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Camera Monitoring System Human Machine Interface Support – Monitor Positioning

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Executive summary

The Bus Safety Standard (BSS)

In 2018 the Mayor of London, Sadiq Khan, set out a 'Vision Zero' approach to road casualties in his transport strategy (Transport for London, 2018). It aims for no one to be killed in, or by, a London bus by 2030 and for deaths and serious injuries from road collisions to be eliminated from London's streets by 2041.

Transport for London (TfL) commissioned the Transport Research Laboratory (TRL) to deliver a programme of research to develop a Bus Safety Standard (BSS) as one part of its activities to reduce bus casualties. The goal of the BSS is to reduce casualties on London's buses in line with the Mayor of London's Vision Zero approach to road safety. The BSS is the standard for vehicle design and system performance with a focus on safety. The whole programme of work includes evaluation of solutions, test protocol development and peer reviewed amendments of the Bus Vehicle Specification, including guidance notes for each of the safety measures proposed by TfL. In parallel to the detailed cycle of work for each measure, the roadmap was under continuous development alongside a detailed cost benefit analysis and on-going industry engagement. The BSS programme is illustrated below in Figure 1.

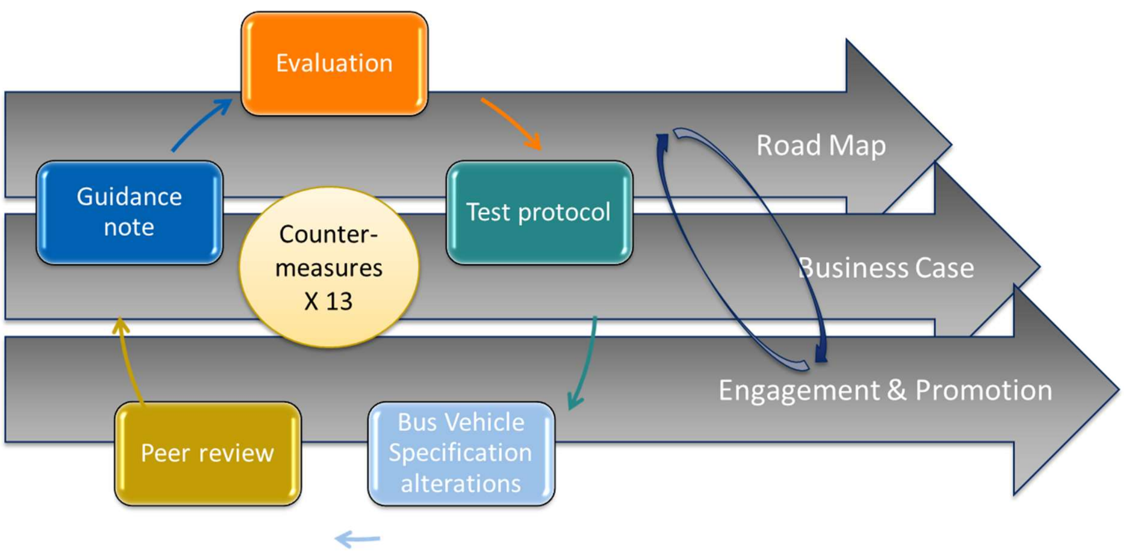


Figure 1: Summary of the BSS research programme

The exact methodology of the testing development depended upon each of the measures being developed. For Autonomous Emergency Braking (AEB) it included track testing and on-road driving, whereas for the occupant interior safety measures it involved computer simulation and seat tests. There was also a strong component of human factors in the tests e.g. human factors assessments by our team of experts. In addition, there were objective tests with volunteers to measure the effect of technologies on a representative sample of road users, including bus drivers and other groups as appropriate to the technology considered.

The test procedures developed were intended to produce a pass/fail and/or performance rating that can be used to inform how well any technology or vehicle performs according to the BSS requirements. The scenarios and/or injury mechanisms addressed were based on injury and collision data meaning it is an independent performance-based assessment.

A longer-term goal of the BSS is to become a more incentive-based scheme, rather than just a minimum requirement. The assessments should provide an independent indicator of the performance of the vehicle for each measure, and they will also be combined in an easily understood overall assessment.

It is important to ensure the money is spent wisely on the package of measures that will give the most cost-effective result. If zero fatalities can be achieved at a low cost, it remains better than achieving it at a higher cost. TRL has developed a cost-benefit model describing the value of implementing the safety measures, both in terms of casualties saved and the technology and operational costs of achieving that casualty saving. Input from the bus industry has formed the backbone of all the research and the cost-benefit modelling. This modelling has helped inform the decisions of TfL's bus safety development team in terms of implementing the safety measures on new buses.

Bus safety measures

The measures selected for consideration in the BSS were wide ranging as shown in Figure 2. Some will address the most frequent fatalities, which are the group of pedestrians and cyclists killed by buses, mostly whilst crossing the road in front of the bus. There are several measures that could address this problem, for example, Advanced Emergency Braking, which will apply the vehicle's brakes automatically if the driver is unresponsive to a collision threat with a pedestrian) or improved direct and indirect vision for the driver. These are both driver assistance safety measures, which are designed to help the driver avoid or mitigate the severity of incidents. Intelligent Speed Assistance (ISA) is another example of driver assistance, and TfL has already started rolling this out on their fleet. The last two driver assistance measures are pedal application error (where the driver mistakenly presses the accelerator instead of the brake) and runaway bus prevention; both of which are very rare but carry a high risk of severe outcomes.

Visual and acoustic bus conspicuity are both partner assistance measures that are designed to help other road users, particularly pedestrians and cyclists, to avoid collisions. Partner protection is about better protection if a collision should occur. For this the work has started with Vulnerable Road User (VRU) front crashworthiness measures, including energy absorption, bus front end design, runover protection and wiper protection.

Passenger protection is focussed on protecting the passengers travelling on board the bus, both in heavy braking and collision incidents. This encompasses occupant friendly interiors with improved seat and pole design and slip protection for flooring. This group of measures that help to protect bus occupants are important because around 70% of injuries occur without the bus having a collision.

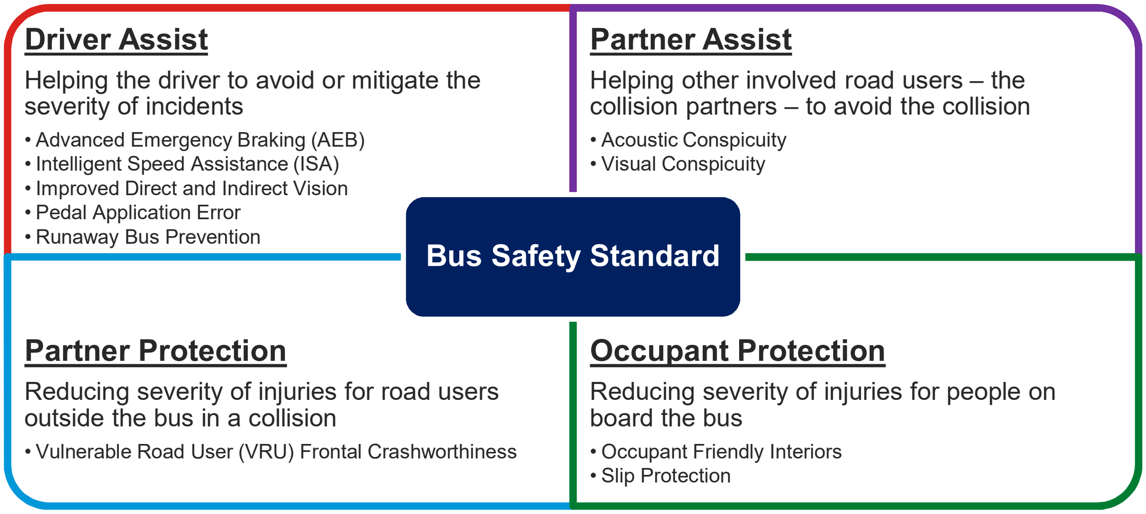


Figure 2: Bus Safety Measures

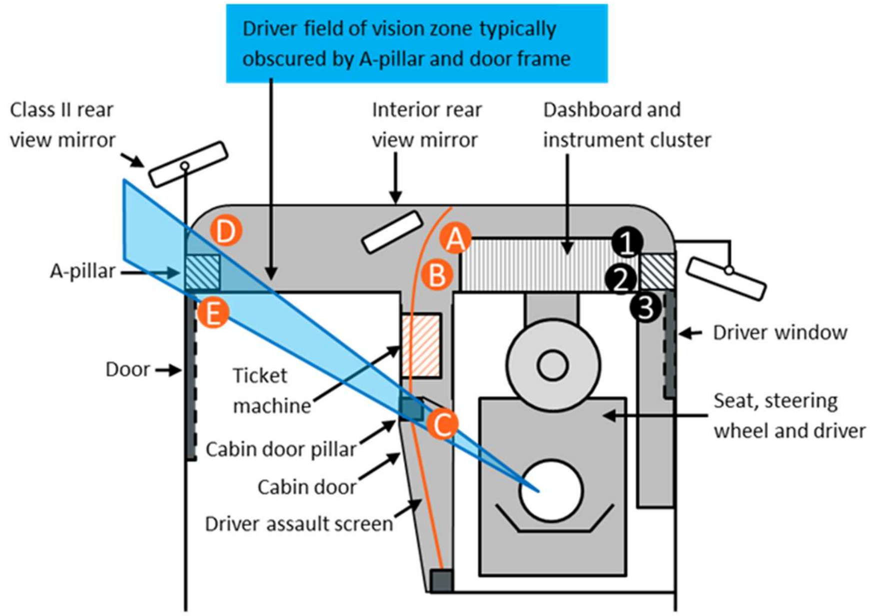
Camera Monitor Systems (CMS)

The BSS launched in October 2018 making CMS a requirement for new buses from 2021 according to the roadmap. TfL and various bus operators are also considering a retrofit of this system on to existing buses in the fleet.

This safety measure means that the mirrors are substituted by CMS, provided they comply with the relevant regulations. CMS is a combination of cameras placed outside the bus with corresponding monitors installed inside the cab. This approach removes the risk of a mirror hitting a pedestrian or infrastructure, as well as potentially reducing blind spots and assisting drivers by improving hazard perception. However, as the replacement of driving mirrors with CMS is a fairly new concept, the effect on driver workload and behaviour is not yet well understood, and there may be risks if drivers do not find the system natural to use. This study has extended the CMS research to fill the gaps in the knowledge regarding the positioning of the monitors, and to develop a set of recommendations for where the monitors should be positioned.

Approach

TRL performed an extensive study investigating the optimal position for CMS monitors in a bus. The first task consisted of reviewing current national and international standards and regulations, particularly UN Regulation 46, because all vehicle types must comply with the requirements stated in this regulation. Once completed, a bus manufacturer trialling CMS was engaged to determine the advantages and disadvantage of the various CMS monitor positions being investigated (Figure 3). A state-of-the-art evidence review was conducted to further inform on, or eliminate, the CMS monitor positions. Lastly, the bus manufacturer trialling CMS was re-engaged to assess and update final recommended monitor positions.



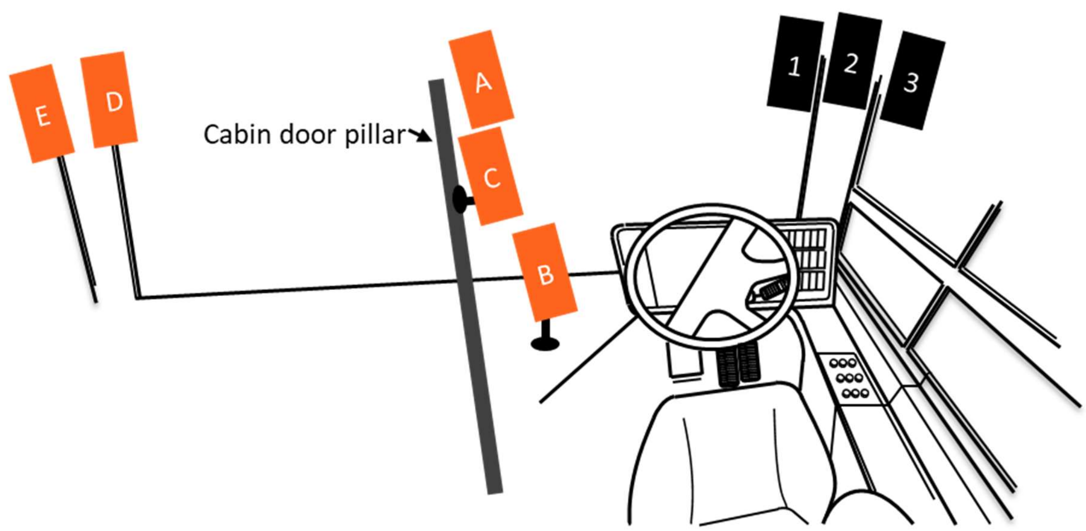


Figure 3: Offside (1-3) and nearside (A-E) CMS monitor positions investigated in this study

Requirements

The ideal position for the offside monitor is on the A-Pillar (Position 2). If this is not feasible Position 1 would be deemed acceptable, whereas Position 3 is deemed unacceptable.

The preferred position for the nearside monitor is Position A. A monitor positioned in Position A, Position D, Position B or a position between these three would be deemed acceptable so long as 1) the image quality is equal to or better than the image quality of the external mirror and 2) the monitor does not affect the direct vision score as tested and assessed by the vision standard. All other positions are considered unacceptable.

Monitors located on the windshield shall not affect the driver's direct field of view (FOV). This may be assessed by revaluating the direct vision performance of the bus with the CMS installed to ensure that direct vision performance is not below the minimum requirements. A monitor located greater than 30° below the direct line of sight is deemed unacceptable.

Table 1 summarises the requirements for CMS monitor positioning. All recommendations and requirements have been used to update the Bus Vehicle Specification text for use in contracting of bus routes within London by TfL.

Table 1: The requirements for the positioning of CMS monitors in a bus

CMS monitor position requirements	
1	The seated driver shall have a clear view of the road ahead
2	Obstruction to direct field of view (FOV) shall be kept to a minimum, with this assessed through the direct and indirect vision standard
3	The monitor shall not be located lower than 30° below the driver's ocular points
4	The driver shall not need to rotate their head more than 55° to view the offside monitor
5	Monitor viewing direction shall be approximately in the same direction as the mirror it is replacing
6	The drivers view of the monitor shall not be obstructed
7	Image of offside and nearside FOVs shall be presented on the respective side of the drivers' ocular reference point
8	Non-continuous images shall be clearly separated
9	Monitor shall not vibrate
10	Monitor shall be interpretable up to 80% of maximum design speed
11	Ambient light (e.g. sunlight and artificial light) illuminating the monitor shall be minimised as far as reasonably practical
12	Reflections on windscreen or other window panes as a result of the monitor shall be reduced as far as reasonably practical
13	Maximum monitor distance to the driver's ocular reference point shall be – Offside: 1.7m | Nearside: 2.6m
14	Minimum magnification factor for Class II monitor – Offside: 0.26 | Nearside: 0.13
15	Average magnification factor for Class II monitor – Offside: 0.31 | Nearside: 0.16
16	CMS components shall not be located within 5cm of any radio device emitting electromagnetic radiation in a frequency range that would interfere with the operation of the CMS
17	The monitor display shall not be affected by extreme cold
18	Minimum monitor distances from the driver's ocular reference point shall be – Offside: 50cm | Nearside: 50cm
19	The monitor shall not be viewed through a glazed surface at an Angle of Incidence (AoI) greater than 70˚ for unpolarised light
20	The nearside monitor shall not be obstructed by reflections or speaking holes as a result of the Assault Screen
21	A display shall be installed that has the ability to view the nearside and offside front end of the bus, where the image for this FOV shall be located either below or above the Class II monitor image on its respective side
22	Driver training shall be provided on CMS monitors and shall include nearside peripheral vision awareness training for nearside monitors positioned in a different location to the traditional nearside external mirror
23	The CMS monitors shall not interfere with any internal mirrors for the saloon or wheel chair bay
24	The view of the camera will be set by the manufacturer in accordance to UNECE Reg 46 and shall not be adjustable by the driver
25	The CMS monitor system shall be protected from tampering

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1 Introduction

The aim of this project was to determine the requirements for implementing Camera Monitor Systems (CMS) as passive indirect vision devices across the TfL fleet. The research focussed on the Human-Machine Interface (HMI) of such systems, in particular on CMS monitor positioning in the bus.

In order to determine and specify the most appropriate position(s) for the monitors inside a bus, the following tasks were conducted:

1. Review of current standards and regulations
2. Stakeholder engagement with a bus manufacturer trialling CMS
3. Evidence and theory review relating to CMS monitor position
4. Stakeholder reengagement

The aims and method for each task, along with the findings, will be discussed in each individual section below, where each task informed the next. Once all three tasks were completed, the information was collated, and the optimal CMS monitor position(s) was determined, along with CMS monitor positioning requirements (Section 5 and 7).

Bhise (2011) defines the concept of field of view (FOV) as "the extent to which the driver can see 360 degrees around the vehicle in terms of up and down angles, and left and right angles of the driver's line of sight to different objects outside the vehicle". In vehicles, a driver's visual field is partially obstructed by the vehicle structures and their forward FOV is obstructed by the A-pillars (Bhise, 2011). Both mirrors and CMS mitigate this effect by relocating the FOV for the drivers – thus providing indirect fields of vision to the driver.

2 Review of current standards and regulations

The recommended positions for the CMS monitors must comply with current international standards and regulations. To ensure this, TRL researchers reviewed the relevant standards and regulations relating to CMS monitor positioning. The documents reviewed included:

- UNECE Regulation 46: Uniform provisions concerning the approval of devices for indirect vision and of motor vehicles with regard to the installation of these devices
- ISO 16505:2015 Road Vehicles – Ergonomic and performance aspects of Camera Monitoring Systems - Requirements and Test Procedures
- ISO 16121-1:2012 Road Vehicles – Ergonomic requirements for the driver's workplace in line-service buses Part 1: General description, basic requirements
- ISO 16121-2:2011 Road Vehicles – Ergonomic requirements for the driver's workplace in line-service buses Part 2: Visibility
- ISO 16121-3:2011 Road Vehicles – Ergonomic requirements for the driver's workplace in line-service buses Part 3: Information devices and control
- ISO 16121-4:2011 Road Vehicles – Ergonomic requirements for the driver's workplace in line-service buses Part 3: Cabin Environment

Regulation 46 describes mandatory requirements, whereas the ISO standards are optional. Only the relevant aspects of these standards and regulations that underpin the design of the CMS, specifically with regards to monitor positioning, were highlighted and will be discussed below.

UNECE Regulation 46 defines the minimum mandatory FOVs a driver must see on the ground plane when using indirect vision devices such as mirrors or CMS (UNECE, 2016). The regulation sets out key FOV installation requirements for M, N and L1 category vehicles. Visibility of the Class II (main rear view) FOV is the only mandatory requirement for indirect vision devices for M3 vehicles (i.e. city buses) (Figure 4). The fitment of Class I (rear view), Class IV (wide-angle rear view), Class V (close proximity) and Class VI (front view) indirect vision devices is optional.

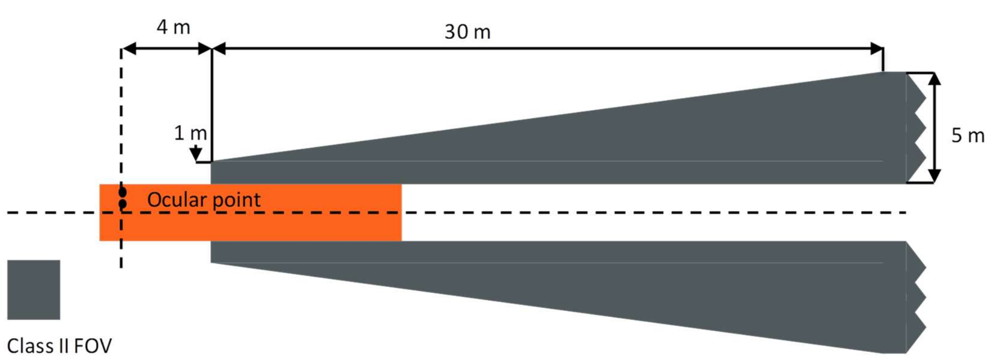

Figure 4: Regulation 46 Class II ground plane dimensions

2.1 ISO 16505 (requirements and test procedures)

ISO 16505 sets out the minimum safety, ergonomic and performance requirements for CMS. The standard states that the monitor should be:

1. Oriented in a way that prevents ambient light illuminating the monitor from a central critical specular light direction (a line from the centre of the display to the centre of the eye ellipse).
2. Installed in a location or orientation which does not lead to annoying reflections on the windscreen or other window panes.
3. The image of the left and right side FOV to be displayed on the respective side of the monitor arrangement and the centre FOV to be displayed on the intermediate region of the monitor.

The standard also limits the maximum offside (the side furthest from the kerb) and nearside (the side closest to the kerb) mirror viewing distances relative to the driver ocular reference point[1], and the average and minimum mirror magnification factors which can be found in Table 2.

Table 2: Table adapted from ISO 16505 (ISO, 2015)

Class II Mirror Positioning and Magnification Requirements	Offside	Nearside
Maximum mirror distance to driver ocular reference point	1.7 m	2.6 m
Mirror average magnification factor[2]	0.23	0.15
Mirror minimum magnification factor	0.21	0.13

[1] The Ocular Reference Point (ORP) is defined as a point 635 mm vertically above the manufacturer defined R-point of the driver's seat. ISO 16505 defines the ORP following the definitions of the responsible national body, in this case those definitions in UNECE Regulation 46.

[2] ISO 16505 defines CMS magnification factor as "the relationship between the angular size of an object as seen by the camera and the angular size as it is perceived by the driver on the monitor of the CMS".

2.2 UNECE Regulation 46 (Indirect Vision)

Regulation 46 expands on ISO 16505 by setting the following monitor installation and ergonomics requirements:

1. The monitor should be positioned in such a way that the driver, when seated in a normal driving position, has a clear view of the road.
2. Any obstruction to the driver's direct FOV should be minimised.
3. The centre of the monitor should not be located below a plane passing through the driver's ocular points[3] and declined 30° below (Figure 5).

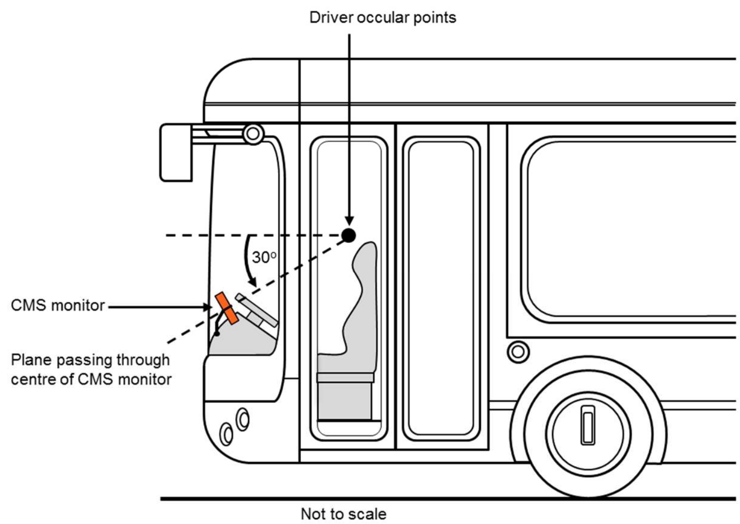

Figure 5: Diagram showing the maximum angle a monitor can be positioned below the driver's ocular points

4. For offside monitors, the angle between the vertical longitudinal median plane of the vehicle and a vertical plane passing through the centre of the monitor and the ocular reference point shall not exceed 55° i.e. the driver must not be required to turn their head more than 55° from their centre line to view the offside monitor (Figure 6). There was no similar requirement stated for the nearside monitor.

[3] UNECE Reg 46 (2016): "The driver's ocular points means two points 65mm apart and 635mm above point R of the driver's seat as defined in Annex 8 of UNECE Reg 46. The straight line joining these points runs perpendicular to the vertical longitudinal median plane of the vehicle. The centre of the segment joining the two ocular points is in a vertical longitudinal plane which shall pass through the centre of the driver's designated seating position, as specified by the vehicle manufacturer"

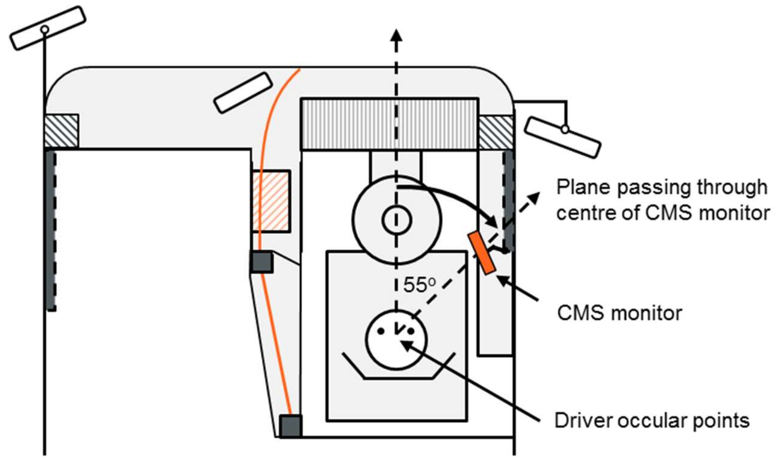

Figure 6: Diagram showing the angle between the vertical longitudinal median plane of the vehicle and the vertical plane passing through the centre of the monitor and through the centre of the driver's two ocular points

5. The viewing direction of the monitor should be approximately in the same direction as the mirror it is replacing and be obstruction free from the ocular reference point[4].
6. The image of the right and left FOV should be presented to the respective side of the drivers' ocular reference point.
7. If the monitor is capable of displaying more than one FOV, non-continuous images should be clearly separated from each other. A combined continuous image without a clear separation is permitted provided that the mandatory FOV of all classes of devices for indirect vision involved is displayed on the monitors.
8. An indirect vision device should not be able to vibrate to such an extent that it significantly changes the drivers FOV.
9. The image must remain interpretable whilst travelling at up to 80 per cent of the maximum design speed but not exceeding 150 km/h.
10. The monitor should be installed in position fitting to the needs of the intended user group. The operator's manual should provide information on how to do this.
11. The minimum and average magnification factors for Class II CMS monitors, in both horizontal and vertical directions is displayed in Table 3.

[4] The ocular reference point is in the middle of the driver's ocular points.

Table 3: Minimum and maximum magnification factors for Class II CMS monitors

Magnification factors for Class II CMS monitors	Offside	Nearside
Minimum magnification factor	0.26	0.13
Average magnification factor	0.31	0.16

2.3 ISO 16121 Series (Ergonomic Requirements)

2.3.1 ISO 16121-3

ISO 16121-3 outlines the fundamental ergonomic principles (e.g. arm reach and shoulder point locations) and locations for key components within the dashboard.

The standard states that the monitors should not obstruct the drivers FOV to the front and sides, and that the driver must be able to identify and resolve any faults using minimum effort. Moreover, the information displayed on the monitors must be relevant and unambiguous, causing the minimum amount of distraction.

The standard states that reflections due to light sources, other illuminated objects and/or reflections by sunlight should have minimal impact on the driver's ability to view the monitor or outside of the vehicle, where in busy environments, e.g. junctions, these may interfere with the driver's judgement.

Other factors in ISO 16121-3 which could impact monitor position include driver cab entry requirements. The standard states that the entrance to the bus should be clear, unrestricted and have a minimum width of 500mm.

2.3.2 Other ISO 16121 Standards

The remaining three standards (ISO 16121-1, 16121-2 and 16121-4) cover basic requirements, visibility and cabin environment respectively (ISO, 2012; ISO, 2011b; ISO 2011c). Of these three remaining standards, only ISO 16121-2 was found to have additional relevance. ISO 16121-2 states the driver shall have an unobstructed view through the windscreen, measured through 15° inclined a plane intersecting V1 (a point 635 mm vertically above the H-point with the seat in its rearmost highest position). Any obstruction caused by rear-view mirror, windscreen wiper arms, split windscreen centre bar, video screens, sun blind or visor, driver's fan and any legally required marking shall not be considered. Thus, ISO 16121-2 may be used to assess what constitutes the drivers forward FOV for the requirements detailed in ISO 16121-3 regarding CMS monitor position.

2.4 Summary

The regulations and standards review has highlighted key mandatory and recommended CMS monitor installation criteria. There were some differences between the regulations and the standards, such as:

- **Monitor location**: ISO 16505 states that the image of the left, centre and right side FOV should be displayed in the respective area of a monitor arrangement, whereas UNECE Reg 46 states the image of the left and right FOV should be presented to the respective side of the drivers' ocular reference point. The regulation is mandatory and therefore images of the offside and nearside FOV should be displayed on the respective sides of the driver.
- **Obstruction to FOV**: ISO 16121-3 states that the monitors should not obstruct the drivers FOV to the front and sides, whereas UNECE Reg 46 states that any obstruction to the driver's FOV should be kept to a minimum. These are two similar, but slightly different requirements. Again, the regulation is mandatory, so minimal obstruction to the driver's FOV should be viewed as the minimum mandatory requirement. In addition, if the ISO standard stating no obstruction to the front and sides can be met, then that would be a better optional goal. This may also be linked into the TfL Direct and Indirect Vision Standard, in order to ensure that the driver FOV does not reduce below the minimum direct vision requirements.
- **Magnification factor**: The ISO 16505 and UNECE Reg 46 recommended different minimum and average magnification factors for the offside and nearside CMS monitors, where UNECE Reg 46 is more stringent in terms of requiring a larger magnification factor. As the regulation is a mandatory requirement, the lower values detailed in the ISO standard are not permitted.

Table 4 summarises and collates the minimum requirements for CMS monitor location as stated across the above regulations and standards.

Table 4: Summary of the requirements for CMS monitor positioning

CMS monitor position requirements	
1	The seated driver shall have a clear view of the road ahead
2	Obstruction to direct field of view (FOV) shall be kept to a minimum, with this assessed through the direct and indirect vision standard
3	The monitor shall not be located lower than 30° below the driver's ocular points
4	The driver shall not need to rotate their head more than 55° to view the offside monitor
5	Monitor viewing direction shall be approximately in the same direction as the mirror it is replacing
6	The drivers view of the monitor shall not be obstructed
7	Image of offside and nearside FOVs shall be presented on the respective side of the drivers' ocular reference point
8	Non-continuous images shall be clearly separated
9	Monitor shall not vibrate
10	Monitor shall be interpretable up to 80% of maximum design speed
11	Ambient light (e.g. sunlight and artificial light) illuminating the monitor shall be minimised as far as reasonably practical
12	Reflections on windscreen or other window panes as a result of the monitor shall be reduced as far as reasonably practical
13	Maximum monitor distance to the driver's ocular reference point shall be – Offside: 1.7m | Nearside: 2.6m
14	Minimum magnification factor for Class II monitor – Offside: 0.26 | Nearside: 0.13
15	Average magnification factor for Class II monitor – Offside: 0.31 | Nearside: 0.16

3 Industry input

Figure 7: A trial bus equipped with CMS

A team from TRL attended a workshop with a bus manufacturer currently trialling CMS on a bus as a replacement for Class II mirrors, with secondary Class IV capabilities (Figure 7). The aim of the workshop was to develop an understanding of the potential advantages and disadvantages of various possible CMS monitor positions (Figure 8).

To gather this information, the first step was a discussion with the manufacturers regarding their CMS system and current monitor positions. This was followed by a static and dynamic demonstration of the system, where the current and alternative monitor positions were discussed focusing on 1) the technical feasibility of the positions and 2) the potential impact of the positions on the bus driver and road safety. The information gathered from the engagement with the stakeholder, which is detailed below, was used to identify technically feasible monitor positions and gaps in the knowledge which need to be investigated further.

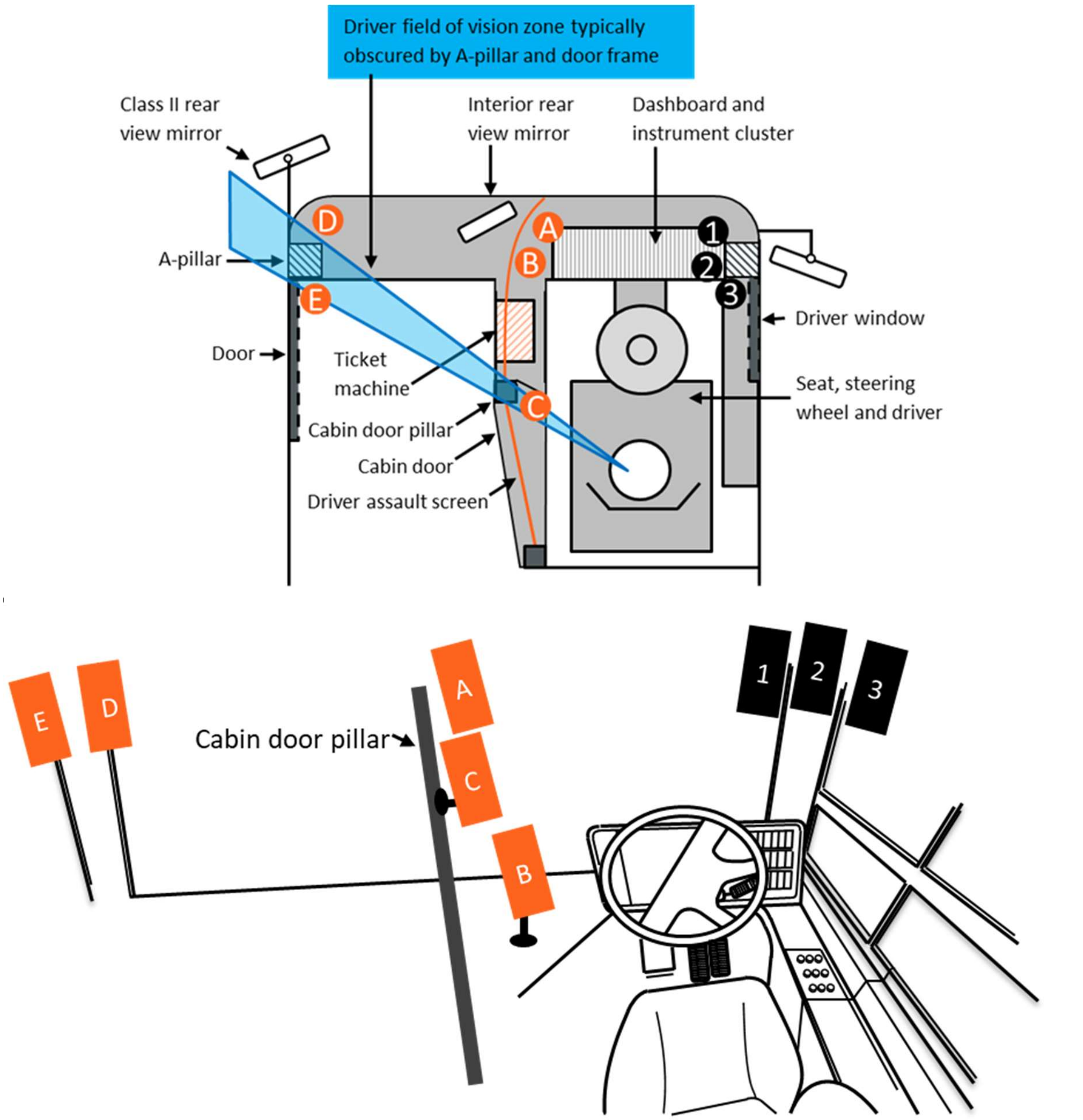

Figure 8: Basic cab layout diagram highlighting potential nearside (orange A-E) and offside (black 1-3) monitor positions

3.1 General monitor positions

A bus body may be fitted to several different chassis types. Each chassis has a different cabin configuration with an adjustable seating position (e.g. forwards, backwards, up and down). As a result of these factors, the driver seating position in relation to the monitor and the monitor mounting positions may vary between models and individual drivers. Similarly, the location of major structural components, such as the A-Pillar, and bodywork may vary between different models. The discussions and diagrams within this section of the report are based on one example bus model, so it may not apply to all bus body/chassis configurations.

3.2 Offside monitor positions

Three offside locations were investigated (Figure 8):

- Position 1: Forward and left of the offside A-Pillar located in front and at the top of the windscreen.
- Position 2: Aligned with and mounted on the top of the offside A-Pillar.
- Position 3: Rearward and right of the offside A-Pillar located next to the driver's window and aligned with the wing mirror.

Position 1 requires the least head movement to view; however, it reduces the driver's forward and upward direct FOV in a critical viewing area. Position 2 is considered the most preferable position for the offside monitor as it would cause the least obstruction to the driver's direct FOV due to it being aligned with the A-Pillar. Both Position 1 and 2 are not in line with the external mirror. The effects of this on bus driver gaze behaviour and offside peripheral vision is unknown. However, it is suspected to have a minimal impact due to the small difference in positioning relative to the external mirror, especially for Position 2, which is located closer to the external mirror.

Position 3 is aligned with the offside Class II mirror reinforcing the drivers natural eye glance behaviour. However, there were four issues raised with this position:

1. The monitor causes greater obstruction to offside FOV compared to the external mirror due to:
    - The monitor being located closer to the driver resulting in the relative size of the monitor being greater than the relative size of the external mirror (relative size is dependent on the viewing distance to the monitor and/or mirror).
    - The monitor is also larger than an external mirror as it comprises of a Class II and Class IV monitor (as well as border frames) resulting in even more obstruction to the offside FOV.
2. The driver's access to the side window will be compromised.
3. The driver's ability to communicate with offside VRU's or other road users travelling in close proximity to the vehicle will be reduced due to the greater obstruction to the offside FOV and reduced side window access.
4. There is an increased risk of monitor failure due to water or dirt entering the monitor casing through the window.

For these reasons, Position 3 is not considered as a feasible option and will not be recommended as a position for CMS monitors. For all three positions, if the monitor is positioned too close to the driver's ocular reference points it might cause eye strain or compromise eye accommodation.

3.3 Nearside monitor positions

Five nearside locations were investigated (Figure 8):

- Position A: Inside the Assault Screen, positioned on the top nearside corner of driver cabin in front of the windscreen.
- Position B: Inside the Assault Screen positioned at the bottom left corner of the driver cabin.
- Position C: Inside the Assault Screen and in line with the nearside external mirror – mounted on the central pillar / door frame of Assault Screen.
- Position D: To the right of the A-Pillar in line with the nearside external mirror and located at the top of the bus cabin and in front of the windscreen.
- Position E: Aligned and mounted at the top of the nearside A-Pillar.

Like its offside equivalent, Position A requires the least head movement to view. The driver is able to glance without moving their head. Key issues relating to this location include:

- The drivers forward and upward direct FOV is reduced.
- Peripheral vision may be compromised (e.g. driver may slip in to the habit of not turning their head to look due to over reliance on the CMS). This might result in a reduced peripheral vision of any VRUs in the nearside close proximity zone.
- Driver's eye accommodation may be compromised due to the screen being too close for the driver's eyes to 1) focus causing strain or 2) efficiently switch focus between the monitor and road scene.

Position B is located in a similar position to Position A; however, it is mounted lower down, e.g. between the dashboard and ticket machine. This location would not require looking through the Assault Screen and does not obstruct FOV. However, in this position drivers would need to look downwards, a movement which they are not accustomed to when assessing indirect vision, and this movement could potentially compromise forward vision due to the drivers' eyes being removed from the road scene, and reliant on the upward peripheral vision only, for long glance durations.

Position C is mounted to the driver cabin door frame i.e. the central pillar of the Assault Screen. When sat in the seating position for a taller driver, the door frame is in line with the A-Pillar causing minimal obstruction. This will not be the case for all drivers; especially those sat further forwards (i.e. shorter individuals). These individuals will need to turn their head significantly further to the left to view the display on the monitor. Moreover, eye accommodation (monitor too close), accessibility to the cab and communication with passengers will likely be compromised. The latter two cannot be addressed easily due to the fixed location of the ticket machine.

Position D is aligned with the nearside Class II mirror and as a result would be neutral in terms of affecting direct vision. Two key issues have been highlighted with this location. Firstly, the bus manufacturers were (as yet) unable to meet the magnification criteria set out in UNECE Regulation 46 (UNECE, 2016) due to technology constraints. One method of achieving the required minimum magnification requirements is by adopting a slightly larger screen. Despite reducing the driver's direct FOV, a larger device is permitted by UNECE Reg 46 as long as the obstruction is restricted to a minimum. Secondly, in the majority of cases the driver will have to look through the Assault Screen to view the monitor. External and internal light sources (including the monitor itself) may cause reflections on the screen or windscreen obstructing the drivers view. The light from the monitor is a particular issue during night time operations when most light sources are dimmed. As yet it has not been possible to evaluate whether these reflections will be realised in practice, and a prototype or mock up is needed to assess this.

Position E would cause the least obstruction to the drivers nearside FOV as it is aligned with the A-Pillar. However, this position presents several issues, for instance:

- Not all individuals are able to see the A-Pillar due to the central pillar of Assault Screen obstructing their FOV (i.e. tall individuals), thus these drivers will not be able to see the monitor.
- Similarly to Position B, the technology may not be able to accommodate the magnification criteria.
- There is no mandatory door interlock on the front doors, meaning the vehicle can pull away with the doors still open which could result in water or dirt landing on the monitor. Or the vehicle could pull away with the door obscuring the monitor.

This position is not aligned with the external mirror; thus, the driver needs to also turn their head slightly further to the left.

3.4 Summary

From the bus manufacturer consultation, it was evident that the most preferable position for the offside monitor was on the A-Pillar in Position 2, followed by Position 1, whereas Position 3 is deemed unacceptable due to the negative effects of the monitor on offside FOV and several technical feasibility issues.

With regards to the nearside monitors, Position C and E are not feasible options, as taller individuals and shorter individuals will not be able to see the monitors respectively. Thus, these two locations will not be recommended as positions for CMS monitors. For the remaining positions, Position A, B and D, the most preferred position could not be determined due to each position presenting several unknown effects. Some of these effects were also highlighted for the offside monitors. These unknown effects included:

- The impact of monitor position on peripheral vision and eye glance behaviour.
- The impact of monitor distance from the driver’s eyes on eye strain and eye accommodation.
- The effect of monitor position on internal obstructions such as the A-Pillar and reflections on the driver Assault Screen obstructing monitor view.

4 Evidence and theory review

In order to verify the suggested positions of the offside monitors and to determine the most preferable position for the nearside monitors, the research questions highlighted in Section 3 need to be investigated. Thus, TRL conducted a literature review on the following topics:

- CMS monitor position: The aim of the review was to identify papers which investigated the optimal positioning of CMS monitors in a vehicle.
- Human vision: This involved theoretical research surrounding human vision including FOV, eye accommodation and eye strain.
- Bus driver eye glance behaviour: A literature review was conducted investigating eye glance behaviour of bus drivers as well as engagement with a bus manufacturer regarding the glance behaviours that bus drivers are taught during training.
- Internal obstructions: The aim of the review was to investigate the impact of various internal obstructions, such as the Assault Screen and A-pillars, on direct and indirect FOV.

The goal of the following evidence and theory review is to fill in the gaps in the knowledge regarding CMS monitor position to recommend positions for locating CMS monitors in a bus.

4.1 CMS monitor position

An evidence review was conducted to identify relevant research surrounding CMS monitor positioning. The aim of the review was to inform and determine the optimal position(s) for CMS monitors. However, due to CMS being a fairly recent concept, limited evidence was found, with only four papers being identified. These included:

- Final Report: Camera monitoring systems as replacement for exterior mirrors in cars and trucks (Schmidt et al., 2015)
- Digital mirrors: supplementary information to increase driver's awareness of surroundings (Payandehmehr and Placzkowska, 2015)
- Digital rear-view mirrors: Physical ergonomic implications of arranging digital rear-view mirrors in a truck cab (Lindin and Zaimovic, 2015)
- Evaluations of camera-based systems to reduce transit bus side collisions (Pei-Sung et al., 2010)

From these papers, one investigated CMS monitor position on a bus, whilst the others investigated the topic in either a car or a truck. Each of the papers was critically reviewed, where the aims, key findings and limitations of each study is highlighted and briefly discussed. This information will then be collated and used to form a discussion surrounding the effectiveness of the various CMS positions, highlighting the positions which were recommended by the relevant paper or that still require further research.

4.1.1 Paper 1 (Schmidt et al., 2015)

This study aimed at investigating whether CMS can provide an equivalent substitute for mirrors in cars and trucks. The study compared and assessed CMS against conventional external mirrors, where three projects were undertaken and discussed in detail below. Two compact vehicles were used in the car trials and a tractor unit with semi-trailer was used in the truck trials. All vehicles had CMS and conventional external mirrors installed. Three monitor positions were assessed in the car trials (Figure 9), whereas only one monitor position was assessed in the truck trials (Figure 9).

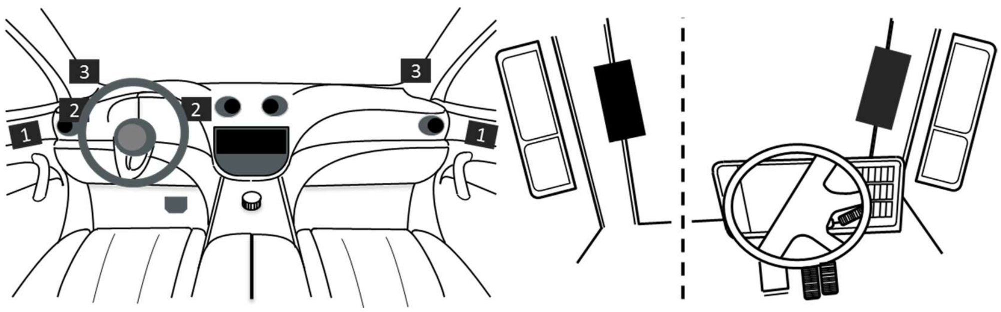

Figure 9: Adapted schematic overview of the monitor positions assessed in the car (Left) and the truck (Right) trials respectively (Schmidt et al., 2015; pp. 13-15)

4.1.1.1 Study 1: Technical aspects of CMS

Study 1 aimed to compare a CMS to a conventional external car mirror with regards to the technical characteristics. Test drives under various conditions as well as static tests were performed.

Key findings relating to CMS monitor location:

- Reflections on the screen and screen glare: In some of the test drives, reflections caused by light on the covering glass were observed on the monitor of the CMS. This resulted in the image content being hardly recognisable, especially on the passenger side. Moreover, when light fell on the monitor, it reduced the contrast and colour perception for the driver. Comparable effects did not occur for mirrors. To minimise these effects the authors suggest either installing the monitor in a different position or shielding the monitor from sunlight or direct light falling on the screen.
- Electromagnetic radiation: Interference with the CMS was observed in the form of image errors on the monitor when the radio device (Topcom, Frequency: 446 MHz) was positioned closer than 5 cm to the CMS controls and was simultaneously sending a call. The radio device was not found to affect images when placed near the monitor or camera. Thus, the components of a CMS, and in particular the CMS controls, must be positioned more than 5cm away from any devices emitting electromagnetic radiation in a frequency range that would interfere with the operation of the CMS. Radiation from a mobile phone (Sony Experia Sola) did not interfere with the CMS.

- Behaviour in extreme cold: The study only examined the effect of -20° C on CMS monitor display. At this temperature, the monitor showed a blurred moving image, whereas the mirror showed a clear moving image. This is due to the liquid crystals in the monitor display becoming sluggish when exposed to cold temperatures, resulting in the image loading more slowly. Monitors can be protected from extreme cold by optimising the monitor position (i.e. positioning the monitor away from the bus doors or close to a heating device) or by obtaining a monitor with a heating device inserted.

4.1.1.2 Study 2: Human-machine interaction for cars

This study aimed to investigate whether the replacement of exterior mirrors with CMS in cars is possible from a human-machine interaction perspective. To do this, 42 participants drove between two exits (14.7 km) on a motorway in Germany. Participants drove in both directions for the test series allowing the four indirect vision conditions (exterior mirrors, CMS 1, CMS 2 and CMS 3; Figure 9) to be assessed on the same route and under similar traffic conditions. The study collected both objective (eye glance behaviour) and subjective (questionnaire) data.

Key findings relating to CMS monitor location:

- Monitor position and acceptance: The most preferred monitor position was CMS 3 and CMS 2 with 52% of participants preferring CMS 3 and 38% preferring CMS 2.
- Eye glance duration: When analysing the glance duration during overtaking and merging manoeuvres, it was evident that duration was shorter for CMS 1 and CMS 2 (low area FOV) compared to CMS 3 and external mirrors (there was no difference between CMS3 and external mirrors). Schmidt et al. (2015) interpreted this as an indicator for low preference for CMS 1 and CMS 2 positions due to reduced spatial attention, which is relevant for safe driving i.e. visual attention decreases with an increase distance from the central FOV. The decreased number of eye glances along with the low preference from the subjective measures further support this conclusion.
- Eye glance frequency: Compared to exterior mirrors, an increased number of glances during overtaking and merging occurred for CMS 3 only. Schmidt et al. (2015) suggest that this may be due to 1) the larger quantity of information displayed due to the wide aspherical area displayed on monitors and 2) depth information or spatial impression not always being possible due to the two-dimensional representation of the image i.e. flat screen (This is not the case for a mirror). This was not the case for CMS1 and CMS 2, which was likely due to the drivers did not look as frequently at the monitors due to feeling unsafe with the monitor location i.e. low area FOV (corresponds with eye glance duration interpretation). Alternatively, the drivers were able to interpret the images quicker due to the monitors being located closer to the driver (i.e. larger magnification factor).

Conclusions:

- The data on glance frequency and glance duration, along with statements given by the drivers for CMS 3 indicates that the monitor located at this position is highly accepted by drivers.
- The data revealed that monitors located below the normal FOV are less preferable, as drivers need to avert their eyes from the vehicle environment and moving traffic, thus making them feel unsafe and resulting in a reduction in their eye glance duration.
- Schmidt et al. (2015) concluded that in order to make a smooth transition from conventional mirrors to CMS, the monitor position should be located in a commonly used position.

4.1.1.3 Study 3: Human-machine interaction for trucks

The study investigated whether driver-vehicle interaction changes in case of replacing external truck mirrors with CMS. Ten male truck drivers carried out test track and on-road trials in Germany. The monitors, which were located on the A-pillars (Figure 9), were evaluated by means of questionnaires and interviews.

Key findings relating to CMS monitor location:

- Nearly 60% of participants mentioned that ability to recognise distant objects was poorer with CMS compared to external mirrors.
- Nearly 40% of participants mentioned the display position was poorer than that of the external mirrors.
- Several drivers (40%) would have preferred the left monitor to be located further away from them. With regards to the right monitor, 30% of the drivers stated it was located too far away.

Conclusions:

- Objects were perceived smaller on the monitor compared to the mirrors, as such, it is important that the display image supports the driver in estimating the real size of objects.
- Drivers likely struggled to recognise objects on the CMS compared to the external mirrors due to the limited availability of depth information provided by the CMS.
- Drivers stated that the monitors do not have to be located on the A-Pillar but can also be located closer to the steering wheel. Drivers believe that this would enhance the detail and, hence recognisability of distant objects and reduce the amount of head movements, whereas installation below the central field of view was considered undesirable.
- It was noted that the display should be as large as possible and that far-sighted individuals should wear glasses when using CMS due to the monitor being located closer to the driver than external mirrors.

4.1.1.4 Limitations

With regards to the technical aspects of CMS monitors, the study only tested -20°C with regards to the effect of extreme cold on monitor display speed. Evidence from other extreme cold and hot temperatures was lacking from this paper.

The main limitation of study 2 was that the authors did not ask the participants why they rated CMS 1 and CMS 2 poorly. If the participants rated it poorly due to unfamiliarity instead of performance, it may be possible that the short eye duration was due to the driver's ability to perceive information quicker due to indirect vision being positioned closer to them. The other limitation is the transference of the results to a bus, as this study was conducted in a car. Moreover, the trials were performed on a motorway, where overtaking scenarios were assessed, which is not an accurate representation of a bus driving in London.

The Truck Study (study 3), which will be referred to as Truck Study A for the remainder of the report, had several limitations including a small sample size, only subjective data was collected and only one monitor position was investigated. From the information gathered, it is difficult to determine what location the driver would prefer the monitor located in. Moreover, as the trials were performed in a truck, the results may not be applicable for a bus because the driving cab environments are quite different.

4.1.2 Paper 2 (Payandehmehr and Placzkowska, 2015)

The study aimed at creating one or more concepts for supplementary information that could be implemented in digital mirrors to increase driver's awareness of the surroundings and therefore contribute to road safety. The study investigated five topics, with one surrounding the placement of the CMS monitors in the truck cab. The user trials for this particular topic consisted of ten drivers suggesting and explaining their preferred monitor position using low level fidelity paper prototypes.

Key findings relating to CMS monitor location:

- The most desired position for the monitors was on the respective A-pillars. This position is close to the conventional exterior wing mirror position; thus, this position reinforces the drivers natural driving behaviour when monitoring their surroundings. Payandehmehr and Placzkowska (2015) suggest that such a position may have a positive effect on user acceptance, as it implies only minor changes.
- Payandehmehr and Placzkowska (2015) suggest that with driving experience, the placement of the passenger side monitor on the middle console could more be preferable due to the decreased amount of head movements and shorter distraction time off the primary task. However, this was not investigated in this study.
- Payandehmehr and Placzkowska (2015) suggest that the monitors showing the right FOV and left FOV should be located on the respective side of the driver's ocular reference point.

4.1.2.1 Limitations

This study, referred to as Truck Study B for the remainder of the report, consisted of several limitations, with the largest being the low fidelity paper prototypes. This type of prototype does not represent or reflect the environment of a truck cab accurately. Also, performance data cannot be obtained i.e. only subjective data. Moreover, only ten participants, who were not truck drivers, participated in the study. Thus, this study is not an accurate representation of the target population. Lastly, the layout of truck cab is different to that of bus, thus transferring these results to a bus may not be appropriate.

4.1.3 Paper 3 (Lundin and Zaimovic, 2015)

The study aimed at investigating the arrangement of digital rear-view mirrors replacing physical main and wide-angle mirrors in a truck, from a physical ergonomics point of view. Twelve participants performed user trials in a driving simulator, where four conditions were tested: three monitor arrangements (AP/IP, IP and AP; Figure 10) and a baseline (conventional external mirrors). The driving scenario was performed on a three-lane motorway and was designed to evaluate driving performance of the participant in a situation demanding adequate rear-view. The study both assessed objective (detection distance and rate, and lane positioning) and subjective data (NASA-TLX questionnaire and interviews).

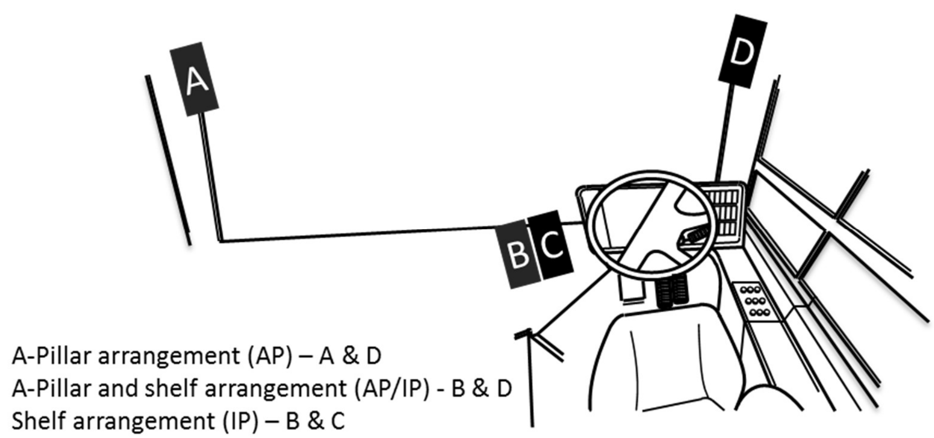

Figure 10: Illustration of A-pillar and shelf arrangement (AP/IP), instrument panel arrangement (IP) and A-pillars arrangement (AP) assessed by Lundin and Zaimovic (2015)

Key findings relating to CMS monitor location:

- There was no significant difference found for the mean detection distance and rate between the four conditions tested. There was a significant difference found for standard deviation of lane positioning (SDLP) between AP/IP and AP, in favour of AP/IP, where AP/IP revealed the lowest SDLP for all four conditions tested.
- With regards to the NASA-TLX scores, drivers perceived workload to be less with AP/IP arrangement than with the other two arrangements. However, a statistically significant effect was not found.
- Ten out of the twelve participants preferred the AP arrangement. The participants felt that the vertical distance from the forward line of sight to the display positioned in the instrument panel for IP and AP/IP arrangements caused aversion of gaze from the forward view and introduces a new type of eye and head movement.

Conclusions:

The authors suggest the AP/IP and AP arrangements should be developed further. This was primarily due to the AP/IP arrangement showing the highest levels of performance in the driving simulator tests and lowest levels of perceived workload, whilst the AP arrangement had the highest levels of acceptance amongst participants, which may be taken together with its resemblance to conventional exterior mirrors.

4.1.3.1 Limitations

An important limitation of this study is the sample size of twelve participants. Although significant differences were observed, it is important to perform further research to ensure the conclusions remain consistent for larger sample sizes. This study was also performed in a driving simulator, which is a less accurate representation of real-world situations than on-road driving, particularly with regards to SDLP. However, it should be noted that simulation does allow for a controlled environment and it ensures driver safety. This study was performed in a truck on a simulated motorway, which is not a reflection of a bus driving in London. This study will be referred to as Truck Study C for the remainder of the report.

4.1.4 Paper 4 (Pei-Sung et al., 2010)

The study aimed at evaluating the effectiveness of a CMS system in reducing bus side crashes during transit through measuring the reduction of blind zones. One of the components of the study was to obtain feedback, by means of a survey, from bus drivers about four potential CMS monitor locations (Figure 11). The locations were presented to the bus drivers on a piece of paper. Out of the 28 bus drivers, the majority preferred Setup 2 (n = 11), followed by Setup 1 and 3 (n = 4 each), and lastly by Setup 4 (n = 1).

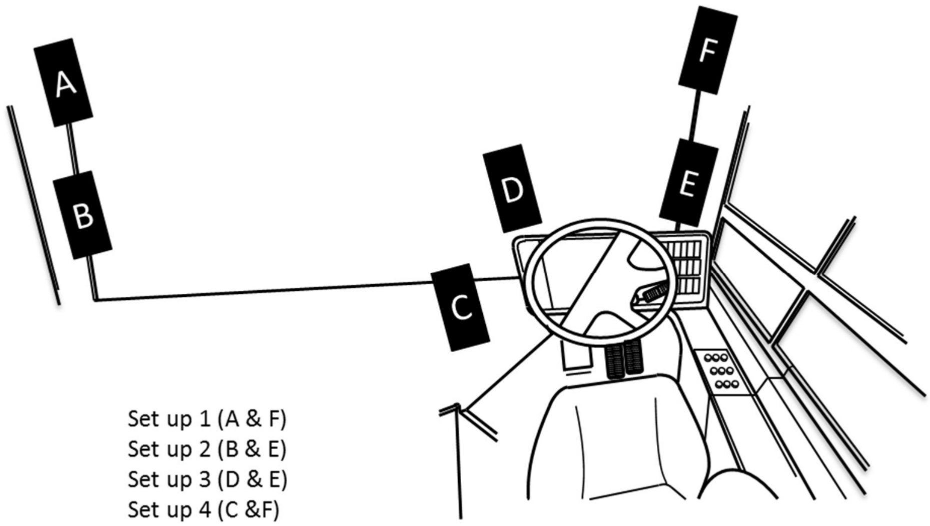

Figure 11: Illustration of the four CMS monitor locations assessed by Pei-Sung et al. (2010)

4.1.4.1 Limitations

The main limitation of this study is that it did not comprise of user trials and only subjective data was obtained i.e. survey. The perspective from the driver seat versus looking at pictures is very different, as such, working prototypes of the setups may deliver different results. However, this effect is likely to be mitigated by the fact that all the participants were bus drivers and have used a CMS system before. Another limitation surrounds the information gathered from the drivers. The bus drivers were only required to indicate their most preferred Setup with no option to rank setups, or to comment on their choice or other options available.

4.1.5 Summary

From the evidence, the negative effects on CMS monitor from reflections on the screen, screen glare, electromagnetic radiation and extreme cold can be mitigated by appropriate monitor location. Thus, the location of the monitor should be situated in such a way that:

1. External light does not cause shadows or glares on the display screen.
2. The CMS components are not located within a 5 cm radius of any radio device emitting electromagnetic radiation in a frequency range that would interfere with the operation of the CMS.
3. The monitor is protected from cold temperatures either outside or inside of the bus.

The monitor being exposed to extreme cold such as -20°C is highly unlikely in the United Kingdom, thus experiments assessing the effect of 0° to -10°C on the display speed of the CMS monitor should be investigated in future research.

Requirement 1 is already covered in the standards and regulations; however, Requirement 2 and 3 are not, and as such have been added to the CMS monitor positioning requirement recommendations summarised in Section 7.

Five studies (two in paper 1) were found to assess CMS monitor positioning in a vehicle where one was performed in a car, three in a truck (Truck Studies A, B and C) and one in a bus. Applying the findings from the research papers to monitor positions in a bus is challenging due to the limitations found in each paper, for instance:

- The truck and car studies are not an accurate representation of a bus i.e. different vehicle cab layouts and driving scenarios (motorway, overtaking scenarios etc.)
- The Truck Studies consisted of very small sample sizes
- The Truck Study A, Truck Study B and the bus study used paper prototypes
- Truck Study C was performed in a driving simulator
- The performance measures across studies were all different

The only location which was recommended by all papers was the positioning of the monitor on the A-pillars and close to the external mirrors. For all papers, this was the most preferred position by participants. This was the most preferred location because it reinforces the driver’s natural driving behaviour when monitoring their surroundings. With regards to the position on the A-Pillar, only the bus study investigated the positioning of the monitors at the top or bottom of the cab. This was likely due to car and truck external mirrors not being positioned as high up the vehicle. It was evident from the bus study that the driver preferred the monitors at the bottom of the A-Pillar compared to the top. It should be noted that design options were presented to the drivers on a piece of paper; as such, this was not a realistic representation of a bus cab or bus driving environment.

There was one issue identified with the positioning of the monitor on the nearside A-Pillar which was the decreased ability to recognise objects on the monitor compared to the external mirror. This could be improved by either making the monitor screen larger or by moving the nearside monitor closer to the driver. The latter was investigated by all studies, where the nearside monitor was located in a position below the driver’s forward line of sight. Most of the evidence revealed a low preference for monitors located in this area i.e. car study, Truck Study A and the subjective data from Truck Study C. This is possibly due to reduced spatial attention, aversion of gaze from the forward view and the introduction of a new type of eye and head movement from the monitor being located in this area. The objective data from Truck Study C, however, revealed the highest driving performance when the monitor was located in the instrument panel, whilst the bus study provided subjective data which showed that bus drivers had a potential preference for CMS monitors being located in a lower position on the A-Pillar.

Drawing conclusions about this location is challenging due the limitations presented in each of the studies. However, it was clear from the evidence that participants were not satisfied with the monitors located below the central FOV. In saying that, none of the studies investigated the positioning of the passenger monitor on the windscreen, as seen in the bus manufacturer’s example bus (Figure 7 and Position A in Figure 8), which does not require as much aversion of gaze from the forward view. Moreover, none of the studies investigated the effect of the passenger monitor being located closer to the driver on peripheral vision. Thus, studies of the effect of monitors located closer to the driver than the A-Pillar on both road safety (including peripheral vision) and driver acceptance needs to be investigated in future studies.

4.2 Human vision

This section of the report consists of a theoretical review on human vision to underpin human visual characteristics and limitations. Specifically, the review will investigate human FOV, eye accommodation and eye strain to inform CMS monitor positions.

4.2.1 Field of view

The ambinocular visual field, highlighted in light and dark grey in Figure 12, is the total FOV obtained by the union of the monocular fields of the right and the left eye (vision through one eye). The binocular FOV, highlighted in dark grey in Figure 12, is the vision through both eyes simultaneously.

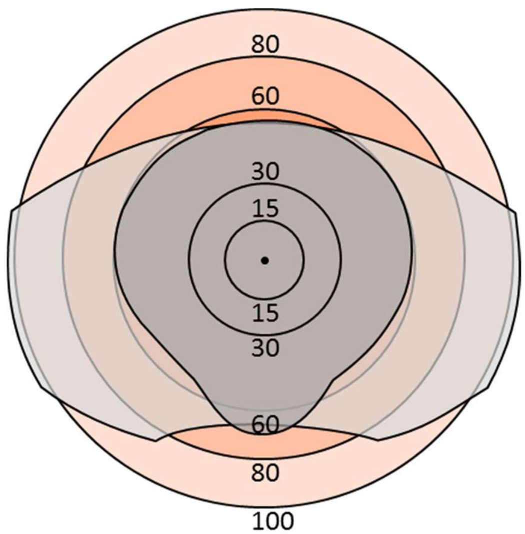

Figure 12: The normal FOV in degrees of visual angle. The light grey areas are visible to only one eye, the light grey area to the right eye and vice versa, whilst the dark grey area marks the binocular FOV (adapted from Lundin and Zaimovic, 2015)

Vision is most detailed in the foveal range, which extends approximately one eccentricity angle for the line of sight. The following range, known as the extrafoveal range, extends up to about 30 degrees eccentricity angle, whereas the last range, known as the peripheral visual range, extends from 30 degrees eccentricity angle up to 100°-110° temporally (away from the nose towards the temple), 60° upwards and 70°-75° downwards (towards the nose) (Figure 12). For both eyes, the combined visual field is 130°-135° vertically and 200°-220° horizontally.

According to Bhise (2011), whilst driving:

- The foveal FOV accommodates the most detailed vision (i.e. scanning of road signs).
- The extrafoveal field provides information in terms of presence and location (i.e. the road way and surrounding vehicles).
- The peripheral vision gives awareness of larger visual targets (i.e. vehicles in adjacent lanes as well as information on moving targets and motion cues).

Drivers can monitor the periphery of their visual field even when focusing their primary attention on its centre, but this ability has spatial limits. According to Flannagan and Sivak (1993), detection performance in the periphery FOV rapidly decreases when detection stimuli are beyond 30 degrees from the line of sight. Moreover, the FOV declines with age, thus older drivers struggle to detect objects in distant fields compared to younger drivers (Bhise, 2011).

Drivers prefer to focus their attention directly ahead whilst driving; therefore, gaze duration away from the road scene should be as short as possible. To achieve this, mirrors and instrument panel displays should be located as near to the driver's forward line of sight as possible, minimising the need for head or eye movements (Haslegrave, 1993). According to Haslegrave (1993), this should occur within 15 degrees of divergence, if possible. In saying this, a balance needs to be obtained between positioning objects as close to the driver's forward line of sight as possible and obstruction to the driver's forward FOV.

4.2.2 Eye accommodation

4.2.2.1 Accommodation and vergence

Drivers change their viewing distances whilst driving to observe objects close such as the speedometer or rear-view mirror, and objects in the distance such as the road scene. In order to change viewing distances, ocular adjustments that include both vergence and accommodation need to occur. Kim et al. (2014) define these terms:

- Vergence: the movement in which two eyes rotate in opposite directions to maintain binocular fixation on objects at different distances.
- Accommodation: the change in focal power of the crystalline lenses in the eye.

These two ocular responses are coupled, meaning that a change in one elicits a change in the other. When looking at near objects the eyes converge and there is an increase in lens focal power, whereas when looking at an object far away the eyes diverge and there is a decrease in lens focal power. Both vergence and accommodation distances are expressed in dioptres (D).

4.2.2.2 Presbyopia

Presbyopia is defined as the progressive decline in the amplitude of accommodation as a person ages due to the hardening of the ocular lenses (Chapman, 2008). It results in a greater difficulty in maintaining a clear focus on near objects with an eye which sees clearly at a faraway distance. Presbyopia is one of the main reasons for the decrease in visual acuity as people age. Some studies (Hofstetter (1965) and Ramsdale and Charman (1989), both cited by Chapman (2008)) suggest that an individual's amplitude falls almost linearly with age and will decline below two dioptres somewhere between the ages of 50 and 60 which is where we often see the largest decline in sight. According to Chapman (2008), unlike many aspects of human physiology, there is very little individual variation in the magnitude of the decline of acuity of sight, and changes in lifestyle and nutrition do not seem to have an effect. Chapman (2008) also mentions that the response time of accommodation slowly declines with age as well.

According to Disha Experts (2017), bifocal lenses consisting of both concave and convex lenses can aid an individual suffering from presbyopia. The upper portion consists of a concave lens which facilitates distant vision, whereas the lower portion consists of a convex lens facilitating near vision. It is also possible to correct the refractive defects with contact lenses or through surgical interventions (Disha Experts, 2017).

4.2.3 Eye strain and fatigue

Visual work performed excessively close to the eyes is fatiguing and leads to eye strain – a poorly defined condition involving blurring of vision, headache and burning sensations around the eye. According to Pheasant (2001), when the eye focuses on an object 6m or further in the distance the lens of the eye is completely relaxed, however to look at objects closer than this requires effort, as both the muscles for convergence and accommodation must be activated.

With regards to the minimum distance for visual display, there is no set figure and authorities differ in the figure they recommend. A minimum distance as low as 350mm to 400mm has sometimes been quoted, however this is not always acceptable under certain circumstances (Pheasant, 2001). According to Pheasant (2001), for most practical purposes a minimum viewing distance of about 500mm is desirable, where a distance of 750mm or more is preferable. According to Bridger (2003), healthy individuals generally set their viewing distance between 51cm and 99cm. Moreover, at a viewing distance of 30cm to a visual display, glasses should be prescribed. It is important to therefore consider what these viewing distances would mean for the driver cab design package to ensure that any future requirements for CMS monitor positions do not conflict with either the minimum viewing distance requirements or the driver cab design package.

4.2.4 Summary

The most important human vision characteristics and limitations relating to CMS monitor position are highlighted below:

- The range of peripheral vision is greater horizontally compared to vertically, totalling 200°-220° and 130°-135° degrees respectively, where upwards peripheral vision is the lowest (60°).
- During driving, drivers need to switch their visual focus between near and far objects. With an increase in age, eye focus response time increases and the ability to focus on a near object reduces. Response time improves with the near object being situated further away, as eye muscle activation would be reduced. With regards to presbyopia, this can be mitigated using bifocal glasses.
- To mitigate eye strain, a visual display should not be located closer than 50 cm to an individual's eyes.

The information surrounding peripheral vision reinforces the low preference for positioning a CMS monitor in a low area FOV. In this position drivers will have minimal visual awareness of the road scene. To prevent eye strain, it is evident the monitor needs to be positioned at a minimum distance of 50 cm away from the bus driver's eyes. This minimum requirement has been added to the summary of requirements displayed in Section 7.

It is evident that age has a negative effect on human vision. It is recommended that TfL considers making eye tests mandatory for bus drivers using CMS monitors, and if required, the driver gets bifocal lenses.

4.3 Bus driver eye gaze behaviour

This section of the report was aimed at establishing the eye glance behaviour of bus drivers whilst driving a bus. This consisted of performing a literature search on the topic and engaging a bus operator regarding driver training. The latter was performed due to the limited research found surrounding bus driver eye glance behaviour – only one paper from 1998. Even though there is no scientific evidence, this will hopefully provide an idea on the areas that bus drivers frequently look at.

4.3.1 Literature search

Only one research paper was found examining the eye glance behaviour of bus drivers "Stress and strain of short haul bus drivers: psychophysiology as a design oriented method for analysis" (Gobel, Springer & Scherff, 1998). Particularly, this study captured bus driver eye movement by a device mounted on the bus drivers' head whilst driving on public roads (n = 8), and the results are illustrated in Figure 13. The results revealed that the drivers looked out the front window of the bus most frequently (over 630 glances per hour) accounting for 73.2% of their total eye glance movements, with only 10.2% being directed at the mirrors and 8.4% being directed at the areas around the A-pillars. All other eye glances accounted for less than 5% of their eye glance movements. More glances were directed towards the offside mirror and objects located to the offside of the bus compared to the nearside respectively. Interestingly, the difference in glance frequency between Offside Mirror and Outside Offside, and between Nearside Mirror and Outside Nearside is similar. This may be due to the drivers looking at objects located outside of the bus as a response to looking at the mirrors (i.e. due to peripheral vision), however this is unknown.

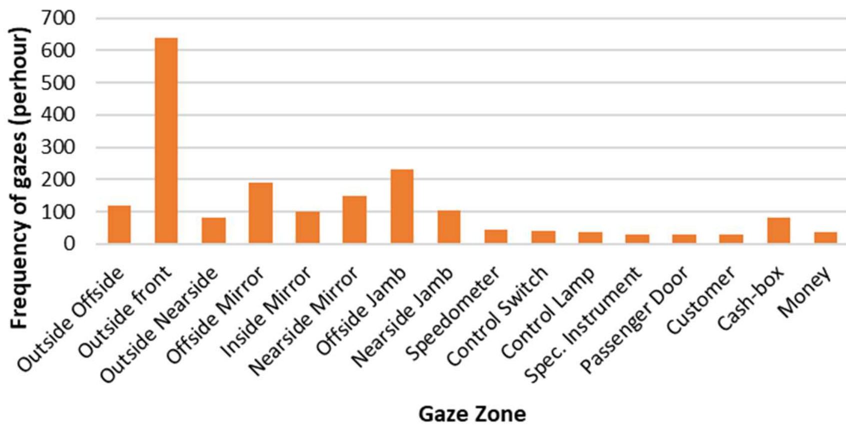

Figure 13: Gaze frequency for the elements of the driver immediate visual environment (adapted from Gobel et al., 1998)

The drivers gaze duration was also assessed (Figure 14), and the longest gaze duration was when the bus drivers were dealing with money and the cash register. With regards to the mirrors and outside objects, the drivers gazed the longest at the inside mirror (approximately 1.1 seconds per glance) followed by outside objects (<0.75 seconds per glance), and then by the nearside and offside mirrors (<0.75 seconds per glance) (Gobel et al., 1998). Interestingly, mean glance durations for all driving relevant tasks (i.e. objects outside, the offside and nearside mirrors and the instrumentation panel) were all found to range from 0.5-0.75 seconds. This would imply that drivers moderate their “eyes off the road ahead” time to a single set duration. This may mean that drivers attempt to process all the visual information available to them within this particular glance duration window in order to perform a driving task or identify a potential hazard. Thus, if the interpretation of monitor images is made more complex (i.e. too low a magnification), this may increase the risks of false negatives (i.e. drivers do not perceive there to be a developing hazard) resulting in increased collision rates.

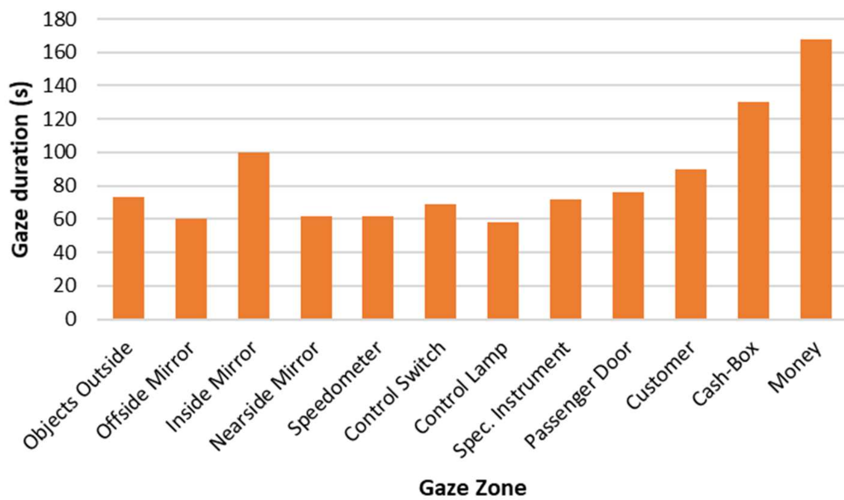

Figure 14: Mean gaze duration for elements of the bus driver's immediate visual environment (adapted from Gobel et al., 1998)

4.3.2 Stakeholder engagement

Further to this, additional information was gathered through stakeholder engagement with a bus driver trainer currently employed by one of TfL's bus operators. The trainer was engaged to determine which behaviours drivers are taught and to determine whether these had the potential to affect driver gaze patterns. The trainer revealed that bus driver training programmes vary amongst bus operators, but there are considerable similarities between the programmes.

When pulling away, this specific operator teaches their drivers to check the following in order:

a) Look through doors,

b) Nearside blind spot,

c) Nearside mirror,

d) Scan across the windscreen,

e) Offside mirror (and traffic),

f) Offside blind spot,

g) Scan across to nearside mirror,

h) Nearside mirror again (to check for any Vulnerable Road Users (VRUs) coming off the pavement),

i) Scan across front to offside mirror,

j) Offside mirror again,

k) Constantly scanning back and across the front windscreen and checking between mirrors as the drivers starts to pull away.

Whilst this is not necessarily applicable to all bus operators, it does provide an idea of what is considered as critical areas to visually check when driving a bus in London, and what kind of areas drivers are currently trained to frequently check.

4.3.3 Summary

There was insufficient evidence available on bus driver eye glance behaviour. From the one paper found, it was evident that bus drivers look out the front windscreen most of the time whilst driving, followed by checking their mirrors and then towards objects outside of the bus. It is unknown whether drivers were looking directly out of the windscreen or whether they were glancing through different areas of the windscreen. Also, it is unknown whether the glances outside of the bus were influenced by the glances to the external mirrors. From the engagement with the bus operator, it is clear that drivers are required to constantly scan the width of the windscreen and check their blind spots. If this is the case, peripheral vision to the offside and nearside might not be affected by the monitors being positioned closer to the driver. However, this training is for when a driver is pulling away opposed to driving and it is unknown whether drivers actually perform these tasks. It would be important to understand glance behaviour during normal driving, and particularly when pulling into a bus stop where VRU presence can be expected to be highest.

4.4 Internal obstructions evidence review

When evaluating the direct and indirect FOV of a bus driver, it is important to consider blind spots, or areas of visual distortion, caused by internal sources as well as external sources. Sources of in-cab obstructions include:

- Driver Assault Screens and related issues
- A-pillars
- Dashboard and dashboard mounted equipment e.g. ticket issuing equipment

The purpose of an Assault Screen is to act as a barrier during violent interactions between passengers and drivers. Assault Screens are typically manufactured from a clear sheet of polycarbonate and split into two components consisting of a forward and rear section. The rear section is integrated into the cabin door. The forward section covers the remaining gap from the door frame to the windscreen. The design of this section can vary depending on which bus model it is installed in. In general the majority of these fall into one of the four following configurations (Figure 15 and Figure 16):

- Configuration 1: Straight Forward
- Configuration 2: Curved Inwards
- Configuration 3: Angled Away
- Configuration 4: Curved Away

Straight Forward | Curved Inwards | Angled Away | Curved Away

Figure 15: Images of example driver Assault Screen design configurations

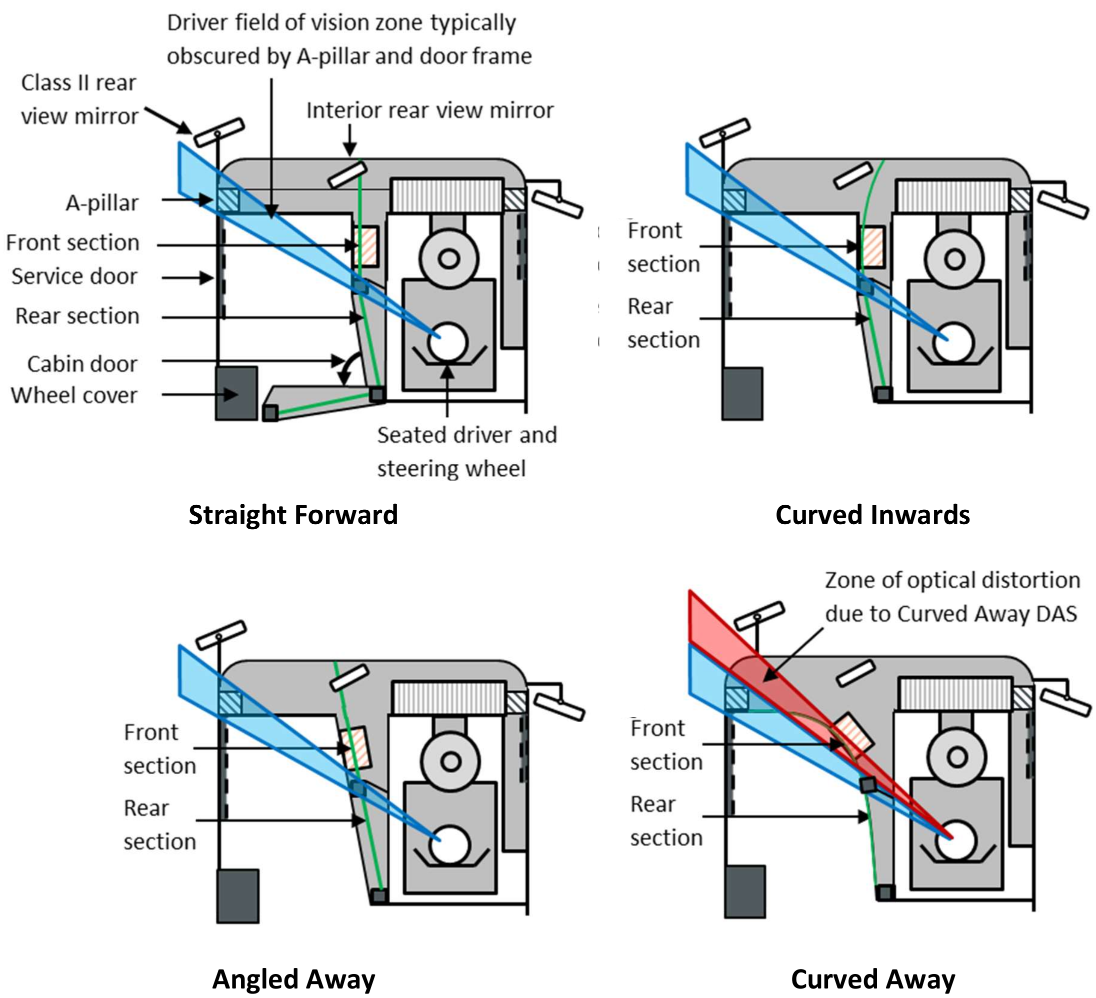

Figure 16: Schematic of Straight Forward (upper left), Curved Inwards (upper right), Angled Away (lower left) and Curved Away (Lower Right) Assault Screen design configurations

For all Assault Screen designs, the driver's FOV is typically obscured by the door frame (central pillar) of the Assault Screen (Figure 17). Obstruction of the A-Pillar is dependent on the anthropometrics of the bus driver (obstruction will be reduced for a short individual), bus model, and Assault Screen. Each of the Assault Screen designs are discussed in more detail below.

"Straight Forward" configured Assault Screens are typically found on older bus models. These are often heavily framed and have glazed areas that partially or completely overlap internal and external mirrors. Moreover, this configuration is difficult to clean as cleaners require access to clean the extremities of the Assault Screen. Newer "Curved Inward" designs mitigate these issues by providing better access to the entire screen for cleaning and by positioning the central pillar of the Assault Screen in line with the A-Pillar reducing obstruction to the direct vision FOV of the driver.

Figure 17: A heavily framed Straight Forward Assault Screen

"Angled Away" and "Curved Away" Assault Screen designs are shaped to avoid the overlapping and obscuring of the mirrors from the driver's point of view (Figure 18). In one bus model with the Curved Away Assault Screen, this has led to an area of optical distortion and reflectance in the front nearside corner beside the A-Pillar which, in certain environmental conditions (such as bright direct sunlight), can double the size of the blind spot created from the front nearside A-Pillar (Figure 16 and Figure 18). This is primarily due to the eye line of the driver aligning with the critical angle (the maximum angle an incidence ray can strike the surface of a medium for refraction to occur) of the material that the driver is trying to look through.

The majority of Straight Forward, Curved Inward and Angled Away Assault Screen designs have a section of the screen cut out providing an uninterrupted view of the internal rear-view mirror (see Figure 18). The UNECE Class II mirror is not always visible through the cut out. Removing or repositioning the Assault Screen would solve this issue; however, this could also put the driver at greater risk of assault, which is in direct violation of the Health and Safety law which requires employees to be in a safe working environment.

Figure 18: Partial A-pillar overlap and reflectance through a Curved Inwards Assault Screen (left). Unobstructed view of external and internal mirrors and area of optical distortion and reflectance caused by Curved Away Assault Screen (right)

A team from TRL carried out an investigation to determine the level of variation in Assault Screen transparency by using transmittance as a measure. Over the course of the testing, 639 test points were measured across 30 Assault Screens, encompassing all four configurations, and eight bus models. All average transmittance scores exceeded the 70% minimum transmittance value set out in UNECE Regulation 43: Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles (UNECE, 2017).

The investigation found that there was limited variation in Assault Screen transparency. Time since last clean, age of screen and Assault Screen configuration were all found to have limited impact on the transmittance levels of the screen. For all Assault Screen designs, internal reflections on the inside of the Assault Screen (inside bus driver cab) were found to be a higher priority issue than transparency. This was most noticeable for “Curved Away” Assault Screen designs as the screen created an area of optical distortion and reflectivity close to and with a similar obstruction width as the A-Pillar (Figure 16).

Internal reflections caused by the CMS monitor on the Assault Screen, and also windows and windscreens are unknown, but as highlighted above must also be considered as a high priority issue and taken into careful consideration when designing the CMS monitor and its location, as the monitor could result in reflections on these surfaces either distracting the driver or interfering with the drivers forward, offside or nearside FOV.

According to Tattersall (2008), light can either be polarised (Primary and Secondary waves) or unpolarised. Figure 19 highlights that at an Angle of Incidence (AoI)[5] greater than 56°, 70° and 78° the Secondary waves, unpolarised light and Primary waves will start to reduce the transmissive properties of an Assault Screen below the 75% minimum threshold respectively. These critical angles must be considered when designing CMS monitors and their locations to mitigate the obscuration of CMS monitors by internal reflections and the impact of the monitors themselves on internal reflections. Specifically, the AoI for unpolarised light, as this is the type of light associated with bus lighting, monitor screens and ambient lighting.

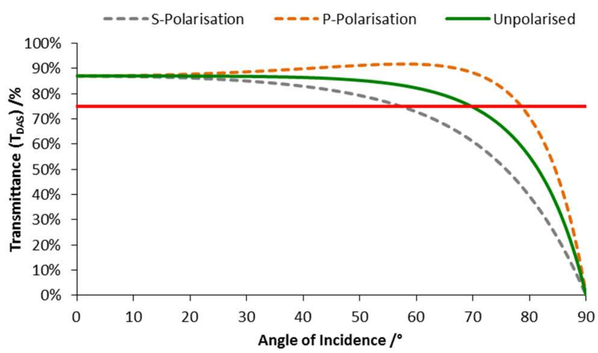

Figure 19: Transmittance of Assault Screen Polycarbonate

Figure 20: Comparison of traditional (left) and wrap-around (right) A-Pillar configurations

Certain internal components, e.g. ticket machines and on-board safe, remain in fixed positions due to driver cab entry requirements. Therefore, monitors cannot be positioned in these areas.

[5] The angle which an incident line or ray makes with a perpendicular to the surface at the point of incidence

4.4.1 Summary

The most important internal obstructions relating to CMS monitor position are highlighted below:

- The central pillar of an Assault Screen typically obstructs the driver's FOV of the nearside A-Pillar.
- "Curved Away" Assault Screen designs were found to create an area of optical distortion and reflectance in the front nearside corner of the bus beside the A-Pillar.
- Some "Straight Forward" Assault Screen designs may reduce the visibility of the nearside external mirror due to internal reflections.
- "Curved Inward" Assault Screen designs were found to cause reflections that obstructed the view of the external mirrors.
- Internal reflections were highlighted as a high priority, where an AoI greater than 70º for unpolarised light reduces the transmissive properties of the Assault Screen below the 75% minimum threshold.

This evidence indicates that positioning a monitor on the nearside A-Pillar may not be a feasible option should the Assault Screen obstruct the driver's view of the A-Pillar. Moreover, some "Straight Forward" and "Curved Inwards" Assault Screen designs may obstruct the driver's view of the nearside monitor. However, this obstruction would be the same as with an external mirror, thus safety risk would be similar. The evidence review highlights the careful consideration of Assault Screen designs to accommodate all driver eye positions and seating configurations to ensure visibility of the nearside CMS monitor.

If a monitor is positioned outside of the Assault Screen, the driver must not view the monitor through a glazed surface angled at an AoI greater than 70°. This requirement has been added to Table 5.

5 Discussion

TRL performed an extensive study investigating the optimal position for CMS monitors in a bus. The project consisted of three tasks, where each task informed the next. These tasks assisted in informing on, or eliminating, the various CMS monitor positions being investigated (Figure 21). The first task consisted of reviewing current national and international standards and regulations, particularly UN Reg 46 because all vehicle types must comply with the requirements stated in this regulation. Once completed, a bus manufacturer trialling CMS was engaged to determine the advantages and disadvantage of the various CMS monitoring positions being investigated. Lastly, a state-of-the-art evidence review was conducted to further inform on, or eliminate, the CMS monitor positions.

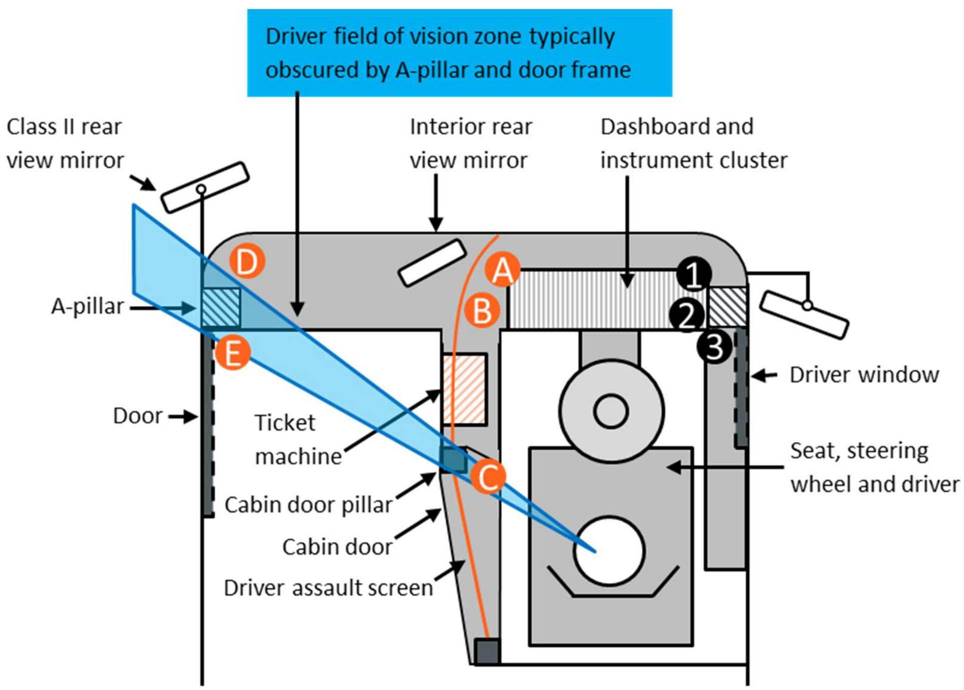

Figure 21: Offside (1-3) and nearside (A-E) CMS monitor positions investigated in this study

5.1 Offside monitor positions

Based off the information gathered and observations made during the industry input, TRL ranked the offside monitors in the following order (see Section 3 for more details):

- Position 2: positioned on the A-Pillar (TRL's most preferred position).
- Position 1: positioned on the windscreen – obstructs forward FOV.
- Position 3: positioned in line with the external mirror – obstructs offside FOV more than an external mirror does and has several technical feasibility issues (see Section 3.2 for more details).

This was confirmed by the evidence review which indicated that the most preferable location for the offside monitor was on the A-Pillar as it reinforces natural driving behaviour. The evidence review also highlighted that the monitor must be located a minimum of 50 cm from the driver's eyes to prevent eye strain. Locating the CMS monitor on the A-Pillar would also improve the direct vision of the driver by removing the offside mirror cluster as an obstruction to the driver's view.

5.2 Nearside monitor positions

Nearside monitor Position C and E were eliminated after the industry input as potential positions. This was due to shorter drivers needing to significantly rotate their head to see the monitor in Position C and taller drivers not being able to see the monitor in Position E due to the central pillar of the Assault Screen being in the way. The latter was reinforced by the evidence review which indicated the central pillar of the Assault Screen clearly obstructs FOV of the A-Pillar. Moreover, Position C would be located too close to the driver, especially for shorter individuals, causing eye strain – minimum distance of 50 cm.

From the information gathered from the industry input and the literature review, it became apparent that the ranked positions for the nearside monitor were:

- Position A and D were the most favourable positions.
- Position B was the least favourable, due to the monitor being located below the driver's forward line of sight.

The evidence review on CMS monitor positioning revealed a low preference for monitors positioned low down as it resulted in reduced spatial attention, aversion of gaze from the forward view and the introduction of a new head and eye movement. This was further supported by the fact that upwards peripheral vision, which is relied on by a driver when gazing downward, is limited to 60° compared to 70-75° for downwards and 100°-110° for right and left peripheral vision.

TRL are unable to determine whether Position A or Position D is more desirable, due to both positions having at least one unknown effect and Position D also being constrained by current technology capability. To determine the optimal position, further research is needed into these factors as current evidence in the field is limited. Each position is briefly discussed below, where the advantages, recommendations and disadvantages are highlighted.

Position A is located close to the driver forward FOV and requires minimal head and eye movement.

- The evidence review revealed that drivers prefer to focus their attention directly ahead whilst driving, therefore authors suggest displays to be located as close to the driver's forward line of sight as possible.
- The evidence review revealed that some drivers struggled to recognise objects when the CMS monitor was located further away (i.e. passenger A-Pillar), suggesting the monitor should be located closer to the driver. This allows for easier recognition of objects on the monitor and reduces eye gaze duration promoting safer driving.

- In this position, drivers do not have to look through the Assault Screen, which may also enhance object recognition and reduce eye gaze duration.
- The evidence review revealed that if a monitor were to be positioned in Position A, it must be located at a minimum of 50cm from the driver's eyes to prevent eye strain, and drivers' eyes must be tested to ensure the drivers are not suffering from presbyopia. Moreover, the monitor must be located above the driver's direct line of sight to mitigate obstruction to the driver's forward direct FOV.
- The bus manufacturer trialling CMS positioned their monitor above the driver's direct line of sight (top of bus cab), where the bottom of the monitors (nearside and offside) were in line with the bottom of the sun visor, when engaged, allowing for minimum obstruction.

The concern with Position A surrounds the effect the position has on a bus driver's nearside peripheral vision due to the driver no longer needing to gaze in the direction of the nearside external mirror. Horizontal peripheral vision has a range between 200° and 220°, as such, when looking at the monitor the driver should be able to see the nearside of the bus in their peripheral vision. However, as stated in the evidence review, detection of stimuli in the periphery vision decreases the further it is located from the direct line of sight and the FOV decreases with age, which raises a potential safety concern. Bus driver training may potentially mitigate these effects. Currently, bus drivers are trained to constantly scan the width of the windscreen and to check their blind spots. If drivers implement this into their driving routine, it may mitigate the effects of the reduced nearside peripheral vision caused by Position A. Therefore, if this monitor position were to be implemented on a bus, the training must include training the drivers to look at the nearside area of the bus whilst driving.

A second concern surrounds Position A obstructing the diver's direct FOV. If the monitor is positioned in line with the driver's forward line of sight, it will cause obstructions to the drivers FOV of the centre of the windshield (i.e. front of bus) and may interfere with the driver's vision whilst scanning the windshield for VRUs. To mitigate this effect and to enhance safety, it is recommended that the monitor is positioned above the driver's line of sight. This will reduce obstruction to the driver's direct FOV and will not interfere when the drivers are scanning their surroundings.

Further research is needed to determine the effect of 1) Position A and 2) bus driver training to enhance nearside peripheral vision on bus driver and road safety.

It should be noted that Position A directs the foveal vision of the driver towards the forward and nearside road scene, which in turn could improve road safety.

Position D is aligned with the nearside Class II mirror; therefore, this position is relatively neutral in terms of affecting direct vision and drivers are familiar with assessing indirect vision in this area i.e. familiar head and eye movements.

- The evidence review on CMS monitor positioning revealed that drivers prefer the CMS monitor to be positioned as close to the external mirror position as possible as it reinforces their natural driving behaviour when monitoring their surroundings.
- Each of the papers recommended this position (close to external mirrors) as a suitable option for CMS monitor positioning.

However, there were some issues identified with this position. The first relates to the technical constraints of current CMS. When positioned in Position D, current monitors are (as yet) unable to meet the magnification criteria set out in UNECE Regulation 46 without conflicting with monitor size requirements. Moreover, the evidence review on CMS monitor systems revealed that drivers, especially truck drivers, had a decreased ability in recognising distant objects on the monitor compared to the external mirror. The driver will also be looking at the monitor through the Assault Screen, which may further decrease the recognisability of objects. These factors may consequently increase gaze duration and/or frequency as well as accident risk. Also, it may result in false negatives (i.e. the driver may not perceive there to be a developing hazard) due to the information being displayed being more complex for the driver to interpret. To solve these issues, a larger monitor can be adopted and implemented. The size of this monitor is unknown, thus future research needs to investigate the minimum and maximum screen size for a monitor positioned in Position D with regards to bus driver and road safety, as well as technical feasibility and the effect of the size on internal obstructions and driver direct vision.

Another issue identified with Position D concerns reflectance issues. It is unknown what the effect of a monitor positioned in Position D will have on Assault Screen and windscreen reflection. Moreover, if this is an issue, it will be likely exacerbated by a larger screen. To ensure the driver can see the monitor through the Assault Screen, the glazed surface of the Assault Screen must have an AoI lower than 70°.

The visibility of a monitor located in Position D must not be obstructed by any internal obstructions such as the central pillars of the Assault Screen and internal reflections.

6 Industry Input 2

A team from TRL attended a second workshop with the bus manufacturer trialling CMS on buses as a replacement for Class II mirrors, with secondary Class IV capabilities. The aim of the workshop was to 1) examine their newly positioned nearside monitor (Position D), 2) gain further insight into some of the unknown effects for Position A and D highlighted in Section 5.2, and 3) further update and refine the CMS recommendations and requirements.

6.1 Position D

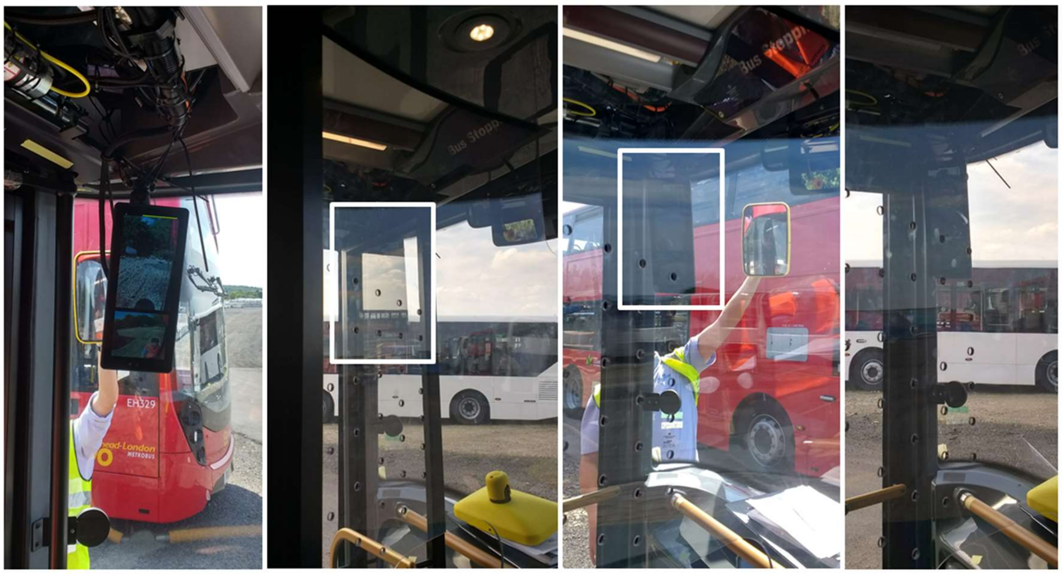

Figure 22: CMS monitor positioned in Position D (left) and the effect an open door (centre left), curved inwards Assault Screen (centre right) and speaking holes (right) on Position D monitor visibility

Three issues regarding visibility of the monitor display were identified with this monitor position. Firstly, when the front bus door was open, the image on the monitor was not visible due to 1) the door obstructing the view of the monitor and 2) the external light reflecting on the opened door (Figure 22). This raised a safety concern with regards to the driver's visibility of passengers embarking and disembarking from the middle or rear doors of the bus. Thus, if the visibility of the monitor is obstructed by the front door being open, the driver must have the ability to close the front door prior to the middle and rear doors (i.e. the front doors must close independently). The drivers must also be provided with training to ensure the correct opening and closing door sequence is achieved. Once the front door is closed and prior to the driver pulling away, the driver must assess the monitor for nearside indirect vision. This must be included into driver training courses.

Secondly, the curved inward Assault Screen caused reflections that obstructed the view of the monitor display, resulting in the image barely being visible (Figure 22). When compared to the external mirror, the image quality of the monitor was poorer (Figure 22). UN Reg 46 states that the image quality of a CMS monitor must be equal to or better than the quality of the external mirror. Only a curved inwards design was assessed in this workshop, as such the effects of different Assault Screen designs on monitor visibility is unknown and should be investigated further. If a monitor were to be positioned in Position D, 1) the impact that the reflections on the Assault Screen have on monitor image visibility should be minimised and 2) the quality of the image must be the same or better than the external mirror it is replacing. It is considered unlikely that this would be possible when viewing a monitor through the glazing of an Assault Screen.

Lastly, the speaking holes on the Assault Screen obstructed the view of the monitor (Figure 22). This made it extremely difficult to recognise objects on the display and it resulted in the number of holes doubling (double vision) as the driver has to look through the holes to view the monitor. When the monitor and external mirror were obstructed by the speaking holes, it was easier to recognise objects on the external mirror compared to the monitor display. The size and location of speaking holes differ on buses, as such, it is unknown whether the same effect will occur for all Assault Screens. Therefore, if a monitor is positioned in Position D, the speaking holes on the Assault Screen must not obstruct the view of the monitor for a 5^{th} percentile female to a 95^{th} percentile male.

The manufacturers reconfirmed that currently CMS monitors located in this position are unable to achieve the magnification criteria set out in UNECE Reg 46. However, this can be achieved if the monitor is located slightly closer to the driver (between Position A and D) or in a narrower bus.

6.2 Position A

One of the concerns surrounding Position A is its effect on nearside peripheral vision. At the workshop TRL investigated this effect in more detail. From the investigation, it was evident that the Class IV monitor installed by the bus manufacturer accommodated nearside peripheral vision up to the front end of the bus. When gazing at the monitor, the remaining peripheral vision (i.e. nearside peripheral vision of the windshield) was accommodated by the eye. Having the monitor located close to the Assault Screen and angled towards to driver further increases the nearside peripheral vision of the eye. Therefore, in order to have a monitor positioned in Position A, 1) a monitor that has the ability to display up to the front end of the bus must also be installed and 2) the monitor should be located in close proximity to the Assault Screen and angled towards the driver as stated in the regulations.

It should be noted that research still needs to be conducted to assess the effect of Position A on nearside peripheral vision for road and bus driver safety.

7 Requirements

The following key recommendations apply to the general CMS monitor positions described previously in Figure 21.

The ideal position for the offside monitor is on the A-Pillar (Position 2). If this is not feasible Position 1 would be deemed acceptable, whereas Position 3 is deemed unacceptable. The preferred position for the nearside monitor is Position A. However, a monitor positioned in Position A, Position D, Position B or a position between these three would be deemed acceptable so long as 1) the image quality is equal to or better than the image quality of the external mirror and 2) the monitor does not affect the direct vision score as tested and assessed by the vision standard. All other positions are considered unacceptable.

For monitors positioned on the windshield, it is recommended that the monitors are positioned above the driver's line of sight to reduce obstruction to the driver's direct FOV. If this is not possible, below or in line with the direct line of sight would be deemed acceptable depending on the position of the monitor in relation to the obstruction of the driver's direct FOV. This may be assessed by revaluating the direct vision performance of the bus with the CMS installed to ensure that direct vision performance is not below the minimum requirements. A monitor located greater than 30° below the direct line of sight is deemed unacceptable.

Table 5 summarises the requirements for CMS monitor positioning. These requirements were established from the national and international standards review and evidence and theory review.

Table 5: The requirements for the positioning of CMS monitors in a bus

CMS monitor position requirements	
1	The seated driver shall have a clear view of the road ahead
2	Obstruction to direct field of view (FOV) shall be kept to a minimum, with this assessed through the direct and indirect vision standard
3	The monitor shall not be located lower than 30° below the driver's ocular points
4	The driver shall not need to rotate their head more than 55° to view the offside monitor
5	Monitor viewing direction shall be approximately in the same direction as the mirror it is replacing
6	The drivers view of the monitor shall not be obstructed
7	Image of offside and nearside FOVs shall be presented on the respective side of the drivers' ocular reference point
8	Non-continuous images shall be clearly separated
9	Monitor shall not vibrate
10	Monitor shall be interpretable up to 80% of maximum design speed
11	Ambient light (e.g. sunlight and artificial light) illuminating the monitor shall be minimised as far as reasonably practical
12	Reflections on windscreen or other window panes as a result of the monitor shall be reduced as far as reasonably practical
13	Maximum monitor distance to the driver's ocular reference point shall be – Offside: 1.7m | Nearside: 2.6m
14	Minimum magnification factor for Class II monitor – Offside: 0.26 | Nearside: 0.13
15	Average magnification factor for Class II monitor – Offside: 0.31 | Nearside: 0.16
16	CMS components shall not be located within 5cm of any radio device emitting electromagnetic radiation in a frequency range that would interfere with the operation of the CMS
17	The monitor display shall not be affected by extreme cold
18	Minimum monitor distances from the driver's ocular reference point shall be – Offside: 50cm | Nearside: 50cm
19	The monitor shall not be viewed through a glazed surface at an Angle of Incidence (AoI) greater than 70˚ for unpolarised light
20	The nearside monitor shall not be obstructed by reflections or speaking holes as a result of the Assault Screen
21	A display shall be installed that has the ability to view the nearside and offside front end of the bus, where the image for this field of view shall be located either below or above the Class II monitor image on its respective side
22	Driver training shall be provided on CMS monitors and shall include nearside peripheral vision awareness training for nearside monitors positioned in a different location to the traditional nearside external mirror
23	The CMS monitors shall not interfere with any internal mirrors for the saloon or wheel chair bay
24	The view of the camera will be set by the manufacturer in accordance to UN Reg 46 and shall not be adjustable by the driver
25	The CMS monitor system shall be protected from tampering

8 Next steps

8.1 CMS monitor position

In order to determine the optimal position for the nearside monitor for the CMS (i.e. between Position A and D) further research is needed. This would need to investigate the effect of Position A and D on bus driver and road safety, as well as determining which position drivers most prefer. This research can either take the form of an on-road assessment in real buses or a simulator study.

For the on-road assessment, TRL suggests that TfL requests a bus operator to install 50% of their nearside monitors in Position A and 50% of their monitors in Position D, for a given route. After a three-month period, driving behaviour will be assessed by means of video-analysis, and bus driver preference and road safety will be assessed by means of a survey. If available, claims data can also be assessed.

For the simulator study, bus drivers will undertake user trials in TRL driving simulator, where both Position A and D will be assessed by each driver. Both objective and subjective data will be obtained including data on driving behaviour, eye glance behaviour, driver preference and acceptance.

The simulator study would be a more robust and valid option, as objective data can be obtained, data can be compared, and the simulator provides for a controlled environment.

8.2 Investigation of other potential CMS requirements

The next step for this research is specifying the CMS HMI requirements to specifically establish the physical and technical requirements of a CMS monitor display. This includes parameters such as screen size, resolution, distortion, number of images, etc. Moreover, the effects of monitor position on direct vision performance needs to be investigated. The effect of overlays (lines, coloured zones, symbols overlaid on top of the camera image on the monitor screen to augment the driver vision) on-road safety outcomes should also be investigated.

A second piece of work surrounds the development of the technical specifications for the HMI of the blind sport warning system. The HMI of this system is directly related to CMS, as the two systems may work together to warn the driver about potential collisions. For example, blind sport warning alerts should be designed in such a way that they direct the driver’s attention to the relative monitor screen, where the monitor can highlight in some way (i.e. red box around danger) the potential collision.

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Camera Monitoring System Human Machine Interface Support – Monitor Positioning

Abstract:

The Bus Safety Standard (BSS) launched in October 2018 making Camera Monitor Systems (CMS) a requirement for new buses according to the roadmap. This means that the mirrors are substituted by CMS, provided they comply with the relevant regulations. This approach removes the risk of a mirror hitting a pedestrian or infrastructure, as well as, potentially reducing blind spots and assisting drivers in perceiving more hazards. However, as CMS is a fairly new concept, the effect on driver workload and behaviour is not yet well understood, and there may be risks if drivers do not find the system natural to use. This study has extended the CMS research to fill the gaps in the knowledge regarding the positioning of the monitors, and to develop a set of recommendations for where the monitors should be positioned.

TRL performed an extensive study investigating the optimal position for CMS monitors in a bus. The project assisted in informing on or eliminating the various CMS monitor positions being investigated. The first task consisted of reviewing current national and international standards and regulations, particularly UNECE Reg 46, as all vehicle types must comply with the requirements stated in this regulation. Once completed, a bus manufacturer trialling CMS was engaged to determine the advantages and disadvantage of the various CMS monitor positions being investigated. Lastly, an evidence review was conducted to further inform on or eliminate a CMS monitor position.

The study has generated a series of recommendations regarding the position of the monitors for a CMS. These are summarised at the end of this report and have been used to update the Bus Vehicle Specification text for use in contracting of bus routes within London by TfL.

Other titles from this subject area

PPR 872 Bus Safety Standard: Executive Summary. TfL & TRL. 2018

PPR 819 Analysis of bus collisions and identification of countermeasures. Edwards et al. 2018

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