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Manuscript title: Naturalistic measurement of driver eye height and object height using photogrammetry

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Abstract

Driver eye height and object height are key factors in the derivation of basic parameters for safe and economically efficient highway design. This study critically reviews previous approaches to the measurement of these values and investigates the changes in them over time. Previous methods of measurement were found to have considerable limitations in terms of coverage or accuracy. A new approach is developed for the naturalistic recording of a sample of vehicles using the principles of photogrammetry, the first time this approach has been used for all vehicle types. A field survey on a typical single carriageway UK trunk road was undertaken and the driver eye and object heights of vehicles using the route were recorded. The work confirms the consumer trend for larger vehicles with a consequential increase in driver eye height and object height. It finds the values used in current design standards are conservative and robust but potential exists for further review. The results of this study will be useful to roads authorities internationally in defining their own highway design standards.

Keywords: Roads & highways; Codes of practice & standards; Traffic engineering

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1. Introduction

1.1. Background

New and improved highway infrastructure is recognised as bringing economic and safety benefits to society. Highway design and construction, however, can be an expensive undertaking not least due to topographic constraints. One of the main contributors to the cost of highway construction is the volume of earthworks required. Minimisation of earthworks improves the economic case for new roads and simplifies construction through more challenging terrain. The critical importance of economically efficient design criteria should not be underestimated in this regard.

Hall and Turner (1989) describe how highway design principles were initially conceived and refined in the last century, including the adoption of stopping sight distance (SSD) along with limiting gradients as key parameters used to determine horizontal and vertical alignment. A satisfactory level of SSD is deemed to be provided if, when presented with an object in the road ahead, a driver is able to bring a vehicle to a complete stop from a particular known speed before colliding with the object.

The definition of the height of such objects varies internationally and sometimes by road feature. It can range from the road surface itself in hazardous situations (i.e. zero object height) through to assumed heights of stationary objects in the road and features of other vehicles (Austroads, 2016). In the UK, the object height is defined as the car indicator/stop light or significant low object on the carriageway (Department for Transport (UK), 1984)

The elements contributing to the distance required to stop a vehicle at a given speed are illustrated in Figure 1. This distance can be considered dependent upon three factors:

- the perception and reaction time of the driver;
- the deceleration characteristics of the vehicle braking system and the tyre/road interface; and
- the heights of the driver's eye and the object in the road ahead.

All of these parameters have been the subject of extensive studies and state of the art review (Fambro et al., 1997; Layton and Dixon, 2012; Olson et al., 1984). Regular review of these parameters is critically important, as change in their value over time has a direct implication on the economic efficiency and safety of any highway design.

Whilst each of the three parameters has an effect on SSD, methods for their study vary due to the diversity of the different problems: perception-reaction time is associated with cognitive ergonomics; deceleration with braking and pavement analysis and driver eye/object height with physical ergonomics. On this basis, studies generally focus on investigation of one specific parameter in isolation.

Arguably, the largest influence on changes to SSD overall is change to vehicle itself. Vehicle design continues to evolve to improve safety and meet consumer requirements. Notably, the size and shape of a vehicle has a direct influence on both driver eye height and object height.

1.2. Research aim and objectives

The aim of this study was to measure the values of driver eye height and object height currently prevalent in the vehicle fleet in the United Kingdom.

The objectives of the study were to:

- critically appraise the previous methods used for driver eye and object height measurement;
- determine an accurate and cost effective method of measurement for current driver eye and object height; and
- estimate the population driver eye height and object height applicable in the UK through a survey.

2. Literature Review

Cox (2008) summarises the two methods used to measure driver eye and object height in studies to date as being:

- analytical, or dimensional studies; or
- empirical, or photographic studies.

Analytical studies use predominantly secondary data sources such as vehicle manufacturer and anthropological data. Using this method, typically a known point on a vehicle (such as the seat height) is used in combination with an average dimension from the human form (such as the average eye height whilst seated). Such studies are possible due to the relative homogeneity of the vehicle fleet when compared with the overall population of vehicles. For example, in 2017 there were 32.2 million cars registered in the United Kingdom. However, over half of these vehicles were accounted for by only 1,200 registered car types, many of which are simply variations of the same make and model (Department for Transport (UK), 2017) This means analytical studies are reasonably simple to update as new vehicles are added to the fleet.

Analytical studies assume ideal conditions and there are several parameters that are difficult to account for, which may have an impact on the accuracy of height estimates. With respect to the driver, seat cushion depression can vary for different vehicles and users, as can the angle of the seat (Manary et al., 1998; Stonex, 1958). Other vehicle related factors include variations in vehicle suspension, tyre pressures and the overall payload (passengers and/or cargo) the vehicle is carrying (Cox, 2008; Newland, 1963)

The analytical approach also requires relevant and accurate anthropological data. Such data may be skewed towards a particular country or ethnicity, or may not be representative of the gender balance of the driver population (Newland, 1963). Anthropological data is also often measured on idealised seating conditions outside of the vehicle environment. When drivers are in a vehicle, variations in posture between different sexes and age groups can be observed. (Parkin et al., 1995) On this basis, recent work recognises whilst the analytical approach has applications, it is not the most accurate model to validate driver eye height in the traffic engineering context (Todd et al., 2017).

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The empirical study approach aims to address these concerns. The most common form of study uses roadside photography. In such studies, still pictures or video of vehicles passing a survey site are obtained and measurements derived from known dimensions on the image. The dimensions may be taken from the vehicle itself (e.g. Anderson, 1970; Capaldo, 2012; Haslegrave, 1979), or a reference object by the roadside (Lennie et al., 2008; Dimoulas et al., 2014). In the former case, only vehicles where manufacturer data is known can be recorded, thus potentially restricting the sample. In either approach, images must be clear, which may not always be the case. For example, in a study by Lee (1963), 800 photographs from a total of 2,000 taken were rejected due to reflections on the vehicle window obscuring the driver's face.

Even when a large number of clear images can be obtained, there is the issue of parallax error. Methods attempting to minimize this have included use of a telephoto lens (Lee, 1963). This approach, may be tolerable where a single vehicle type is being investigated with a small range of driver eye heights. However, measurement of wider range of driver eye heights, such as those of both car and truck drivers requires a much wider field of view. On this basis, some studies (Fambro et al., 1997; Lennie et al., 2008) have used a hybrid approach where some driver eye heights have been recorded in motion by photography, whilst others have been measured whilst stopped in a controlled location. Cobb (1990) undertook all measurements manually in a motorway service area and did not use photography at all. Whilst this method may result in more accurate recordings, it could be argued recording of driver eye height whilst vehicles are stationary does not reflect normal driving posture.

One vehicle type which is subject to significant variations in posture is the powered two wheeler. The height of a motorcyclist's eye will vary depending whether the rider chooses to sit upright or in a crouched position. Furthermore, the height will change as the motorcyclist negotiates curves, particularly as speed increases and the rider and bike lean over. In such cases, a more dynamic approach to measurement is required. A twin camera set-up using the principles of photogrammetry has been previously used in this regard (Dimoulas et al., 2014)

Several of the studies reviewed have been used to determine or inform changes to formal design standards in the respective host country. A percentile value is generally used as the adopted figure for practical and economic

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purposes. The percentile chosen varies by host country; for example the UK adopts the 5th, the United States the 10th and Australia the 15th percentile driver eye heights respectively (Haslegrave, 1979; Fambro et al.,1997; Cox, 2003)

All studies to date have been undertaken on a single vehicle type or using stratified samples; the percentile figure used in the standards is always for the lowest vehicle type – i.e. cars. This does mean some caution be exercised when comparing results, as the definition of a 'car' is not universal and samples are not always of the same composition. Analytical studies tend to focus on the most popular models, which may result in skewed samples – for example a bias towards popular family saloon cars. Some empirical studies include vehicles such as 4-wheel drive pick-ups, which could be equally valid in larger vehicle categories. Only one study was found which investigated HGVs (Fambro et al., 1997) although notably the 5th percentile driver eye figure of 2304mm quoted is higher than the upper driver eye height currently assumed in UK standards.

The trend in car driver eye height is shown in the scatter plot shown in Figure 2. For consistency, the 15th percentile values have been adopted as these were the most commonly quoted in the studies reviewed. The figure suggests driver eye height reduced between the 1950s and early 1980s, before gradually increasing to present day values. The decrease in driver eye heights in the 1950s and 60s has been attributed to aesthetic and vehicle performance reasons (Newland, 1963) with further falls due to vehicle manufacturers producing smaller cars in response to the fuel supply issues of the 1970s (Fitzpatrick et al., 1998). The reversal of this trend has been attributed to increased stature (Hogema et al., 2015) and to the increased popularity of suburban utility vehicles and other high seated vehicles (Layton and Dixon, 2012). Further investigation of this apparent continuing trend of increasing driver eye heights forms the basis of this current work.

3. Method

3.1. Experiment Design

The review of previous work indicated several choices were available. An analytical study could be undertaken at relatively low cost on a desktop basis. However, this approach may result in skewed results towards certain models and would not take into account vehicle-by-vehicle variations due to changes in posture, payload, tyre pressure etc. It was the intention of this work to potentially inform the development of future standards, so this approach was considered inadequate.

An empirical study has the potential to provide an increased level of accuracy, but brings with it the challenge of obtaining high quality, accurate image data of drivers in-situ, ideally in a naturalistic setting - i.e whilst actually driving. Over the period of studies reviewed, camera technology has improved substantially; in suitable lighting conditions, a modern high-frame rate, high definition video camera is capable of capturing still images of drivers in vehicles, even at high vehicle speeds. However, the camera alone will not eliminate the other problems experienced by previous research, namely the issues of parallax error and limited field of view.

The issue of parallax error can be resolved by the use of stereoscopic photogrammetry. This approach has been used previously in the measurement of driver eye height for powered two wheelers (Dimoulas et al., 2014). However, the literature search suggested it has not, until now, been applied to all vehicle types. It was decided to further develop the photogrammetric approach with an aim to achieve the desired level of accuracy in a truly naturalistic driving setting for this study.

3.2. Site selection

National design standards tend to focus on the inter-urban, strategic road network and the UK is no exception (Department for Transport (UK), 2018). Such roads have the most onerous SSD parameters given their generally high vehicle speeds. On this basis, they are the most sensitive to changes in driver eye height and object height, and a representative site was sought on the UK trunk road network as a result.

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To ensure consistency and accuracy in the photogrammetric measurement was maximised, criteria for an ideal site were developed as follows:

- horizontal alignment of the road through the survey site should be straight, reducing the likelihood of any head movements due to curvature;
- vertical alignment of the road should be flat, reducing the likelihood of any head movements related to crest or sag curves;
- carriageway crossfall should be as small as possible, to potentially avoid the need for latitudinal height corrections;
- the survey site should be located away from potential hazards or distractions, such as nearby junctions, which may induce unwanted head/eye movements;
- the road should carry a volume and composition of traffic under free-flow conditions commensurate with current published UK trunk road traffic statistics (see Department for Transport (UK), 2018; Transport Scotland, 2018);
- the site should be single carriageway, to minimize the focal distance from camera lens to subject and maximize image quality; and
- provision should be available for the mounting of camera equipment, with a safe and discreet waiting area for survey staff from which to monitor operations.

A suitable site was located on the A1 trunk road approximately 60km east of the city of Edinburgh adjacent to Dunglass Bridge (55.94265°N, 2.368707°W). The A1 is the eastern of the two strategic trunk roads which cross the border between Scotland and England and the only one of the two which is a single carriageway. As such, it carried the desired mix of traffic, and the specific site location met the other geometric and operational criteria stated above. The speed limit applicable at the site is 60mph (97km/h) which is the standard limit for an interurban single carriageway trunk road in the UK.

Figure 3 shows the location of the site. The mounting point for the equipment was chosen as one of the poles for the East Lothian administrative boundary sign. Behind this sign is a small turning circle which was used for parking of operational vehicles during the survey. The turning circle was well screened with bushes so ensured drivers were not distracted by survey staff, whilst providing a safe working area for the monitoring activities. On the right of the picture, between the two bollards is a minor property access which was not deemed to generate sufficient traffic activity to adversely affect the survey.

Whilst Figure 3 shows several roadside features such as road signs, it is important to note that the survey only considered drivers travelling in an eastbound direction. Drivers would see only the rear of these signs and as a consequence would be unlikely to look at them. In addition, the scenery looking east at this point is relatively bland, so the majority of drivers would be focused on the road ahead. On this basis, any visual distractions which might inadvertently affect eye position were considered to be negligible at this location.

3.3 Photogrammetric approach

The parallax error referred to in earlier research occurs where a single camera observation point is used with a single reference, such as a measuring staff. If the camera is at exactly the same height as the driver's eye, the reading on the staff will be the true height of the driver's eye. However, if the camera is at a different height, the apparent height on the staff will not be the true height due to parallax error. The greater this difference, the more extreme the error will become. Whilst this error may be negligible for a reasonably close range of heights, where a variety of different vehicle types are being investigated, the error becomes much more of an issue.

If the height of the camera is known, a correction can be made using simple trigonometry; however, this also requires the lateral distance from the camera to the driver's eye to be known. As vehicle types vary in size and drivers choose to adopt different lateral positions within the running lane, this is difficult to ascertain precisely. Dimoulas et al. (2014) used a second camera mounted on an overhead structure to measure lateral displacement in the lane; however at the site chosen for this study no such structure existed. Furthermore, whist this approach may work well for powered two-wheelers where the view to the rider's head is clear, in cases of vehicles where the driver is sitting within the vehicle it was deemed to be potentially problematic. There was also a high risk the driver's face may be difficult to see from an elevated position due to obstruction of view by the vehicle roof and/or direct reflection of the sky on the vehicle's windscreen.

A different solution was required for this study and the final approach adopted was the use of two cameras, both mounted in a vertical plane at the side of the road as shown in Figure 4.

In this approach, two reference points for heights are adopted, one on the centreline of the road and the other on the white edge marking. The height of the driver's eye is found from the intersection point of the two straight lines.

For the lower camera:

$$\begin{bmatrix} 0.5 & 1 \\ 5 & 1 \end{bmatrix} \begin{bmatrix} m_l \\ C_l \end{bmatrix} = \begin{bmatrix} h_{l2} \\ h_{l1} \end{bmatrix}$$

$$\begin{bmatrix} m_l \\ C_l \end{bmatrix} = \begin{bmatrix} h_{l2} \\ h_{l1} \end{bmatrix} \begin{bmatrix} 0.5 & 1 \\ 5 & 1 \end{bmatrix}^{-1}$$

For the upper camera:

$$\begin{bmatrix} 0.5 & 1 \\ 5 & 1 \end{bmatrix} \begin{bmatrix} m_u \\ C_u \end{bmatrix} = \begin{bmatrix} h_{u2} \\ h_{u1} \end{bmatrix}$$

$$\begin{bmatrix} m_u \\ C_u \end{bmatrix} = \begin{bmatrix} h_{u2} \\ h_{u1} \end{bmatrix} \begin{bmatrix} 0.5 & 1 \\ 5 & 1 \end{bmatrix}^{-1}$$

If x is distance from kerb line of driver eye, then:

$$m_l x + C_l = m_u x + C_u$$

$$x = \frac{C_u - C_l}{m_l - m_u}$$

So therefore:

$$h = m_l x + C_l = m_u x + C_u$$

3.4. Survey Site Setup and Operation

To establish the site, traffic management was provided by the national roads authority maintenance contractor. As the camera equipment was to be mounted on the south side of the road, only drivers proceeding in an easterly direction were recorded. The date of the survey was Thursday 22 February 2018.

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The camera setup is shown in Figure 5. The camera type was a GoPro Hero 5 in a waterproof housing (Figure 5(a)). This camera was chosen due to its small size for ease of mounting and discreet appearance, and its ability to capture high definition, high frame rate video. The small sensor size of this camera type results in a very large image depth of field by default, eliminating any focus issues that may have arisen from variations in lane positioning. This did require good lighting conditions, but the south facing nature of the site was ideal to facilitate this. The camera was set to linear field of view mode to eliminate barrel distortion; this was verified on site by collecting test images featuring a large checkerboard pattern (see Figure 5(c)). Polarising filters were not found to be necessary as reflections on the side windows of vehicles were negligible; the sun being low in the sky due to the time of year and directly illuminated the passing driver from the side.

The two cameras were mounted on bespoke camera mounting plates attached to the sign post by large diameter stainless steel hose clamps (Figure. 5(b)). Both cameras were aligned such that the sensor was parallel to the post in a vertical direction. Horizontally, the cameras were aligned to the junction bollard marker on the opposite side of the road (Figure. 5(c)). This provided a reference point to define a virtual plane through which vehicles would pass for measurement in the subsequent analysis.

Following installation of the cameras, a topographical survey of the road profile was undertaken (Figure 6(a)). Whilst the survey site was chosen with minimal crossfall, the topographical survey enabled the cross sectional profile to be known to allow for any corrections to be made to recorded heights if necessary. Levels were taken at 0.5m intervals across the eastbound lane whilst traffic was under control by maintenance contractor operatives. At the same time, reference photographs on the measuring staff were taken from the upper and lower cameras (Figure 6(b)). These reference photographs would later be used to measure driver eye heights from passing vehicles. Camera lens calibration photographs were also taken during this period, using a checkerboard with 200mm x 200mm squares (Figure 6(c)).

Once the camera set up and topographical survey was complete, the traffic management was removed from site and the video recordings commenced. During recordings, the research staff retired to their vehicles which were parked out of direct view to reduce the likelihood of driver distraction. Monitoring was undertaken remotely from the vehicle using a WiFi connection to the camera. Recording commenced at 1140 and concluded at 1300. This produced just over two hours of actual video allowing for a battery change midway through recording.

4. Analysis

4.1. Cross-sectional profile

To allow for drainage, all carriageways have some form of cross-sectional profile. The effect of this profile means the apparent height of any object may vary because of changes in the datum height below the object – i.e. the road surface itself. In addition to profile, localized issues such as rutting or general surface wear may also have an effect. The correction for such variations in road profile in the context of this work becomes quite a complex one. This is because any variations in the road profile are laterally offset from the actual point being measured. The points at which the vehicle touches the road surface (i.e. the wheel) is not directly below the eyes of the driver. This is why a site with a predominantly flat possible was preferred.

To assess the impact of such issues, the topographical survey was used to plot the cross-sectional profile of the road at the observation site. Upon inspection of the profile, it was found that the actual profile of the road at this location closely followed a straight line, with a maximum deviation of -11mm at its central point. At the points most likely to be occupied by vehicle wheels (1m from the edge margin or centreline), this deviation was found to be around -6mm. Given these values were relatively small in relation to the overall driver eye heights, it was determined this level of tolerance would be acceptable for the purposes of this study and a straight line effective road profile was assumed. The actual and assumed road profiles are shown in Figure 7.

4.2. Photogrammetric Analysis

Still images were extracted from the upper and lower camera video recordings using video editing software. For smaller vehicles, such as cars, a single image was extracted at the points when the driver eye was close to the defined analysis plane. As the work also investigated headlamp and taillight height, additional images were extracted on a vehicle-by-vehicle basis as required. For example, the rear of larger trucks tended to extend beyond the frame and the rear lights were often mounted flush with the flat rear tailgate of the vehicle. In this case a second photograph of the vehicle's rear would be extracted.

Photogrammetric analysis of the images was then undertaken using the vanishing point tool in Adobe Photoshop. The tool works by defining perspective planes within photographs based on known points within the image. As both the upper and lower cameras were in a fixed position throughout the survey, images previously taken of the staffs could be digitally superimposed together. The known lengths (4m) of the measuring staffs could be entered to allow the software to create the measurement grid (Figure 8(a)). The measurement grid then enabled measurements to be taken of any dimension within the defined plane, between points selected using the mouse pointer. Two readings were taken for each camera: one from the nearest extent and the other from the furthest extent of the grid (i.e. in the staff positions shown in Figure 8(a)) The four height values then allowed the driver eye height to be determined in accordance with the methodology outlined previously.

During the on-site work, the driver eye heights of three vehicles (two survey staff cars and one contractor's wagon) were accurately measured using a staff and level. To verify the accuracy of the measurement approach, the dimensions of these measured eye heights were checked against heights derived from the corresponding photographs (example shown in Figure 8(b)). The calculated eye heights were found to be within +/- 7mm of the actual eye heights, validating the accuracy of the approach.

This method was found to be successful for driver eye height, but some vehicles were found to have headlights and/or taillights visually below the furthest most staff (Figure 8(b) illustrates an example). To resolve this, a modified method was developed by extending the perspective plane within the software. By extending the plane vertically downwards, a 'virtual datum' was created that was, in effect, 2m below the road surface (Figure 8(c)). This allowed dimensions to be taken on lower parts of the image that could not previously be measured. The data recorded was entered into a spreadsheet and a numeric correction made to account for the amended datum prior to analysis.

4.3. Results

Overall, 251 vehicles were analysed and the descriptive statistics for each vehicle type are shown in Tables 1, 2 and 3 for driver eye height, headlamp height and taillight height respectively. As headlamp and taillight units were found to be of a wide variety of shapes and sizes, measurements were taken to the base of the lighting cluster as a worst case.

5. Discussion

The literature review revealed evidence to suggest that driver eye heights across the world are increasing; in this regard the UK is no exception. This work estimates the current 5th percentile population car driver eye height to be 1078mm. The current UK highway design standard assumes a lower bound driver eye height of 1050mm (Department for Transport (UK), 1993). All the driver eye heights surveyed were greater than this value, with the minimum driver eye height of any vehicle being 1062mm.

Current object height in the UK, which includes the rear tail light is defined as 260mm (Department for Transport (UK), 1993). Again, all vehicles surveyed were found to be in excess of this figure. HGVs were found to have lower tail light heights than cars, with the 5th percentile values being 420mm for HGVs and 688mm for cars respectively. These figures are approaching those adopted in standards used in other countries such as the US at 600mm (AASHTO, 2011) and Australia at 800mm (Austroads, 2016)

Based on the findings of this research, both the driver eye height and object height figures given in the current UK standards are robust and conservative. There is scope for relaxation of these figures, if an appropriate economic and safety case were made.

The upper bound driver eye height in current UK design standards is 2000mm (Department for Transport (UK), 1993) This figure is to “ensure that a sufficient portion of a vehicle ahead can be seen to identify it as such” (Department for Transport (UK), 1984). However, this figure is substantially lower than the majority of driver eye heights exhibited by larger vehicles in the UK fleet. If the reverse approach to the lower bound standard were adopted, i.e. defining the upper bound such that 95% of large vehicles (HGVs) were below the quoted height, this would suggest a value of 2812mm. Whilst this difference is much larger than the lower bound height, its impact is less important. The upper bound driver eye height has relevance in sag curve design where overhead structures span the carriageway. It could be argued in such cases, the obstruction is a temporary and potentially slender one, which might not be critical in terms of the driver's forward visibility, as suggested by the previous design standard. More relevant would be its use in the design of tunnels, although these are very rare in the UK road network.

6. Conclusions and further work

This study estimated driver eye height and object height based on a sample of vehicles on a typical UK trunk road. The naturalistic approach to the study meant the sample obtained was highly representative, accounting for variables such as fleet mix, payload, tyre pressures, variations in posture etc. The use of stereoscopic photogrammetry maximised the accuracy of readings and eliminated the impact of parallax error.

The study has built on previous work and has developed a new technique for future measurement of these design parameters. The approach has been found to be flexible, scalable and easily repeatable. The method could also be used to determine whether variations occur in driver eye height in specific scenarios, for example interurban versus urban driving, cognitively intense routes such as mountain roads and so on.

The results of this study suggest the values currently adopted for driver eye height and object height in the UK are robust and conservative and have potential for relaxation. However, no case is made here for whether or not new values should be adopted or the status quo maintained. Further work could look at the economic and safety case for changing these figures and the resultant implications on SSD and FOSD, comparing with international practice as appropriate. In the meantime, it is hoped the figures determined as part of this study will inform such future work.

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List of notation

SSD is stopping sight distance

h is driver eye height

h_{u1} is the apparent driver eye height (staff 1) recorded by the upper camera

h_{u2} is the apparent driver eye height (staff 2) recorded by the upper camera

h_{l1} is the apparent driver eye height (staff 1) recorded by the lower camera

h_{l1} is the apparent driver eye height (staff 2) recorded by the lower camera

m_l is the gradient of the line bisecting the lower camera staff readings

m_u is the gradient of the line bisecting the upper camera staff readings

C_l is the intersect of the line bisecting the lower camera staff readings

C_u is the intersect of the line bisecting the upper camera staff readings

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Table captions

Table 1. Driver Eye Height (mm)

Table 2. Height to base of headlamp (mm)

Table 3. Height to base of taillight (mm)

Table 1. Driver Eye Height (mm)

	n	Mean	SD	SE	Min	5%ile	10%ile	15%ile	Median	85%ile	90%ile	95%ile	Max
Car	142	1240	101	8	1062	1078	1125	1142	1230	1323	1379	1450	1505
Motorcycle	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LGV/Van	40	1576	172	27	1135	1183	1377	1424	1643	1735	1736	1793	1798
HGV	65	2516	289	36	1720	1818	1953	2272	2599	2774	2804	2812	2812
Bus/Coach	3	2213	n/a	n/a	2212	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2214
Other	1	2719	n/a	n/a	2719	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2719
All Vehicles	251	1641	576	36	1062	1124	1147	1162	1327	2565	2672	2763	2812

Table 2 Height to base of headlamp (mm)

	n	Mean	SD	SE	Min	5%ile	10%ile	15%ile	Median	85%ile	90%ile	95%ile	Max
Car	142	654	103	9	443	461	549	557	645	747	781	864	920
Motorcycle	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LGV/Van	40	775	109	17	493	578	625	675	749	895	915	958	968
HGV	65	721	124	15	406	470	582	622	725	810	912	917	1144
Bus/Coach	3	900	n/a	n/a	900	n/a	n/a	n/a	n/a	n/a	n/a	n/a	901
Other	1	1884	n/a	n/a	1884	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1884
All Vehicles	251	698	142	9	406	513	555	570	685	824	880	913	1884

Table 3 Height to base of taillight (mm)

	n	Mean	SD	SE	Min	5%ile	10%ile	15%ile	Median	85%ile	90%ile	95%ile	Max
Car	142	854	107	9	635	688	747	759	836	1000	1047	1077	1157
Motorcycle	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LGV/Van	40	802	136	22	450	454	538	616	850	881	887	914	1129
HGV	65	669	173	21	353	420	466	474	620	954	970	985	1050
Bus/Coach	3	1039	n/a	n/a	1030	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1059
Other	1	2099	n/a	n/a	2099	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2099
All Vehicles	251	805	175	11	353	478	589	616	826	954	1009	1055	2099

Figure captions

Figure 1. Elements of stopping sight distance

Figure 2. Car driver eye heights (15th Percentile) from previous studies

Figure 3. Survey Site Location (Looking West)

Figure 4. Schematic diagram of survey

Figure 5. Camera unit (a), twin camera setup (b), and reference plane to bollard (c)

Figure 6. Topographical survey (a), example staff reference photograph (b), and camera lens calibration (c)

Figure 7. Measured and Assumed Cross-Sectional Profiles

Figure 8. Vanishing point plane (a), verification photograph (b) and modified datum (c)

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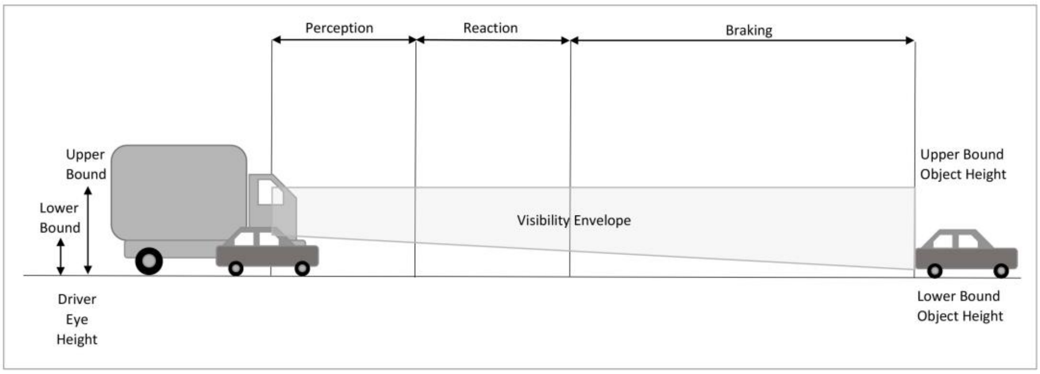

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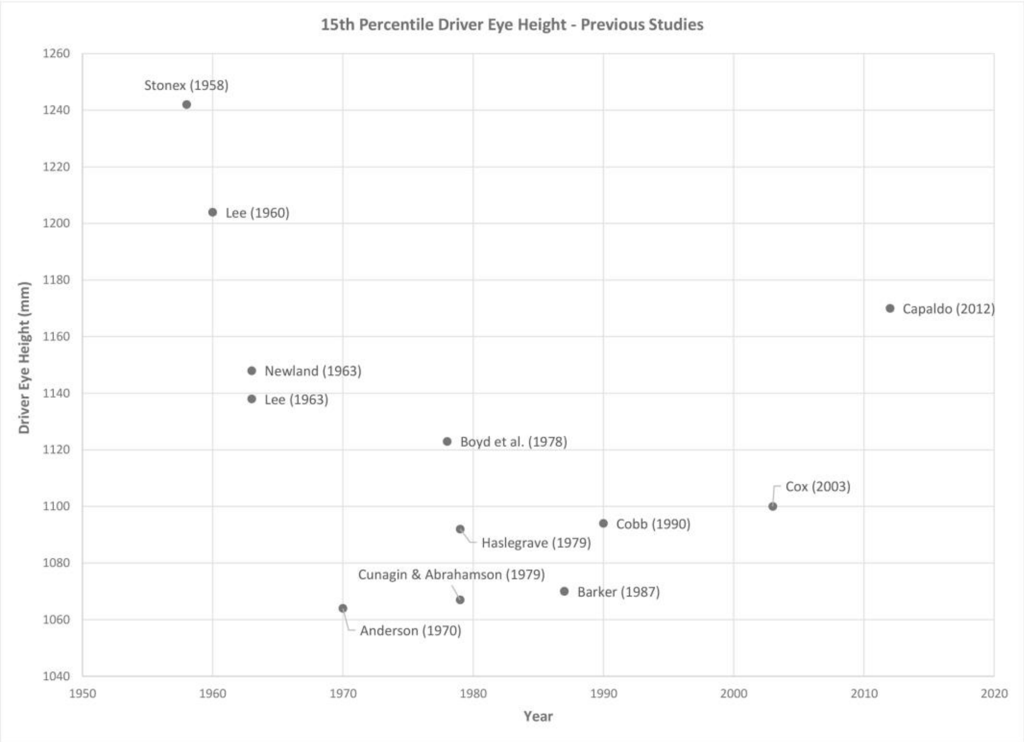

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Figure 3.jpg

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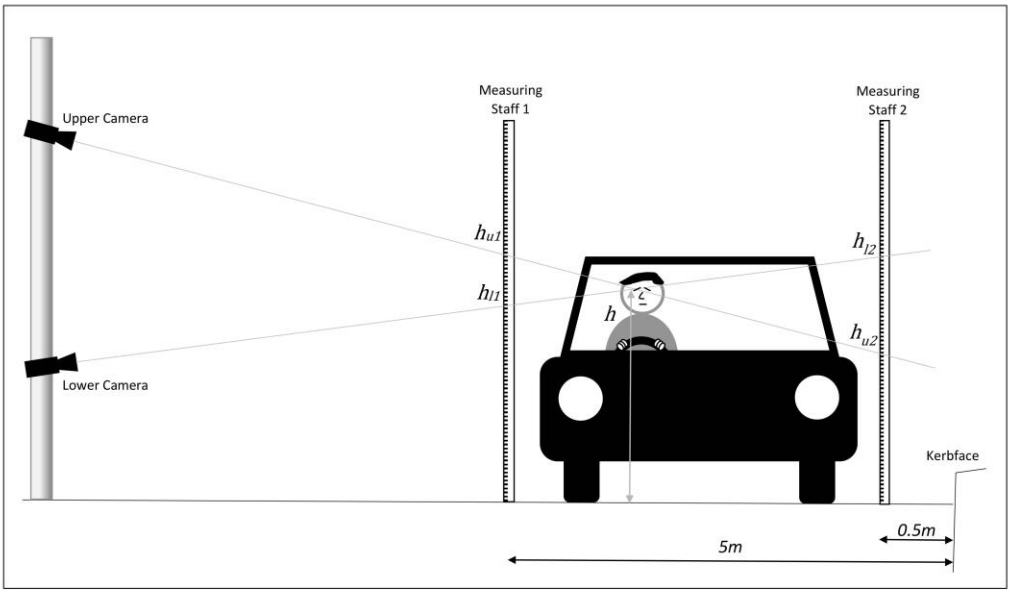

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Figure 5.jpg

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Figure 6.jpg

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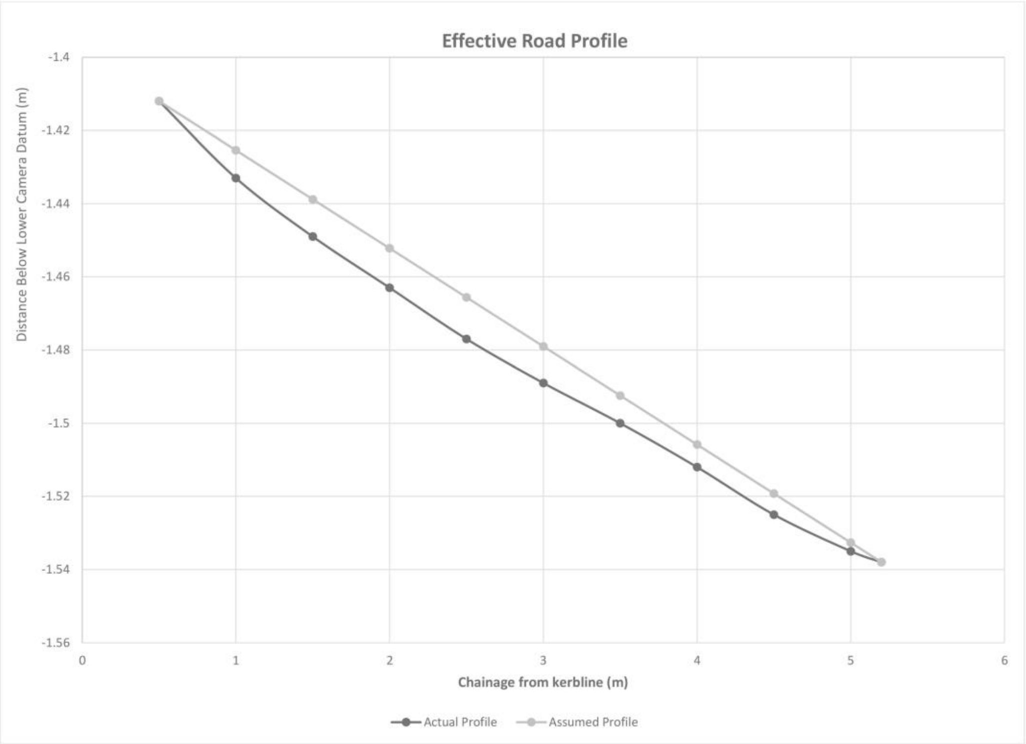

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Figure 8.jpg