A Comparative Analysis of LGV Visibility Mapping: Does Size Really Matter?

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Abstract

Plotting a driver's 'sight lines' is often an important part of investigations into collisions between vehicles (particularly LGVs and PCVs), and vulnerable road users such as pedestrians and cyclists. Such investigations are carried out in order to determine whether one party could have been visible to the other, had they been looking in a particular direction at a given moment. An analysis that seeks to represent the exact vision available to a particular driver can be flawed. Incident drivers are often unavailable for analysis, so a traditional method has been for an investigator or colleague to sit in the driver's seat and direct a person outside the vehicle marking out the areas of visibility, usually by placing markers at the extents of the areas where their feet are visible.

Where a driver is unavailable, a stand-in of similar stature is used. The chosen stand-in will be as close in height as possible to the standing height of the incident driver, or if the driver's height is not known, an 'average height' stand-in is used.

Generally for these "stand-in" assessments the vision plots have been accepted as not being 100% accurate, but the actual level of inaccuracy has not been known. This study seeks to quantify what, if any, error is introduced into line of sight measurements when different height drivers are used, with the aim of calculating the percentage error, allowing it to be applied as a confidence range to subsequent assessments.

Introduction

The number of vulnerable road users (pedestrians and cyclists) killed or seriously injured in collisions with Large Goods Vehicles (LGVs) is disproportionately high compared to the number of such vehicles on UK roads. Such collisions are often high profile, particularly when they occur in London. The problem of restrictions to vision caused by the high cabs of LGVs is well documented.

In reconstructing these types of collisions, it is important to establish where the parties were in relation to each other, and then establish whether it was possible for each to see the other, whether through direct vision (through windows) or indirect (mirrors). *Could* the injured party be seen *if* the driver were looking in a particular direction at a particular time? Whether one *should* have seen the other is then a separate issue, requiring, for example, consideration of the vehicle and other parties' movements, the surrounding environment, and timings for mirror checks and other observations.

Particularly in Police investigations, it may be rare for the incident driver to be available for visibility assessments, especially if the assessment is carried out at a live collision scene while the driver is elsewhere being interviewed. The more usual method is therefore to use a colleague of as close a height as possible (if the driver's height is known) to sit in the driver's seat and establish the areas where they can see the ground.

The areas of vision and vehicle outline can then be measured in two dimensions, with a theodolite, or in three dimensions, with a 3D laser scanner. The resulting scaled two-dimensional drawings may, however, be misleading if they simply show the areas of ground that can and cannot be seen. It is important to consider the visibility in three dimensions, since it may be that, though the ground at a particular point may not be visible, a pedestrian standing on that point may be visible, for example, from the knees up.

Figure 1 shows an example of a two dimensional visibility plot. The blue area shows the ground that can be seen through the windscreen, and the green areas show the ground visible through the nearside window. The white areas show the areas of ground that are not visible to the driver. It could be interpreted that the pedestrian standing in front of the vehicle was not visible.

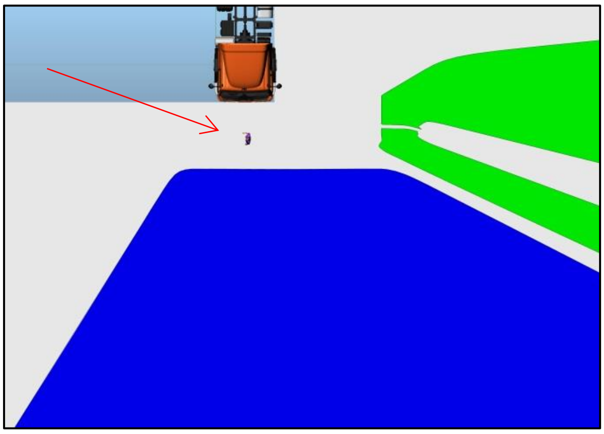

Figure 1: example two dimensional visibility plot

When the same visibility plot is shown in three dimensions, as at Figure 2, it is evident that the pedestrian is actually available to be seen from the waist up (the area inside the blue cone represents what is available to be seen by the driver).

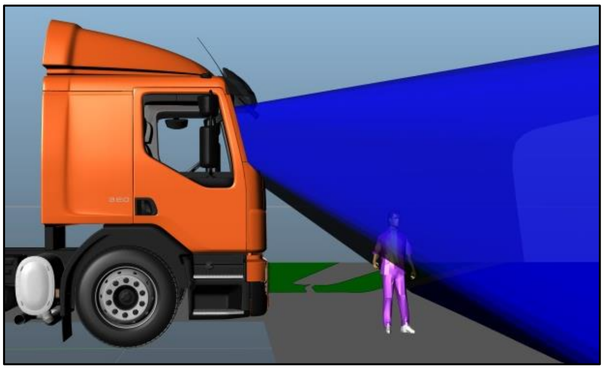

Figure 2: example three dimensional visibility plot

An alternative method (compared to using a stand-in driver to direct an outside colleague placing markers), developed at TRL, uses a laser pen positioned on a movable arm to plot the visibility. This gives a more accurate representation as it removes subjectivity – markers are simply placed at the points where the laser hits the ground as it is traced along the edges of a window, mirror or other obstruction.

The positions for the laser and its 'eyeball' mount are determined by measuring a driver's (or stand-in's) eye point (their monocular view point, represented by the bridge of the nose), relative to several features within a vehicle cab, then placing the eyeball mount on its movable arm at that point. The apparatus allows for neck and eye rotation.

It is accepted that, even for a set height, the eye position of different drivers will not always be the same. It can vary based on, for example, body/leg length proportions, or the driver's weight and the effect it has on the seat's air suspension. It is also accepted that a driver's eye position will not be static.

It is impossible to account for the actual level of, for example, eye and head rotation, fore/aft movement, posture adjustment, or movement of the air-sprung seat up and down. Visibility assessments of this type will always represent the 'line of best fit'; while it is known that the actual line of visibility plotted on the ground can move, there is a limited range it can move within, and the proportions of ground that can and cannot be seen will stay the same as the eye moves relative to the obstructions.

For this study only direct vision has been considered, forwards through the windscreen and sideways through the nearside window, in order to provide a simple comparison between the direct vision available to drivers of different heights.

For simplicity, only a monocular view point has been considered here, since the study simply seeks to compare the vision available to drivers of different heights. It is accepted that, in reality, it is more accurate to consider ambinocular views, which take into account the differing viewpoint available to each eye.

Modelling Method

The modelling for this study was carried out using digital models of the two vehicles used for physical measuring of the subjects. In collision investigation the modelling will more often be carried out using a 3D laser scanner to create a model of the vehicle itself along with the ground markers used to identify the points where the driver's line of sight meets the ground. A collision investigation may also use a theodolite to capture the ground markers and outline of the vehicle in two or three dimensions.

Using digital vehicle models in this study allows all variables to be kept consistent except for the eye point of the driver. It also removes all subjectivity, as straight lines can simply be plotted from the eye point to the edges of the respective windows, using the same window outline for each participant and vehicle.

Although it is accepted that there are multiple vehicle–related variables which can affect the driver visibility, they have all been kept consistent for each participant in order that only the variation caused by the eye point movement is assessed. Variable vehicle-related parameters could include, but are not limited to;

- Suspension positioning
- Vehicle tyre pressure
- Fuel level
- Driver/passenger/luggage and payload weight

In collision investigation cases these variables should be kept the same as at the time of the incident wherever possible.

This study used five drivers of varying heights, and two vehicles[1].

Subject	Standing Height, mm (ft' in")	Sitting Hip to top of Head, mm	Sitting Hip to Eye, mm
1.	1610 (5' 3")	865	740
2.	1740 (5' 8.5")	915	810
3.	1820 (5' 11.5")	920	800
4.	1830 (6' 0")	960	800
5.	1930 (6' 4")	1010	890

Table 1: heights of participants

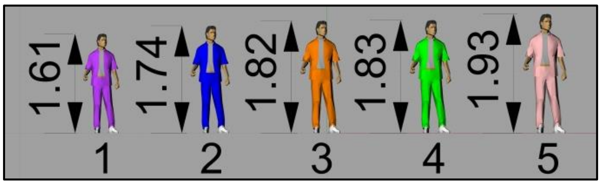

Figure 3: heights of participants

[1] The colour coding applied to the participants in this table applies throughout the study

Vehicle one was a Volvo FE 18 tonne rigid LGV. Vehicle two was a Volvo FH 40 tonne articulated LGV.

Figure 4: the Volvo FE used for participant measurement

Figure 5: the Volvo FE digital model

Figure 6: the Volvo FH used for participant measurement

Figure 7: the Volvo FH digital model

Each participant was asked to sit in each vehicle and adjust the seat fore/aft, height, rake and back rest position, until they were in a comfortable driving position where they could reach all the controls. Their monocular eye position (the bridge of the nose) was then measured with respect to the following points;

- Horizontal measurement to a plumb line from the centre of the first axle
- Vertical measurement to the top of the door
- Vertical measurement to the ceiling
- Diagonal measurement to the top of the dashboard
- Diagonal measurement to the bottom of the tachograph

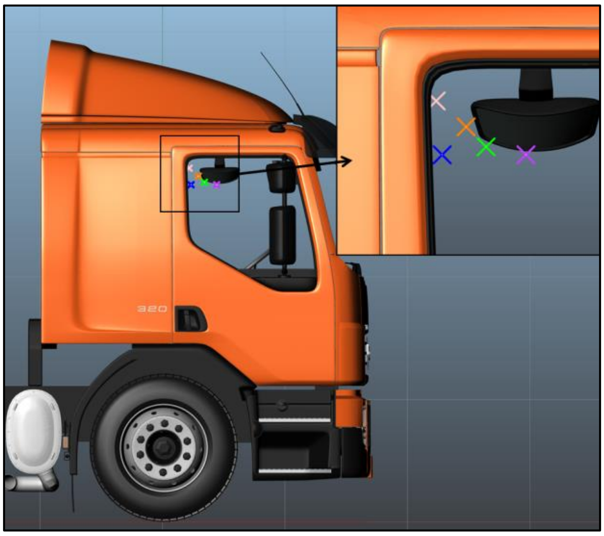

Figure 8: eye positions in Vehicle One (see enlargement at Appendix 1)

These measurements allowed the eye point to be replicated, within the digital vehicle models, for each participant in the horizontal and vertical planes. The lateral position was not measured as the monocular eye point was considered to be in line with the centre of the steering wheel for each participant.

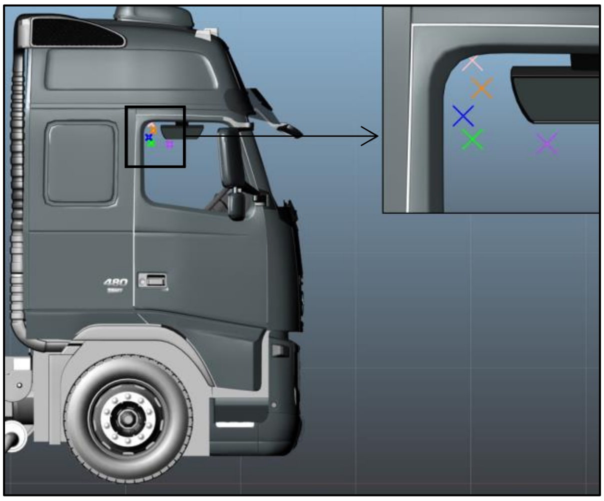

Figure 9: eye positions in Vehicle Two (see enlargement at Appendix 1)

For each vehicle the windscreen, nearside window and nearside mirror housing were traced around within the modelling software[2], in order to determine the limits of vision in each direction. Usually the steering wheel and dashboard (and any dashboard- or windscreen-mounted objects such as dash-cams or sat-navs) are traced around as they also affect the visibility points at the bottom of the windscreen. In the digital models used here the cab interiors had not been modelled with enough detail to provide an accurate representation. Since it is the comparison between eye points that is of relevance here, however, it is largely irrelevant as long as the same features are modelled for each participant. The same windscreen, window and mirror housing outlines were used for each participant, for the respective vehicle. For the side windows the eye point was rotated about a point 98mm rearwards of the forward facing eye point, to represent the neck pivot point.

Within the modelling software, the eye point position was joined to the window or obstruction extents by the use of a polyline, which was then extended outwards until it met the ground plane. In turn a surface was

[2] Rhinoceros® 3D

then created to form the boundary to the visibility zone, and the point where the surface meets the ground plane can be easily defined. The areas inside the coloured shapes are the areas available to be seen.

Figure 10: the outlined window, mirrors and windscreen

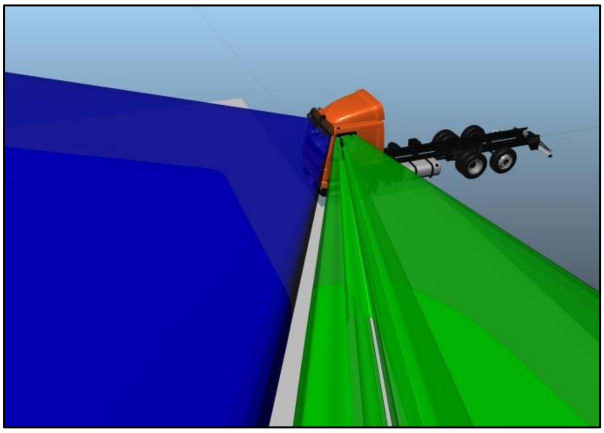

Figure 11: overview of the forwards and side visibility; note the area between the green and blue shapes showing the A pillar obscuration

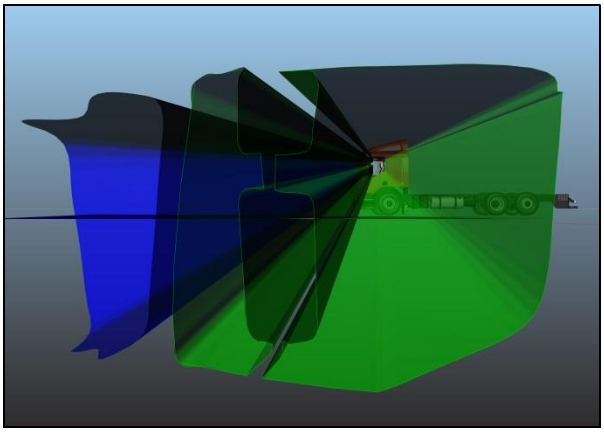

Figure 12: overview of the forwards and side visibility; note the area between the two green shapes showing the mirror housing obscuration

Analysis of Available Views

When the eye points of the five participants are compared, it can be seen that they fall within a reasonably small distance of each other. This is to be expected following seat adjustment. In each vehicle the shortest participant's eye point was generally the lowest and furthest forwards, and the tallest person's was the highest and furthest back, as would be expected.

The intermediate height participant's eye points did not follow a pattern, though they did all fall within a short distance of each other. If a line is drawn between the 'shortest' eye point and the 'tallest', and this is used as the diameter of a circle, the other eye points all fall within the same semi-circle. The radius of the semi-circle did not vary greatly; 131mm for vehicle one and 120mm for vehicle two (though further analysis of more vehicles would be required to determine if this radius can be more variable).

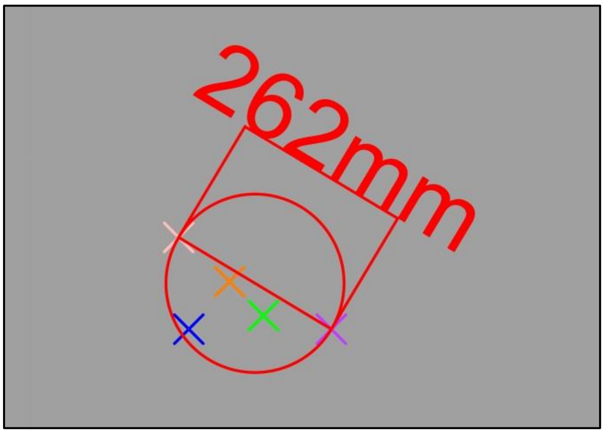

Figure 13: the eye points in vehicle one

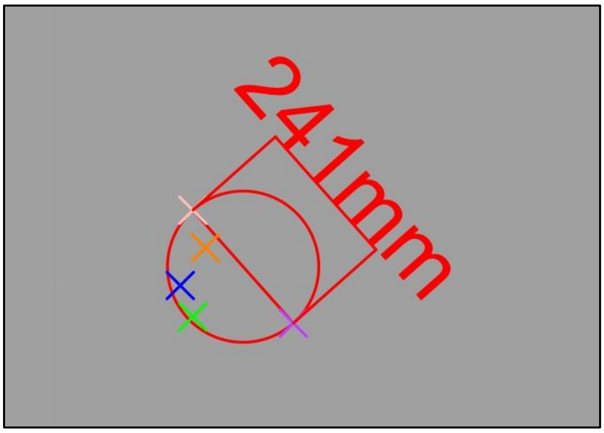

Figure 14: the eye points in vehicle two

It would be expected that, if more participants were measured for the same vehicles, their eye points would fall within the same semi-circle.

Figure 15 and Figure 16 show the visibility at ground level for the median height participant for each vehicle. It can be seen in each case that a significant area of obstruction is caused by the mirror housings; this is commonly seen in modern LGV's.

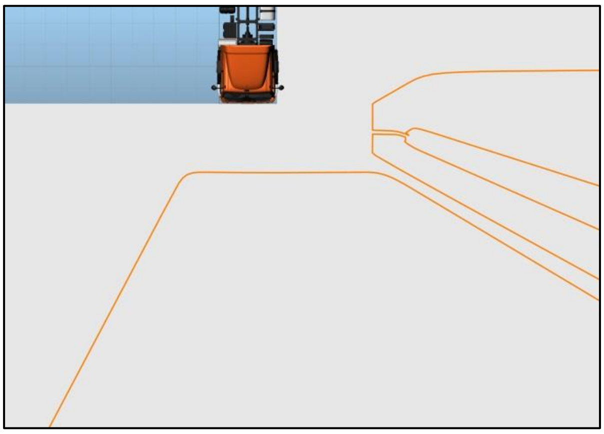

Figure 15: the ground visibility for the median height participant, vehicle one

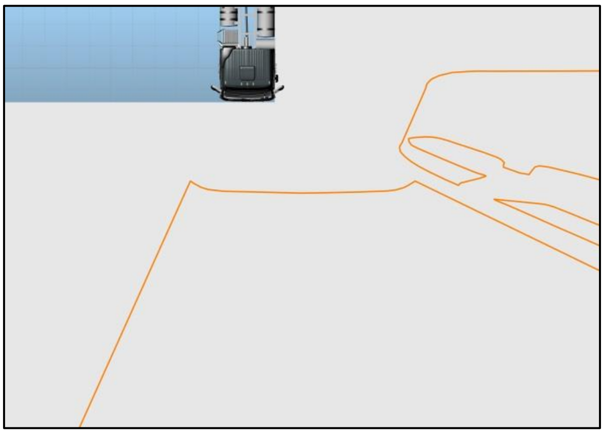

Figure 16: the ground visibility for the median height participant, vehicle two

Predicting that an eye point will fall within a given area does not necessarily, however, predict the level of vision available from that eye point. It does not follow that the shortest person has the worst view and the tallest has the best, or vice versa.

The person sitting closer to the windscreen will always have a wider field of view through the windscreen than someone sitting further back. However, it is not necessarily true that the shortest person will be sitting the closest to the windscreen, due to the variability in preferred seating position (though it was true for these five participants). When the intermediate height participants are considered, with respect to Figure 13, it can be seen that participant four (green), the fourth tallest participant, is positioned further forward than the second and third tallest participants. For side vision, the angle of visibility will change as the driver moves closer to the windscreen, but the overall area of vision will not necessarily change.

Figure 17 shows a comparison of the ground visibility for the shortest (purple) and tallest (pink) participants for vehicle one. It can be seen that the point where the visibility plane from the bottom of the windscreen meets the ground is very similar for both participants, but the field of view is significantly wider for the shorter participant.

The similarity of the first point of vision in this instance is because the line between the two viewpoints (as shown at Figure 13) corresponds very closely to the line between the view points and the bottom of the windscreen, so the taller viewpoint is an extension of the shorter one. This may be purely coincidental, however. Assessment of more vehicles and participants would need to be carried out to confirm this point.

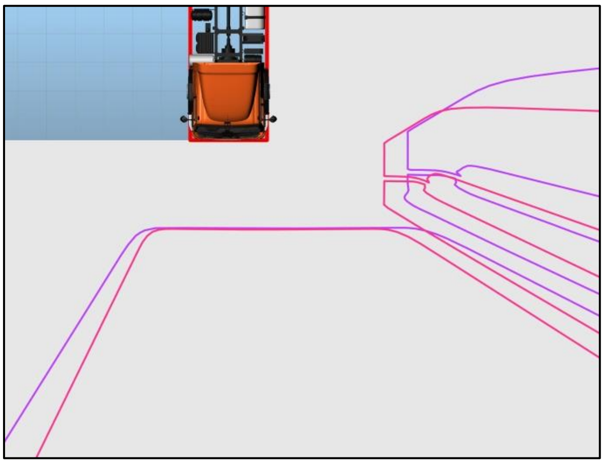

Figure 17: comparison of tallest and shortest views, vehicle one

The same plot for vehicle two (Figure 18) shows that the equivalent correspondence of viewpoints does not occur; the shorter field of view is still wider but it also reaches the ground significantly further from the vehicle than the taller view point.

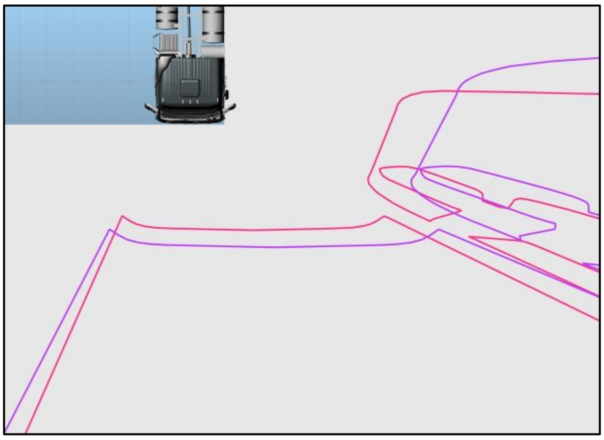

Figure 18: comparison of tallest and shortest views, vehicle two

For vehicle one, the distance between the front of the vehicle and the first point of ground visibility varies, dependent on the participant, between 3060 and 3774mm, or about 23% from the lowest value. The furthest visibility applies to participant two, while the closest applies to participant one.

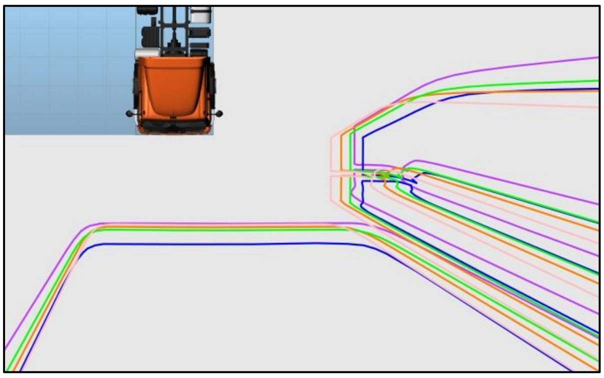

Figure 19: visibility from the front and side of vehicle one (see appendix for enlargement)

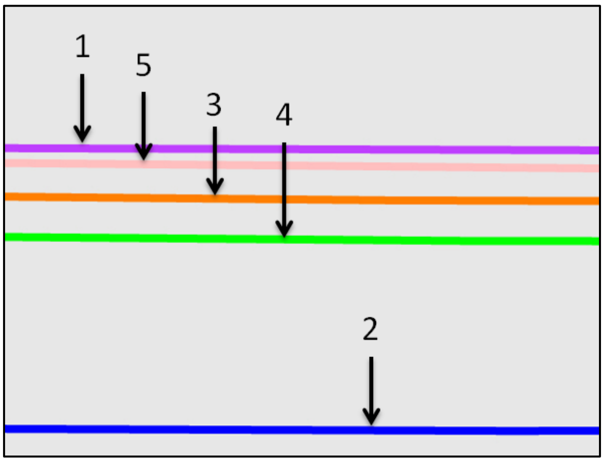

Figure 20: closer view of front visibility lines, vehicle one

For the side window on the same vehicle, the distance from the front nearside corner to the first point of ground visibility (perpendicular measurement) varies slightly more, from 4082 to 5195mm, or 27% from the lowest value. The spread between participants does not follow the same order; the closest visibility applies to participant five and the furthest to participant two.

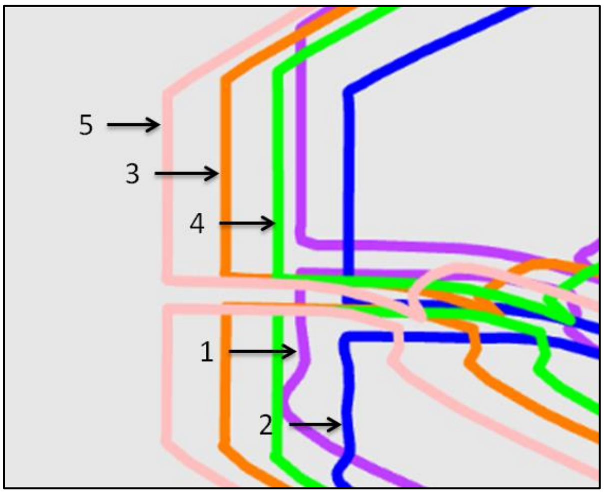

Figure 21: closer view of side visibility lines, vehicle one

The front visibility for vehicle two had a more even spread between participants, but again did not follow a pattern with respect to participant height. The distance from the front of the vehicle to the first point of visibility varied between 3838 and 5061mm, or about 32% from the lowest value. Participants three and four varied in height by only 10mm, but there was 941mm variation in the points at which their visibility planes met the ground (see diagram with measurements at appendix, Figure 38).

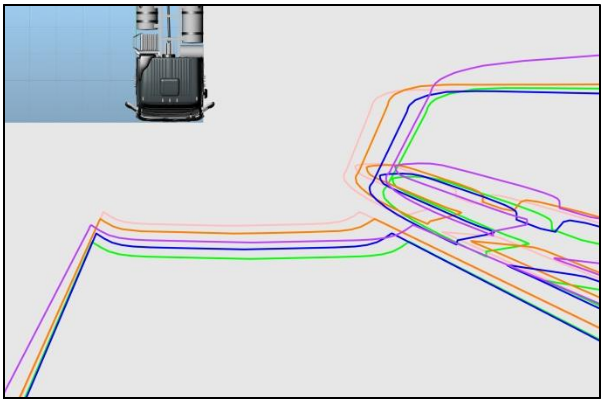

Figure 22: visibility from the front and side of vehicle two (see appendix for enlargement)

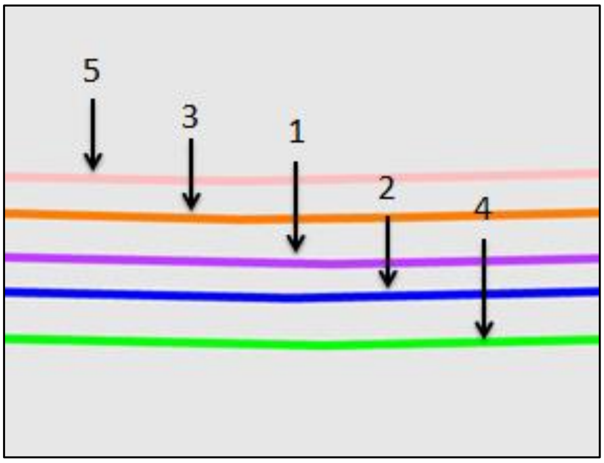

Figure 23: closer view of front visibility lines, vehicle two

For the side window on vehicle two, there was the greatest spread in the distance from the vehicle at which the ground could first be seen; between 6079 and 8150mm (measured perpendicular to the front nearside corner), or 34% from the lowest value.

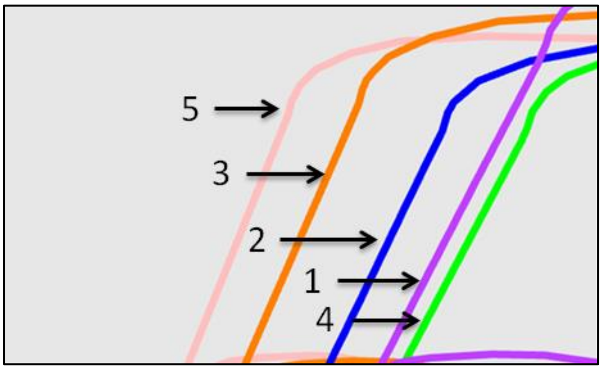

Figure 24: closer view of side visibility lines, vehicle two

There appears to be little, if any, correlation between driver height and the distance from the vehicle at which they can first see the ground, despite the seat adjustment allowing the eye points to vary over a much lesser difference than the overall heights of the drivers do. A very small change in the distance from one eye point to another appears to have the potential to have a very significant effect on the amount of ground visibility.

Table 2 shows the distances, from the front nearside corner of the vehicle, to the point where the visibility plane meets the ground, for each participant and vehicle. The median values are highlighted in each column. It can be seen that the median height definitely does not equate to the median amount of visibility. Nor is there necessarily a link between forwards and sideways visibility for a given driver.

	Distance of ground visibility from vehicle			
Subject	V1 Screen	V1 Window	V2 Screen	V2 Window
1	3.0585	4.9028	4.4467	7.9396
2	3.7624	5.1938	4.7097	7.4345
3	3.1805	4.4426	4.1180	6.6296
4	3.2903	4.7598	5.0612	8.1373
5	3.1033	4.0822	3.8386	6.0797

Table 2: distances at which visibility planes meet ground plane, perpendicular to FNS corner, with median values highlighted

The graphs that follow show the visibility distances from Table 2 plotted against participant number, in ascending standing height order. The only clear pattern is that the overall visibility is consistently better for vehicle one than vehicle two; as the smaller (and lower cabbed) vehicle, it would be expected that vehicle one would have better visibility.

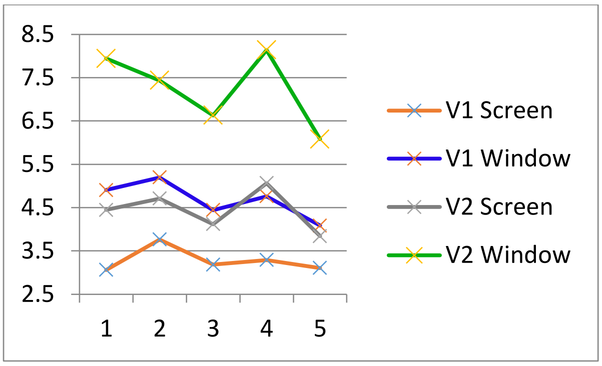

Figure 25: visibility for all four measured areas

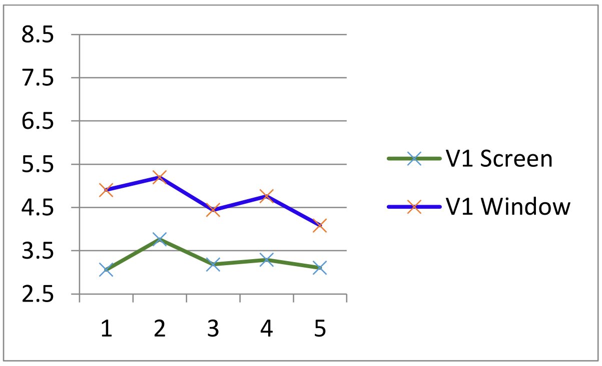

Figure 26: vehicle one visibility

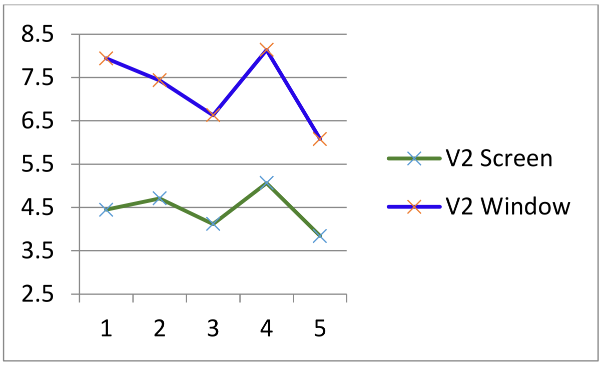

Figure 27: vehicle two visibility

Comparative Modelling

The difference in the point at which the driver's vision meets the ground will have the greatest significance when it is objects at the limits of vision that are being considered. There was 0.65 metre difference in the vision through the windscreen available to participants two and three in vehicle one. The standing heights of these two participants are 80mm apart, but the seated heights are only 5mm apart. As an example, the two following images show a 50th percentile pedestrian standing 1.5 metres in front of the vehicle (the area above the blue plane is available to be seen by the driver). For participant two, the pedestrian is visible from the waist to chest upwards. For participant three, they are visible from the hip to waist up. Clearly, in this situation, the actual level of visibility makes little difference; the pedestrian is in view, enough to be recognisable as a pedestrian to the driver, at both levels of visibility.

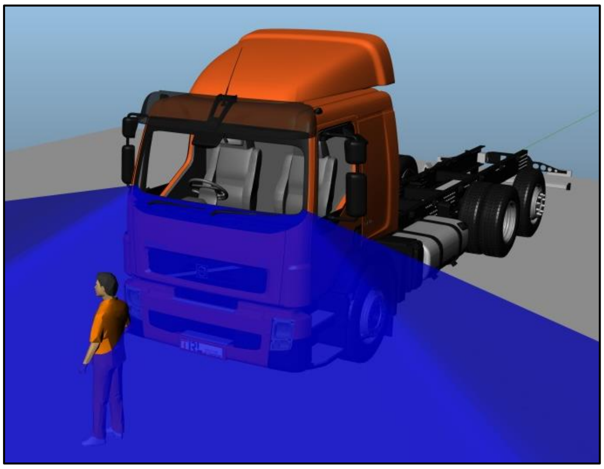

Figure 28: vehicle one visibility available to participant three – pedestrian 1.5m away

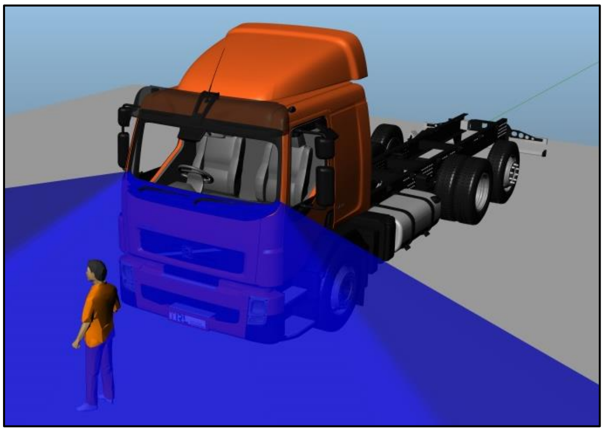

Figure 29: vehicle one visibility available to participant three – pedestrian 1.5m away

For vehicle two, the largest variance in side visibility was between participants four and five. These participants' standing heights were 100mm apart, and their seated heights were 50mm apart. The distance from the side of the vehicle to their first ground visibility varied by over two metres. The two following images show a cyclist 0.75m from the nearside of the vehicle. It is easily apparent that, even with such a large difference in the visibility between the two participants, this cyclist would not be available to be seen through direct vision for either driver.

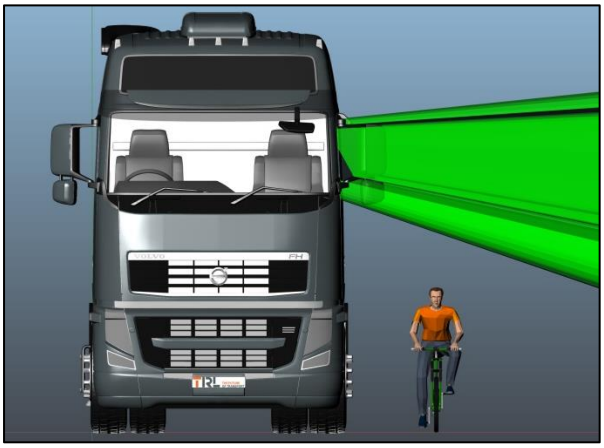

Figure 30: vehicle two side visibility available to participant 4 – cyclist 0.75m away

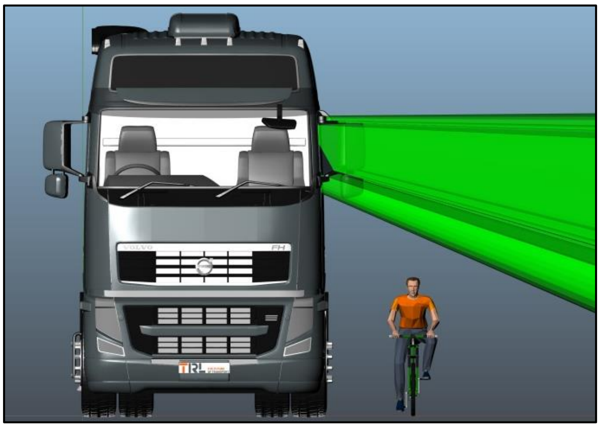

Figure 31: vehicle two side visibility available to participant 5 – cyclist 0.75m away

The significant differences in visibility, between drivers, occur when the object is at the limits of vision, or "only just" in view. When the pedestrian is located 1 metre from the front of the vehicle, only their hair can be seen by participant two, whereas most of their head is available to be seen by participant three. This could be the difference between the pedestrian being seen or not.

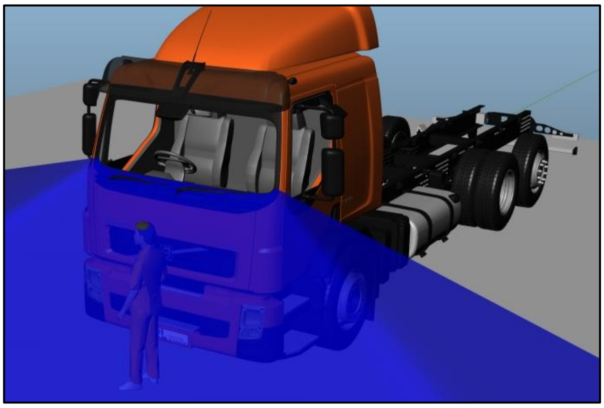

Figure 32: vehicle one visibility available to participant two – pedestrian 1m away

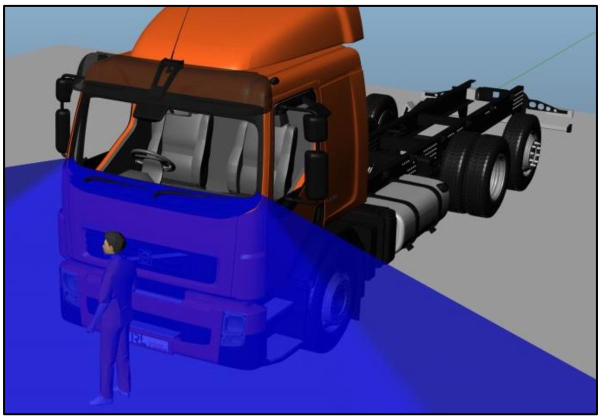

Figure 33: vehicle one visibility available to participant three – pedestrian 1m away

With respect to vehicle two, when the cyclist is positioned 3 metres from the vehicle, their head and some of their shoulders are available to be seen by participant five, whereas only the very top of their hair is available to be seen by participant four. Again, this could be the difference between the cyclist being seen or not.

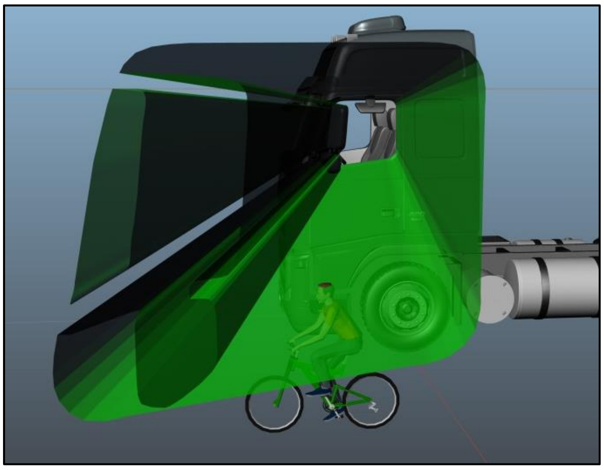

Figure 34: vehicle two side visibility available to participant four – cyclist 3m away

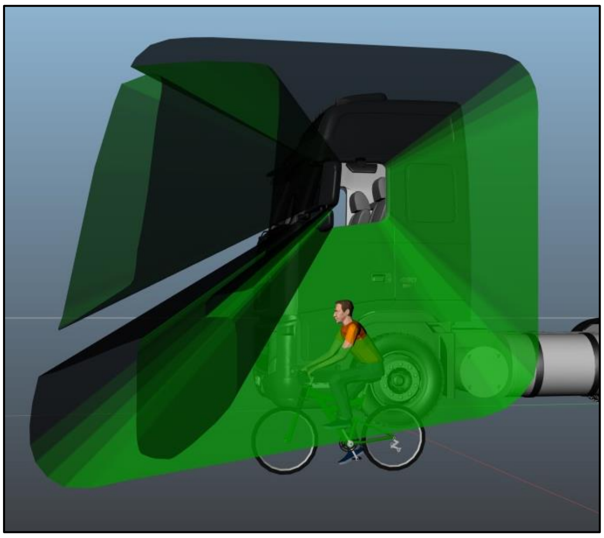

Figure 35: vehicle two side visibility available to participant five – cyclist 3m away

Summary

This study has shown that there is not a definitive relationship between the height of the driver and the actual amount of direct vision available to them. The variety of possible seat adjustments can mean that a range of different height drivers can have very similar eye positions when driving. Or, conversely, several drivers of the same height may have markedly different eye positions. Particularly when combined with un-knowable parameters such as vertical seat movement under suspension, posture and head rotation, it is impossible to predict the exact position of a driver's eye point based simply on their height.

This study has shown that very small variances in eye position can make a very large difference to the level of ground visibility available to a driver. This means that there is no way to predict exactly what visibility will be available to one driver, based on another driver's visibility assessment. The magnitude of variance in the visibility was larger than expected; over two metres for one of the measured areas.

Best practice must always be to use the incident driver for a visibility assessment. If a driver cannot be available to participate in an assessment, it may be possible to measure their eye point within the vehicle, or with respect to other definable points and then use the movable arm and laser pointer method to plot their vision. This may be more accurate than plotting the vision of a different driver.

Where an incident driver cannot be used for an assessment, great care must be taken in drawing conclusions from a 'stand-in' assessment, where the limits of vision are concerned. A common sense approach should be used; if an object is nearly completely visible, based on a generic assessment, it is probably true that the object will be at least partly visible if the limit of vision is moved. If a conclusion is to be drawn that an object was available to be seen, but the incident driver has not been used, it may be necessary to 'test' the modelling; move the line of ground visibility closer to and further away from the vehicle, redraw the visibility plane, and check whether the conclusion still stands. It is likely that this approach would also assist in accounting for the unknowable variables such as seat height movement.

Further work with a greater driver sample size (within a similar height range) and more vehicles is needed to establish whether the percentage error range (the amount by which the line of visibility should be moved to test the modelling) is predictable. Further work is also required to determine whether indirect vision changes by similar magnitudes for different drivers.

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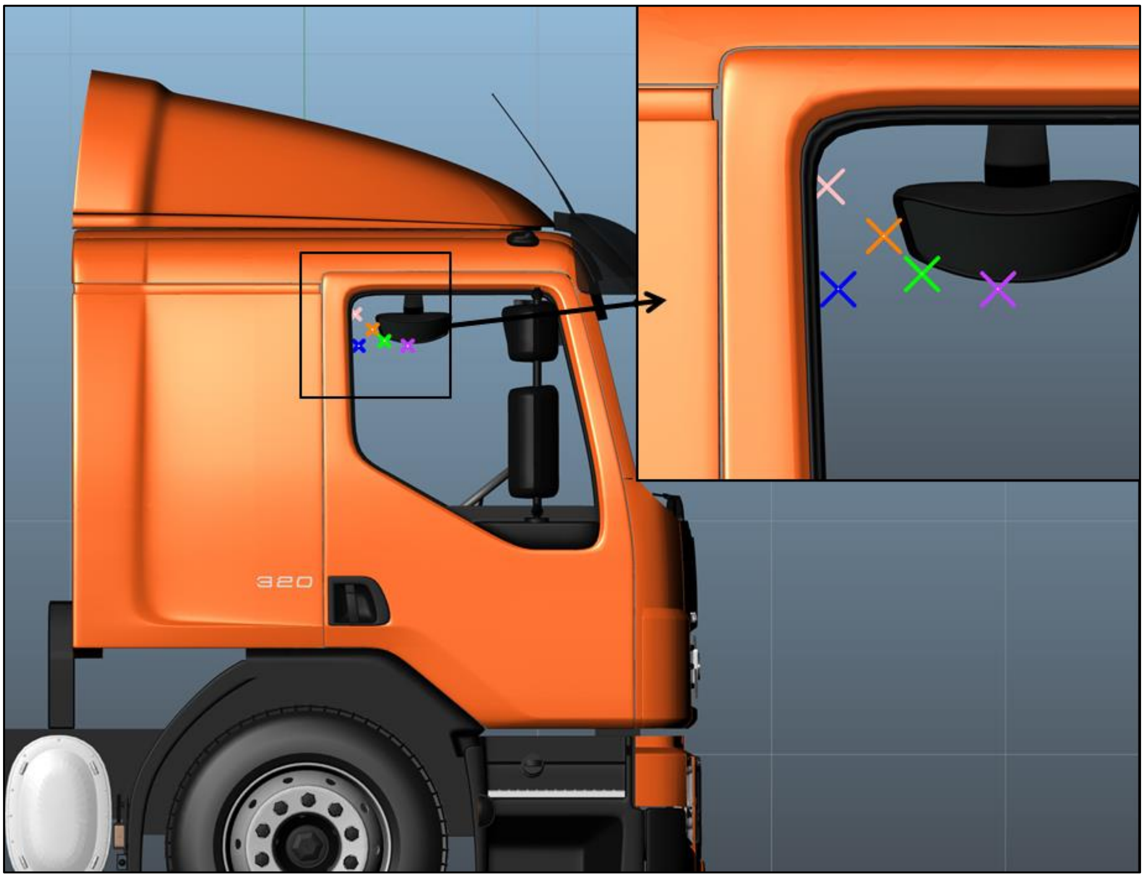
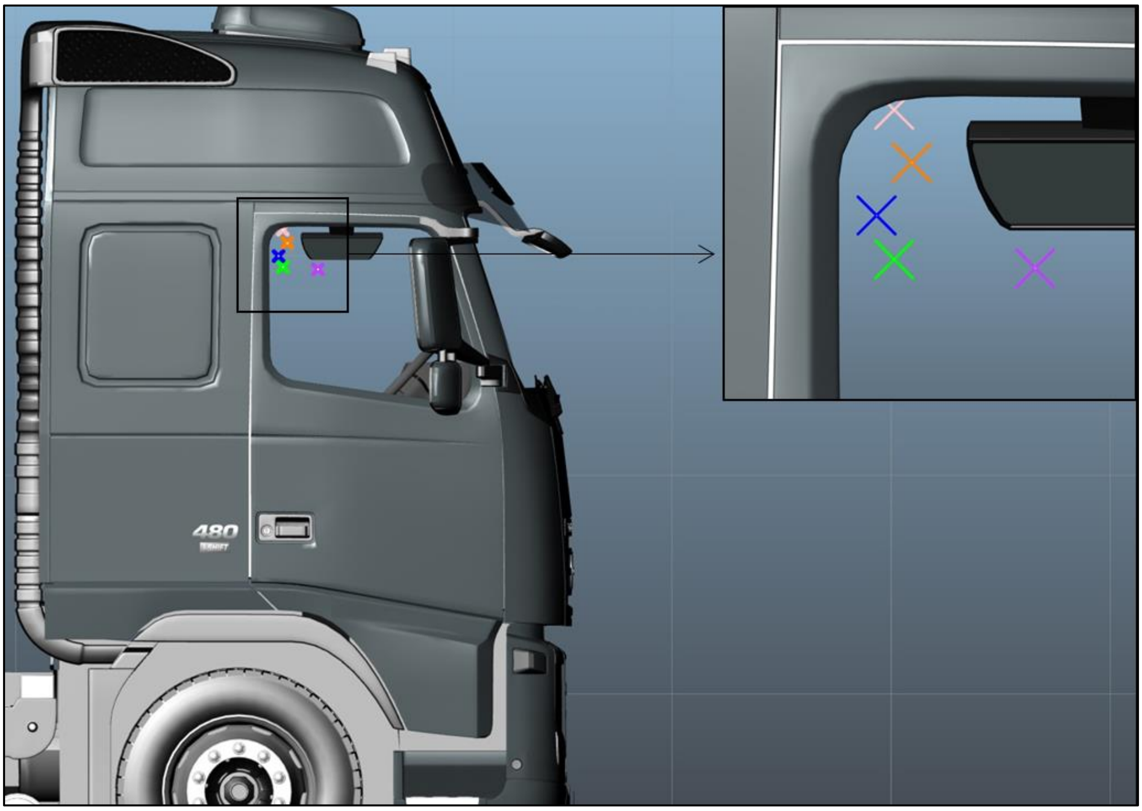
THE FUTURE OF TRANSPORT

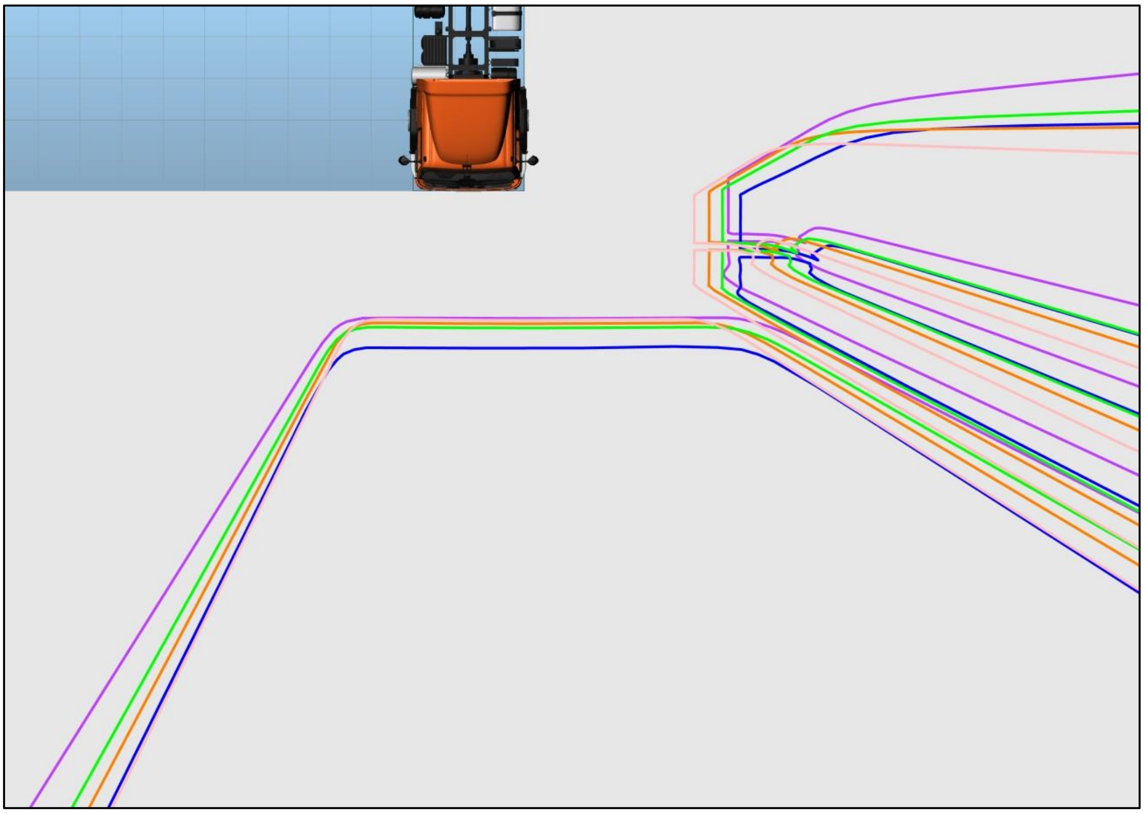
Appendix



Enlargement of Figure 8



Enlargement of Figure 9



Enlargement of Figure 19

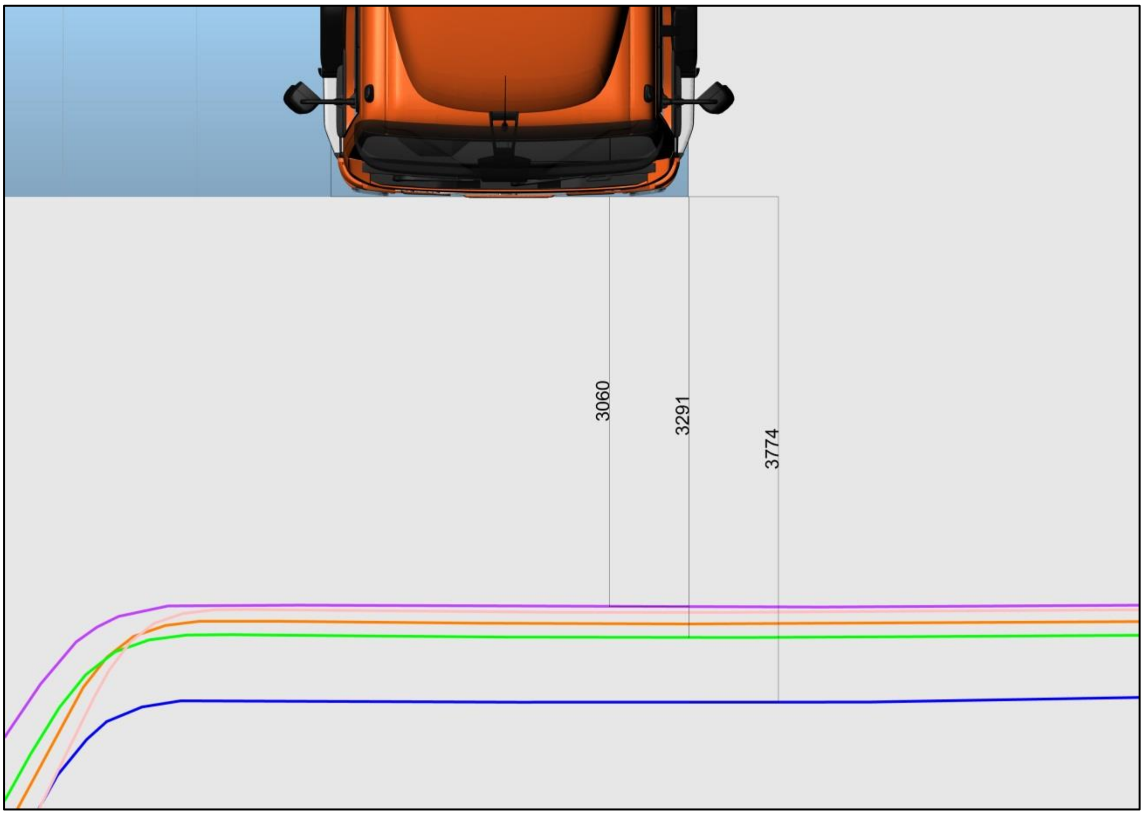


Figure 36: front visibility from vehicle one

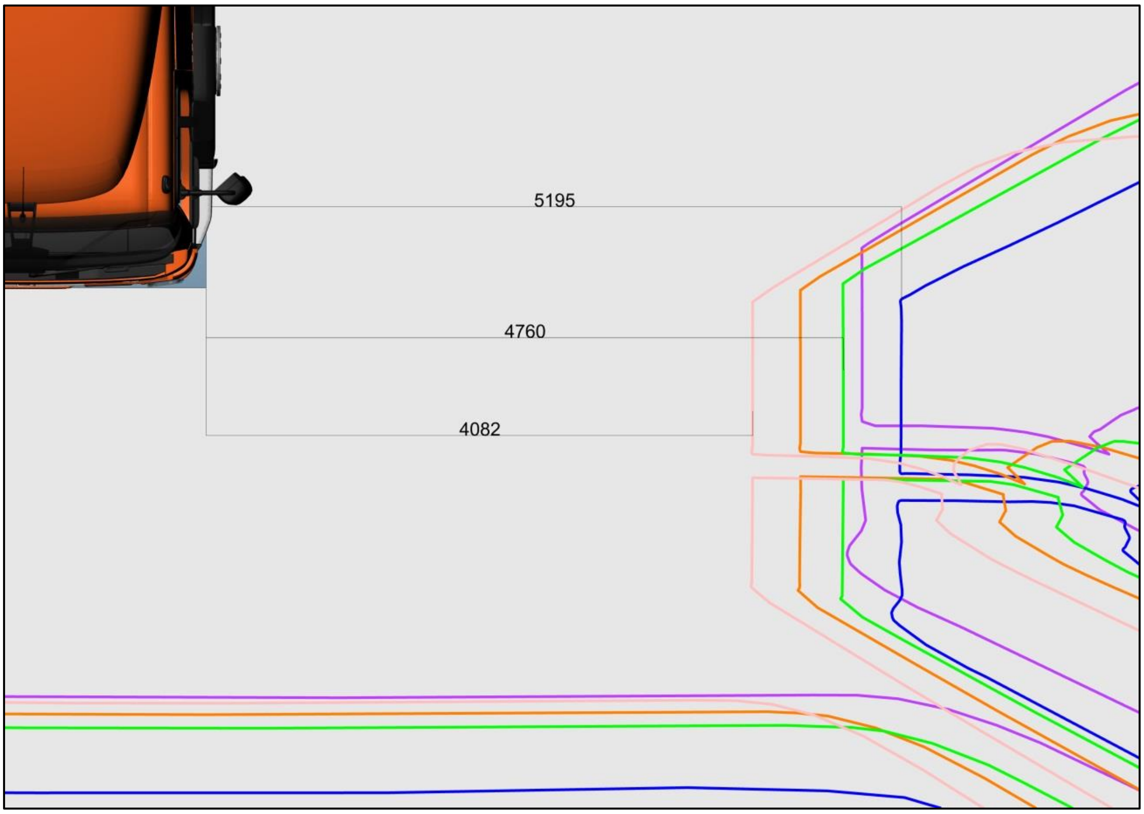
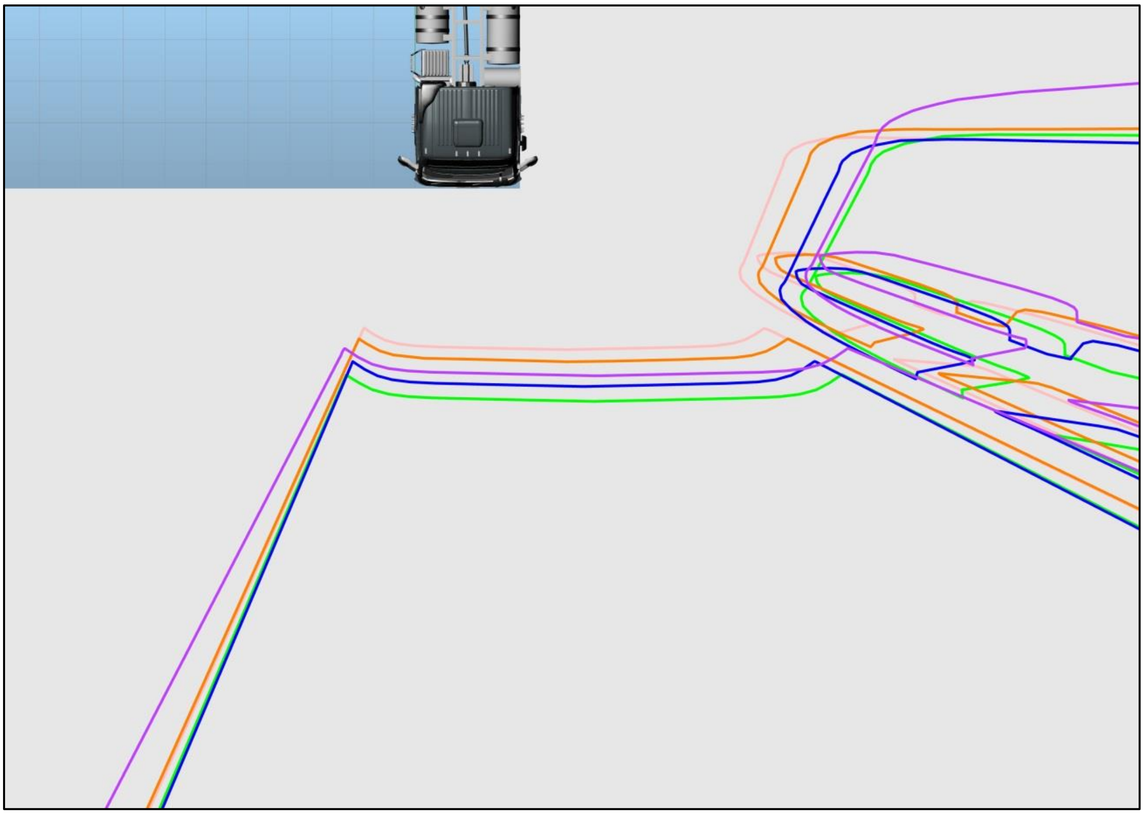


Figure 37: side visibility from vehicle one



Enlargement of Figure 22

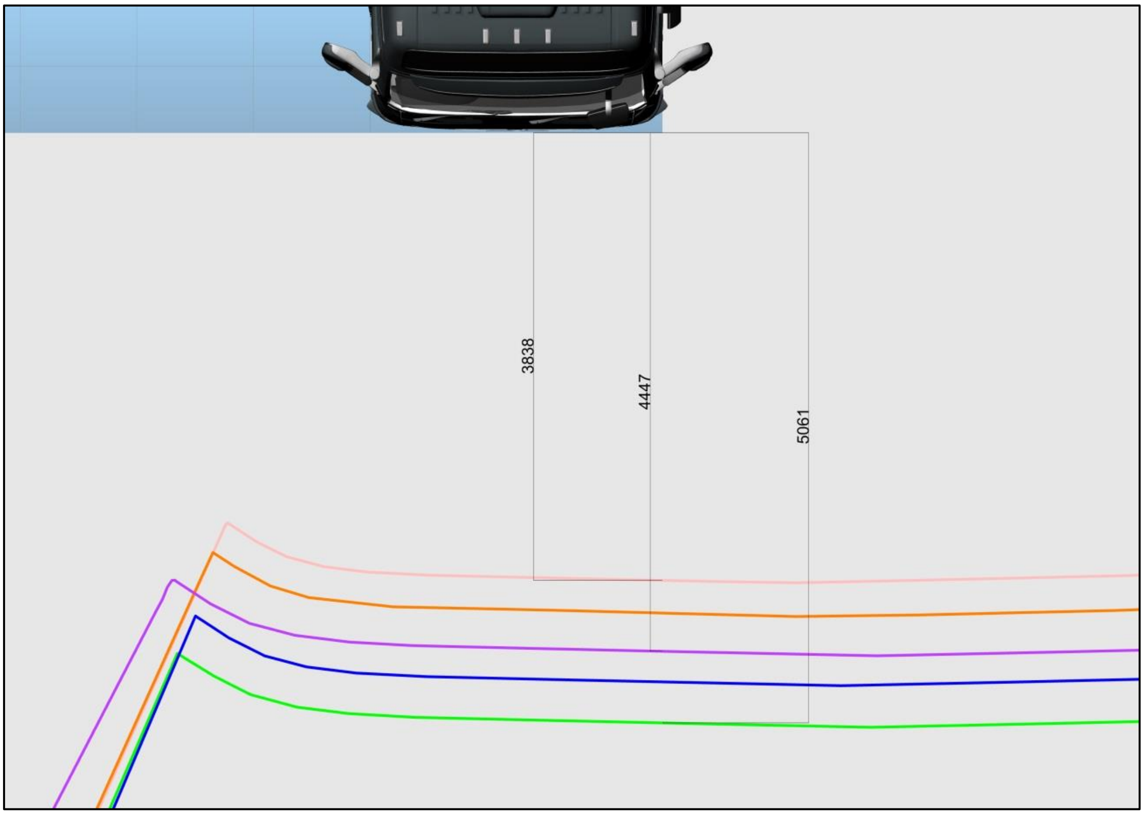


Figure 38: front visibility from vehicle two

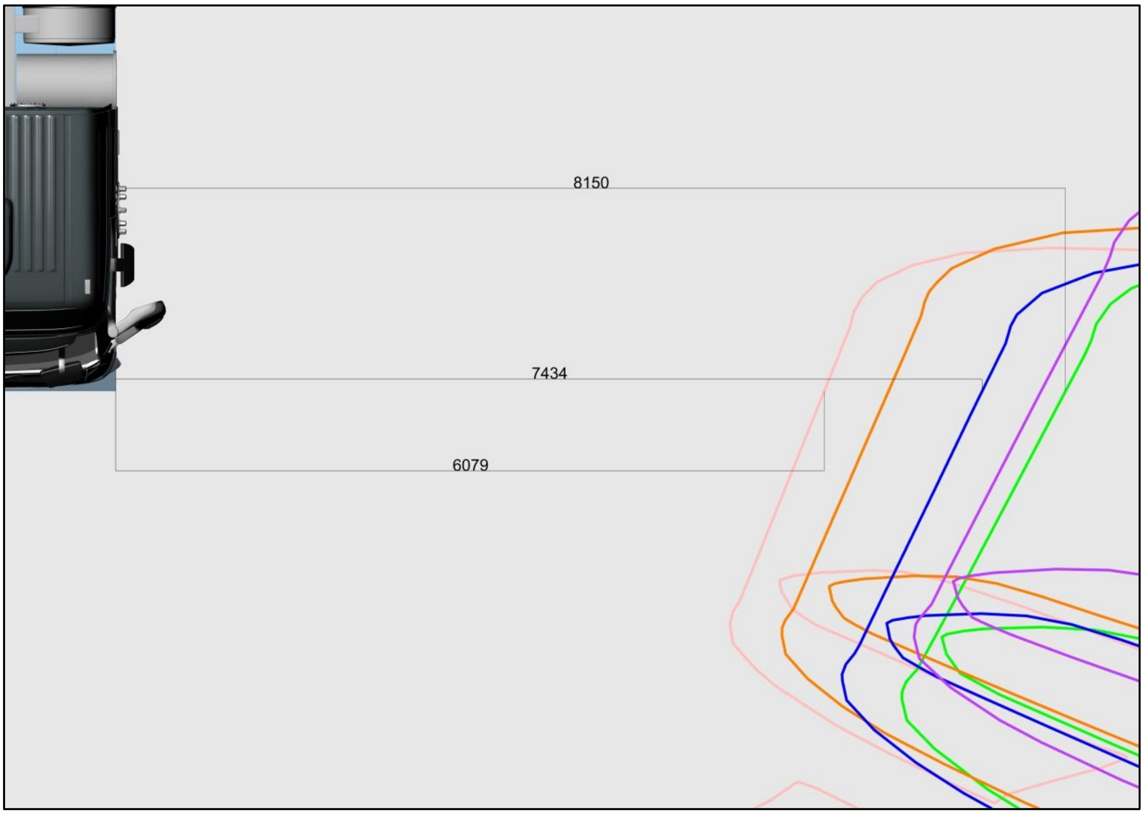


Figure 39: side visibility from vehicle two