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CLIENT PROJECT REPORT CPR1353

Future Managed Motorways Concept Development
Task 3: Synthesis of Evidence

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0.1	20/06/12	Draft	P.B.	N.R.
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1	03/07/12	Final report with updated references	P.B.	N.R.

1 Introduction

1.1 Background

Since October 2010, TRL have undertaken a series of research tasks to support the Highways Agency (HA) with the development of a new approach to the design of Managed Motorways schemes. This approach has now been formalised and is referred to as Managed Motorways – All-Lane Running (MM-ALR). In March 2011, the HA issued design guidance in the form of IAN161/12 along with an accompanying Concept of Operations document. These should be referred to for a full description of the MM-ALR approach.

As part of the most recent set of tasks TRL were asked to synthesise the relevant findings of all of the previous tasks, and organise them in terms of how they relate to the MM-ALR concept. This document represents the output of this task. It is intended to act as a reference document for use by stakeholders when considering the available findings relating to the MM-ALR concept, and to indicate where further investigation may be advantageous.

1.2 Summary of tasks and key documents

This document refers to seven main tasks that have been carried out by TRL which are listed in Table 1 below. Each has been given a short name for ease of reference within this document.

As well as these TRL tasks, it has been necessary in places to refer to work carried out by other parties. This synthesis is not intended to cover all of the evidence generated outside of TRL, but for clarity it has been necessary to include some key external references.

Table 1: Main TRL tasks in support of the MM-ALR concept

| Short Name	Formal Task Reference	Main Ref Document
Gantry Spacing	Task 2 of the MM2 Concept Development project	CPR1602 TRL MM2 Tasks 2, 3, 4 and 5 Key Findings Report
Sign Comprehension	Task 3 of the MM2 Concept Development project	
MS4 Obscuration	Task 4 of the MM2 Concept Development project	
Verge vs Gantry	Task 5 of the MM2 Concept Development project	
Design Comparison	Task 1 of the Future MM Concept project	CPR1335 TRL Future MM Concept Task 1 Final Report
Design Assurance	Task 2 of the Future MM Concept project	CPR1351 TRL Future MM Concept Task 2 Final Report
ADS Obscuration	Additional task of the Future MM Concept project	CPR1352 Future MM Concept ADS Obscuration Report

1.3 Key questions

TRL's work has centred around the information that will be communicated to road users while using a section of MM-ALR. This information can be split into the following types:

- *The speed limit* – In MM-ALR schemes, variable mandatory speed limits (VMSL) can be set automatically for congestion management or queue protection as well as manually for incidents and road works. These are set by a combination of gantry-mounted Advanced Motorway Indicators (AMIs) and verge-mounted variable message signs (MS4s).

- *The lanes that are open/closed to traffic* – The MM-ALR design has four permanent running lanes and the technology within a MM environment allows operators to dynamically open and close lanes.

- *Where and how to stop in the event of a breakdown* – Existing hard shoulders will be converted to a permanent running lane within MM-ALR schemes and Emergency Refuge Areas (ERAs) will be provided at maximum intervals of 2.5km.

- *Where the next diverge (off-slip) is and where it is for* – IAN161/12 suggests two options for providing Advanced Direction Signs (ADS), either verge-mounted or gantry- and cantilever-mounted.

The Highways Agency are formally required to provide 'adequate guidance'[1] of what the speed limit is to motorists. This concept has been used to consider the suitability speed limit provision and of the other types of information provided within an MM-ALR environment.

This suitability can be considered from two aspects: whether the information provided is suitable for road users to *understand* what is expected of them; and whether it is suitable for them to actually *exhibit* appropriate behaviours.

This has led to the key question and sub-questions of this task being defined as follows:
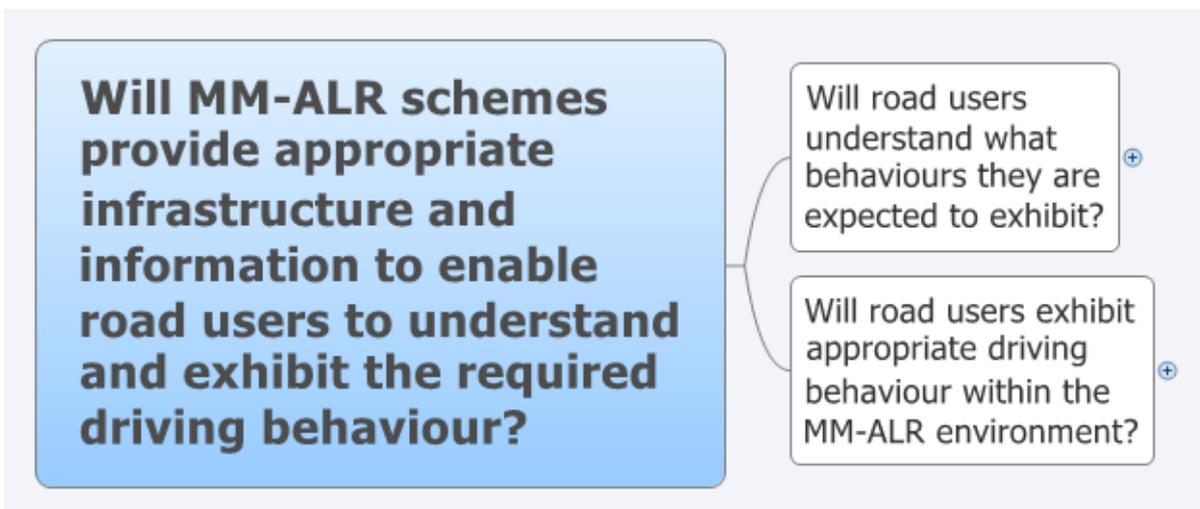
Clearly, these two sub-questions are intrinsically related; what road users understand is likely to have an influence on how they behave, and evidence of road user behaviour could usually also be considered as evidence of their understanding. However, it has

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[1] Section 85(1) Road Traffic Regulation Act, 1984

been determined that these should be treated separately to account for the different ways in which the responsibility of the HA could be considered.

1.4   Structure of this document

This document is structured as follows:

- Section 2 provides a summary of the evidence in relation to each of the sub-questions and the types of information provided;
- Section 3 presents a 'mind map' representation of how the evidence relates to the key question and sub-questions;
- Section 4 presents a list of the evidence referenced in Section 3 and a location of where it can be found in documentation;
- Section 5 suggests where further investigation could be carried out to develop the existing evidence-base.

2 Summary of Evidence

Key question:

Will MM-ALR schemes provide appropriate infrastructure and information to enable road users to understand and exhibit the required driving behaviour?

2.1 Will road users understand what behaviours they are expected to exhibit?

2.1.1 Will road users know what the speed limit is?

Whether or not road users will know what the speed limit is at a particular location within an MM-ALR scheme will firstly depend on whether or not they can see the signals communicated on AMIs and verge-mounted MS4s. The findings of the MS4 Obscuration task estimated a small proportion of drivers would be unable to see a speed limit on an MS4 for a sufficient duration (assuming that they do not adjust to their driving to be able to do so). Obscuration rates are significantly reduced when the speed limit processing time of 0.5 seconds suggested in the Sign Comprehension task is applied. Furthermore, the MS4 Obscuration task suggested that in almost all cases drivers would be able achieve a sufficiently long duration where the sign was unobscured by making a slight adjustment to their driving, usually a reduction in speed.

Upon seeing the speed limit there are four elements that road users would be required to understand: what the speed limit is, where it applies, the fact that it is mandatory and the fact that it is variable. Various questionnaire data and the Sign Comprehension task suggest that the vast majority of drivers will be able to discern each of these elements.

The situational awareness assessment carried out in the Design Assurance study, however, suggests that some road users would not be aware of what a speed limit is shortly after passing it for the first time. The other evidence suggests that this is unlikely to be due to not seeing it in the first place nor due to not understanding what the aspect is communicating. Furthermore, the responses to the equivalent situational awareness question within an MM-Dynamic Hard Shoulder (MM-DHS) environment suggest that this is not an issue specific to speed limits displayed on MS4s.

A more likely explanation then is that drivers will at times de-prioritise their awareness of the speed limit. This will presumably be because in busy traffic conditions where the speed of an individual is highly influenced by the speed of the surrounding traffic, the displayed speed limit would have very little influence on the speed that the individual chooses to drive at.

2.1.2 Will road users know which lanes are open/closed to traffic?

As with speed limits, driver information regarding lane use in an MM-ALR environment is given via gantry-mounted Red X indicators and Wicket aspects displayed on MS4s. The MS4 Obscuration study cited in 2.1.1 above, and the MS4 visibility trials, suggest that in almost all cases, drivers would be able to see lane specific information regarding open or closed for a duration sufficient for the driver to achieve an understanding of the information being communicated.

The Sign Comprehension Study demonstrated that the speed of comprehension of information presented on verge mounted MS4s was greater than or equal to that of

comparable gantry mounted signals, and that there were high levels of understanding of the lane closure aspects displayed on both gantry and verge mounted signs.

Questionnaire data suggested that while the meaning of both the Red X and the 'wicket' aspect was understood to represent a lane closure, there was some difference in how the two approaches were perceived to be communicating *where* the closure began. This is perhaps understandable given that, formally, the Red X means that the lane is closed from that point onwards while the Wicket aspect means that a lane is closed *ahead.* The accompanying 'Lane closed' text is likely to help clarify this.

Findings also suggest that drivers will understand both approaches to be enforceable, although, some findings suggested that the Wicket is considered 'less severe' in its instruction. However, while some participants expressed this subjectively, it was not necessarily supported by their behaviour in the driving simulator (see Section 2.2.2).

Participants' perception of different options for communicating a full-carriageway closure on a single MS4 was also assessed. Findings suggested a preference for a text-based message rather than aspects in the Wicket or single Red X style, although it should be noted that this would likely be legible for a shorter distance than the other two and would not be understood by non-English speakers. The Red X aspect was least favoured, with some participants stating that it was unclear as to which lane(s) the closure applied.

Regarding the availability of four running lanes in normal MM-ALR operation, drivers will be made aware that the nearside lane is a running lane as opposed to a hard shoulder through three means: the 'No hard shoulder for X miles' sign, lane markings and the lane specific signalling on the initial gantry on each link (when VMSL is operating). Situational awareness results suggest that the vast majority participants were aware of the availability of four running lanes upon first entering the scheme.

2.1.3   Will road users know when they should/should not change lanes?

In advance of a lane closure in an MM-ALR environment, drivers will be presented with either and Lane Divert Left/Right arrow on a gantry-mounted signal or a Hooked Arrow aspect on an MS4. As with the Wicket aspect above, the MS4 Obscuration study and the MS4 visibility trials suggest that in almost all cases, drivers would be able to see lane specific information for a duration sufficient for understanding.

Furthermore, the Sign Comprehension Study demonstrated that the speed of comprehension of information presented on verge mounted MS4's was greater or equal to that of comparable gantry mounted signals, and that the Hooked Arrow aspect appeared to give clearer instruction of the need for traffic to move out of lane than other aspects that were trialled.

Questionnaire data suggested that the meaning of the Hooked Arrow aspect was well understood for a single lane closure but less so for a double lane closure where two hooked arrows would be used.

In addition to lane closure instructions, the 'Stay in lane' message will be used in an MM-ALR environment during dense traffic conditions to reduce the amount of unnecessary lane changing and the risk of flow breakdown. The situational awareness assessment in the Design Assurance trial suggested that that the 'Stay in lane' message was more prominent that some of the other text messages presented in the environment. However, several participants commented that using this message around a junction was

confusing since lane changing would be required in order for them to leave the carriageway.

2.1.4   Will road users know what to do in the event of breakdown?

The most appropriate action in the event of a breakdown in an MM-ALR environment will depend on the severity of the breakdown, the location of the vehicle and the traffic conditions. The findings of situational awareness assessment in the Design Assurance trial suggest that the preferred response of road users would be different depending on where the participant was within an MM-ALR scheme when they were asked. There may be too much ambiguity in the question asked to conclude much more than this. When asked after first entering the MM-ALR section, half of the participants responded that they would use an ERA, whereas when they were approaching an off-slip 29% said they would use an ERA, 23% the verge and 21% the off-slip.

There were two participants who responded that they did not know what they would do. Furthermore, all participants suggested that reading an informational leaflet about how to respond in an MM-ALR environment in the event of a breakdown improved their understanding of what they should do. Both of these findings suggest that education could play a role in improving understanding of how to respond.

2.1.5   Will road users know where and how to leave the motorway at a particular junction?

Designers of MM-ALR schemes have two options for using ADS for communicating junction information to drivers: either verge-mounted or gantry- and cantilever-mounted.

The ADS obscuration assessment estimated that some drivers would have to make an adjustment to their driving or range of view to be able to see the ADS for long enough to extract destination information. However, it should be noted that the highest obscuration rate was estimated to be in Lane 4 where drivers are less likely to be considering leaving at the next junction. The situational awareness assessment provided evidence that suggests, despite being in an environment with a high proportion of HGVs, participants were almost all able to identify the junction destination correctly after passing the '1 mile to junction' sign.

Obscuration has been assumed not to be an issue with cantilever and gantry mounted ADS. Participants' responses to the questionnaire suggest that the cantilever-mounted ADS were found to be less clear than the verge-mounted equivalent. When shown images of each of the signs, participants found the verge-mounted signs to be significantly more effective at communicating both information about the junction and the lanes which should be used.

2.1.6   Will road users know users know when they are entering and exiting an MM-ALR environment?

On first entering the MM-ALR environment road users will encounter a series of fixed signs informing them that VMSL are in use, no hard shoulder is present and that ERAs should be used in emergency situations only.

Questionnaire data suggest that the fixed signs telling road users that variable speed limits are used and enforced are well understood. Obscuration was not assessed but, as

the design guidance states that they should be mounted on either side of the carriageway, this is unlikely to be an issue.

Participants' responses to the situational awareness question regarding what they would do in the event of a breakdown (see Section 2.1.4) provide an indication of the effectiveness of the ERA sign; half of the participants indicated that they would stop in an ERA despite being asked before they had passed any ERAs.

The sign informing drivers of the absence of a hard shoulder is widely used on the network so was not assessed directly. Obscuration for the hard shoulder and ERA information signs is likely to occur at similar levels to the verge-mounted ADS.

It should be noted that all three of these signs are in English and, therefore, are unlikely to provide the same level of information to non-English speakers using the strategic road network.

The situational awareness assessment found that all participants, after moving out of an MM-ALR environment, successfully recognised that only three lanes were now available, i.e. that the hard shoulder had been reintroduced.

2.2 Will road users exhibit appropriate driving behaviour within the MM-ALR environment?

2.2.1 Will road users comply with variable speed limits?

As could be expected, compliance with speed limits depends on why the road user perceives them to be set and the behaviour of traffic around them. The evidence from the Gantry Spacing, Verge vs Gantry and Design Comparison trial suggests that a proportion of drivers, if unrestricted by the presence of other traffic, will exhibit 'surfing' behaviour in response to the variable mandatory speed limits in an MM-ALR environment, i.e. some drivers will reduce their speed to below the speed limit (or a perceived enforcement threshold) to pass under a gantry or MS4 before speeding up then slowing down again for the next perceived enforcement point.

Compliance with the speed limit for the majority of participants under free flowing conditions, however, was much better. Unsurprisingly, it was observed that compliance was generally proportional to restrictiveness of speed limit, e.g. compliance with 60mph limits was greater than compliance with 50mph limits.

The evidence from the Design Assurance trial suggests that in busy traffic conditions the speed of an individual driver will be greatly influenced by the speed of surrounding traffic. As discussed in Section 2.1.1, some drivers may not even feel the need to maintain awareness of the current speed limit because it influences their speed choice so little in this kind of circumstance.

The strong influence of the other traffic in the simulated scenario makes it difficult to discern the role of speed limits in influencing speed choice of individual drivers in dense traffic conditions. Monitoring and evaluation of compliance with speed limits in early MM-DHS schemes are considered to be high, but the extent to which this is due to this 'group behaviour' is unclear.

Furthermore, achieving the desired benefits of VMSL means compliance with the speed limits is much more important under some conditions than others. For example, queue protection speed limits set in advance of a queue forming due to an incident late at night could achieve greater safety benefits than the same signals set during peak-hour congestion when traffic is slow moving. The required compliance by road users could be considered as different for each of these scenarios.

However, while the actual driver behaviour effects of VMSL remain unclear, the evidence from the relevant simulator studies suggests that there would be no major differences that could be attributable to the particular design features of the MM-ALR scheme tested. Behaviour in both the Verge vs Gantry and Design Comparison trials suggest that speed choice is not significantly affected by whether the speed limit is shown on an MS4 or on a gantry-mounted signal. The main differences were observed immediately following a speed limit; compliance in the vicinity of gantries was found to be higher than for equivalent MS4 sites. However, the effect of this on road users who exhibited 'surfing' behaviour appears to be a reduction in the magnitude of surfing, resulting in a smoother speed profile following speed limits displayed on MS4s.

2.2.2 Will road users comply with lane status instructions?

The Verge vs Gantry simulator study suggested that compliance with a lane closure communicated via verge-mounted MS4s will be generally comparable with closures communicated via gantry-mounted Red X indicators. The Design Comparison trial suggested that compliance with lane status instruction in an MM-ALR environment, combining gantries and MS4s, will be also be comparable.

As discussed in Section 2.1.2, compliance with the Red X is technically different to compliance with a Wicket symbol. While this difference is reflected in people's understanding, there is no evidence to suggest that this will have a significant impact on behaviour. In all environments there were a small minority of participants who waited until the obstruction or coning was visible before moving out of the lane and there was a tendency for some participants to exhibit non-compliance after having passed the incident, and before indication of the lane being reopened was provided.

Slightly lower levels of compliance were observed for offside lane closures but the post drive questionnaire suggested that non compliance was not as a result of poor comprehension. More likely this was due to the dense traffic present in this scenario and the requirement to find a suitable space to move out of the close lane.

As well as compliance with lane closures, drivers' lane utilisation under normal operation is of interest particularly regarding use of Lane 1. In the Design Assurance trial, Lane 1 was not well used by participants when they first drove the MM-ALR environment, although this was a similar degree to which the nearside lane was used in the standard 3-lane environment. The large number of HGVs using Lane 1 is likely to be a key factor in participants' decision not to use the lane.

Lane 1 utilisation increased greatly when participants drove in the MM-ALR environment for the second time as part of a transition route (where they would drive through an MM-ALR section into either a MM-DHS or Controlled Motorway environment). This was likely to be due to participants anticipating that they would leave at the next junction and pre-emptively moving into Lane 1.

2.2.3 Will road users change lanes/not changes lanes at an appropriate location?

As described in Section 2.1.3, drivers in an MM-ALR environment will be presented with either a Lane Divert Left/Right arrow on a gantry-mounted signal or a Hooked Arrow aspect on an MS4 in advance of a lane closure. The Verge vs Gantry simulator study suggested that driver behaviour in response to the Hooked Arrow aspect will be generally comparable with closures communicated via gantry-mounted Lane Divert arrow indicators. The Design Comparison trial suggested that behaviour in an MM-ALR environment, combining gantries and MS4s, will be comparable again.

In the Design Comparison trial, under free flow conditions, the majority of participants (around 70%) moved out of Lane 1 upon, or shortly after, encountering an gantry with a Lane Divert Right arrow. Similar behaviour was observed in the gantry- and MS4-only routes although movement in response to the Hooked Arrow aspect was slightly more dispersed.

Behaviour observed in response to a closure of Lanes 3 and 4 where the Lanes 1 and 2 were filled with traffic followed a similar pattern, except that the participants took longer to move out of the closing Lane 3 as they first had to find a suitable gap in traffic.

2.2.4 Will road users stop an appropriate location in the event of a breakdown (if possible)?

Participants' response to a breakdown in an MM-ALR environment was investigated in three different scenarios: on the approach to an ERA where the majority of participants stopped in the ERA; on the approach to an off-slip where most participants stopped on the hard shoulder located on the off-slip; and in a scenario where no location other than a sloped verge was available. In this scenario most of the participants stopped in Lane 1. There were some participants who stopped in Lane 4, presumably because there was hardly any traffic using this lane in at the time of the simulated breakdown.

These findings should be considered as indicative only due to the limitations of the simulated scenario. Participants were informed of the breakdown via a voice instruction at a particular location and the seriousness of the breakdown was left to their own interpretation (For participants experiencing a breakdown on the approach to a junction, their vehicle speed was limited to 30mph – this perhaps helps to explain why there were some participants who stopped their vehicle before they reached the off-slip). Some participants stopped almost immediately after receiving the instruction, in whatever lane they happened to be in. This is unlikely to be representative of real life behaviour. Similarly, there may have been an unrealistic willingness to stop in a live lane, perhaps due to participants being unsure as to whether they could drive the simulated vehicle on the verge.

2.2.5 Will road users leave that the motorway at the required junction and use the correct lane?

As described earlier, ADS in MM-ALR schemes can be either verge-mounted or cantilever/gantry-mounted. The Design Assurance trial was used to assess these signs by asking participants to leave the motorway by following signs to a particular destination (given before the start of their drive) and then observing their behaviour. For both approaches the vast majority of participants left at the correct junction.

When considering driver behaviour, of interest is not just whether drivers will leave at their required junction but that they will do so in a safe and timely manner. The position at which participants moved into Lane 1 to leave the motorway was examined. Section 2.1.5 suggested that although the participants' awareness of the junction destination following the '1 mile junction' sign indicated that obscuration may not adversely affect their awareness of the junction destination, one explanation of participant behaviour in the Design Assurance trial may suggest otherwise; participants generally took longer to move into Lane 1 to leave the motorway if presented with verge-mounted ADS than if presented with cantilever-mounted ADS.

The conditions in the Design Assurance trial in many ways reflected a 'worst case scenario' – the traffic was dense with a high proportion of HGVs and participants did not have any other sources of information concerning their route other than the ADS (such as from previous experience or satellite navigation systems). Environmental factors (such as road curvature and visibility) could present a more difficult environment in which participants are required to discern correctly the necessary route guidance information. However, unless any of these factors are found to present a serious issue then the evidence suggests that, despite some obscuration of individual signs, either verge-mounted and cantilever/gantry-mounted ADS should be sufficient for drivers to exhibit the required behaviour in an MM-ALR environment.

2.2.6 Will road users comply with the reintroduction of a hard shoulder following an MM-ALR scheme?

On the two transition routes there was no evidence to suggest that drivers will be more inclined to use the hard shoulder illegally after having driven through an MM-ALR environment. The two occurrences of non-compliance were of participants who had just rejoined the main carriageway and had overshot the merge, probably due to difficulty in finding a suitable gap in traffic.

2.3 Conclusion: Will MM-ALR schemes provide appropriate infrastructure and information to enable road users to understand and exhibit the required driving behaviour?

The findings of the work referenced in this report support the hypothesis that an MM-ALR scheme (of the design tested in the simulator) will, in general, provide sufficient information for road users to understand how they are expected to behave. In some cases, particularly when a high volume of HGVs are expected, obscuration of some verge-mounted information may occur. The relative importance of this issue will depend on the expectations of road users to make slight and safe adjustments to see the sign – which the findings suggest is almost always possible.

Some findings suggest that awareness of certain areas information could be considered as ambiguous, such as the use of Wicket aspects to communicate lane closures and how road users would be expected to respond in the event of an emergency breakdown. Clarifying these areas may be beyond the influence of on-road information provision alone and, therefore, the role of road user education could be considered.

It should be recognised that the information presented in infrastructure is only one of several factors that can influence road user behaviour. For example, findings suggest that in busy traffic, it is the speed of that traffic that is the dominant factor in determining individual driver speed choice. However, given the numerous factors influencing behavioural response, none of the findings suggest that the guidance provided will be insufficient to encourage appropriate behaviour.

Some findings suggest that a minority of road users will show poor compliance with both speed limits and lane closure instruction in an MM-ALR environment. However, this would not be expected to be specific to particulars of the MM-ALR design, i.e. speed and lane choice is not significantly affected by whether the information is shown on an MS4 or on a gantry-mounted signal.

Similarly, although some findings suggest that some road users will not be aware of the prevailing variable speed limit in busy traffic conditions, no findings suggest that this is specific to speed limits displayed on MS4s and it is difficult to see how this could be improved by more or clearer on-road information.

In summary, the work conducted to examine behavioural issues related to MM-ALR has identified minor areas of concern with regard to participants' perception of how MM-ALR schemes operate and what behaviours they are expected to adopt, but has not identified any compelling evidence from observed driving behaviours to suggest that an MM-ALR scheme of the design tested in the simulator does not provide sufficient information to understand and exhibit the required driving behaviour to a level comparable to existing Managed Motorway schemes.

3 Evidence Mind-Map

This section presents a 'mind map' representation of how the evidence relates to the key question and sub-questions.

The full mind-map is contained in Appendix A.

Figures 1 to 3 show the same information communicated through three smaller diagrams for ease of communication.

The labels within the mind-map are colour coded according to the following legend:

> **Sub-question –** The key questions has been broken down into several layers of sub-questions, the number of which will be dependent on the nature of the evidence referenced. For example, much of the evidence from the driving simulator trials is directly related to the sub-questions around behaviour so less of a structure is required
>
> **Evidence** – Each section of evidence is given a unique reference based on the task name and number. These can then been looked-up in the table in Section 4.
>
> **Enabler** – These labels refer to how the information is communicated in a MM-ALR environment.
>
> **Assumption** – Several reasonable assumptions have been made within this task.
>
> **See a separate branch** – Instead of repeating an identical section of the diagram, a reference is made to a different branch in places.

The mind-maps also include a few references to the Highway Code. These are also listed in Section 4.

Figure 1: Understanding of expected behaviour in an MM-ALR environment (1 of 2)

CPR1353

Figure 2: Understanding of expected behaviour in an MM-ALR environment (2 of 2)

CPR1353

Figure 3: Behaviour within an MM-ALR environment

4 Table of References

Reference	Document Location	Subject	Type of Evidence
ADS Obscuration 1	CPR1352 p20	Estimated proportion of traffic unable to see a piece of information on a verge-mounted ADS sign under different traffic and design conditions	Obscuration Model
Design Assurance 1	CPR1351 p23	Awareness of a variable speed limit in an MM-ALR environment	Situational Awareness Assessment
Design Assurance 2	CPR1351 p25	Awareness of how many lanes are open to traffic in an MM-ALR environment	Situational Awareness Assessment
Design Assurance 3	CPR1351 p32	Understanding of what to do in the event of a breakdown in an MM-ALR environment	Situational Awareness Assessment
Design Assurance 4	CPR1351 p28	Awareness of where the next junction is for in an MM-ALR environment when information is verge-mounted or gantry/cantilever-mounted	Situational Awareness Assessment
Design Assurance 5	CPR1351 p35	Speeds observed in an MM-ALR environment under busy traffic conditions	Driving Simulator
Design Assurance 6	CPR1351 p36	Willingness to use Lane 1 in an MM-ALR environment under heavy traffic conditions	Driving Simulator
Design Assurance 7	CPR1351 p49	Response to a breakdown scenario in an MM-ALR environment on the approach to an off-slip	Driving Simulator
Design Assurance 8	CPR1351 p40	Response to either verge-mounted or gantry/cantilever mounted ADS in an MM-ALR environment	Driving Simulator
Design Assurance 9	CPR1351 p55	Hard shoulder compliance on sections of motorway following an MM-ALR sections	Driving Simulator
Design Assurance 10	CPR1351 p64	Awareness of text messages in an MM-ALR environment	Situational Awareness Assessment
Design Assurance 11	CPR1351 p62	Perception of the Emergency Breakdown Storyboard	Questionnaire

Reference	Document Location	Subject	Type of Evidence
Design Assurance 12	CPR1351 p48	Perception of ADS	Questionnaire
Design Assurance 13	CPR1351 p56	Awareness of changes to the environment moving from an MM-ALR section to either a MM-DHS section or a Controlled Motorways section	Questionnaire
Design Comparison 1	CPR1335 p44	Compliance with variable speed limits set for an incident under free flow conditions	Driving Simulator
Design Comparison 2	CPR1335 p28	Response to instruction regarding a lane closure for an incident in an MM-ALR environment	Driving Simulator
Design Comparison 3	CPR1335 p30	Response to instruction regarding a lane closure for road works in an MM-ALR environment	Driving Simulator
Design Comparison 4	CPR 1335 p32	Response to a breakdown scenario in an MM-ALR environment on the approach to an off-slip	Driving Simulator
Design Comparison 5	CPR1335 p40	Clarity of combination of gantry and MS4 signals to communicate a reduced speed limit	Questionnaire
Gantry Spacing 1	CPR1062 p51	Speeds observed under different gantry spacings in free flowing conditions	Driving Simulator
Gantry Spacing 2	CPR1062 p53	Red X compliance under different gantry spacings	Driving Simulator
Gantry Spacing 3	CPR1062 p53	Immediacy of response to lane closure instruction under different gantry spacings	Driving Simulator
Gantry Spacing 4	CPR1062 p42	Comprehension of speed and lane closure instruction communicated on gantries	Questionnaire
Gantry Spacing 5	CPR1062 p43	Participants perception of legal status of speed limits and Red X	Questionnaire
Gantry Spacing 6	CPR1062 p46	Awareness of speed limit and lane instruction under different gantry spacings	Questionnaire
Gantry Spacing 7	CPR1062 p49	Awareness of enforcement indicators under different gantry spacings	Questionnaire
MS4 Obscuration	CPR1062 p185	Estimated proportion of traffic unable to see a variable speed limit or lane closure aspect	Obscuration Model

Reference	Document Location	Subject	Type of Evidence
1		on a verge-mounted MS4 under different traffic and design conditions	
MS4 Obscuration 2	CPR1062 p145	Estimated proportion of traffic unable to see a variable speed limit or lane closure aspect on a single AMI	Obscuration Model
MS4 Trial 1	MMFD-MS4-037Issue2 p13	Legibility of speed limit aspects on MS4s	Technology Trial
MS4 Trial 2	MMFD-MS4-037Issue2 p16	Legibility of lane closure aspects on MS4s	Technology Trial
M42 M&E 1	203754/10/D /30 (5-10)	Observed compliance with speed limits in the M42 ATM pilot	On-road
Sign Comprehension 1	CPR1062 p122	Processing of speed limit and lane closure information presented on gantries and MS4s	Visualisation and Response Monitoring Software
Sign Comprehension 2	CPR1062 p101	Interpretation of different approaches to displaying lane closure information	Questionnaire
Sign Comprehension 3	CPR1062 p104	Participants perception of legal status of different lane closure aspects	Questionnaire
Sign Comprehension 4	CPR1062 p104	Understanding of required behavioural response of different lane closure aspects	Questionnaire
Sign Comprehension 5	CPR1062 p109	Perception of legal status of variable speed limits	Questionnaire
Sign Comprehension 6	CPR1062 p117	Likelihood of different aspects to cause participants to reduce their speed	Questionnaire
Sign Comprehension 7	CPR1062 p120	Perception of effectiveness of MS4s for lane closures, managing incidents and improving driver behaviour	Questionnaire

Reference	Document Location	Subject	Type of Evidence
Sign Comprehension 8	CPR1062 p123	Effect of additional information on the processing of speed limit and lane closure information presented on gantries and MS4s	Visualisation and Response Monitoring Software
Verge vs Gantry 1	CPR1062 p256	Speeds observed in free flowing conditions in routes where only gantries or only MS4s are used to communicate instruction	Driving Simulator
Verge vs Gantry 2	CPR1062 p220	Red X compliance for an incident in routes where only gantries or only MS4s are used to communicate instruction	Driving Simulator
Verge vs Gantry 3	CPR1062 p258	Immediacy of response to lane closure instruction in routes where only gantries or only MS4s are used to communicate instruction	Driving Simulator
Verge vs Gantry 4	CPR1062 p231	Driver workload between routes where only gantries or only MS4s are used to communicate instruction	Questionnaire
Verge vs Gantry 5	CPR1062 p253	Participants awareness and perception of gateway signs	Questionnaire
Verge vs Gantry 6	CPR1062 p244	Interpretation of verge and gantry-mounted speed limits	Questionnaire
Verge vs Gantry 7	CPR1062 p220	Red X compliance in for road works routes where only gantries or only MS4s are used to communicate instruction	Driving Simulator
Verge vs Gantry 8	Fault Scenario Briefing Note p2	Response to a breakdown scenario with no hard shoulder and no ERA	Driving Simulator

Ref	Area	Subject	Hyperlink
Highway Code 1	Road Markings	The meaning of solid and dashed lines along a carriageway	http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/documents/digitalasset/dg_070563.pdf
Highway Code 2	Motorways (261)	Stipulation that mandatory variable speed limits must be observed	http://www.direct.gov.uk/en/TravelAndTransport/Highwaycode/DG_069862
Highway Code 3	Light signals controlling traffic	Stipulation that Red X signals must be observed	http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/documents/digitalasset/dg_070561.pdf

Highway Code 4	Traffic signs	Explanation of 'wicket' signs indicating a temporary road closure	http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/documents/digitalasset/dg_070644.pdf
Highway Code 5	Motorway breakdowns (275)		http://www.direct.gov.uk/en/TravelAndTransport/Highwaycode/DG_069863

5   Areas for Further Investigation

This section suggests where further investigation could be carried out to develop the existing MM-ALR evidence-base:

- The 'surfing' behaviour observed by some participants within the simulator trials suggests the way in which some drivers will comply with the speed limits within an MM-ALR environment will depend on how they perceive those speed limits as being enforced. Further work could look at both the role of indicators of enforcement (e.g. speed camera signs and markings) on driver behaviour and of the effect of different means of enforcement (e.g. average speed checks).

- Discussion of the impact of variable speed limits raised questions on the role of information and instruction provided by the road operator vs the group behaviour effects of other traffic. Further work could look at how much ability the on-road technology actually provides to manage traffic when the other factors are considered.

- Work to date has mainly looked at the role of on-road driver information provided through signals, variable messages signs, fixed signs and lane markings. Further work could consider the role of other sources of information (e.g. publicity and education and in-car technologies).

- Work to date has looked at how drivers may respond in the event of a 'generic' breakdown. Further work could look at more specific, detailed scenarios and also at how others will respond to vehicles broken down on the live carriageway.

- While the trials have generally looked at 'worst case scenarios' there could potentially be further investigation into different emergency scenarios, particularly focussing on 'blind spots' within schemes which may be created due to technology failures, road geometry and environmental factors.

- This work aims to assess appropriate behaviour but a full definition of what behaviour is appropriate does not necessarily exist. Further work would look at what behaviour is actually required to achieve the desired benefits, recognising the importance of different levels of compliance under different conditions.

- Work to date has only considered the understanding and behaviour of car drivers in an MM-ALR environment. Further work could consider other road users such as HGVs and motorcycles.

Appendix A: Full Synthesis Mind-Map