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An objective methodology for blind spot analysis of HGVs using a DHM approach

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AN OBJECTIVE METHODOLOGY FOR BLIND SPOT ANALYSIS OF HGVS USING A DHM APPROACH

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Abstract

This paper presents research into the quantification and evaluation of driver's field of view (FOV) from Heavy Goods Vehicles (HGVs). The research explores the nature of any blind spots to drivers' vision resulting from the vehicle design and configuration. The paper is the first of two submitted to ICED17. This paper focuses upon the methodology for the quantification of blindspots and the second paper presents the results and outlines the need for a direct vision standard (Summerskill and Marshall, 2017). The research builds upon previous work by the authors exploiting a volumetric projection technique that allows the FOV to be visualised in order to quantify the magnitude of any blind spots. The approach also provides a means to compare vehicle designs and scenarios involving the vehicle and other road users. Using this volumetric approach, the research determined the size and location of any bind spots around 19 HGVs. The sample consisted of the most sold vehicles in the year up to 2014 from major manufacturers. This paper describes the methodology employed for the evaluation of the HGV blind spots aimed at providing an objective approach to the evaluation of drivers' FOV.

Keywords: Design methodology, Evaluation, Computer Aided Design (CAD), Visualisation

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1 INTRODUCTION

This paper presents research into the quantification and evaluation of driver's field of view (FOV) from Large or Heavy Goods Vehicles (LGVs / HGVs). The research explores the nature of any blind spots to drivers' vision resulting from the vehicle design and configuration. The paper is the first of two papers submitted to ICED17: the 21st International Conference on Engineering Design. this paper focuses upon the methodology for the quantification of blindspots in HGVs in the UK and Europe and the second paper presents the results from the research and outlines the need for a direct vision standard to address the current issues (Summerskill and Marshall, 2017). The research was performed for Transport for London (TfL) as part of their Construction Logistics and Cyclist Safety (CLOCS) programme. The CLOCS programme was established to address concerns into road safety and specifically issues around the prevalence of accidents between construction vehicles and vulnerable road users (VRUs). An exploration of road accident data in the UK via the police accident database STATS19 shows a general improvement in road safety in the UK with fatal casualties reducing. However, the number of killed or seriously injured cyclists has increased. In addition, the situation in London shows that construction vehicles are over represented in these accidents (Talbot et al, 2014).

This research builds upon previous work by the authors into exploring FOV from vehicles and the exploration of blind spots (Cook et al, 2011, Marshall et al, 2013, Summerskill et al, 2015a, Summerskill, et al, 2016), and how to improve these blind spots (Summerskill, (2014) and Summerskill 2015b). A common approach in this research was to exploit a volumetric projection technique that allows the FOV available to the driver to be visualised and projected onto surfaces around the vehicle, such as the ground, in order to quantify the presence and magnitude of any blind spots. The approach also provides a means to compare different vehicle designs and scenarios involving the vehicle and other road users. This volumetric FOV projection technique was implemented in the digital human modelling (DHM) system SAMMIE (Case et al, 2016).

Using this volumetric approach, the research determined the size and location of any bind spots around 19 HGVs. The sample consisted of the most sold vehicles in the year up to 2014 from five major manufacturers including DAF, MAN, Mercedes, Scania and Volvo. Variants from each manufacturer were evaluated that included distribution, long distance haulage and construction variants. Furthermore, five low-entry cab designs were explored from Scania, Mercedes, Volvo and Dennis. This paper describes the methodology employed for the evaluation of the HGV blind spots aimed at providing an objective approach to the evaluation of drivers' FOV.

2 VISION FROM HEAVY GOODS VEHICLES

Due to the weights and dimensions legislation that controls vehicle size in Europe most HGVs in Europe and the UK have the same basic configuration. Restrictions on the overall length of vehicles has placed pressure on manufacturers and operators to maximise load carrying capacity, placing a premium on the space behind the cab. This results in the distinctive flat fronted design, with the cab mounted directly above the engine and in particular a high driving position and eye point for the driver.

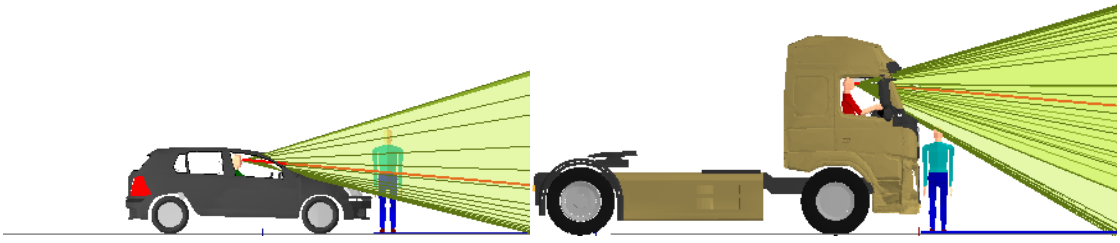


Figure. 1. Basic Illustration of the impact of driver eye height on field of view. Volkswagen Golf M1 Car (left), Volvo FM N3 HGV (right)

Figure 1 shows a simplified interpretation of the impact of driver eye height on FOV. In the figure, the left image shows the projection of the visible volume of space available to the driver through the front windscreen area from a Volkswagen Golf category M1 car with 50th %ile UK Male driver. The right image shows the equivalent projection from a Volvo FM category N3 HGV with 50th %ile UK Male driver. A 50th %ile UK male pedestrian is shown standing directly in front of the vehicle, in the case

of the car driver, the pedestrian would be visible from the thighs upwards through the windscreen of the car. For the HGV driver the pedestrian would be completely hidden from direct vision through the windows.

Vehicle height, or specifically the height of the driver's eyes plays a significant role in the FOV. There are a number of contributing factors to the height of HGVs which are independent of the vehicle design. The largest HGVs in the UK and Europe are categorised as N3. N3 vehicles are defined as those used for the carriage of goods and having a maximum mass exceeding 12 tonnes. Many of the mid-sized category N3 vehicles sold in Europe and the UK are available in two basic configurations: N3 often used in a distribution role, and N3G often used in a construction role. Whilst this categorization is a simplification there are typically height differences between those vehicles categorized as N3 and those categorized as N3G, even though the cab design is the same. The height differences can easily be in the order of 100s of millimeters and are a result of the specification of different suspension types, tyres, and the need for ground clearance. Ground clearance is of particular importance for those vehicles operating on-site where the conditions are more demanding than those on-road. This naturally leads to complexities in the specification and management of construction traffic, particularly operating in urban environments. For much of their working life these vehicles will be operating on normal roads with smooth road surfaces where their off-road specification is unnecessary and where the potential reduction in FOV is critical.

3 ESTABLISHING A REPRESENTATIVE VEHICLE SAMPLE

The criteria for establishing which vehicles should be used in the research evaluations were defined as follows:

- The vehicle makes and models should be defined by UK registration figures to ensure that they are representative of vehicles that are in use
- In addition to standard vehicles, the benefits of low entry cab vehicles in terms of the ability of the driver to use direct vision (through windows) should be explored
- The sample should include specifications of vehicles which represent appropriate variability in vehicle height as defined by their use case e.g. general haulage and construction use

With the support of the UK Society of Motor Manufacturers and Traders (SMMT) the data for the registrations of new Euro 6 category N3/N3G vehicles were obtained and examined to determine which makes and models of vehicles were to be tested in the project. The manufacturers that were included were, DAF, Dennis, MAN, Mercedes, Scania and Volvo.

A review of the vehicles available from these manufacturers established that there are distinct configurations which are available to meet the demands of specific applications. With a research focus on the differences between makes and models, but also between construction and non-construction vehicles, a balanced sample was identified which included the following models and configurations (see Figure 2), with over 95% of new vehicle registrations being covered by these models (Summerskill, 2015b).



Figure 2. The 19 vehicles used in the research evaluations

As previously described vehicle design is one key factor in the sample, the other is the vehicle configuration that can have a significant effect on the cab mounting height and thus the driver's eye height. This resulted in a strategy where the 'most sold' configuration for each vehicle was selected for analysis. This method had the advantage of representing the largest number of vehicles that are in operation, in a fair and equitable manner. For the purposes of illustration each vehicle cab that was produced in the project has been shown in a tractor configuration (4X2). The 'most sold' configurations would most likely be different to this, including rigid and articulated configurations however these variables have no direct influence on direct FOV.

3.1 Vehicle Models

In order to perform the projections of the driver's FOV, the HGV sample needed to be modelled in the SAMMIE DHM system. Due to the research timescales and the sensitivity in obtaining manufacturer CAD data, a 3D scanning approach was adopted. The process consisted of using a FARO Photon 120 laser scanner (maximum resolution of 2mm up to 20m away) to capture six scans: four exterior and two interior, of each vehicle in the sample. A key aspect of the data requirements for the research was the accurate reproduction of the mirrors and window apertures. The projection technique in the DHM system requires the shape of the outer edge of the window or mirror glass, and the radius of curvature of the mirror surface to allow a ray tracing technique to produce the volume of space that is enclosed by what can be seen from the driver's point of view. In order to accurately capture these data, the FARO scans were augmented with the use of a ZCORP laser hand scanner (1mm resolution) to scan the mirror arms, bodies and glass. Each mirror had to be scanned in four positions to record the adjustability of the mirror surface. The scanning process was a laborious one taking a significant number of days for each vehicle model to be produced. The six exterior scans were post processed to refine the data into manageable file sizes, remove noise and to align the multiple scans using standard reference spheres included in each scan. The initial processing was done in the FARO SceneLT software and then taken into 3D Systems Geomagic software. The radius of curvature of the mirrors was also established from the Geomagic software and validated with a spherometer from the mirror itself. Finally, the data were imported into the SAMMIE system that was then used to set the eye points of the driver, the mirror properties and adjustability, the vehicle mounting heights and to perform the analysis.

3.2 Setting up Vehicles in the DHM System

3.2.1 Defining the Eye Point of the Virtual Drivers

The SAMMIE DHM volumetric projection techniques rely upon an understanding of the variability in driver's eye location as this is the origin of the rays used in the projection method. The eye position variability of the driver population is defined by factors including: the anthropometry of the driver population, the available seat and steering wheel adjustability in vehicles, and the driving posture that results from the available adjustability. The process of vehicle design and assessment is supported International Standards Organisation (ISO), Society of Automotive Engineers (SAE) and European Community Standards. The variability of eye location within the vehicle due to driver size variability is specifically covered by SAE J941 (SAE, 2002). However, this standard does not take into account HGVs with height adjustable seats and is therefore not applicable to modern designs. To address this a technique defined by Reed (2005) was used. Eyellipses were subsequently generated using equations provided by Reed for each vehicle which places the Eyellipse within the three-dimensional model of the vehicle cabs. Within the DHM system, human models were then postured in a manner which required the ball of foot marker to be correctly located on the accelerator pedal, the heel on the floor, the seat adjusted to a position to allow the thigh to be supported horizontally by the seat cushion and thoracic spine and other DHM joint elements to be within comfortable posture limits, the steering wheel to be effectively reachable and finally, the eye point of the DHM located in the appropriate location with the Eyellispe. This process was successful for all vehicles, providing a range of driver eye positions based upon small female drivers (only 5% of UK females are shorter) and tall males (only 5% of UK males are taller), with an average sized driver also being incorporated. The key benefit of this process is that a range of eye positions can be consistently defined for each vehicle being tested, providing a fair and equitable method for the comparison of vehicles in terms of direct and indirect vision for a range of driver sizes.

3.2.2 Setting Up Mirrors

A key aim of the research was to provide a consistent method for the comparison of direct (through windows) and indirect (through mirrors) vision capabilities of drivers from a range of vehicles. The high range of mirror adjustment that is found in these vehicles required a method to constrain the mirror adjustment positions in a manner that is repeatable across all vehicles. This was addressed by adjusting all mirrors to ensure that they meet the requirements of 2003/97/EC. The standard defines the locations on the ground plane (floor) that should be visible to the driver. The standard defines a total of six zones, one for each mirror. Figure 3 shows an example of the specified zones for the Class II mirror.

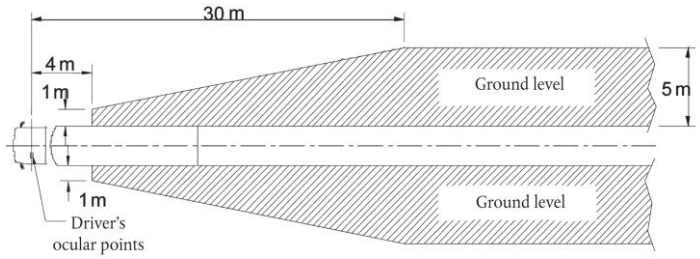


Figure 3. Field of vision of Class II mirrors as specified in 2003/97/EC

In almost all cases multiple positions of the mirrors were able to cover the required standard. Therefore, an approach was taken where the mirrors were adjusted so that the edge of the mirror projection was just in contact with the edge of the required area. Figure 4 shows the process for the Volvo FE LEC.

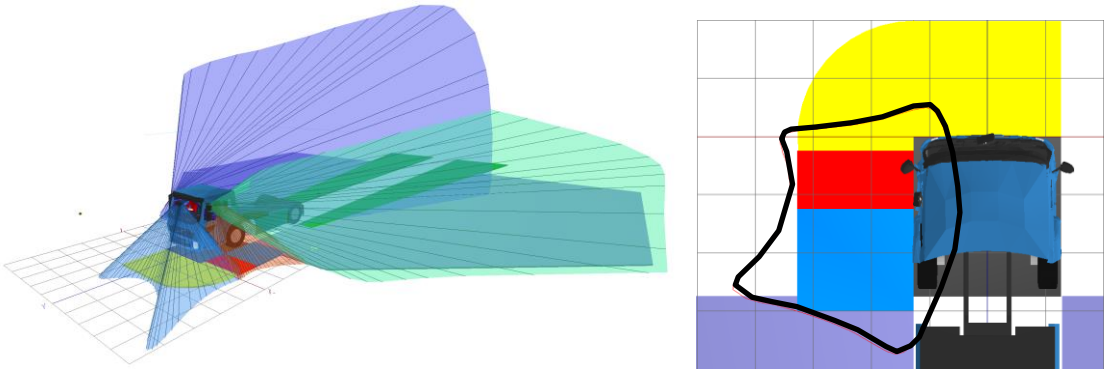


Figure 4. Volumetric mirror projection (left). Example of Class V mirror coverage adjusted to the mandated area for the Volvo FE LEC (right).

4 THE METHODOLOGY FOR THE EVALUATION OF FIELD OF VIEW

The methodology for assessing the visibility of VRUs was developed to evaluate the visible areas adjacent to each vehicle. The technique utilises three dimensional (3D) projections of the visible volume of space from the eye point of the driver through apertures (windows), and via mirrors. The volumetric projection involves extending a ray from the eye point of the driver through a series of vertices that define the boundary of a window aperture or the perimeter of a mirror surface. In the case of the window aperture the ray is extended directly, whereas with mirrors, the ray is reflected from the spherical mirror surface (Marshall et al. 2013).

Having defined the Eyellipse for each vehicle it was decided to simplify the issue of multiple eye locations to a single point for the majority of the analysis. The 50th %ile UK male human model and corresponding eye point was selected. The eye point is the mean value for the UK male population and serves as a comparative and consistent value for all analyses. However, it is important to note that the eye point will have an effect on the FOV afforded the driver and thus the nature and extent of any blind spots. Thus, for each vehicle the differences due to eye point location across the 5th %ile UK female to 95th %ile UK male range were also explored but in a simplified form.

The volumetric projection provides a visual means of evaluating FOV such that any part of an object in the driving environment, such as a VRU, that intersects with the projection would result in it being visible to the driver. Conversely anything falling outside of the projected volume would not be visible.

However, the volumetric projections often provide complex fields of view and a combination of 3D and 2D assessments were developed.

4.1 2D Area Analyses

As previously described, the volumetric FOV projections can be intersected with other geometry, such as the ground plane to produce a 2D areas of visibility (see Figure 5). This 2D approach can be used to provide an overview of visibility on the ground or at a specified height above the floor. Anything that intersects with a 2D projection, at the height of the projection, can be seen by the driver.

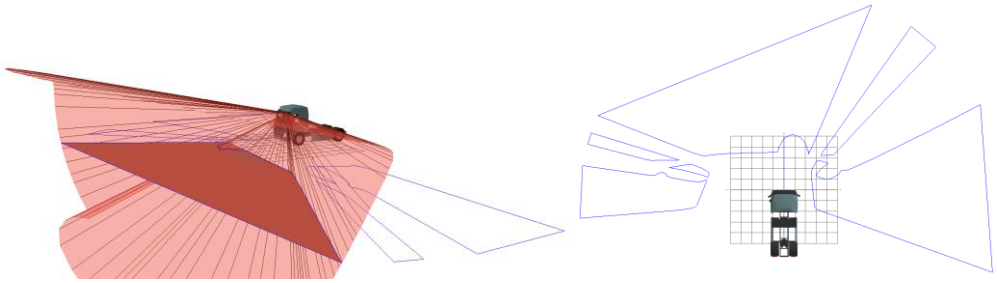


Figure 5. 3D Field of View Projection clipped to the ground plane to form 2D ground plane projections for direct vision

This 2D approach is used to define the necessary areas of visibility on the ground for indirect vision (through mirrors) in 2003/97/EC and UNECE Regulation 46 and thus is a familiar methodological approach in FOV modelling. It should be noted that whilst the 2D projections are a familiar means of presenting FOV information they are subject to distortion and care should be taken in interpreting what is actually visible to the driver. For example, the 2D projection of the Class V in Figure 6 suggests that the cyclist would be visible to the driver as they are within the ground plane area. However, because the projections generated are largely conical volumes the majority of the cyclist is outside of the visible volume and thus only a very small part of the cyclist would be visible in the very bottom edge of the mirror.

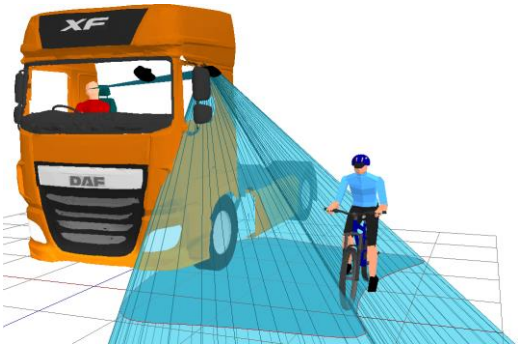


Figure 6. Objects within the 2D projection area, may not be visible to the driver

To partially address this issue, the analyses use three 2D plane heights:

- Ground plane. This is used as a standardised projection to provide an overview of direct vision baseline for all test vehicles.
- Ground plane + 1738mm. This is used to represent the FOV at a height coincident with the top of the cyclist model's head (helmet).
- Ground plane + 1755mm. This is used to represent the FOV at a height coincident with the top of the pedestrian model's head.

4.2 VRU Analyses

Informed by the previous research performed by the authors which included a review of UK STATS19 accident data analysis, a number of analysis configurations were identified for evaluation (Summerskill et al. 2015a). These configurations were derived from accident scenarios and involved VRUs adjacent to the HGV. The basic premise is that models of VRUs would be placed around the vehicle and their visibility evaluated. One of the potential complexities of this approach concerns the difficultly in

determining how much of a VRU would need to be intersected by the projection in order for it to be seen. This is an extension of the 2D area issue outlined earlier where merely being within the area / volume does not necessarily equate to being visible to the driver. Thus, the approach that was developed attempted to position the VRU model at a point at which they are just 'not' visible to the driver, i.e. they will be completely obscured from the driver's vision. This would serve to highlight the limits of visibility for the driver of the VRUs around the vehicle.

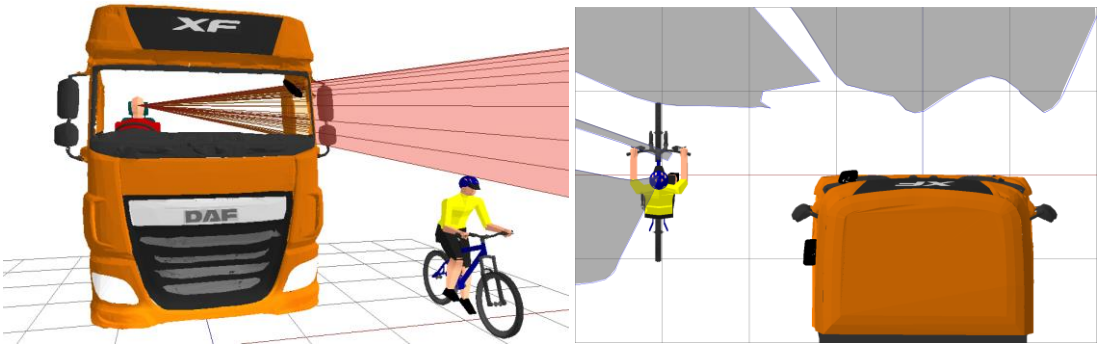


Figure 7. Positioning of cyclist model at a point where they are just not visible (against the projected volume), shown in 3D (left) and 2D (right)

Figure 7 shows a cyclist model to the passenger side of the test vehicle. The cyclist has been moved laterally away from the side of the vehicle until the helmet of the cyclist is at a point where it just fails to intersect with the projected visible volume from the passenger window. This represents the furthest the cyclist could be away from the vehicle and still not be visible. By positioning the VRU in this way the size of any blind spot in direct vision is illustrated. In the right image in Figure 8 the grey areas represent the space visible to the driver at the head height of the cyclist. Conversely, the white areas at the same height cannot be seen. The position of the VRU relative to the vehicle is then directly measured as the linear distance to the side or front of the vehicle. This provides objective measures for the comparison of direct vision between test vehicles. By comparing the distances away from the vehicle front and side at which VRUs can be hidden, the size of the blind spots can be quantified in a manner which relates to real-world implications. The further away that a VRU can be hidden the larger the blind spot is.

Based upon the scenarios used for the 3D analyses, two VRU models were utilised:

- A 50th %ile UK male (stature 1755mm) used to represent a pedestrian
- A 50th %ile UK male (top of head height of 1738mm) cyclist

These two VRU models would be assessed in three main areas: the pedestrian model used to the front of the vehicle; and the cyclist model to the driver and passenger sides of the vehicle.

4.3 Forward Visibility

This test evaluates the visibility of a pedestrian across the front of the vehicle. Three pedestrian VRU models are positioned in line with the centre line of the vehicle and at each of the outer edges. This is designed to represent a pedestrian crossing in front of the vehicle. Each pedestrian is positioned at a point furthest away from the vehicle at which they are not visible to the driver. The linear distance from the front of the vehicle is then reported for each pedestrian. Figure 8 shows the three pedestrian models, the image to the right shows a top down view highlighting the different distances the pedestrians can be positioned from the front of the vehicle without being visible to the driver. It can be seen from the figure that the pedestrians can be between 0.7m and 1.2m from the front of the vehicle without being visible to the driver. The grey area represents the projection of the visible area of the windscreen at the 1755mm height as described previously.

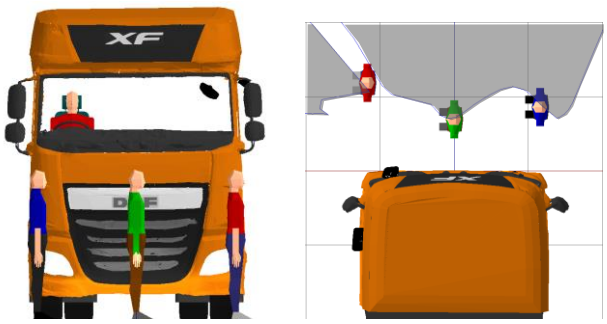


Figure 8. The configuration of the pedestrian models positioned in front of the vehicle. The image to the left shows a view to the front of the vehicle. The image to the right shows a plan (top-down) view.

4.4 Driver and Passenger Side Visibility

These tests evaluate the visibility of a cyclist to the driver and passenger sides of the vehicle. Two cyclist VRU models are positioned to each respective side of the vehicle. The rear cyclist is positioned to align the top of their head with the driver's eye-point, the front cyclist is 1m in front of the first. This is designed to represent a cyclist overtaking the test vehicle. As with the forward visibility assessment the models that represent the cyclists are positioned in these locations to represent common accident scenarios and each cyclist is positioned at a point furthest away from the vehicle at which they are not visible to the driver. Figures 9 and 10 shows two cyclist models positioned to the driver and passenger sides of the test vehicle. In the case of the driver side there is no location at which they are not visible (i.e. they are always visible). For the passenger side the cyclist can be positioned between 1m and 1.5m from the side of the vehicle and not be directly visible to the driver.



Figure 9. Cyclist models positioned to the driver side of the vehicle.

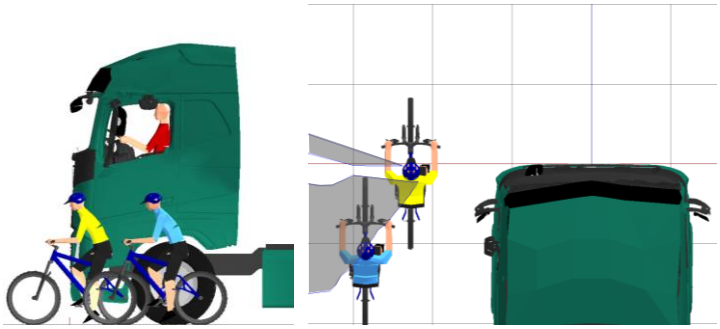


Figure 10. Cyclist models positioned to the passenger side of the vehicle.

4.5 Indirect Vision Analyses

Whilst the focus of this research prioritised direct vision (via windows), it is important that indirect vision (via mirrors) was also considered as they are currently a critical part of the regulations in addressing blind spots around the vehicle. For all of the analyses described previously, 3D and 2D analyses were also performed for mirror projections. Figure 11 shows the projection of the Class VI mirror to the front of a vehicle. In comparison to Figure 8, whilst the VRU models are not visible to the driver via direct vision, the pedestrians would be visible in the Class VI mirror. The middle pedestrian

is completely visible, the right pedestrian is visible from the shoulders down, the left pedestrian is visible from the waist down. The grey area represents the projection of visible area of the Class VI mirror at the 1738mm height as described previously. This indirect vision analysis was also performed for offside and nearside visibility using the appropriate mirrors.

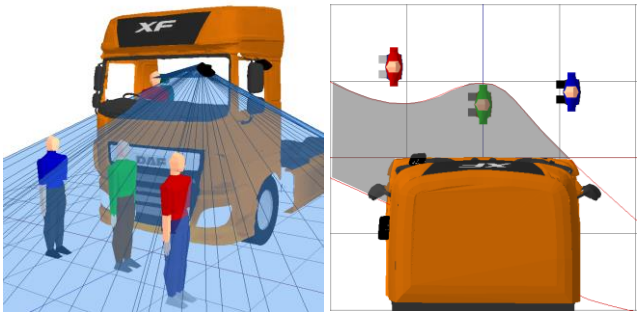


Figure 11. The configuration of the pedestrian models positioned in front of the vehicle for indirect vision analysis. The image to the left shows a 3D view to Class VI mirror projection. The image to the right shows a plan (top-down) view.

5 DISCUSSION AND CONCLUSIONS

The results of applying the methodology to the full vehicle sample provided a wealth of data that could be used to provide illustrations of the field of view afforded to the driver of a HGV. In addition, the objective data allowed statistical tests to be performed on the distances at which a VRU could be hidden from view. It is beyond the scope of this paper to document the results of the analyses, however the these are presented in the accompanying paper (Summerskill and Marshall, 2017). However, there are a number of discussion points regarding the methodology developed that should be highlighted.

For the volumetric analyses, the positioning of the VRU models is an important issue. The use of pedestrian and cyclist models provides both representative and accessible evaluative objects. In addition, the approach provided objective metrics that allowed a direct comparison to be made between vehicles. However, in limited numbers the VRU models do not fully provide an exploration of the magnitude of the blind spots around each vehicle. If a VRU is shown to not be visible in one location this does not provide a full understanding of whether they would be visible or not if the location was changed. In general, it is likely that moving the VRU closer to the vehicle would result in the VRU remaining obscured, moving them further away would result in them becoming visible. The experimental setup of the VRU models aims to partially address this positioning issue through the use of multiple locations across each side of the vehicle in critical areas.

The use of 2D projections in these analyses also raises a number of associated issues. In general, a VRU positioned in a white area is likely to result in them being obscured, whilst a VRU positioned in a grey area is likely to result in them being visible. However, the 2D projections, as discussed previously, are only a snapshot of visibility at the specific height of the 2D plane. The right image in Figure 8 shows a cyclist positioned at a location where they are not visible to the driver. The image also shows that the left shoulder / upper arm of the cyclist is within the grey area suggesting that part of the cyclist would be visible. As the left shoulder / upper arm of the cyclist is below the plane (+1738mm) at which the 2D areas are projected it is not possible to infer visibility or not of the cyclist (or part of the cyclist) at this height. The conclusion is that it is not straightforward to predict what would happen if a VRU model were moved from the assessed locations and to draw more general conclusions about visibility of VRUs around the vehicle anywhere other than in the assessed locations or at the 2D projection heights.

These issues highlight the need to take multiple approaches to assess and communicate the FOV afforded the driver of any of the test vehicles. In addition, the results of these assessments should not be simplified or taken out of context to the extent that they lose the richness resulting from the multidimensional approach employed in this research. It is only together that an understanding of what is, or is not, visible can be obtained.

This research has resulted in an objective methodology for the evaluation of FOV. In combination, the methods utilised provide a standardised means to compare the FOV across a range of vehicles. For the specific locations selected the visibility of VRUs adjacent to the vehicles can also be objectively evaluated and the performance of vehicles assessed. This assessment allows the implications of vehicle

height to be considered, and thus inform operators on the implications of choosing a specific vehicle configuration, but also design features specific to each manufacturer that allows good cab design to be highlighted.

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