealed several potential safety issues. Many of these are associated with the use of ERAs in general rather than the particular design itself. Specific concerns are as follows:

- In the Unlit ERA condition, 11% of participants failed to stop the vehicle in the following ERA and had to travel to next one downstream. This might mean that during hours of darkness, a driver whose vehicle has broken down may not be able to reach an ERA at all, thus obstructing Lane Below Signal 1 (LBS1).
- In the simulation, participants had sufficient time to move into LBS1 before parking the vehicle within the ERA. It would be desirable to consider how easily the various ERA designs might be to use under conditions of complete breakdown whilst the vehicle is not driving in LBS1.
- Some drivers stopped very close to the edge of the LBS1 lane with all the designs and may have partially obstructed that lane. It is to be hoped that this is an artefact of the simulation and that this would not occur in real traffic conditions.
- The rear headways when vehicles rejoin LBS1 vary somewhat between designs but the overall mean value is about 60 m. Given that the speed at which a car rejoins is only about 25 mph, this will require a following vehicle to brake or change lane. These figures are mean values for car drivers. The relative speed differential seems likely to be greater if an HGV is accelerating from the ERA (though presumably if the reason for stopping is the occurrence of a genuine breakdown, then the HGV would be assisted in some way to exit from the ERA, either by a towing truck or by closure of the LBS1). It would perhaps be useful to conduct a new simulator trial where a simulated car (or an HGV) leaves an ERA with typical speeds and headways, to discover how a participant would respond whilst driving on the LBS1.
- Related to the above is the speed at which the participants rejoined the LBS1 which had a mean of at least 25 mph for all of the designs except the Small ERA for which the mean speed was only 22 mph.
- There is also the further issue of the ease with which HGVs which are in the process of breaking down can negotiate safe entry to the ERA. Clearly, it was not possible to test this using the car driving simulator.
- The Small ERA will have the capability of holding one articulated HGV only. Any other vehicle would need to travel on to the next ERA or stop on the LBS1. A

further possible occurrence is that the second vehicle attempts to enter the ERA but cannot fully do so, thus partially obstructing the LBS1. There is also the issue of how a second vehicle entering an ERA can leave it if there is another stationary vehicle ahead.

- In summary, from a safety point of view, it seems preferable that the ERA be lit and be of the Revised design.

  The Revised design showed the following benefits in daylight conditions which seem likely to improve safety:

  - Lowest maximum brake force
  - Highest speed on entering
  - Fewest number of times participants stopped within the ERA after first accelerating on exit
  - Highest speed on returning to the running lanes

  The Low lit ERA showed the following benefits which seem likely to improve safety:

  - Lower maximum brake force
  - Higher speed on entering the ERA
  - Fewer number of times participants stopped within the ERA after first accelerating on exit

  However, the relative safety of the various designs remains unclear. Bearing in mind that there is already considerable misuse of ERAs and of motorway hard shoulders for non-emergency stops, the easier ERAs are to use, the more likely they will be misused. This may mean that safety would be improved if they were Unlit and were Small.

  For those who break down, the combination of the Revised design with lighting may be seen as some compensation for their loss of the provision of the normal hard shoulder.

Network performance interpretation

To maximise network performance, any effects that would reduce capacity should be minimised. Once in an ERA, a vehicle will have little or no effect on capacity. A reduction in capacity could occur as a vehicle entered or left an ERA:

- The design of the ERA has a small effect on vehicle behaviour as it enters an ERA, with braking levels being higher for the Small and Unlit ERAs. This might cause braking from following vehicles, but this is unlikely to cause flow breakdown unless there are high flows, with the motorway running at capacity.

  With the exception of Unlit ERAs under night-time conditions, there is no evidence that vehicles would be unable to stop in an ERA, and be forced to stop on the hard shoulder instead.

  Therefore, the design of the ERA is unlikely to have a significant impact on network performance when a vehicle enters an ERA.

- Drivers found it difficult to leave an ERA, and the speed upon rejoining was lower for the small ERA. This might cause braking from vehicles already using the hard shoulder, but this is unlikely to cause flow breakdown unless there are high flows, with the motorway running at capacity.

  The capacity would be significantly reduced if a driver felt unable to leave an ERA safely. It would then be necessary to close the hard shoulder to enable the

vehicle to rejoin the carriageway. In the ERA simulator study, all drivers were able to leave the ERA, although some had to make several attempts to do so (five attempts being the maximum). It might be that in real life, one or more of these drivers would have been unwilling to take the risk of leaving the ERA onto a live hard shoulder. This would be most likely to occur with the small ERA, but would also depend on the lighting and the available line of sight.

Conclusions

- ERA location (i.e. between or within a junction) did not affect driving behaviour and subjective evaluations of the ERAs
- ERAs located within junctions are unlikely to introduce road safety and network performance concerns beyond those associated with ERA use in general
- Participants were more cautious entering the Small and Unlit ERA as indicated by lower approach and entrance speeds
- Specific ERA designs affected the number of participants parking in the correct location within the ERA
- Highest percentage of correct parking positions were observed for the Small and Unlit ERA
- Most undesirable parking positions were observed in the Standard ERA
- Hatchings provided an effective means to modify parking behaviour within ERAs
- Use of Unlit ERAs is not advisable as motorists may not be able to locate them in time
- Speed upon re-entering the motorway from a Small ERA is significantly lower
- Great concerns were expressed about re-entering the motorway irrespective of ERA design
- ERAs were considered too small to pick up speed and safely rejoin the traffic at the motorway
- A trade-off is created between safe use of ERAs and road safety implications of ERA misuse: ERAs that are harder to use might compromise safe use but avoid misuse
- ERA design is unlikely to have a significant impact on network performance when a vehicle enters an ERA
- Network performance may be significantly affected upon closure of the hard shoulder to enable a vehicle to rejoin the carriageway

1 Introduction

1.1 Emergency Refuge Area

Greater use of the hard shoulder as an active running lane places increased pressure on use of the Emergency Refuge Areas (ERA) as safe havens in the event of a vehicle breakdown.

Considering current proposals to extend hard shoulder running within junctions, i.e. Through Junction Running (TJR), this study investigates drivers' response and subjective evaluation of ERAs positioned both between and within junctions. In particular, TJR is considered to operate at 70mph which may have implications for road safety, i.e. drivers' ability to safely rejoin the motorway.

The Highways Agency's objective is to create an intra-junction ERA that is less attractive as a non-emergency stopping point. This is because more than 80% of ERA use is non-legal and non-emergency with a commensurate increase in exposure to risk.

In addition there is evidence that stops can occur in the wrong place within ERAs which may have consequences for emergency vehicle access as well as the ability to leave the ERA safely and rejoin the carriageway.

To discourage inappropriate ERA use, as well as to modify the stopping position within ERAs, a number of ERA design considerations have been identified including ERA lighting conditions and ERA designs. The aim of this study was to evaluate the effect on driver behaviour of four ERA design modifications which are listed below (for further details see section 2):

1. Low lit ERA at unlit motorway (night drive)
2. Unlit ERA at fully-lit motorway (night drive)
3. Small ERA format
4. Revised ERA design

Each of the four designs was evaluated compared to a current standard ERA with the ERA located either between or within junctions.

To this purpose, simulated breakdown scenarios were created requiring drivers to stop in an ERA. This allowed for the evaluation of drivers' ability to exit the motorway and drivers' stopping position within the intra-junction ERA. By repairing the simulated fault, drivers were subsequently asked to rejoin the carriageway which in turn allowed for the evaluation of factors such as gap acceptance and speed choice. In the light of the 70mph intra-junction[1] speed limit, drivers' ability to enter into live traffic travelling at 70mph was evaluated.

1.2 Roof-bar lighting

A further aim of this study was to investigate the safety case for different roof-bar lighting configurations on Traffic Officer Service vehicles. The vehicles currently display flashing amber lights when required (for example, whilst stationary on the hard shoulder). This study investigated driver behaviour in response to different configurations in simulated night-time driving conditions[2]. Note that the roof-bar lighting trial formed part of a bigger study into behavioural responses to Traffic Officer Service vehicle roof-bar lighting configurations. Consequently, the results obtained in the present

[1] It is assumed that the maximum speed limit is 70mph for all lanes within a junction, except when signals are set for congestion and/or incident management (see "Managed motorways implementation guidance - Through junction hard shoulder running").
[2] Note that drivers' response to the TO vehicle was evaluated in the night-time condition only. Daytime conditions were evaluated in the Through Junction Running study.

study will not be reported here but can be found in a separate TO Service vehicle configuration report.

2 Methods

2.1 Participants

Seventy-two participants were recruited from the TRL participant database to take part in this study. All participants had previously been familiarised with the TRL driving simulator and all possessed a current valid driving licence. There were no particular inclusion/exclusion criteria based on previous experience of hard shoulder use.

Driving behaviour across the age range varies considerably (e.g. Schlag, 1993). Younger drivers tend to drive at faster speeds and are more likely to engage in lane-changing behaviour compared to older drivers. Consequently, there were two levels of age across participants. An equal number were recruited to the younger (17-44 yrs) and older (45+ yrs) groups and there were an equal number of males and females in each age group.

2.2 Experimental design

Following an initial familiarisation drive to acquaint them with the controls of the vehicle and allow them to settle down to normal behaviour in the simulated environment, the design required each participant to undertake three drives in the simulator for a period of around 10 minutes each. Each participant session lasted for one hour, and included introduction, familiarisation and debriefing. The breakdown of participants across the different ERA designs and positions (i.e. between- or within-junction) is shown in Figure 6.

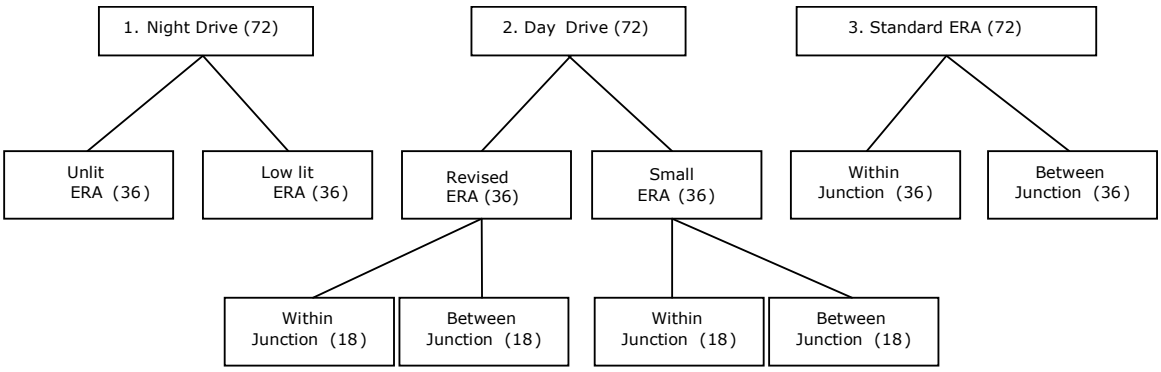

Figure 6: Breakdown of participant groups

1. In the night drive, all (72) participants were required to stop the vehicle in a between-junction ERA.

   Unlit: Half (36) the participants encountered an ERA that was unlit at an otherwise fully-lit motorway. This ERA is referred to as 'Unlit' and is shown in the top part of Figure 7[3].

   Low lit: The other half (36) encountered an ERA that was lit at a low level with the motorway unlit. This ERA is referred to as 'Low lit' and is shown in the bottom part of Figure 7. The lighting design used for the low lit ERA was based on the "Orus" range as manufactured by "Thorn", specifically designed for low level road lighting to reduce glare. Further details can be found in Appendix 1.

[3] Note that the image characteristics (e.g. luminance, contrast, hue, saturation) of the Figures do not exactly correspond to the projections in the driving simulator.

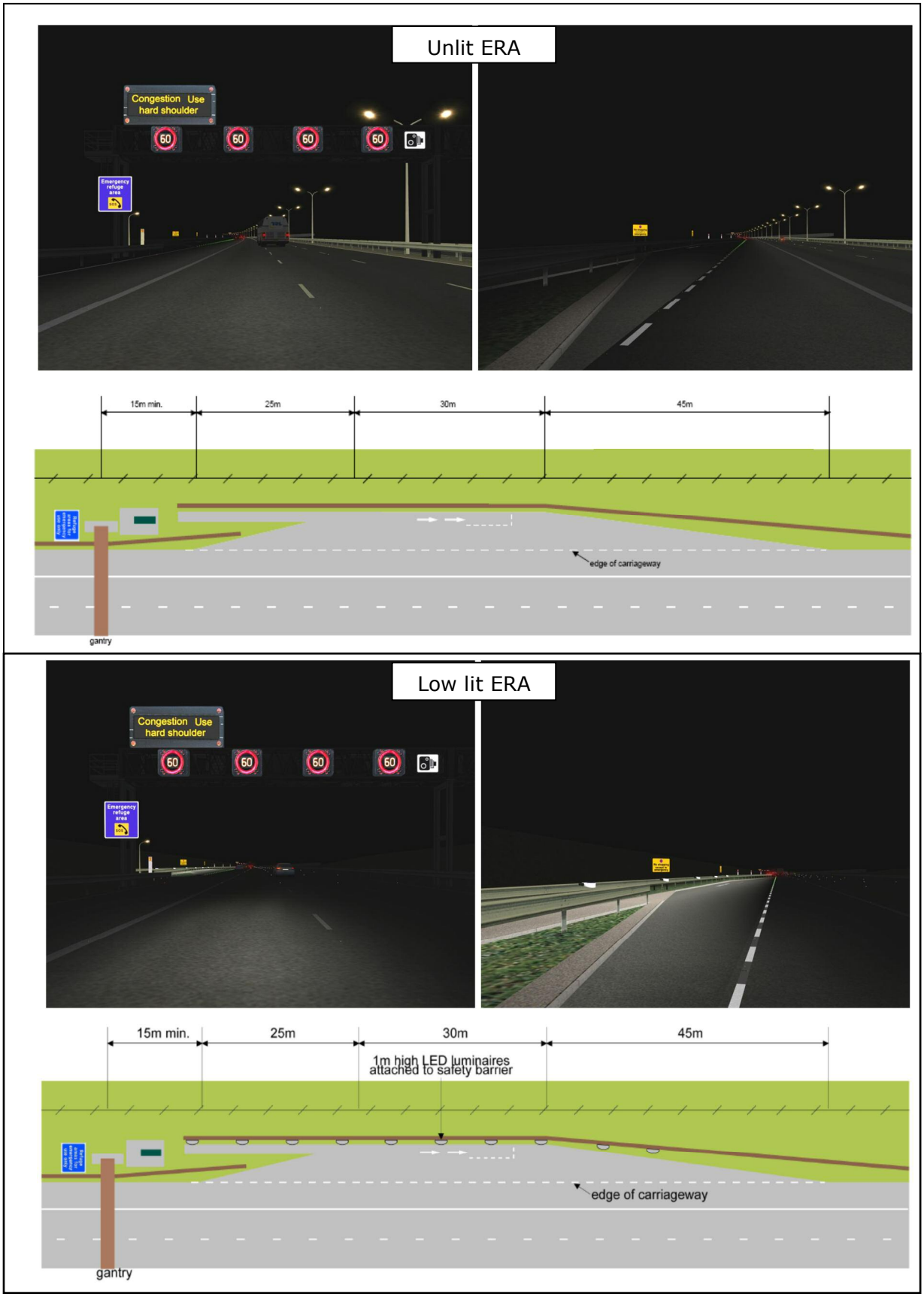

Figure 7: Unlit ERA (Top) and Low lit ERA (Bottom) on approach (left) and upon entering (right). Diagram for each ERA design are shown below the screenshots.

2. **Revised:** In the day drive, half (36) the participants were required to stop the vehicle in an ERA equipped with new line markings and telephone position. This ERA is referred to as 'Revised' and shown in Figure 8.

   Small: The other half (36) was asked to use a shortened or small ERA. This ERA is referred to as 'Small' and shown in Figure 9.

   Within each of these two participant groups, half (18) the group stopped in a within-junction ERA, whereas the other half (18) stopped in a between-junction ERA.

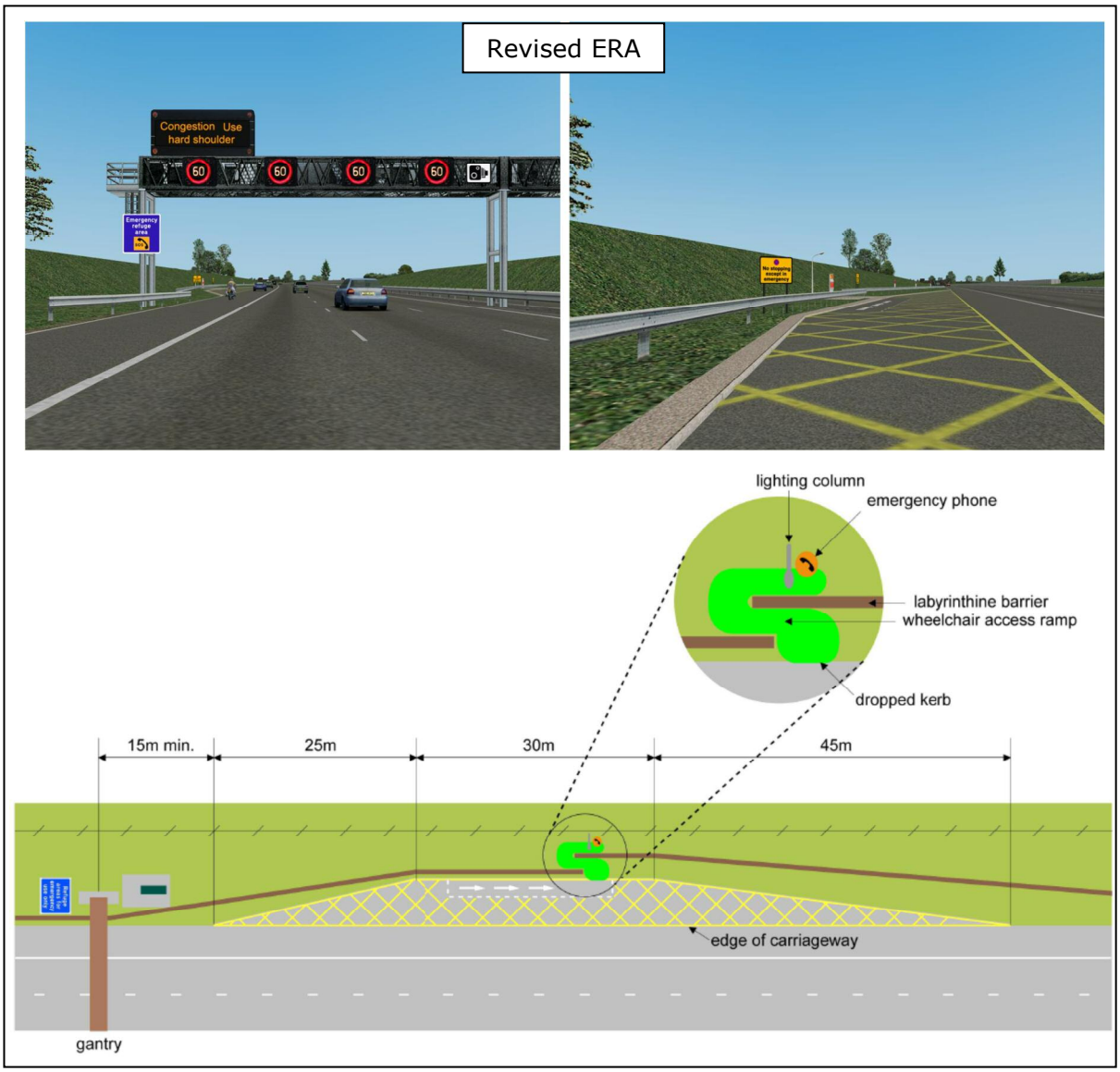

Figure 8: <u>Revised</u> ERA on approach (top left) and upon entering (top right). Bottom: Diagram of the Revised ERA design.

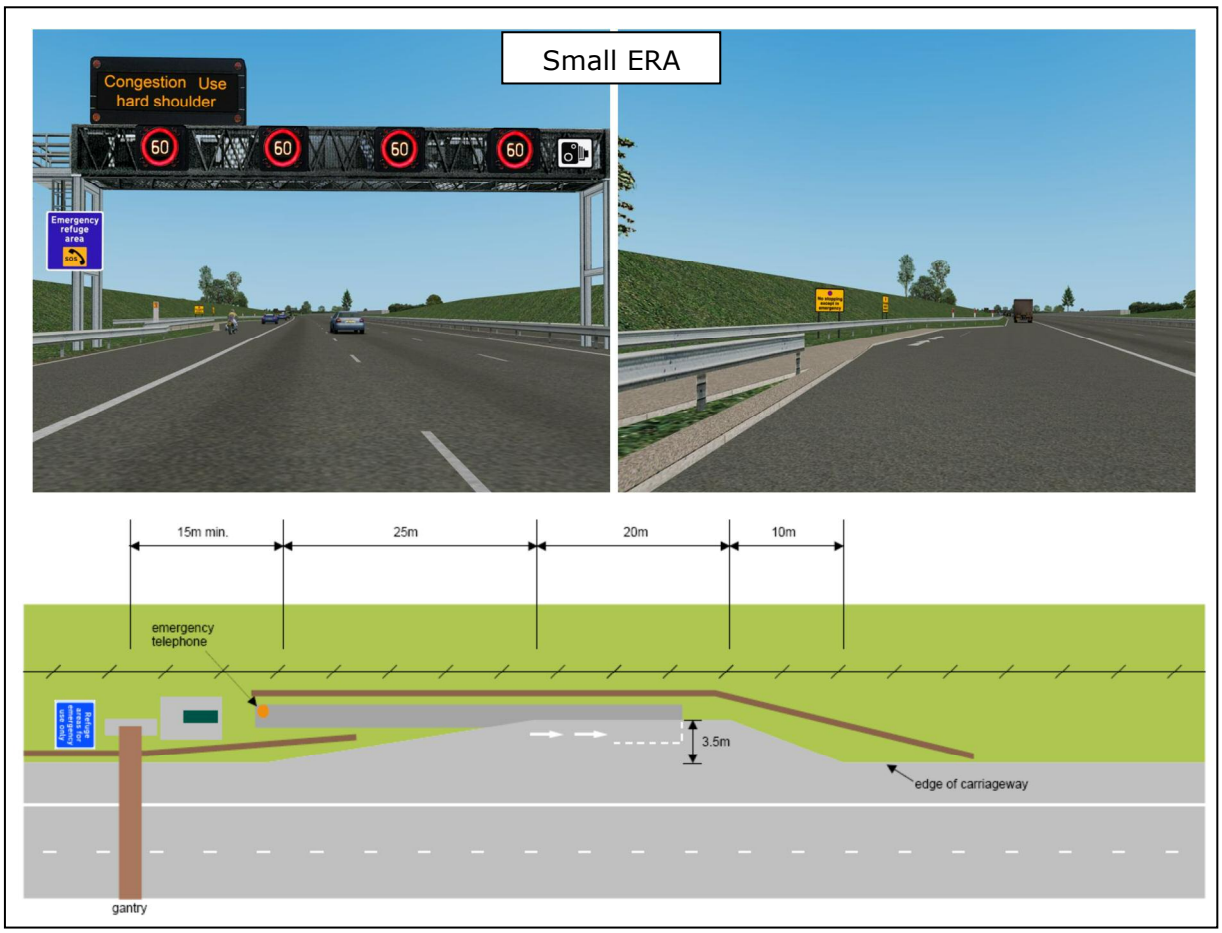

Figure 9: <u>Small</u> ERA on approach (left) and upon entering (right). Bottom: Diagram of the Small ERA design.

3. **Standard:** In the standard ERA drive, half (36) the participants stopped in a within-junction ERA, whereas the other half (36) stopped in a between-junction ERA. The 'Standard' ERA is shown in Figure 10.

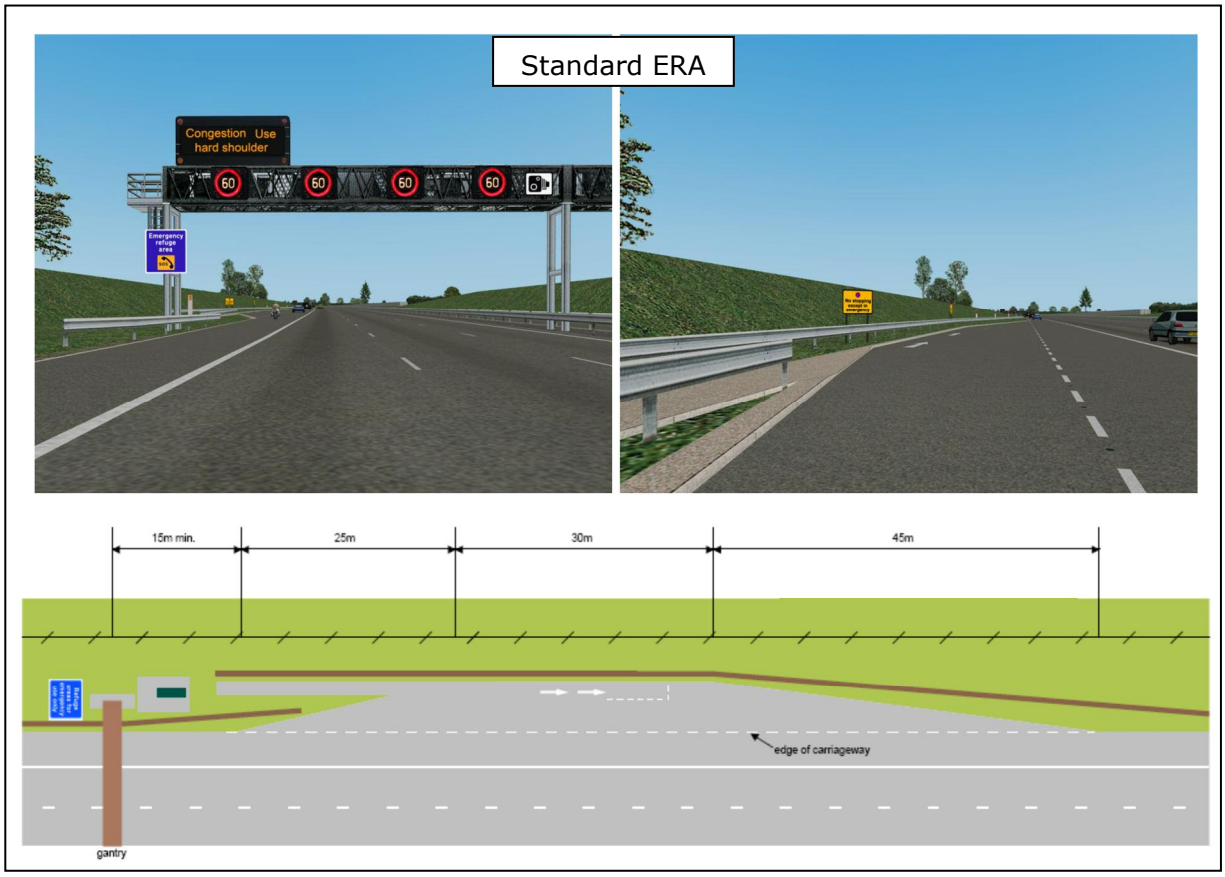

Figure 10: <u>Standard</u> ERA on approach (left) and upon entering (right). Bottom: Diagram of the Standard ERA design.

For each of the ERA designs, there were no differences between ERAs located either within- or between-junctions with respect to dimensions, line of sight, or curvature of the motorway.

2.3 Trial procedure and instructions

On the trial day, the first part of the trial session was a stretch of motorway which allowed the participants to re-familiarise themselves with the driving simulator and to get used to driving at normal motorway speeds. Participants were given standard instructions before driving the simulator. They were told to 'drive as you normally do' and that their 'driving is not being judged'. They were also told that they 'should not treat the simulator like a computer game'.

Following the familiarisation drive, participants were briefed regarding the purpose of ERAs. They were informed about Hard Shoulder Running and the role of ERAs within such schemes. Note that no reference was made as to the correct use of ERAs in terms of stopping position and correct behaviour regarding rejoining the motorway.

They were told that during each of the drives they would experience a vehicle breakdown requiring them to bring the vehicle to a halt in the nearest ERA possible. To avoid unnecessarily inducing stress on behalf of the participants, they were told that the vehicle breakdown would not affect the driver's ability to control the vehicle (e.g. the breakdown would be running out of petrol or a complete engine failure).

Vehicle breakdown was indicated by a voice command instructing the driver to park the vehicle in the upcoming ERA which, depending on condition, was located either within or between a junction. The voice command was delivered 1000 metres in advance of the upcoming ERA. If for some reason, the participant failed to park the vehicle in the designated ERA, no other voice instruction was played.

After the participant had brought the vehicle to a halt and had switched off the engine, following a 7 seconds gap, a further voice command informed the participant that the engine fault was repaired and that he/she should rejoin the motorway again when safe to do so.

All participants began the trial in LBS1 of the motorway and were instructed that they must leave the motorway at junction 4. 800m in advance of junction 4, a voice command instructed participants to leave the motorway at the next exit. As they entered the designated motorway off-slip they were instructed that they had reached the end of the trial and that they may bring the vehicle to a stop. This completed the simulated drive.

2.4 Route design

General features

The road was 32km of a 4-lane motorway with hard shoulder running available (but only open to traffic on some sections). The road layout, signage, and lane markings in the route were based on Highways Agency documents, '*Managed Motorway Implementation Guidance – Dynamic use of the hard shoulder*' (Highways Agency IAN111/08) and '*Managed Motorway Implementation Guidance – Through junction hard shoulder running*' (Highways Agency IAN112/08).

The motorway surroundings were generic with fields and trees. There were some bridges going across the motorway and junctions were included.

Where heavy traffic conditions are specified, each autonomous vehicle within the simulation was programmed to follow the vehicle ahead as closely as possible. Whilst this creates a high density of traffic, there do remain gaps between vehicles into which it is possible to drive the simulator vehicle.

Route summary

Table 1 summarises the sections that drivers experienced through the trial.

Table 1: Summary of the sections within the ERA simulator trial.

Section	Brief description
Lead-in	Familiarisation; heavy traffic; HS open
Junction 1	TJR @ 60mph
Section A	Heavy traffic, 3 normal lanes open; HS open. Depending on assigned condition, ppt stops at *between*-junction ERA and rejoins m/way
Junction 2	TJR @ 70mph Depending on assigned condition, ppt stops at *within*-junction ERA and rejoins m/way with traffic travelling at NSL
Section B	Heavy traffic, 3 normal lanes open; HS open
Junction 3	TJR @ 70mph
Section C	Heavy traffic, 3 normal lanes open; HS closed. TO vehicle parked on hard shoulder
Junction 4	Ppt exit motorway. End of simulator drive

This information is presented in Figure 11.

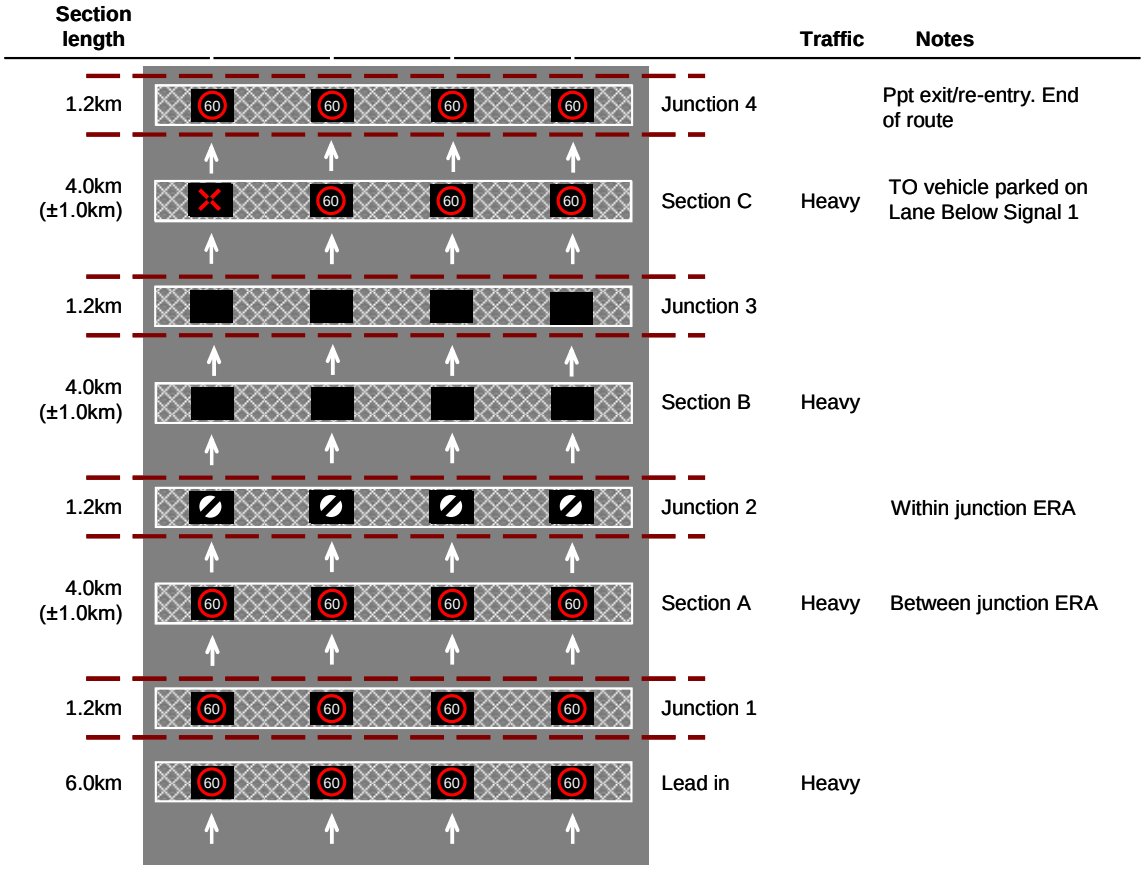

Figure 11: Schematic plan of the simulator scenario

2.5 TRL Driving Simulator – CarSim

TRL's full mission, high fidelity driving simulator was used for this study. This consists of Honda Civic (2002) cabin surrounded by display screens onto which are projected the graphic images that represent the external environment to the driver (see Figure 12).

Figure 12: TRL's driving simulator, CarSim.

All the controls operate as would be expected in a comparable real vehicle. The simulator has a motion system that can provide representation of the acceleration forces that a driver would experience in a real vehicle for three axes of motion (heave, pitch and roll).

2.6 Measures of interest

To evaluate participants' driving behaviour in response to the different ERA designs, various measures of interest were considered and are summarised in Table 2.

Table 2: Measures of interest for an ERA

Measures:
Stopping position
Approach speed
Braking profile
Time to re-enter motorway
Gap acceptance at motorway re-entry (rear-headway)
Speed at motorway re-entry

3 Results

3.1 Driving behaviour results

3.1.1 Speed profile

Figure 13 shows the speed profile on the approach and entrance into the ERA and when rejoining the motorway after the simulated breakdown, for each of the ERA designs4. As can be seen, the speed profiles are not differentiated according to the location of the ERAs (between-, within-junction). This is because initial analyses indicated no consistent or significant differences in the speed profiles as a function of ERA location (see Appendix 4).

Figure 13 shows the speed profiles for the different ERAs to be very similar, with the exception of the Small ERA. As expected, the speed profile for the Small ERA differs from the other ERA designs: participants brought the vehicle to a halt sooner, and accelerated sooner and faster to rejoin the motorway. This was because the Small ERA was only 55m long requiring faster acceleration to accommodate the traffic upon rejoining the motorway.

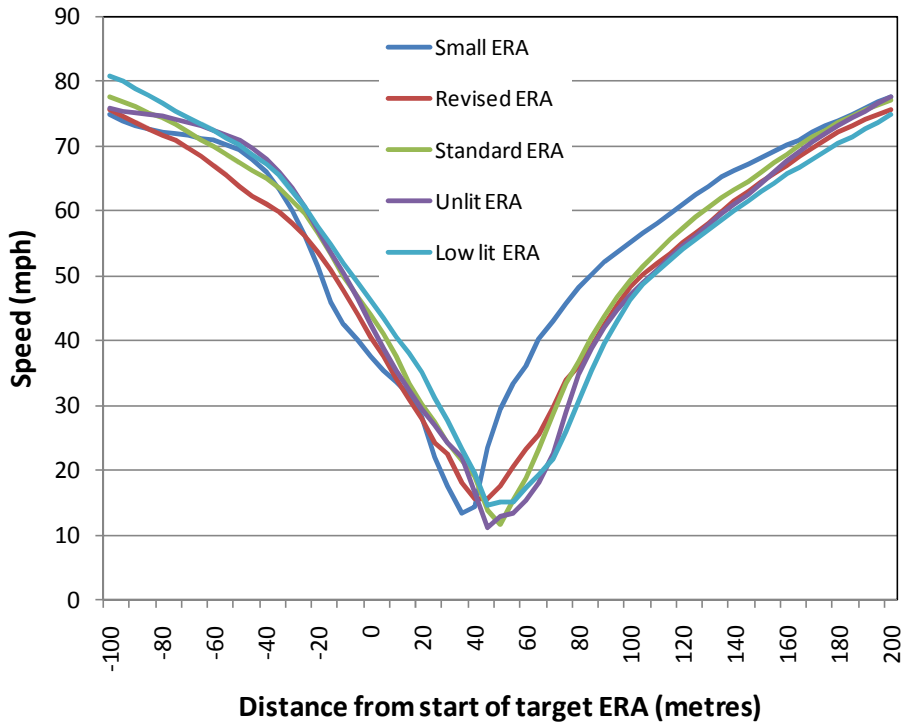

Figure 13: Speed profile on approach to and upon rejoining the motorway from each ERA

3.1.2 ERA approach speed

Figure 14 shows the average Time-Distance graphs for each of the five ERA designs on approach and entering the ERAs. A horizontal line represents a stationary vehicle, and a steeper gradient represents a faster vehicle speed.

[4] Note that the average speed did not reach zero despite the fact that all participants came to a complete halt within the ERA. The reason for this is that the stopping positions were spread across the whole area of the ERA.

The graph shows that the average is very similar for all ERA designs with the exception of the Small ERA. For the Small ERA, the average approach speed is lower and the average stopping position is earlier than all other designs, as expected. The average stopping position of the Revised ERA is earlier than the other three remaining designs.

The graph further suggests that the average approach speed 20m before the ERA is marginally higher for the Unlit ERA compared to the Low lit ERA. This may be because participants saw the ERA earlier and more clearly in the Low lit scenario.

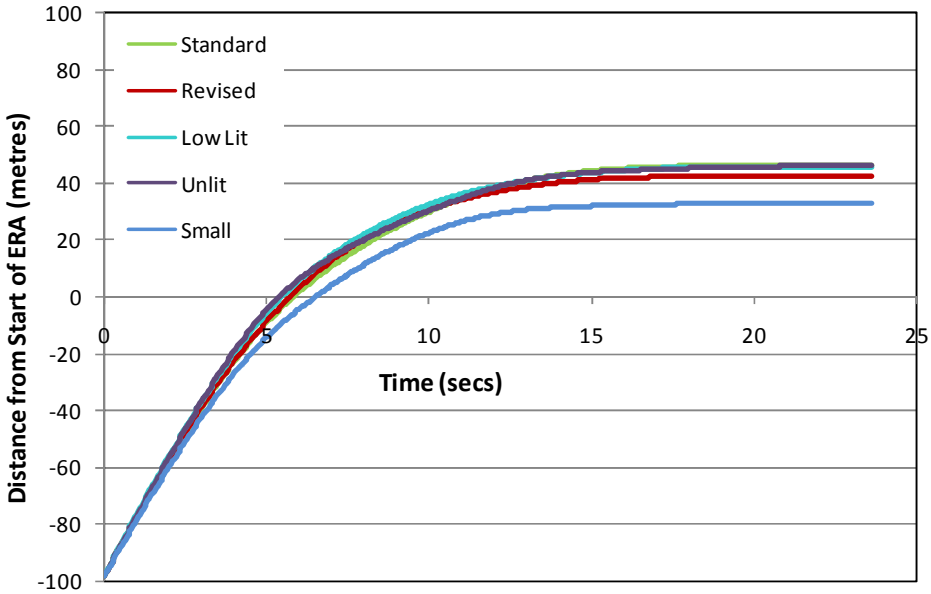

Figure 14: Average Time-Distance graph on approach and entering of each ERA

3.1.3 Braking profile

Figure 15 shows the mean braking profile across participants on approach and entrance to the ERA for each of the ERA designs. Braking force was measured as a relative value and ranged from 0-1, where 0 represents no brake pedal application and 1 represents maximum brake pedal application. As for the speed profile (see 3.1.1), the braking profiles are not differentiated according to the location of the ERAs (between-, within-junction) since initial analyses indicated no consistent or significant differences in the braking profiles as a function of ERA location (see Appendix 5).

In Figure 15 it can be seen that the braking profile for the Small and Unlit ERA differed when compared to the other ERA designs. A considerably later and sharper braking level was observed for participants approaching the Small and Unlit ERA. The Revised, Low lit and Standard ERA showed a very similar braking profile.

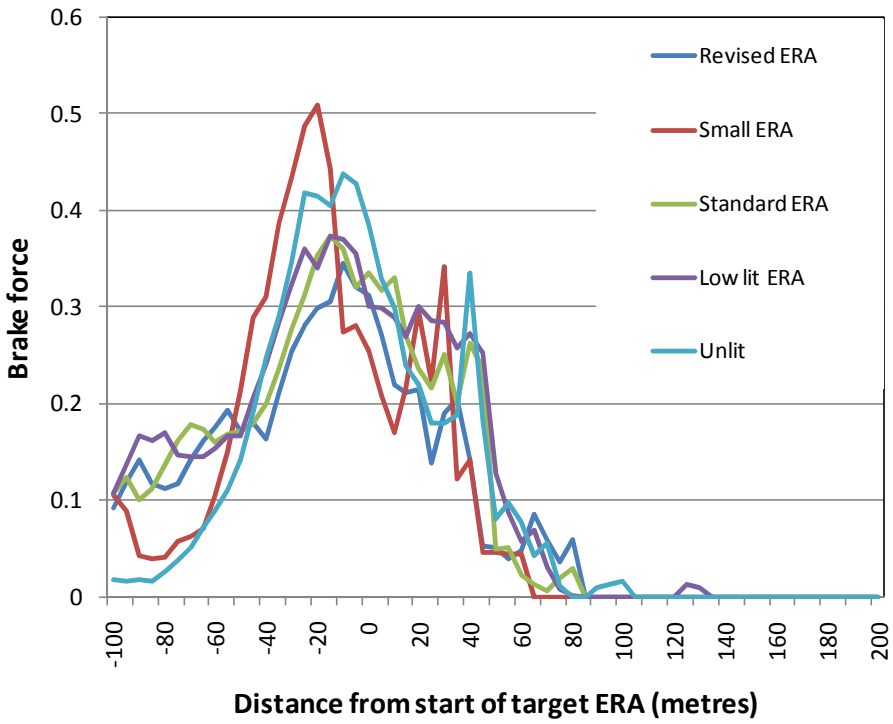

Figure 15: Brake force applied upon approach and entrance into each ERA. Brake force values range from 0-1

Maximum braking force: Figure 16 shows the maximum braking force applied within 100m preceding the start of the ERA and entrance to the ERA. It can be seen that highest braking forces were applied in the Unlit and Small ERAs, with the smallest braking force applied in the Revised ERA. A statistical analysis of variance indicated no significant effect of ERA on maximum braking force ($F(4,199)=2.181$, $p=.072$).

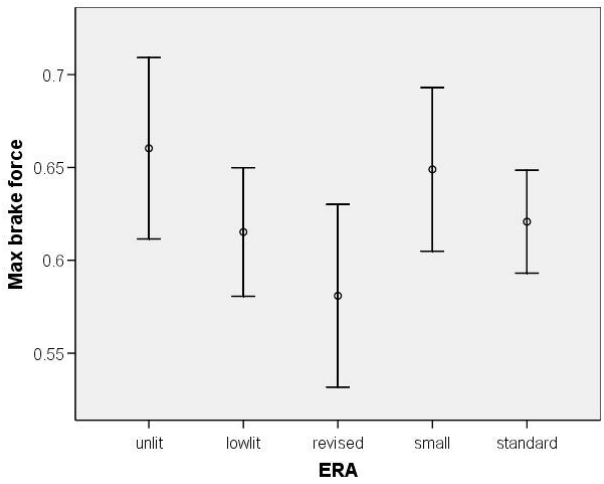

Figure 16: Maximum brake force (range = 0-1) within 100m preceding the start of the ERA and entrance to the ERA. Error bars indicate the 95% confidence interval of the mean (95% CI)

Maximum braking force distribution: Figure 17 shows the frequency distribution of the maximum force applied as a function of distance from the ERAs. It can be seen that

in the standard, Revised, and Unlit ERA, most participants applied maximum braking force approximately 10 metres into the ERA. In the Small and Low lit ERA, on the other hand, participants tended to apply maximum braking force earlier, approximately 10 metres in advance of the start of the ERA.

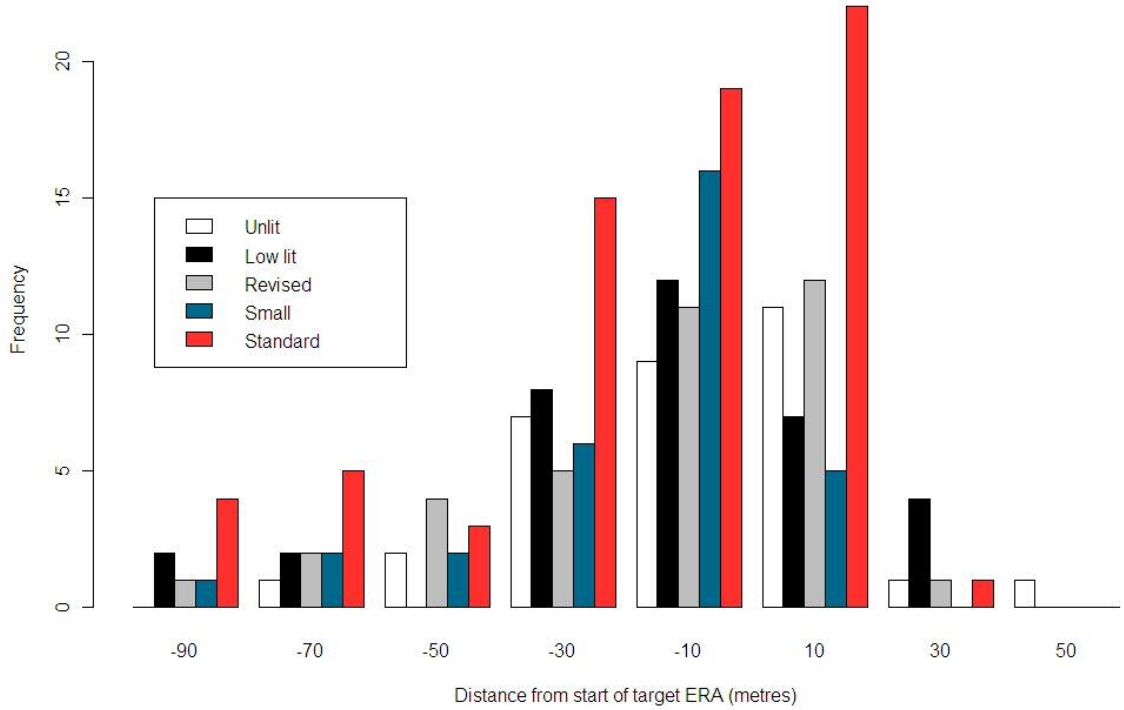

Figure 17: Frequency distribution of applied maximum brake force as a function of distance from the ERAs

3.1.4 Speed upon entering ERA

When comparing the speed upon entering the ERA between the different ERA locations (i.e. between- and within- junctions), again, no significant differences were observed as a function of ERA location. In the subsequent analysis, the different ERA designs were therefore evaluated without reference to ERA location.

Figure 18 shows the mean speed upon entering each of the five ERAs. When compared to the Standard ERA, participants tended to enter the Small and Unlit ERAs at lower speeds, whereas the speed upon entering the Low lit and Revised ERAs tended to be slightly higher. However, these differences were not found to be statistically significant ($F(4,199)=1.779$, $p=.134$).

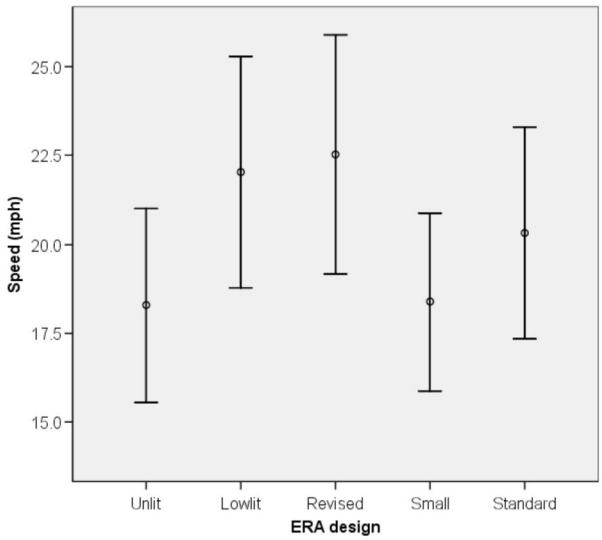

Figure 18: Speed (mph) on entering each ERA (95% CI)

3.1.5 Stopping position

Analysis of stopping position indicated no significant differences in X and Y positions for within- and between-junction ERAs. Therefore, the following results are presented for the five ERA designs without further reference to ERA location.

Figure 19 shows the stopping positions (X and Y coordinates) of the vehicle in each of the five ERA designs. Note that the stopping position refers to the position of the rear axle of the simulator vehicle. For reference, the distance from the rear axle to the front of the car was 2.45m.

Correct parking location was defined as the area within the dashed parking area with a total length of 10m from the top of the area (i.e. area between metre 40 and 50. For the Small ERA correct parking position refers to the area between metre 40 and 30). The highest number of participants parking in the correct location was observed in the Unlit (78%) and Small ERA (75%). In the other ERA designs, approximately 60% of the participants parked in the correct location.

With regard to the Unlit ERA, the vast majority of participants (78%, see Table 4) stopped in the correct position. However, one participant stopped before the start of the ERA on LBS1 and turned off the ignition. The participant's behaviour was sufficiently atypical to warrant subsequent exclusion of the participant's data from the statistical analysis.

An important finding was that in the Unlit ERA condition, 4 out of 36 (11%) participants failed to stop the vehicle in the ERA and stopped the vehicle in the following ERA instead. In none of the other ERA designs did participants fail to stop in the dedicated ERA.

It can further be seen that in the Small ERA design, one participant parked the vehicle on the verge beyond the ERA. This participant was found to drive unusually erratically and was subsequently also excluded from the statistical analysis.

In the Standard ERA, there were a larger number of participants parking the vehicle 1) near the road side, and 2) in the first half of the ERA when compared to the other ERAs.

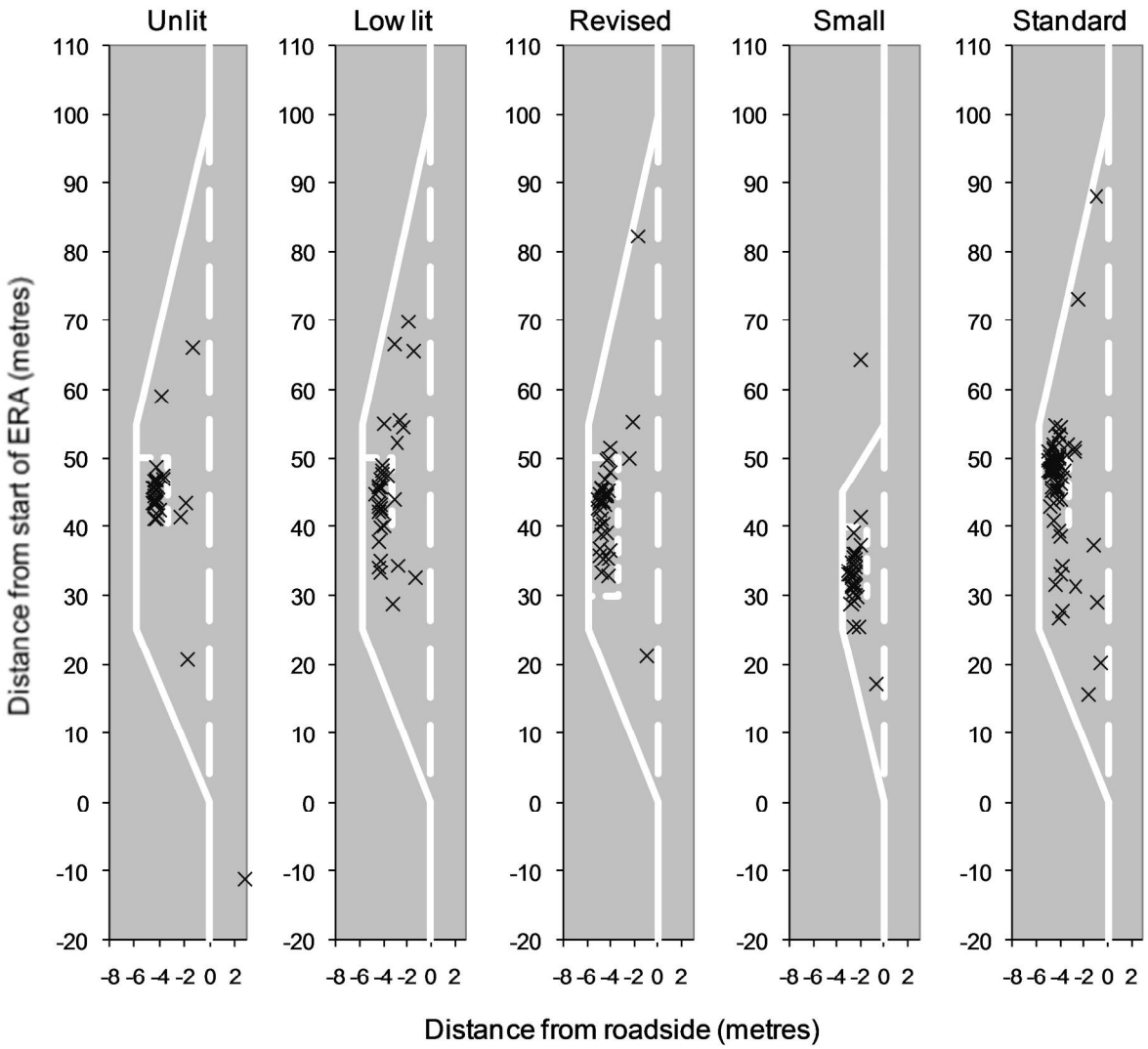

Figure 19: Stopping positions in each ERA. Stopping positions refer to the position of the rear axle of the simulator vehicle. Distance from the rear axle to the front of the car was 2.45m

With regard to variability in parking position, the graphs in Figure 19 suggest the variability to be smaller in the Unlit, Revised and Small ERA. To statistically evaluate the differences in variability, Levene's Tests for Equality of Variances were performed for X and Y positions separately. Meaningful comparisons with the Small ERA were not possible considering its dimensions and the small ERA was therefore excluded from the analysis. Results of the analyses showed no statistically significant differences in parking position variability with regard to X positions between the Unlit, Low lit, Revised, and Standard ERA. Unlike the X positions, variability in Y positions was significantly higher in the Low lit ERA compared to the Unlit, Revised, and Standard ERA ($p<.05$, Levene's test).

To compare the mean stopping positions in the different ERAs statistically, the X and Y positions were compared between the Unlit, Low lit, Revised and Standard ERA. Again, meaningful comparisons with the Small ERA were not possible considering its dimensions. The small ERA was therefore excluded from the analysis. Table 3 shows the mean X and Y coordinates of the stopping positions within each of the ERAs. ERA design was found to have a significant effect on the X coordinates of the stopping position ($F(3,176)=3.966$, $p=.009$). Post-hoc analysis indicated that participants parked

significantly closer to the roadside in the Low lit ERA compared to the Revised and Standard ERAs (Tukey's HSD, $p < .05$). Table 3 also shows that in the Standard ERA, participants parked the vehicle further into the ERA. However, these differences were not found to be statistically significant ($F(3,176)=1.109$, $p=.347$).

Table 3: Mean X and Y coordinates of the stopping positions in the ERA designs

ERA design	X-coordinate	Y-coordinate
Unlit	-4.60	45.71
Low lit	-4.23	44.65
Revised	-4.93	43.62
Standard	-4.78	46.62

Table 4 shows the percentage of participants parking in the correct location within each ERA. Again, the correct parking location refers to the area within the dashed parking area with a total length of 10m from the top of the area (i.e. area between metre 40 and 50. For the Small ERA correct position refers to the area between metre 40 and 30). The highest percentage correct was observed in the Unlit and Small ERA. In the other ERA designs, approximately 60% of the participants parked in the correct location. Note that for the Revised ERA, the vast majority parked the vehicle in the un-hatched area. When considering this to be the correct parking location for the Revised ERA, the percentage rose to 83%.

Table 4: Percentage of participants parking the correct location within each ERA

ERA	Percentage of participants parked in correct location
Unlit	78%
Low lit	57%
Revised	58%
Small	75%
Standard	57%

3.1.6 Total time spent in ERA

Initial analysis considered any differences in the total time spent in the ERA as a function of ERA location. Again, no consistent or significant differences were observed with regard to ERAs positioned either between- or within- junctions. Hence, in the following, the data are presented collapsed across ERA location.

Figure 20 shows the mean total time spent in each of the five ERAs. As can be seen, in both the Unlit and Low lit ERA (i.e. night drive), participants tended to stay in the ERA for a longer period of time when compared to the other ERAs. However, the diference failed to reach statistical significance ($F(4,199)=2.304$, $p=.06$).

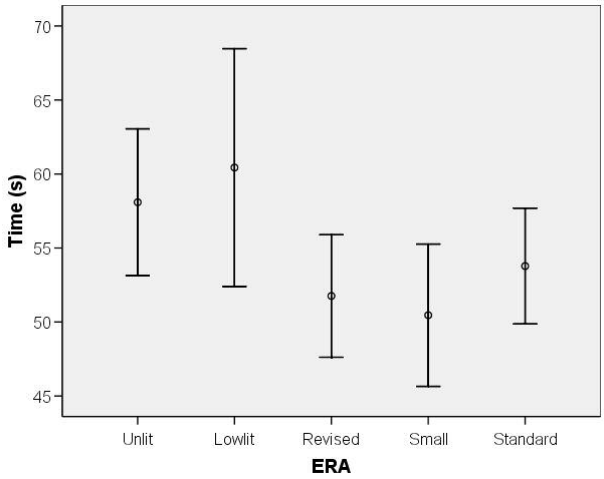

Figure 20: Mean total amount of time (s) spent in each of the ERAs (95% CI)

3.1.7 Number of exit attempts

Figure 21 shows the average number of times participants stopped within the ERA after first accelerating to leave the ERA. This measure can be interpreted as an indication of participants' confidence or hesitance to leave the ERA and rejoin the motorway. For example, a value of two would indicate that a particular participant brought the vehicle to a complete halt twice within the ERA before rejoining the motorway.

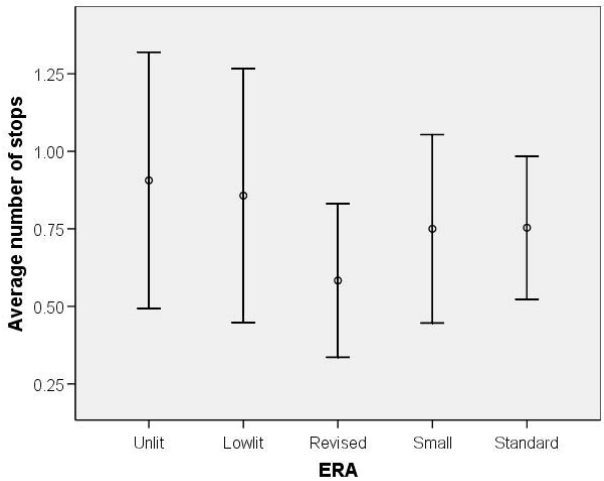

Figure 21: Average number of times participants stopped within the ERA after first accelerating on exit (95% CI)

The figure shows that, on average, the number of times participants stopped within the ERA was highest under night time conditions (Unlit and Low lit ERA). With the Small and Standard ERAs showing intermediate values, the lowest number of stops was observed in the Revised ERA. The latter finding might, at least partly, be explained by the fact that a larger proportion of participants stopped the vehicle closer to the beginning of the ERA and subsequently had more space to accelerate upon exit. This interpretation is also in

line with the finding that the average Y position was smaller for the Revised ERA (see Table 3). A statistical analysis of variance however indicated that this trend was not significant (F(4,199)=.553, p=.697).

3.1.8 Rear headway

Headway refers to the distance in space that separates two vehicles traveling the same route. With regard to the current study, rear headway refers to the headway between the simulator vehicle (i.e. participant) and the vehicle approaching from the rear in LBS1 at the time the participant exits the ERA and rejoins the motorway.

Table 5 shows the decriptive statistics of the rear headway in metres for each of the five ERA designs. It can be seen that the longest mean rear headway was observed upon exiting the Unlit ERA (73.85 metres). Although participants tended to leave larger gaps between approaching traffic before rejoining the motorway when exiting from the unlit ERAs in comparison to the other ERA designs, a statistical analysis of variance (ANOVA) indicated that these differences failed to reach statistical significance (F (4,178)=1.249, p =.29).

Table 5: Descriptive statistics for the rear headway in metres upon exiting each ERA

ERA	Mean (m)	St Dev
Unlit	73.9	55.4
Low lit	60.8	35.6
Revised	53.7	34.8
Small	50.9	46.4
Standard	61.4	43.4

3.1.9 Reversing within ERA

A number of participants reversed within the ERA before exiting the ERA to rejoin the motorway. There were three instances of participants reversing with one instance in each of the Standard and Revised ERA. The greatest distance reversed was in the Small ERA, with a distance of 20 metres.

3.1.10 Speed upon re-entering motorway

As with the previous measures, there were no significant differences in speed upon re-entering the motorway between the within– and between-junction ERAs. Subsequently, the below results are presented for each of the five ERA designs without reference to ERA locations.

Figure 22 shows the mean speed (mph) upon rejoining the motorway from each of the five ERAs. It can be seen that in comparison to the standard configuration, the speed upon rejoining was very similar in most ERAs with the exception of the small ERA. Statistical analysis of variance showed the effect of ERA design to be significant (F(4,199)= 5.319, p=.000). Post-hoc analysis indicated the speed upon rejoining from the small ERA to be significantly lower compared to the other four ERA designs (p<.05).

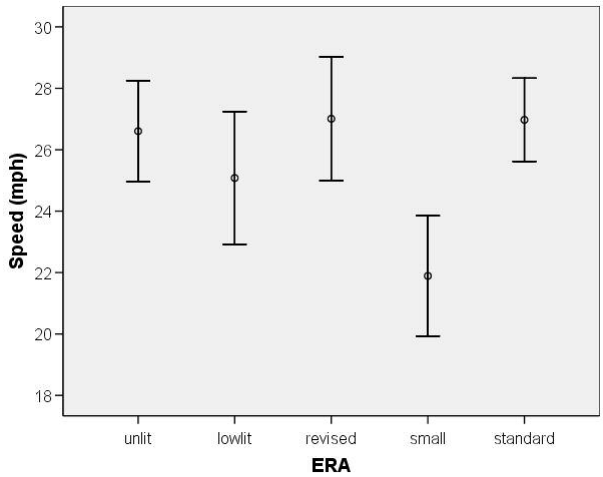

Figure 22: Speed (mph) upon rejoining the motorway from each ERA (95% CI)

3.2 Questionnaire results

Figure 23 to Figure 34 display the mean scores for a number of questions addressing participants' subjective impression of the different ERAs. Note, all figures (except for Figure 34) display mean ratings for within- and between-junction ERAs, as well as the 'combined' mean for both locations, for all configurations (Standard, Revised and Small ERA).

3.2.1 Ease of locating ERA

Mean scores for participants' perceptions of how easy it was to locate the ERA once they had been prompted to stop are shown below in Figure 23. It can be seen that similar to the behavioural measures in the above section, the mean scores for within- and between-junction ERAs are very similar. Statistical analyses indeed indicated no significant effect of ERA location and, hence, these scores were combined to produce an overall mean ('combined') for the Revised, Small and Standard ERAs.

A one way ANOVA revealed a significant main effect of ERA location ($F(4,208) = 2.98$, $p = .02$). Not surprisingly, the Unlit ERA was rated as more difficult to locate compared to the Low lit ERA. A Tukey HSD post-hoc test revealed this difference to statistically significant ($M = 6.26$, $SD = 2.45$ for Unlit, and $M = 7.63$, $SD = 1.83$ for Low lit). No other differences were found to be significant and the differences appeared to be rather small.

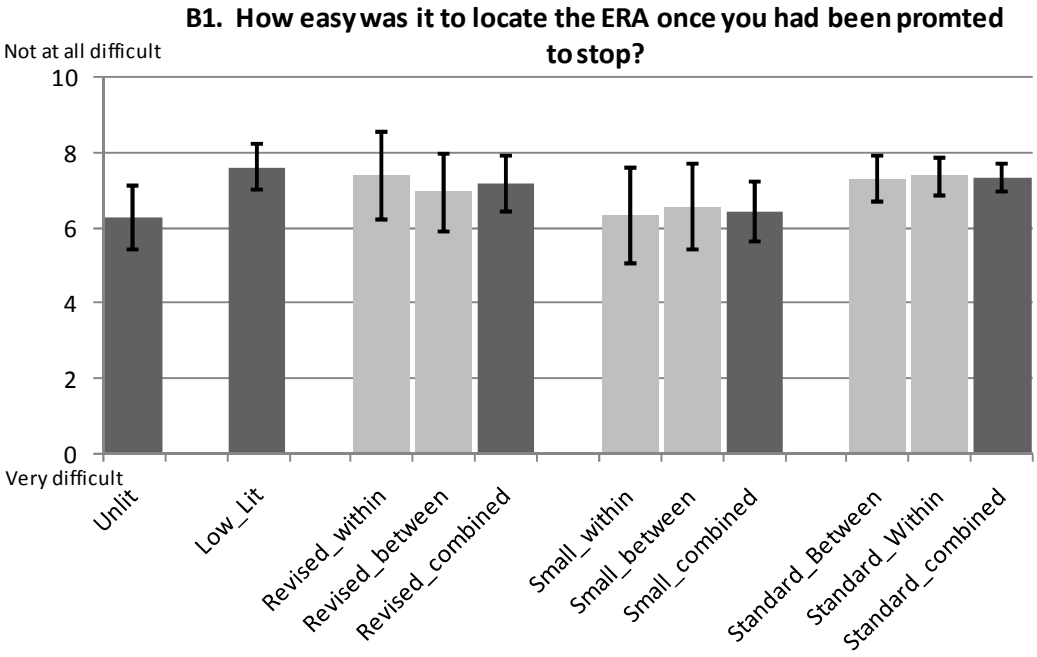

Figure 23: Mean ratings for ease of locating the ERA (95% CI)

3.2.2 Clarity of ERA signs

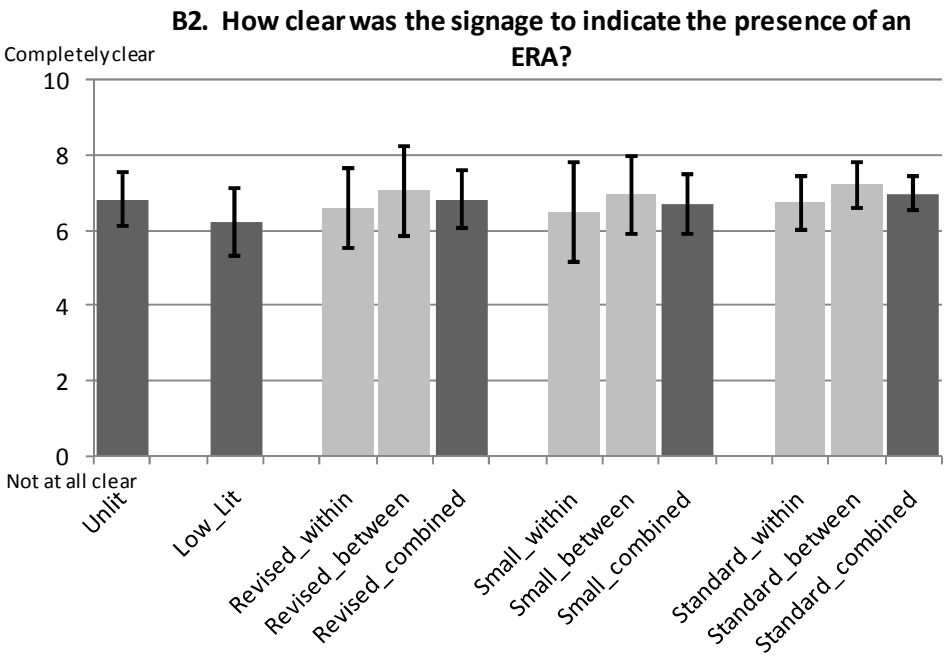

Figure 24: Mean ratings of clarity of signage (95% CI)

Participants were asked to rate the clarity of the signs indicating the presence of the ERA (question B2.). Figure 24 shows the mean ratings for each ERA and indicates only marginal differences between the different ERAs as also confirmed by the statistical analysis ($F(8,276)=.455$, $p=.89$).

3.2.3 Perceptions of safety when entering ERA

Inspection of the mean scores in Figure 25 suggests that participants felt broadly the same levels of safety regardless of ERA design as also confirmed by the statistical analysis indicating no significant effect ($F(8,276) = .173$, $p = .99$). Again, location of the ERA (within- or between-junction) did not appear to affect the safety ratings.

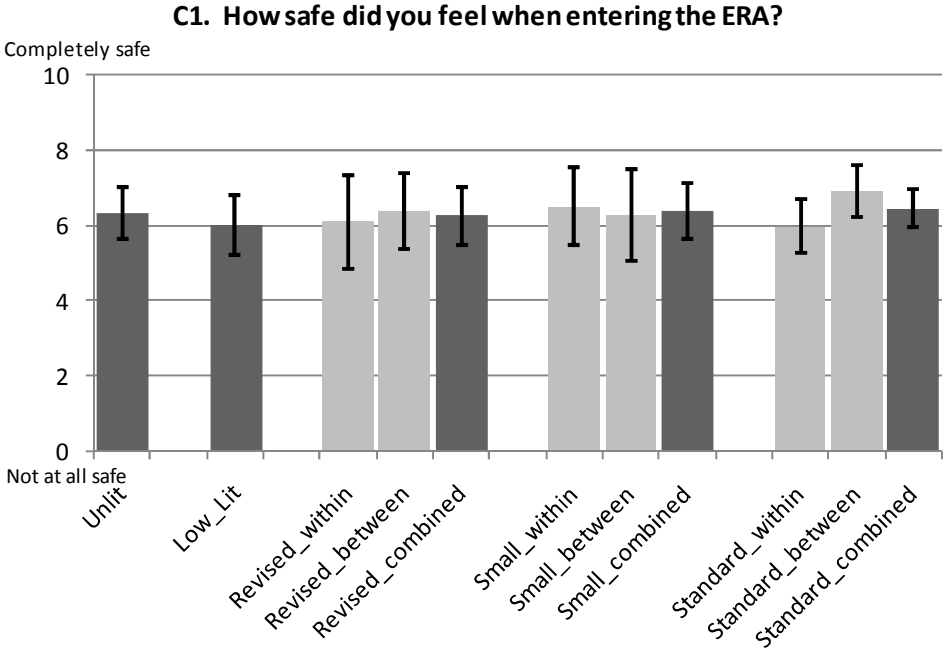

Figure 25: Mean scores for the safety of entering the ERA (95% CI)

3.2.4 Sufficiency of stopping distances

Figure 26 shows the mean ratings to the question whether there was sufficient stopping distance within the ERA. As can be seen, most scores hover around the average rating of 5 with only marginal differences between the different ERA designs. A one way ANOVA computed on the data showed no significant main effect of ERA design ($F(8,274)=.581$, $p=.79$).

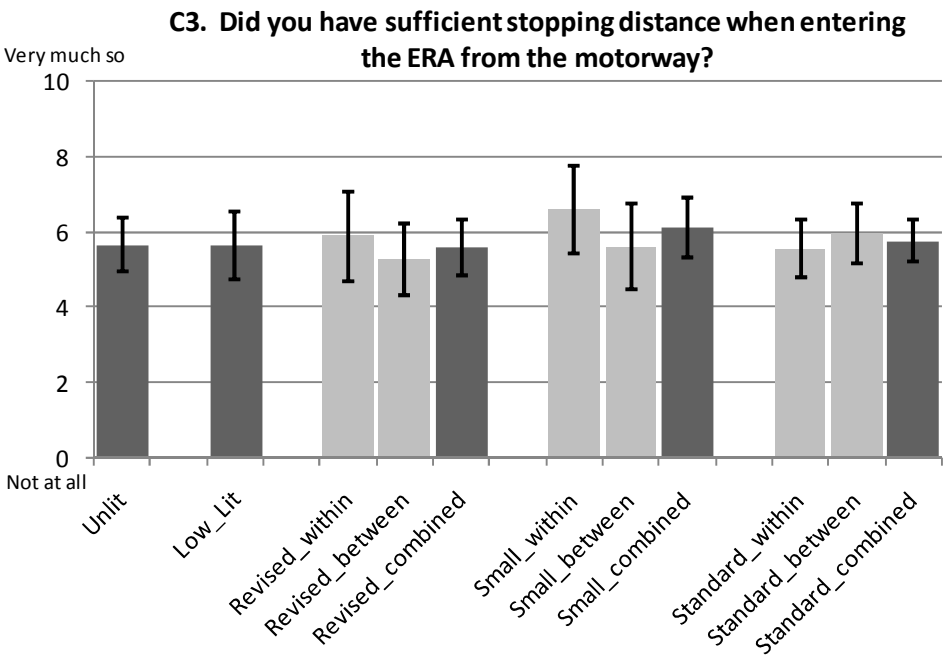

Figure 26: Mean scores for sufficient stopping distances when entering the ERA from the motorway (95% CI)

3.2.5 Impressions of safety when parked in ERA

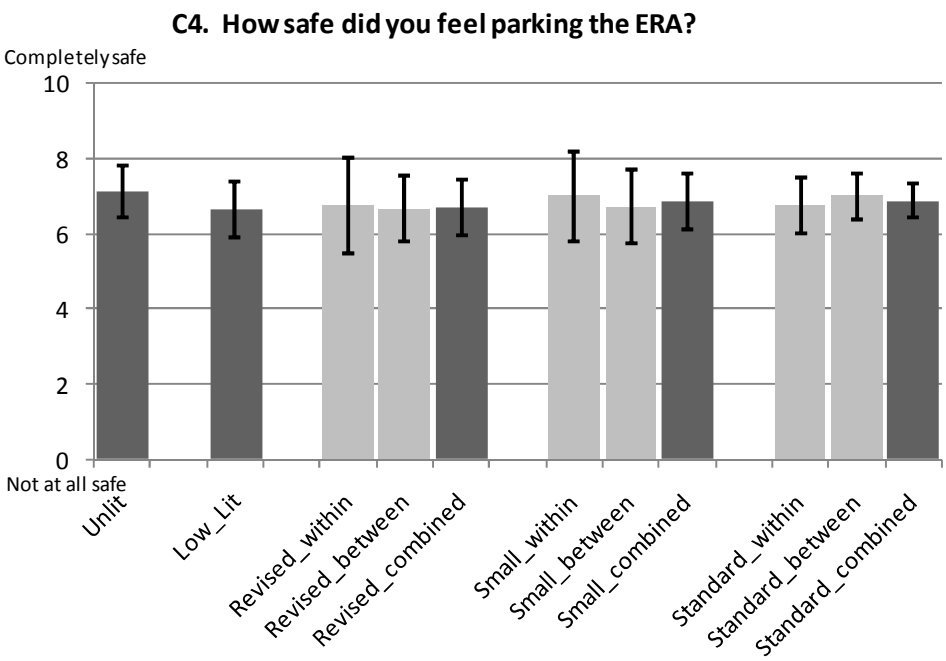

Figure 27: Mean ratings of safety for parking in the ERA (95% CI)

Generally, participants felt safe when parking in the ERA since the mean scores in Figure 27 are at the high end of the scale (7). Again, the differences between mean ratings were small and no significant main effect of ERA design was observed ($F(8,273) = .169$,

p = .99). This suggests that participants felt equally safe parking in the ERA irrespective of its design.

3.2.6 Clarity of indication of parking area within ERA

Figure 28 shows the mean rating to the question whether the correct parking location was clearly indicated. Considering an average rating of 6 across the different ERA designs, it can be concluded that the correct parking location was deemed to be fairly well indicated. The correct parking location appeared to have been clearest in the Small ERA. However, ERA design was not found to significantly affect participants' ratings ($F(4,207) = 1.05$, $p = .38$).

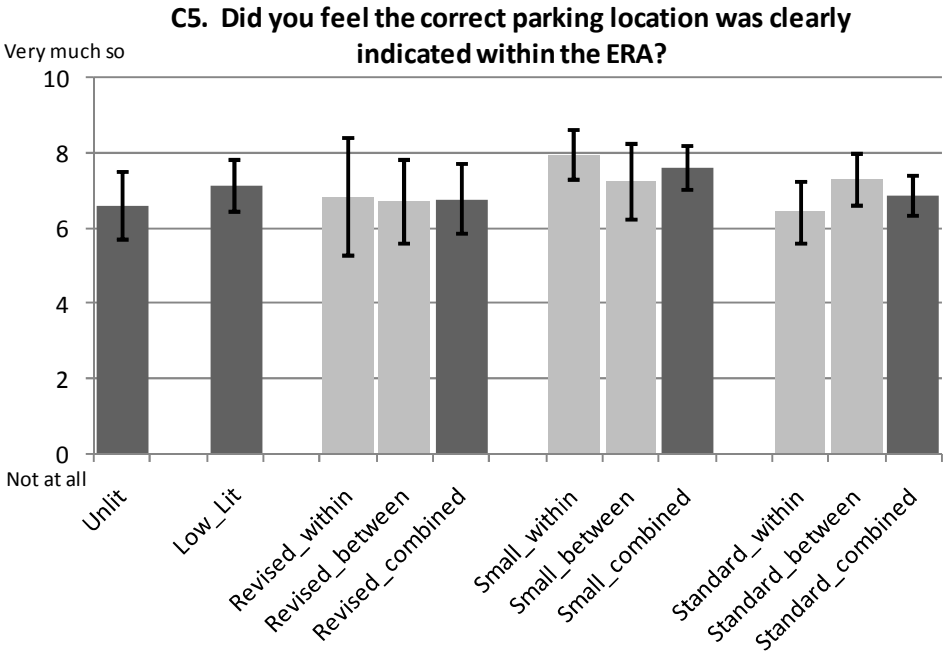

Figure 28: Mean ratings for whether the correct parking location was clearly indicated in the ERA (95% CI)

3.2.7 Confidence of having stopped in most appropriate location within ERA

Participants' mean ratings of confidence that they had stopped within the correct location of the ERA mirrored those obtained for their perceptions of the clarity of the indication of parking location. Figure 29 displays the mean ratings for this question. No significant differences are apparent in this figure, although there is a suggestion that ratings for the revised layout were lower when the ERA was placed within junctions than when it was placed between. However, this difference was not significant ($F(8,275) = .555$, $p = .82$)

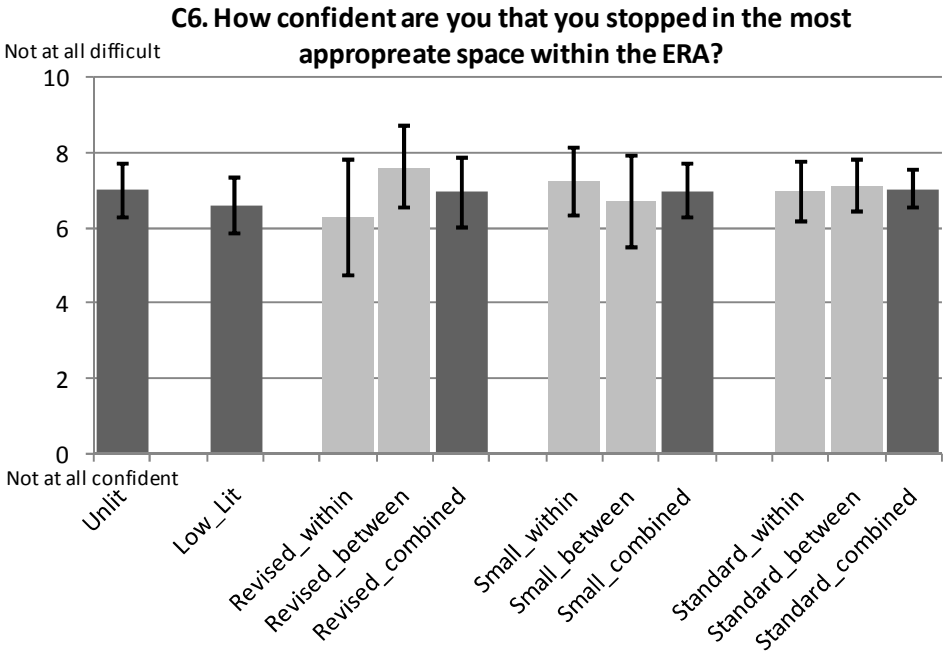

Figure 29: Mean confidence for stopping in the most appropriate space within the ERA (95% CI)

3.2.8 Difficulty when rejoining motorway

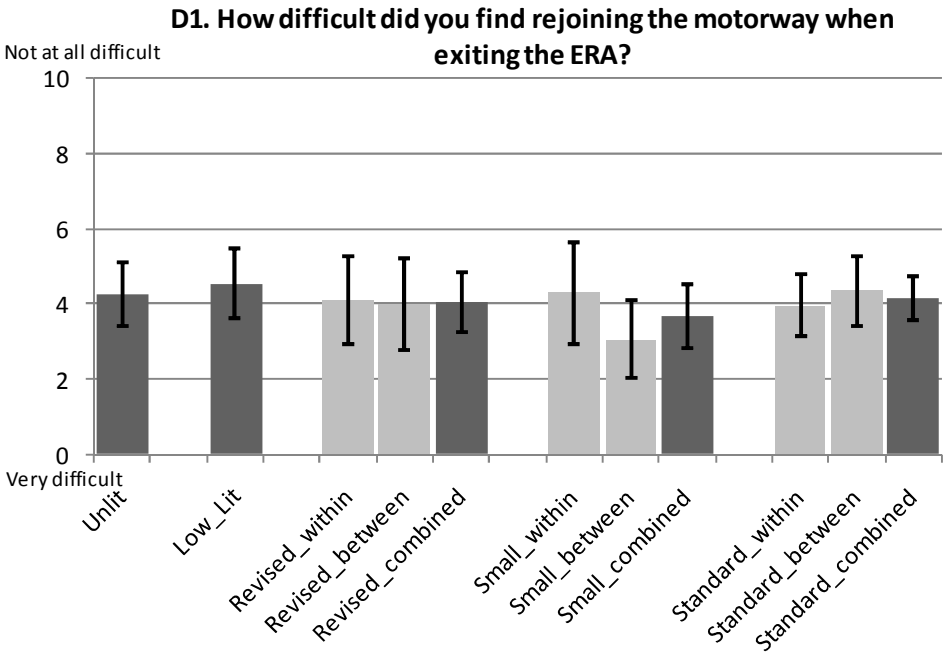

Figure 30: Mean scores for difficulty of rejoining the motorway when exiting the ERA (95% CI)

Figure 30 illustrates the mean scores attributed to the difficulty of rejoining the motorway when exiting the ERA. Mean scores indicate that participants across all conditions found it difficult to rejoin the motorway when exiting the ERA. A one-way

ANOVA revealed no significant effect of ERA design ($F(8,268) = .68$, $p = .71$) indicating participants found it equally difficult to rejoin the motorway independent of ERA design.

3.2.9 Confidence when rejoining motorway

As for the previous question, participants rated their confidence to be low when rejoining the motorway when exiting the ERA across all conditions. Figure 31 shows was not much variation in the mean scores and again no main effect of ERA design was observed (F (8,269) = .70, p = .70).

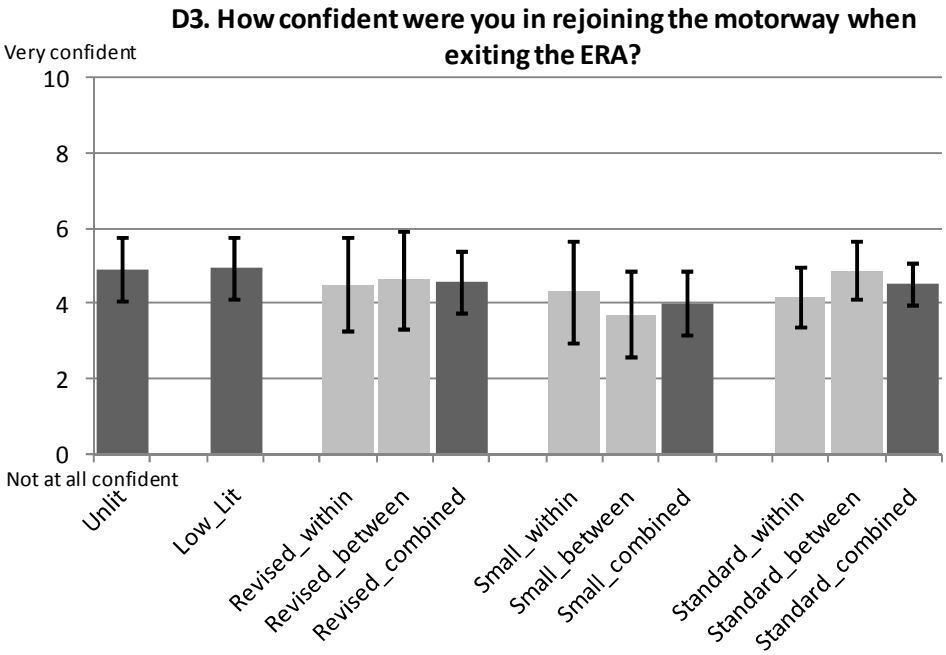

Figure 31: Mean scores for confidence in rejoining the motorway when exiting the ERA (95% CI)

3.2.10 Speed when rejoining motorway

Figure 32 demonstrates that mean scores for whether participants felt that they had rejoined the motorway at sufficient speed were at the low end of the scale. Again, there was little variation in ratings between conditions and these variations were too small to reach statistical significance (F (8,269) = .44, p = .89).

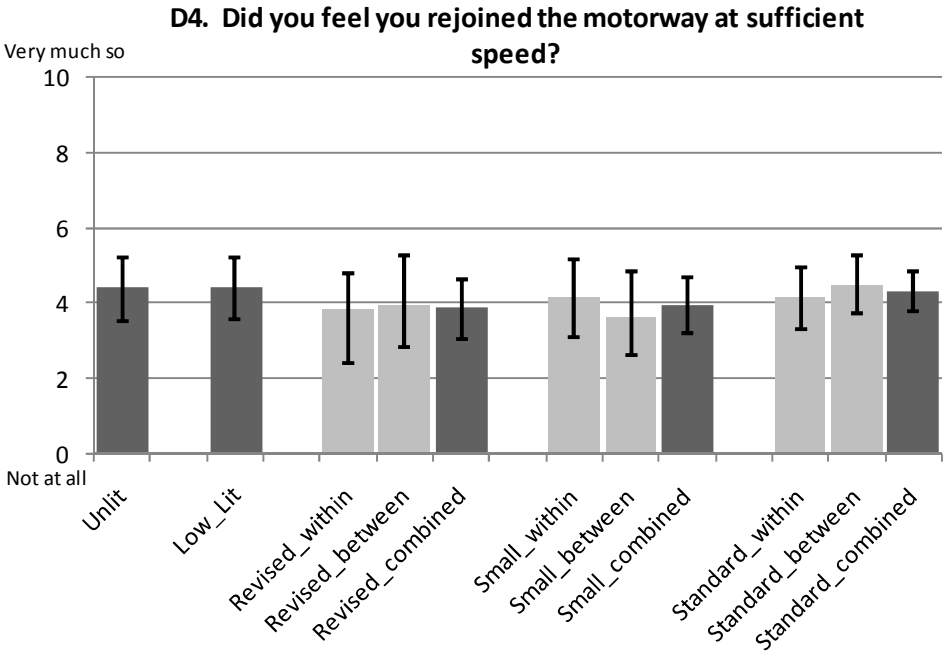

Figure 32: Mean scores for whether the motorway was rejoined at sufficient speed (95% CI)

3.2.11 Sufficient space to accelerate within ERA

Figure 33 shows the mean ratings to the question whether there was sufficient space within the ERA to accelerate and indicates that, overall, participants rated the space insufficient to accelerate before rejoining the motorway (mean score < 4). Again, differences between the different ERA designs were small and failed to reach statistical significance (F (8,267) = .51, p = .85).

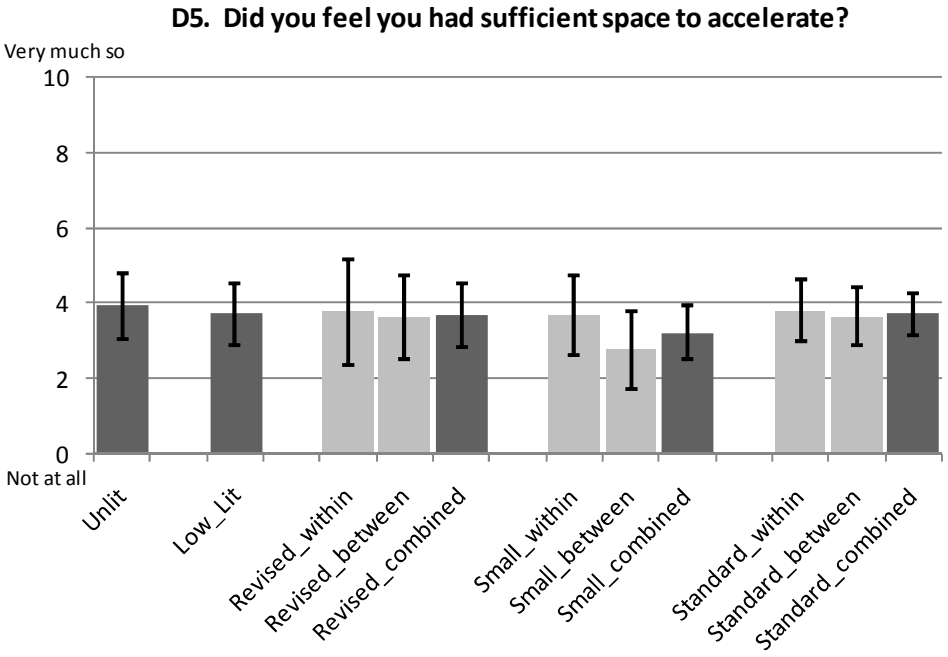

Figure 33: Mean ratings of whether there was sufficient space to accelerate (95% CI)

3.2.12 Factors which influenced participants stopping position

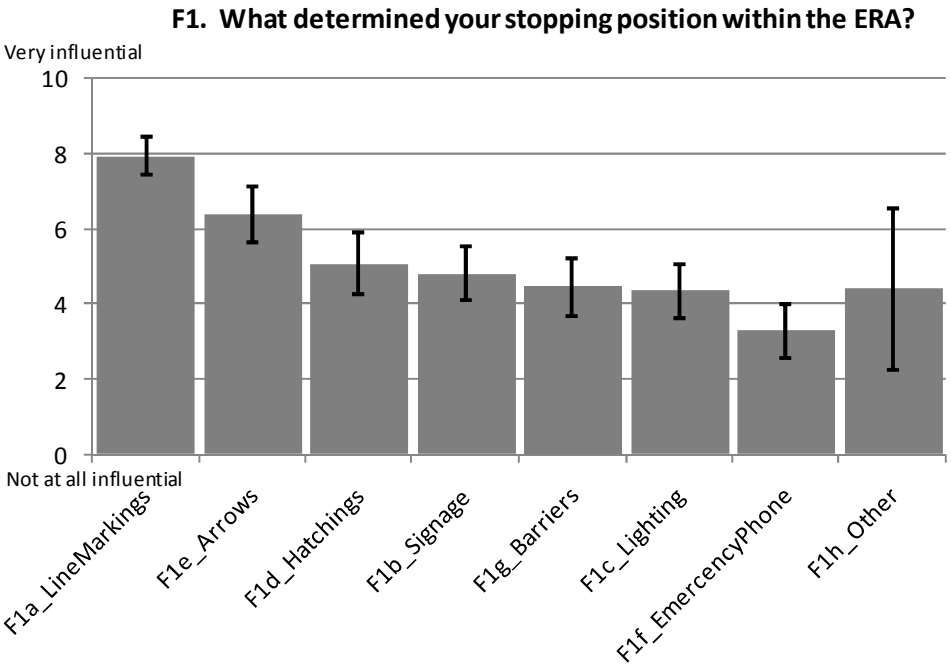

Figure 34: Mean scores for the influence that ERA aspects have on stopping position (95% CI)

Question F1 asked participants what determined their stopping position within the ERA. As shown in Figure 34, line markings of the ERA, followed by arrows and hatchings were

considered by participants to play the greatest role when determining their stopping position. The emergency telephone was judged the least influential.

3.2.13 Comments

Participants were given the opportunity to enter comments regarding specific features of the drive, as well as general comments. These comments were subjected to a thematic analysis to reveal common issues and themes offered by participants.

3.2.13.1 Comments regarding safety when entering ERA

Participants were asked "C2. If you found it somewhat unsafe to enter the ERA please state why". Their responses broadly aligned into four categories, with typical examples:

- **ERAs were not of sufficient size:**

  "As the sign was just before the ERA you had to pull in quite quickly and brake sharply." (Low lit configuration)

  "It looked like a small ERA to be able to pull in and stop, but it was OK." (Low lit configuration)

  "There was not much space to slow down." (Unlit configuration)

- **Signage seemed inadequate:**

  "Signage still could have been clearer - ERA came along very quickly." (Low lit configuration)

  "Insufficient advanced signage for the ERA." (Low lit configuration)

  "Needs signs before ERA so you have time to prepare and slow down" (Revised configuration)

  "Signage could have been further back to give more time." (Small configuration)

- **Concerns over multi-vehicle occupancy of ERA**

  "Would be extremely worried if there was another car already in ERA - not only would I have stalled but crashed also." (Unlit configuration)

- **Worries over vehicles behind when entering ERA or rejoining motorway**

  "Conscious of fast moving traffic behind." (Revised configuration)

  "Amount of traffic and speed of the traffic using the hard shoulder." (Small configuration)

3.2.13.2 Comments when rejoining the motorway

Participants were asked "D2. If you found it somewhat difficult to rejoin the motorway, please specify in the box below why you found this difficult." Two main groups of responses were identified:

- **Lack of visibility**

  "Had difficulty seeing traffic in mirror, too much traffic." (Standard configuration)

  "Lack of judgement as to how/when there were cars approaching." (Standard configuration)

  "Could not see vehicles on hard shoulder coming from rear." (Standard configuration)

- **Not enough room to get up to speed**

  "No space to get up to motorway speed." (Revised configuration)

"There is not sufficient room to gain speed like there is on a slip road where you normally join a motorway." (Standard configuration)

"Did not feel I had enough opportunity to gain speed before entering the motorway." (Short configuration)

3.2.13.3 Comments regarding ERA layout

When asked "D6. Please provide any comments regarding the ERA's below. For example this could relate to the signs and road markings used, lighting levels, the physical layout of the ERA, etc.", participants provided a variety of answers:

- **Lighting. ERA seemed to be easier to identify at night.**

  "ERA much easier to see at night because of lighting." (Low lit configuration)

  "Lighting good and clear." (Low lit configuration)

  "Lighting levels were good with use of green diode." (Low lit configuration)

- **Signage not early or clear enough. Would like a 'countdown' sign indicating distance to ERA**

  "Clearer signage needed - maybe more lit up at night-time" (Unlit configuration)

  "…sign was far too close" (Unlit configuration)

  "Distance signs (similar to the slipway markers, similar idea not design) would be helpful [countdown markers]." (Small configuration)

- **ERA not large enough. Not enough room to stop or accelerate to motorway speed.**

  "…found the general size of the ERA too small to enter or exit at the correct/safe speed" (Unlit configuration)

  "Need bigger space to accelerate out and slowing space when entering." (Small configuration)

  "If the ERA was longer, cars could build up some momentum before rejoining the motorway" (Small configuration)

Comparison of comments between Low Lit and Unlit conditions revealed that in both drivers felt the ERA was not large enough to get up to speed before rejoining the motorway. Lighting was viewed much more positively in the low lit condition (as would be expected). In the unlit condition several drivers were unhappy with the signage, which may be related to the lack of lighting.

A distinction in comments between revised and small layouts was present. In the revised layout participants were largely positive regarding the crossed hatched road markings and designated stopping location. There were some commented suggesting that that revised ERA was not of sufficient size, however, there were many more such comments for the small configuration suggesting (as might be expected) many drivers found the size of the small configuration to be inadequate.

Only in the revised layout did participants not feel the size of the ERA was too small. Considering the size of the standard ERA and the revised ERA are the same, this may be due to one of two reasons. First, the clarity of the road markings reduced driver anxiety resulting in them feeling more comfortable with the size of the ERA. Secondly, in the revised ERA a larger proportion of participants stopped the vehicle closer to the beginning of the ERA and subsequently had more space to accelerate upon exit.

3.2.13.4 Comments regarding factors which determined stopping position

As well as rating the influence of various factors which affected participants choice of stopping location (see 3.2.12), participants were also asked to explain why they made some of their decisions ("F2. What determined your stopping position within the ERA? Please state the reasons for your choices). One strong theme emerged from the responses:

- **By far the most common answer related to the arrows and line markings. They were identified as providing clear instruction as to where to stop and were positively perceived by participants.**

  "Arrows because easy to see and can follow exactly."

  "The arrows gave clear signage of where to stop and the broken line at end of parking area gave clear indication not to go further than that line."

  "The hatching made it extremely clear where to park."

3.2.13.5 General comments regarding ERAs

Finally, participants were given the chance to express any general opinions regarding the ERA layouts ("F3. Please provide any further comments regarding the ERAs you have experienced in the simulator below"). Most comments were similar to those already provided, but two informative themes were:

- **Concern that the ERA would not be able to cope with more than one vehicle.**

  "If more than one car was going to be using the ERA at any one time, I don't think that there would be enough room and it would be quite unsafe."

  "Only space for one vehicle really. Not enough warning with signs."

- **Repeat of comments that ERA did not feel large enough.**

  "Good idea but too small."

4 Discussion

To discourage inappropriate ERA use, as well as to modify the stopping position within ERAs, four new ERA designs were created. The aim of this simulation study was to evaluate the effect on drivers' behaviour and subjective evaluation of these ERA designs in comparison to a current standard ERA design.

The first finding was that the location of the ERA, that is, whether it was located between or within a junction, did not differently affect driving behaviour and participants' subjective evaluation of the ERAs. This suggests that the use of ERAs within junctions is unlikely to introduce driving behavioural concerns beyond those associated with ERA use in general.

With regard to the speed profile on approach and entrance to the ERAs, it was found that the average approach and entrance speed tended to be lower for the Small and Unlit ERAs. In addition, the braking profile for the Small and Unlit ERAs also showed considerable later and sharper braking levels compared to the Revised, Low lit, and Standard ERA. The highest maximum braking force applied within 100m preceding the start of and entrance to the ERA was observed in the Small and Unlit ERA.

These results can be interpreted as participants being more cautious when entering the Small and Unlit ERA. With regard to the Unlit ERA this can be understood considering the reduced visibility making it harder for participants to locate the start of the ERA, judge the ERA's dimensions and whether the ERA provided sufficient space to bring the vehicle to a halt. As expected, when asked to indicate the ease of locating the ERAs, participants indicated that it was harder to locate the Unlit ERA compared to the other ERAs.

A similar argument can be put forward for the small ERA whereby the reduced length of the ERA may have instigated participants to lower their travelling speed to ensure they can safely and comfortably bring the vehicle to a halt. Subjective comments provided further support for these interpretations.

With regard to stopping positions, the largest number of participants parking the vehicle in the correct location was observed in the Small (75%) and Unlit ERA (78%). In the other ERA designs, including the Standard ERA, the percentage was lower and hovered around 60% of the participants. It is not entirely clear why this percentage was higher in the Small and Unlit ERA when compared to the Standard ERA considering that the signs and road markings were very similar.

The obvious difference was the absence of the dashed line marking in the Small ERA delineating it from the motorway (see Figure 9). This may have had the effect that participants perceived the ERA as forming part of the motorway rather than a refuge distinct from the motorway. In turn, this may have encouraged participants to "follow the instructions" more readily and park the vehicle in the dedicated area (by attending to traffic signs and road markings delineating correct stopping location more diligently). A similar argument can be made regarding the Unlit ERA: whilst a delineating line was present, it may have been less prominent due to the reduced visibility under the night-time conditions. Together with the fact that the ERA was unlit, consequently rendering a parked vehicle less visible to other traffic, this may have resulted in participants being more aware of their parking location resulting in more participants parking in the correct location.

The Revised ERA was designed with the sole purpose of increasing the number of drivers parking the vehicle in the correct location. To this purpose hatched road markings were drawn within the ERA, excluding the area where drivers were intended to park (the parking bay – See Figure 8). These hatched road markings indeed had the intended effect of discouraging participants from parking in the hatched area. However, the arrows signalling participants to park towards the front of the parking bay were not as effective (see Figure 8 for illustration of arrows). A considerable proportion of participants appeared to misinterpret the arrows as signalling the correct parking location and parked their vehicles on the arrows. From this it can be concluded that

hatchings effectively discourage participants from parking on them, however, the addition of arrows may be unnecessary. Future designs might benefit from extending the hatched area within the ERA, only leaving the correct parking bay as un-hatched.

Parking at the beginning of the ERA in particular is considered to endanger the parked motorist and hinder emergency vehicle access. When comparing the stopping positions across the ERAs (see Figure 19), the Standard ERA performed worst in that a larger proportion of participants parked not only at the beginning of the ERA, but also closer to the road side. From a road safety perspective, alternative ERA designs would therefore be preferable. The Revised ERA appears to be the most robust design ensuring correct parking positions under daytime conditions. Future research might benefit from evaluating the Revised ERA under night-time conditions.

Regarding the Unlit ERA, a high percentage (78%) of participants parked the vehicle in the correct location. However, the ERA design appeared to have a significant shortcoming in that 4 out of 36 participants (11%) failed to stop in the dedicated ERA altogether despite being instructed to bring the vehicle to a halt in the upcoming ERA. Based on the assumption that the failure to use the ERA could be ascribed to reduced ERA visibility, the use of completely unlit ERAs therefore appears not to be advisable. Failure to use the ERA might lead to motorists having to park on LBS1 (i.e. hard shoulder) thereby compromising road safety and network performance.

When comparing the time spent in the ERA before re-entering the motorway, participants tended to stay in the ERA for longer under night-time conditions (Unlit and Low lit ERA). This may not be surprising considering that it is harder to gauge speed and distance of upcoming traffic under night-time conditions. This was also reflected in the number of exit attempts (i.e. number of times participants stopped within the ERA after first accelerating to leave the ERA) which tended to be higher under night-time conditions.

With regard to rear headway upon re-entry (gap acceptance), no significant effects of ERA design were observed. This was surprising as rear headways were expected to be longer in the Small ERA considering the limited acceleration space available. The smaller dimensions did however affect re-entrance behaviour as indicated by driving speed upon re-entering the motorway. This was found to be significantly lower when leaving the Small ERA in comparison to the other ERA designs. It was also in the Small ERA that the vehicle was reversed furthest in order to increase acceleration space.

Subjective comments indicated that problems re-entering the motorway were not unique to the Small ERA. Overall, participants expressed great concern about re-entering the motorway. They indicated the ERAs in general to be too small to pick up speed and safely rejoin the traffic at the motorway.

Finally, a large number of participants indicated the advanced warning signs indicating the presence of the ERAs to be positioned to close to the ERAs. Participants expressed a preference for signs further in advance of the ERA.

4.1 Safety Interpretation

The study of ERA use has revealed several potential safety issues. Many of these are associated with the use of ERAs in general rather than the particular design itself. Specific concerns are as follows:

- In the Unlit ERA condition, 11% of participants failed to stop the vehicle in the following ERA and had to travel to next one downstream. This might mean that during hours of darkness, a driver whose vehicle has broken down may not be able to reach an ERA at all, thus obstructing LBS1.
- In the simulation, participants had sufficient time to move into LBS1 before parking the vehicle within the ERA. It would be desirable to consider how easily

the various ERA designs might be to use under conditions of complete breakdown whilst the vehicle is not driving in LBS1.

- Some drivers stopped very close to the edge of the LBS1 lane with all the designs and may have partially obstructed that lane. It is to be hoped that this is some artefact of the simulation and that this would not occur in real traffic conditions.
- The rear headways when vehicles rejoin LBS1 vary somewhat between designs but the overall mean value is about 60 m. Given that the speed at which a car rejoins is only about 25 mph, this will require a following vehicle to brake or change lane. These figures are mean values for car drivers. The relative speed differential seems likely to be greater if an HGV is accelerating from the ERA (though presumably if the reason for stopping is the occurrence of a genuine breakdown, then the HGV would be assisted in some way to exit from the ERA, either by a towing truck or by closure of the LBS1). It would perhaps be useful to conduct a new simulator trial where a simulated car (or an HGV) leaves an ERA with typical speeds and headways, to discover how a participant would respond whilst driving on the LBS1.
- Related to the above is the speed at which the participants rejoined the LBS1 which had a mean of at least 25 mph for all of the designs except the Small ERA for which the mean speed was only 22 mph.
- There is also the further issue of the ease with which HGVs which are in the process of breaking down can negotiate safe entry to the ERA. Clearly, it was not possible to test this using the car driving simulator.
- The Small ERA seems to have the capability of holding one articulated HGV only. Any other vehicle would need to travel on to the next ERA or stop on the LBS1. A further possible occurrence is that the second vehicle attempts to enter the ERA but cannot fully do so, thus partially obstructing the LBS1. There is also the issue of how a second vehicle entering an ERA can leave it if there is another stationary vehicle ahead.
- In summary, from a safety point of view, it seems preferable that the ERA be lit and be of the Revised design.

  The Revised design showed the following benefits in daylight conditions which seem likely to improve safety:

  - Lowest maximum brake force
  - Highest speed on entering
  - Fewest number of times participants stopped within the ERA after first accelerating on exit
  - Highest speed on returning to the running lanes

  The Low lit ERA showed the following benefits which seem likely to improve safety:

  - Lower maximum brake force
  - Higher speed on entering the ERA
  - Fewer number of times participants stopped within the ERA after first accelerating on exit

  However, the relative safety of the various designs remains unclear. Bearing in mind that there is already considerable misuse of ERAs and of motorway hard shoulders for non-emergency stops, the easier ERAs are to use, the more likely they will be misused. This may mean that safety would be improved if they were Unlit and were Small.

For those who break down, the combination of the Revised design with lighting may be seen as some compensation for their loss of the provision of the normal hard shoulder.

4.2 Network performance interpretation

To maximise network performance, any effects that would reduce capacity should be minimised. Once in an ERA, a vehicle will have little or no effect on capacity. A reduction in capacity could occur as a vehicle entered or left an ERA:

- The design of the ERA has a small effect on vehicle behaviour as it enters an ERA, with braking levels being higher for the Small and Unlit ERAs. This might cause braking from following vehicles, but this is unlikely to cause flow breakdown unless there are high flows, with the motorway running at capacity.

  With the exception of Unlit ERAs under night-time conditions, there is no evidence that vehicles would be unable to stop in an ERA, and be forced to stop on the hard shoulder instead.

  Therefore, the design of the ERA is unlikely to have a significant impact on network performance when a vehicle enters an ERA.

- Drivers found it difficult to leave an ERA, and the speed upon rejoining was lower for the small ERA. This might cause braking from vehicles already using the hard shoulder, but this is unlikely to cause flow breakdown unless there are high flows, with the motorway running at capacity.

  The capacity would be significantly reduced if a driver felt unable to leave an ERA safely. It would then be necessary to close the hard shoulder to enable the vehicle to rejoin the carriageway. In the ERA simulator study, all drivers were able to leave the ERA, although some had to make several attempts to do so (five attempts being the maximum). It might be that in real life, one or more of these drivers would have been unwilling to take the risk of leaving the ERA onto a live hard shoulder. This would be most likely to occur with the small ERA, but would also depend on the lighting and the available line of sight.

5 Conclusions

- ERA location (i.e. between or within a junction) did not differently affect driving behaviour and subjective evaluations of the ERAs
- ERAs located within junctions are unlikely to introduce road safety and network performance concerns beyond those associated with ERA use in general
- Participants were more cautious entering the Small and Unlit ERA as indicated by lower approach and entrance speeds
- Specific ERA designs affected the number of participants parking in the correct location within the ERA
- Highest percentage of correct parking positions were observed for the Small and Unlit ERA
- Most undesirable parking positions were observed in the Standard ERA
- Hatchings provided an effective means to modify parking behaviour within ERAs
- Use of Unlit ERAs is not advisable as motorists may not be able to locate them in time
- Speed upon re-entering the motorway from a Small ERA is significantly lower
- Participants expressed concerns about re-entering the motorway, irrespective of ERA design
- ERAs were considered too small to pick up speed and safely rejoin traffic on the motorway
- A trade-off is created between safe use of ERAs and road safety implications of ERA misuse: ERAs that are harder to use might compromise safe use but avoid misuse
- ERA design is unlikely to have a significant impact on network performance when a vehicle enters an ERA
- Network performance may be significantly affected upon closure of the hard shoulder to enable a vehicle to rejoin the carriageway

Acknowledgements

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References

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Glossary of terms and abbreviations

95% CI: 95% Confidence Interval

ERA: Emergency Refuge Area

HS: Hard Shoulder

HSR: Hard Shoulder Running

LBS1: Lane Below Signal 1

LBS2: Lane Below Signal 2

LBS3: Lane Below Signal 3

LBS4: Lane Below Signal 4

TJR: Through Junction Running

TO: Traffic Officer

VMS: Variable Message Sign

VSL: Variable Speed Limit

Appendix 1 – Low lit ERA lighting details

The low lit ERA lighting was based on the Orus luminaire range produced by Thorn (http://www.thornlighting.com.au/download/Orus(3).pdf). The Orus range was specifically designed for low level road lighting to reduce glare.

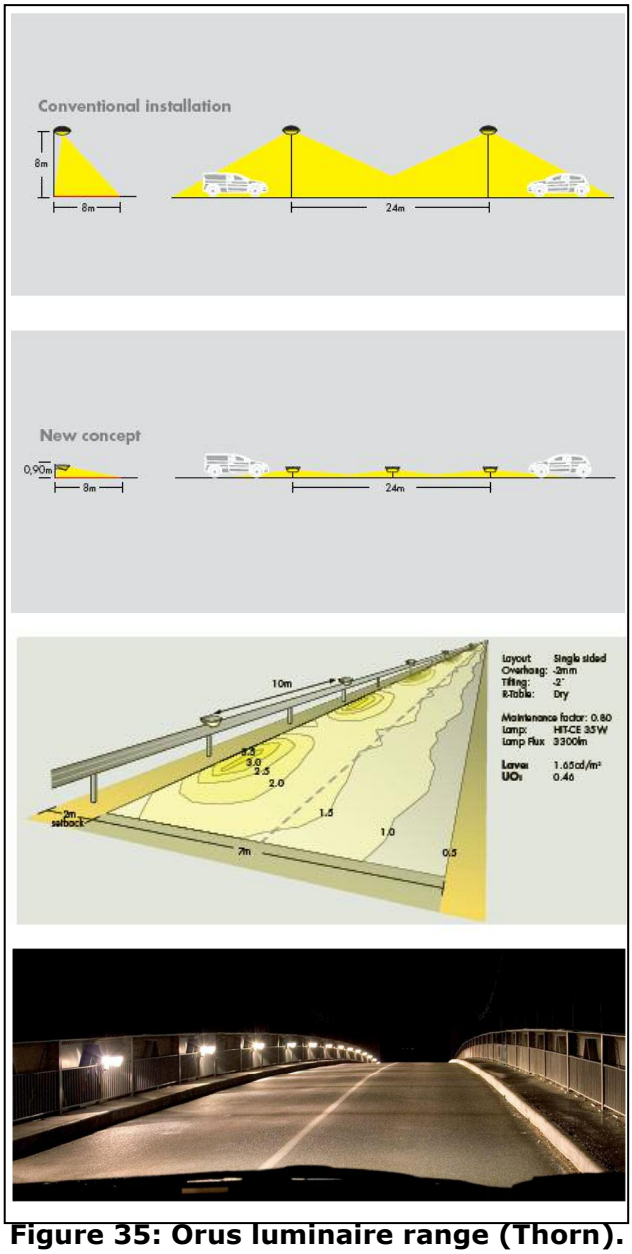


Figure 35: Orus luminaire range (Thorn).

Appendix 2 – TRL CarSim

TRL has successfully operated a driving simulator for more than 15 years and in that time the simulator has seen a number of different incarnations to keep pace with improvements in vehicle, projection, computing, and simulation technologies and as such is one of the most advanced simulators in the UK. The latest iteration uses a Honda Civic family hatchback (see Figure 36). Its engine and major mechanical systems have been replaced by a sophisticated electric motion system that drives rams attached to the axles underneath each wheel. These impart limited motion in three axes (heave, pitch, and roll) and provide the driver with an impression of the acceleration forces and vibrations that would be experienced when driving a real vehicle. This significantly enhances the realism with which drivers approach the driving task and reduces the incidence of simulator sickness (a condition with symptoms similar to those of motion sickness) among participants. All control interfaces have a realistic feel and the manual gearbox can be used in the normal manner (automatic gears can be simulated).

Figure 36: TRL driving simulator, CarSim

Surrounding the simulator vehicle are large display screens onto which are projected the graphic images that represent the external visual environment to the driver. The level of environmental detail includes photo-realistic images of buildings, vehicles, signing, and markings, with terrain accurate to the camber and texture of the road surface. We have also recently added the capability to simulate night-time driving scenarios. The driving environment is projected at a resolution of 1280×1024 onto three forward screens to give the driver a 210º horizontal forward field of view. The presence of the two flat side screens adjacent to the driver gives a very strong impression of other vehicles travelling alongside of the vehicle. A rear screen provides a 60º rearward field of view, thus enabling normal use of all mirrors.

Surveillance video cameras are mounted in the car and participants can be recorded during their drive. There is also an intercom facility for communication between the vehicle and the control room. An in-car colour LCD display can also be used to give instructions or provide other task-related information.

Figure 37: TRL CarSim: Control Room

More than one hundred autonomous traffic vehicles can be programmed to participate in the simulation. TRL has a library of different vehicle types to choose from including cars, trucks, buses, emergency vehicles, bicycles, and pedestrians. Each obeys specific driving rules to behave in a normal manner with respect to other traffic vehicles. However, these can be overridden causing them to perform specific manoeuvres e.g. emergency stop, sudden lane change etc. The autonomous vehicles also have dynamic properties of their own – they appear to pitch realistically under acceleration and braking, and vehicle graphics include body tilt and roll under braking, acceleration and turning; speed dependent rotating wheels and fully working brake, indicator, fog, and head lights. These provide additional cues to the driver and greatly enhance the realism of a scene. To generate scenarios with a heavy traffic load (> 1700 vehicles per lane per hour) we can generate a vehicle 'swarm'. The swarm function allows us to define a region around the driver where vehicles will be placed and controlled. A vehicle moving out of the visible range of the driver is replaced by a new vehicle positioned to maintain the desired traffic density. This gives the impression of very high volume of traffic while maintaining the performance of the simulator.

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. The software used to implement the simulation is called SCANeR II and was created by OKTAL to provide a flexible and powerful simulation with a highly advanced traffic model. It is employed by more than twenty research institutes across the globe and TRL leads the user group with access to OKTAL expertise for trial set-up and integration, if required.

The dynamics of the vehicle are modelled using a validated vehicle model that is used for product development by Renault. The model interprets the driver’s control inputs, relates them to the current vehicle status and computes a prediction of how a real vehicle would behave in the given circumstances. The system then responds to present to the driver its optimal representation of how this behaviour would be perceived through the visual, sound, and motion sub-systems. The vehicle dynamics are updated at 100Hz whilst the visuals are refreshed at 60Hz so that the driver perceives a seemingly continuous driving

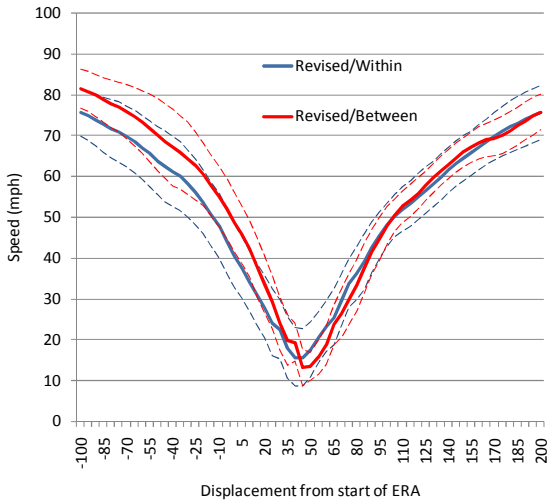
experience. Data is then recorded relating to all control inputs made by the driver, including steering, pedals, gear, indicators; vehicle parameters such as speed, RPM; and parameters to assess behaviour in relation to other vehicles such as distance and time headways. The data recording rate is fully controllable dependent upon the trial demands, up to a rate of 100Hz.

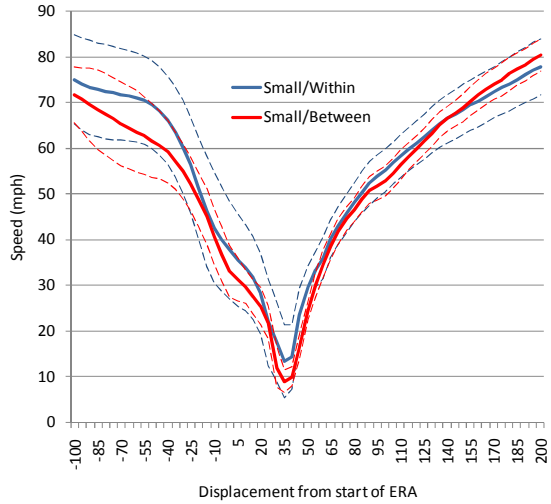
The simulator also includes a full integrated SmartEye eye–tracking system for the analysis of driver visual behaviour. This system, in addition to being able to report the driver's gaze direction, is integrated with the 3D environment presented in the simulation, such that the eye-tracker can report in the simulator data the specific element on which the participant is fixating – a specific road sign, traffic light, the road ahead, or interior items such as the instrument panel or infotainment system. This dramatically improves the accuracy and efficiency of post-trial data analysis.

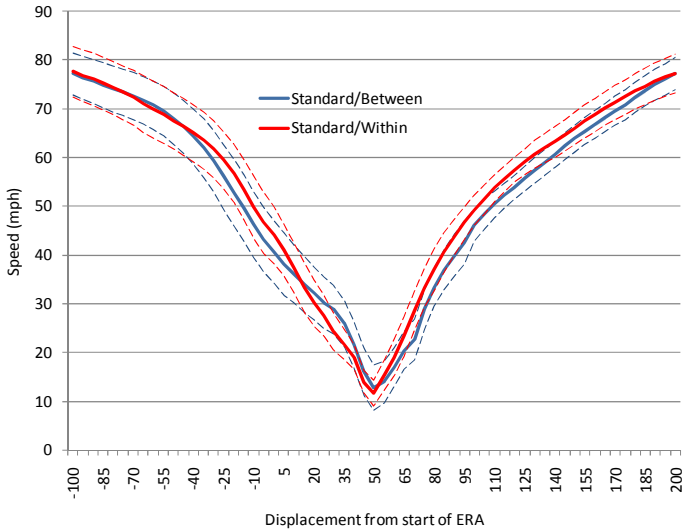
Participants for trials are recruited from a dedicated database of over 1000 members of the public. This comprises drivers from a wide range of ages and backgrounds, all of whom are familiar to TRL such that participants from particular demographic bands or driving experience/ability ratings can be selected to suit the trial requirements. The simulator facilities include a medical room for taking any physiological measures and trials management staff are trained in Good Clinical Practice. There is an interview room for questionnaire completion and debriefing and an information room for conducting computer based test or training tasks. Data management procedures are well established and compliant with the Data Protection Act 1998 to ensure security, confidentiality, and integrity of all records.

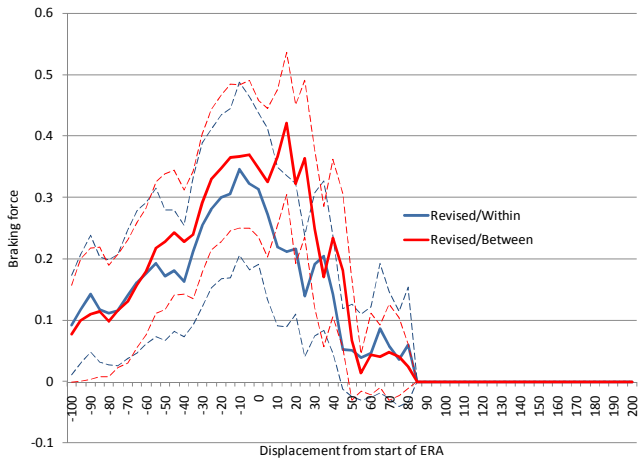
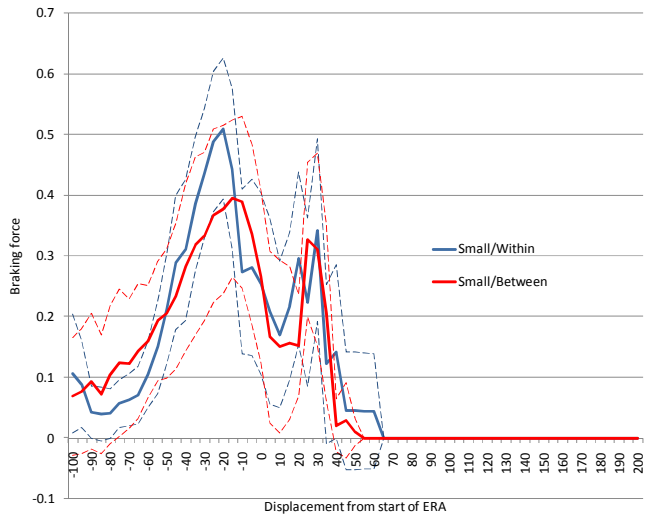
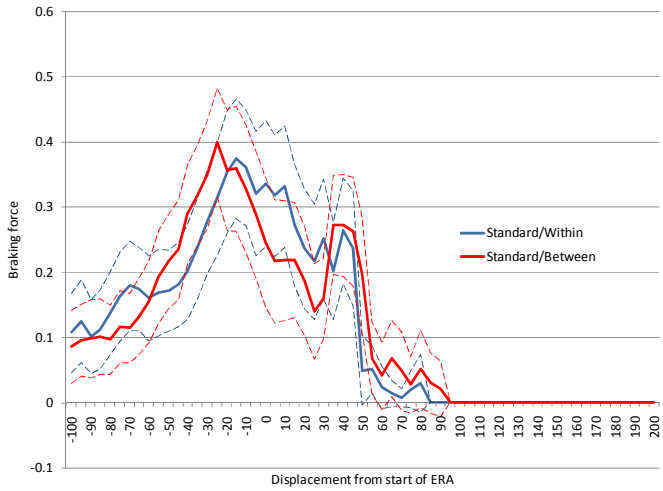
Appendix 4 – Speed profiles as a function of ERA location

The below graphs show the speed profiles on approach and entrance into the ERA and when rejoining the motorway after the simulated breakdown, for the Revised, Small, and Standard ERA. Solid lines separately indicate the speed profiles for the ERA located either within- or between-junctions. Dashed lines indicate the 95% Confidence Intervals.







Appendix 5 – Braking profiles as a function of ERA location

The below graphs show the braking profiles on approach and entrance into the ERA for the Revised, Small, and Standard ERA. Solid lines separately indicate the braking profiles for the ERA located either within- or between-junctions. Dashed lines indicate the 95% Confidence Intervals.