Apollo Vehicle Safety

Automotive Research and Consultancy

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HGV Safety Permit for London

Evidence of effectiveness and candidate technical requirements for the Safe System

By [redacted]

Prepared for:	Transport for London (TfL)
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Executive Summary

London's mayor has committed to a 'vision zero' approach to road safety that targets zero collision deaths or serious injuries by 2041. Blind spot collisions between vulnerable road users and HGVs undertaking low speed manoeuvres are a significant contributor current casualty totals and several upgrades to the field of view from mirrors has not eliminated the problems. TfL's Direct Vision Standard (DVS) aims to substantially reduce the risks and it is proposed that all vehicles entering London must have a DVS rating of at least 1-star by 2020 and 3-star by 2024. If this standard cannot be met it is proposed that they must demonstrate a 'Safe System' approach to at least partly compensate for the poorer standard of direct vision. The measures proposed for inclusion in the 'Safe System' are:

- Blind spots minimised via indirect vision
- Blind spot information or warnings systems for the HGV driver
- Warning the VRU of the vehicle's intended manoeuvre
- Protection in the event of a collision
- Driver training on the safety of vulnerable road users (advised, not mandatory)

Apollo Vehicle Safety was commissioned to assess the effectiveness of the proposed measures & define clear standards based on technical evidence & operational experience. This involved a combination of scientific literature review, analysis of collision data and surveys of equipment suppliers, freight operators and HGV drivers.

None of the proposed solutions benefitted from the highest standards of evidence that they would reduce casualties, but this is at least partly due to a lack of data rather than evidence of a lack of effect. All proposed systems had at least some evidence that they could be effective, though the extent and confidence in the data varied. For all systems, the evidence suggested that the extent of benefits would depend strongly on the technical performance standards applied to the systems.

Based on a combination of identified best practices for system design and information about the standard of systems already in the market place in numbers, three broad categories of requirements were defined for each proposed system: Basic, Advanced and Superior. Three policy options were defined for TfL's consideration:

a. **Basic:** requires all systems at the basic level.

b. **Advanced:** requires all systems at the advanced level.

B. **Flexible:** awards points for each system fitted (1-Basic; 2-Advanced; 3-Superior) and defines a minimum-points total to be achieved.

Option a. minimises the number of vehicles where existing safety systems would need to be upgraded, while option b. increases the safety performance but requires a much higher burden of system upgrade and a higher cost to industry. Option 3 attempts to recognise that a high performing single system may offer greater casualty benefits than 2 or even 3 basic systems and, therefore, to allow the industry flexibility in how they achieve the safety aims.

1 Introduction

London's mayor has committed to a 'vision zero' approach to road safety that means no loss of life should be considered acceptable or inevitable and has set a target that by 2041 there should be no deaths or serious injuries resulting from road collisions in London. Within this overall population, collisions involving HGVs are a significant contributor, particularly where collisions involve vulnerable road users.

A huge range of research literature has identified large vehicles turning left across the path of a cyclist and HGVs running over pedestrians as they pull away from rest as particular concerns, with blind spots identified as one of the principle causes. Enhanced blind spot mirrors became mandatory for new vehicles through Directive 2003/97/EC and later for most existing vehicles through the retro-fit Directive 2007/38/EC. However, collisions between HGVs undertaking low speed manoeuvres and vulnerable road users moving in close-proximity to them continued to occur.

The concerns around these issues led TfL to examine improvements in direct vision through the windows of the vehicle rather than further improvements to mirrors. In parallel, a method of objectively measuring and quantifying the direct vision from HGVs was developed, allowing direct vision performance to be rated. This is known as the Direct Vision Standard (DVS). This led to the concept of the 'Safe System' approach that would mandate that vehicles either meet the DVS requirements or, if they cannot do so, then they must be equipped with other safety features that at least partly compensate for the poorer standard of direct vision.

As proposed, the 'Safe System' incorporates the following mandatory elements if a vehicle does not meet the requirements for direct vision:

- Blind spots minimised via indirect vision
- Blind spot information or warnings systems for the HGV driver
- Warning the VRU of the vehicle's intended manoeuvre
- Protection in the event of a collision
- Driver training on the safety of vulnerable road users (advised, not mandatory)

The intention of these requirements is to recognise the positive steps that some operators in London have already taken to improve the safety of their vehicles in London and to make such an approach mandatory for all operators. As such, it is based on the best practices outline in the Fleet Operators Recognition Scheme (FORS) Silver Award.

FORS is a voluntary accreditation scheme for industry to give recognition to operators that are doing more to improve safety and environmental performance and to share industry best practice. Its approach is not prescriptive and there are no specific technical requirements defining exactly what each system must do, and no objective measurement of its performance. TfL proposes implementing comparable requirements as a legally binding mandatory minimum standard. It was therefore deemed necessary to independently gather evidence to support these specific mandatory requirements.

This project was commission by TfL with the following objectives:

- To demonstrate the positive impact of fitting vulnerable road user (VRU) safety equipment and technology to HGVs over 12 tonne gross vehicle weight.
- To define a minimum set of clearly defined standards for each of the safe system requirements based on evidence, research and operational experience

2 Research Methods

2.1 Literature review

A literature review was undertaken using a wide range of published research, supported wherever available, with unpublished material direct from stakeholders such as the members of the UNECE informal working group on close-proximity collisions and VRUs, or the members of FORS or CLOCS. The review covered each of the technologies considered for mandatory application through the Safety Permit.

2.2 Collision data analysis

An in-depth analysis of available STATS19 collision data was completed. Data in the casualty impact of the Direct Vision Standard (DVS), (Knight, et al., 2017) covered a 10-year period up to 2015. This was updated to include the latest data for 2016 and 2017. Contributory factors, attributable to both the driver and vulnerable road user (VRU) were analysed to support the likely effectiveness of any safety measures.

The UK Department for Transport's (DfT) Road Accident In-Depth Studies (RAIDS) database and, specifically, the legacy Heavy Vehicle Crash Injury Study (HVCIS) data within it, was also analysed. This contains more detailed information about the circumstances of the incident, including travel and impact speeds and potential countermeasures, identified by the coders, to assess the likelihood that they would have prevented the fatality from occurring.

2.3 Experience surveys

A set of four separate on-line surveys were developed and distributed to:

- Technology Suppliers
- HGV Operators
- HGV Drivers
- VRU Groups and road safety experts

The surveys were used to generate mainly qualitative information about what types of blind-spot safety systems are typically fitted/supplied, their capabilities, limitations and costs, and to seek stakeholders' views on a potential minimum standard in London.

Links to the surveys were distributed by TfL and the research team by email, and recipients were further encouraged to forward the links on to their contacts. In total, over 200 individuals and organisations contributed responses to one or other of the surveys, mostly HGV operators and drivers. Given the very short timescales available to respond and the quite technical nature of many of the questions, this is considered a very good response rate.

2.4 Evaluating the quality and robustness of evidence

There are a wide range of possible sources of evidence of the effect of safety measures. All have their advantages and disadvantages, and some represent stronger evidence than others. By defining and using a consistent framework to analyse the evidence identified, the relative strength of competing evidence, or relating to competing measures can be transparently considered.

3 Framework of Evidence Required

The main objective of this research is to assess whether the measures proposed by TfL for inclusion in the HGV Safety Permit are likely to be effective in terms of casualty reduction, and what technical controls might need to be included in the Permit to ensure that the expected levels of effectiveness are achieved in practice.

There are a wide range of ways to assess whether a safety feature does actually result in a reduction in casualty risk. None are perfect, each can play a role, and each has advantages and disadvantages. Ideally, the evidence base would include studies of multiple different types, all providing estimates of effect at least in the same direction and preferably of similar magnitude. However, this can be very difficult to achieve in practice and is typically only possible with measures that have a relatively large effect, are relatively mature and widespread in the market while still being a long way from a universal fitment. A brief summary of the different types of study is provided below and more details are available from, for example, (Elvik & Vaa, 2004) (Fenaux, 2003) (Knight, 2011).

3.1 Post hoc statistical studies

These studies treat the safety feature under investigation as a risk factor and use statistical techniques to compare the relative risk of casualties in real world collision data where vehicles were or were not equipped with the feature. In theory this is the most reliable estimator of actual benefits because they measure the actual in-service effect including any behavioural changes by drivers or other road users and any unintended consequences of the systems. However, the range of variables influencing the frequency or severity of collisions is enormous and study results can be strongly influenced by 'confounding factors' that interact with the measure being studied. Thus, the accuracy depends very strongly on the quality of the data and statistical methods used.

It is important to remember that this type of study proves an *association* between the safety feature and a lower or higher risk, but it does not prove that the safety feature *caused* that change. The principle limitation of this technique is that vehicles with the safety feature must be available on the road in significant numbers and it must be possible to identify whether or not a feature is present, at least in the collision data but preferably also in 'exposure data' such as the number of vehicles registered or used in traffic (e.g. vehicle km travelled).

3.2 Causation studies

Causation studies examine real world collision data at an aggregate level to identify types of collision with a common set of characteristics and contributory causes. These can inform the design of safety features and test procedures for evaluating them. They can also be compared with the characteristics of safety features to assess generally whether those safety features are, or are not, likely to be effective in that type of collision. Thus, this level of study can demonstrate whether a safety feature has clear *potential* to be effective but does not *prove* that it will be effective. It can give a quantification of the *maximum* potential benefit of the system (on the assumption of eliminating all collisions or casualties of a defined type) but has limited ability to refine this estimate such that it reliably predicts an *actual* casualty reduction. This quantification is often referred to as defining the 'target population' for a measure.

3.3 Predictive studies

Predictive studies are similar to causation studies but rely on the examination and detailed reconstruction of a series of individual collisions in order to increase confidence that a safety feature will or won't be effective and to refine the quantification of the scale of benefit to be more realistic. The base collision data will be incidents where the safety feature was not present, and the reconstruction will assess mathematically the likelihood that the feature would have prevented the collision or changed its outcome if present.

The advantage of predictive studies is that it can give reasonable confidence in effectiveness even before the safety feature reaches the market. The main disadvantage is that it can be very difficult to account for the potential of unintended consequences or any changes in the behaviour of drivers or other road users.

3.4 Experimental evidence

Experimental evidence can be used to accurately measure the effect of a safety feature in defined circumstances for example in a laboratory, on a test track, or on the public road. The experiment can be used to assess the physical performance of the system (e.g. how effectively a sensor detects a vulnerable road user in specific circumstances) or it can assess how well the relevant road users react to the presence of the safety feature. It can be used to assess the effectiveness in situations it is intended to work in but can also usefully help to identify any unintended consequences of the feature. The main advantage of an experimental approach is that the experiment can be closely controlled to isolate the effect of the specific safety feature assessed and it can provide information not available in collision data. The main disadvantages are that experimentation can be high cost and it can be difficult to define experiments that are well controlled and sufficiently representative of complex real-world operation

3.5 Survey evidence

This can be used to quantify how a safety feature changes the behaviour of drivers and other road users and to identify other supporting information. Surveys can provide a range of evidence from simply supporting opinion through to relatively robust quantitative evidence and can be broadly divided into two categories:

- **Observed preference.** For example, surveys of real world road user behaviour in normal circumstances where the safety feature was/was not present., e.g. do cyclists move around HGVs equipped with a warning of intended manoeuvre differently to those that are not equipped? This has the advantage of measuring actual behaviour but has the disadvantage that the behaviour is displayed in situations that are not actual collisions and it remains possible that behaviour in a more critical situation may be different.
- **Stated preference**. For example, surveys of road user experience and/or opinion as to whether they have experienced driving and/or incidents around the relevant safety features and whether they think safety features allow them to make better decisions or whether they distract them, annoy them etc. In large quantities this can quantify collision rates for statistical comparison in a robust post-hoc study, though the base data is self-reported such that accuracy depends on the ability of respondents to correctly identify incidents and risk.

3.6 Evaluation matrix

The quality of study is clearly also an important variable within each study type. The extent to which the study is applicable to the precise problem considered is also important. For this research study, the ideal situation is that for each safety feature being considered for inclusion in the Safety Permit, there would be multiple studies of different types each applied very specifically to the operation of HGVs in London. However, where that exceptionally high standard of evidence is not available, then it is possible that at least some elements of studies of the safety feature applied to HGVs but in other geographical locations, or studies of the same sort of safety feature applied to other types of vehicle, could be used to infer some level of confidence in the effects.

Based on the above different types of evidence, the following evaluation matrix can be defined. It should be noted that where cells are left blank, no evidence was identified, where a small x is marked then relatively weak evidence was identified and where a large X is marked stronger evidence was identified.

Table 3-1: Matrix for identification of the type of evidence available for each potential safety feature under consideration

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical			
Causation			
Predictive			
Experimental: Physical			
Experimental: Behavioural			
Survey: Observed			
Survey: Stated			
x = Limited/weak evidence; X = Stronger evidence			

It is also important to note that each study of effectiveness will be based either on one or more actual or theoretical safety features with a defined set of performance levels and operational characteristics. In reality, those performance characteristics are not fixed and may well vary depending on what, if any, technical requirements TfL place within the Safety Permit but also on any changes driven by other buyers of systems, the manufacturer themselves, or regulators. Thus, it was also important to link, wherever possible, any evidence of effect with the key characteristics of the systems.

4 The problems that the Safety Permit (2020) is intended to mitigate

4.1 Overall analysis

Blind spots around HGVs have long been identified as a potentially significant contributor to the cause of serious collisions with pedestrians and cyclists (Robinson, et al., 2016).

Across GB, there were 1,793 reported road deaths in 2017. This is similar to the level seen since 2012. There were also 24,831 serious injuries in road traffic accidents reported to the police in 2017 which is a similar number to 2016 but represents a small increase compared to the preceding years[1].

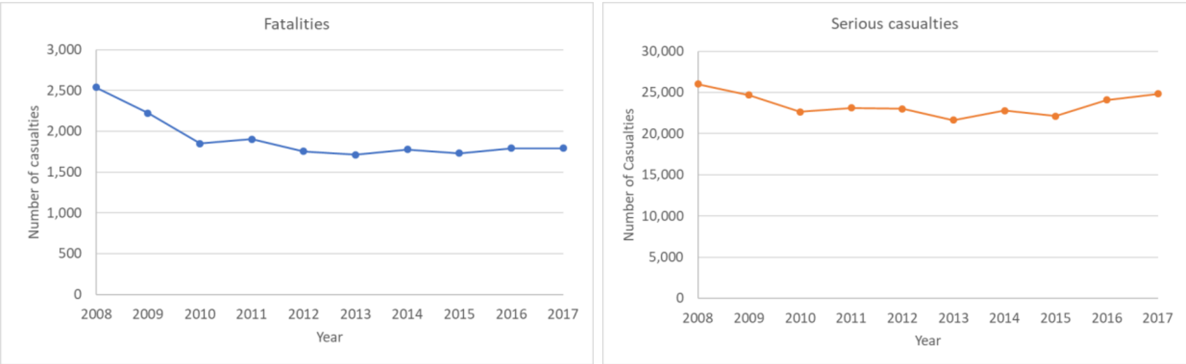


Figure 4-1: Trend of fatal (left) and seriously injured (right) road users in GB (2008 – 2017) Source: STATS19 database

Vulnerable road users (VRUs, pedestrians and pedal cyclists) represented almost one-third of all recorded GB road deaths (pedestrians 26%, pedal cyclists 6% in 2017) (Figure 4-2, left). In London, this proportion is doubled, with VRU accounting for 64% of road user deaths (pedestrians 56%, pedal cyclists 7% in 2017) (Figure 4-2, right).

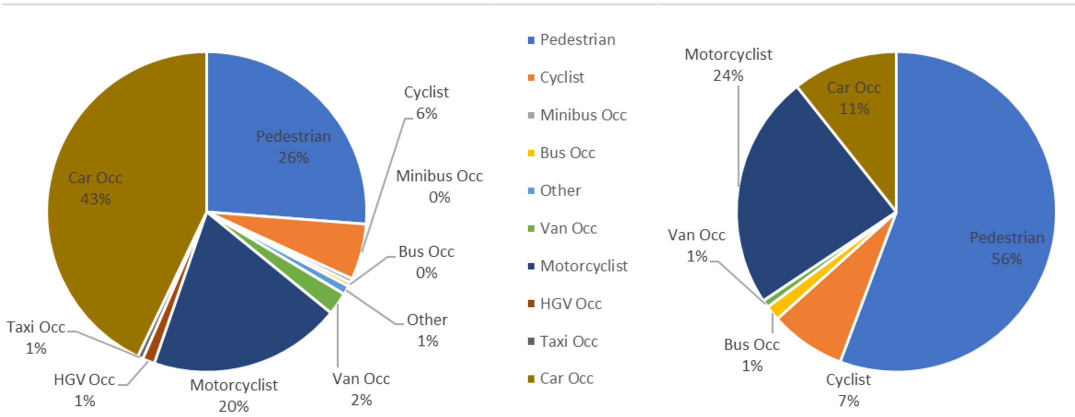


Figure 4-2: Breakdown of road deaths by road user type in 2017 for GB (left) and London (right). Source: STATS19 database

4.2 Incidents involving HGVs

When only incidents involving at least one HGV are considered, the distribution of road deaths by road user type in Great Britain (Figure 4-3, left) is relatively unchanged when compared to all road deaths (any vehicle type involved). However, when considering incidents in London that involve an HGV (Figure 4-3, right), VRUs account for an even

[1] There have been changes to the systems for severity reporting and so this might account for some of the increase. [ADD DETAILS]

greater proportion, 87% (pedestrians, 68%, cyclists 19%) highlighting the over-involvement of HGVs in VRU incidents specifically in London.

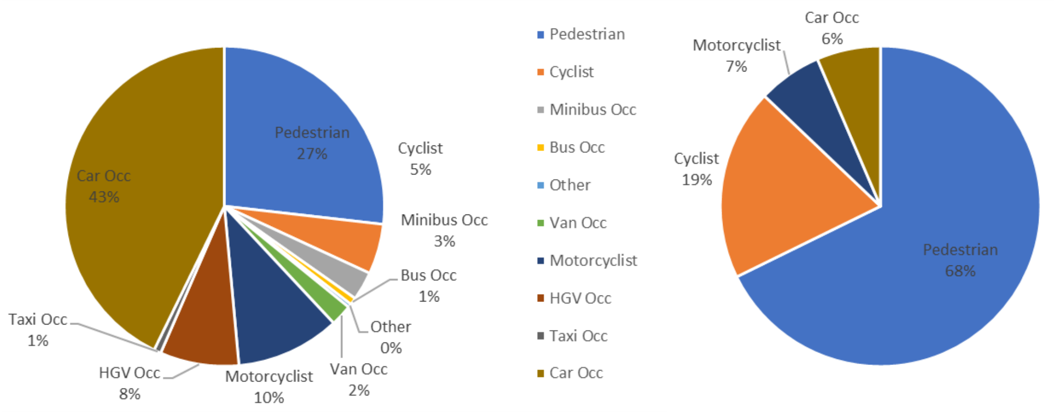


Figure 4-3: Breakdown of road deaths by road user type in 2017 for GB (left) and London (right), when involving an HGV (>3.5t). Source: STATS19 database

Furthermore, when only considering HGVs with a GVW > 7.5t, this VRUs as a proportion of all casualties is slightly higher again at 91% (pedestrians, 70%, cyclists 22%), emphasising that larger HGVs are more problematic.

4.2.1 VRU fatalities by HGV manoeuvre

Analysis of the STATS19 data (Table 4-1) also showed that the majority of VRU fatalities in London occurred when the HGV was undertaking one of three manoeuvres: Moving off from rest, turning left, or going ahead other.

Table 4-1: VRU fatalities by manoeuvre from incidents in London involving an HGV (>7.5t). Source: STATS19 database 2008-2017.

Manoeuvre	Pedestrian		Cyclist		Total	
5 - Moving off	37	41%	5	12%	42	32%
7 - Turning left	12	13%	22	52%	34	26%
9 - Turning right	2	2%	2	5%	4	3%
18 - Going ahead other	32	36%	8	19%	40	30%
All other manoeuvres	7	8%	5	12%	12	9%
Total	**90**	**100%**	**42**	**100%**	**132**	**100%**

Manoeuvres grouped under “going ahead other” include cases when the HGV is travelling at speeds typically experienced in normal traffic conditions. In these situations, the vulnerable road user is typically not in close proximity to the HGV at the critical moment when each party would need to act to avoid a collision. This study is focussed on low speed manoeuvres and so the following analysis has concentrated on scenarios where the vehicle is either moving off from rest of turning left.

4.2.2 HGV speed prior to incident

The data recorded for each incident in the Heavy Vehicle Crash Injury Study (HVCIS) database includes an estimate of the travel and impact speed of each vehicle at the time of the incident. An analysis of incidents resulting in a pedestrian or cyclist casualty where the HGV involved was moving off from rest or turning left showed that the average travel and impact speed was less than 10 mile/h. A maximum travel speed of 20 mile/h (32km/h) was also identified (Table 4-2).

Table 4-2: Travel and impact speed of HGV involved in moving off or turning left incidents with a VRU. Source: HVCIS database.

	Moving off		Turning Left	
	Travel Speed (mile/h)	Impact Speed (mile/h)	Travel Speed (mile/h)	Impact Speed (mile/h)
Min	0.0	2.0	3.0	3.0
Average	5.9	6.3	9.6	9.2
Max	15.0	15.0	20.0	19.0
Number of cases	34	34	57	57

It is also worth noting that on average there is very little difference between the travel speed and the impact speed recorded. This shows that very few cases involved any pre-collision braking, which suggests that in most cases the driver either did not see the hazard at all or saw it so late that he or she was unable to even apply the brakes before collision.

4.2.3 Lighting conditions

The lighting conditions at the time of an incident are an important consideration because some systems rely on technology that only works effectively during daylight, with a diminished level of performance during darkness.

A review of all incidents in London involving an HGV (>7.5t GVW) and resulting in a pedestrian or cyclists casualty (all severities) between 2008 and 2017 showed that 84% of pedestrian casualties and 90% of cyclist casualties were injured during daylight hours. Only a very small number of incidents were reported during darkness without streetlighting.

Table 4-3: Breakdown of pedestrian (top) and cyclist (bottom) casualties in London from incidents involving an HGV (> 7.5t GVW). Source: STATS19 database 2008 – 2017

Pedestrian casualties

Lighting Condition	Fatal	Serious	Slight	All
Daylight	86.7%	83.6%	82.8%	83.7%
Darkness - lights lit	12.2%	16.4%	15.9%	15.4%
Darkness - no lighting	1.1%	0.0%	0.3%	0.4%
Darkness - lighting unknown	0.0%	0.0%	1.0%	0.6%
Total	**100%**	**100%**	**100%**	**100%**

Cyclist casualties

Lighting Condition	Fatal	Serious	Slight	All
Daylight	95.2%	85.7%	91.1%	90.4%
Darkness - lights lit	4.8%	13.2%	8.9%	9.4%
Darkness - no lighting	0.0%	0.0%	0.0%	0.0%
Darkness - lighting unknown	0.0%	1.1%	0.0%	0.2%
Total	**100%**	**100%**	**100%**	**100%**

4.3 HGV-VRU incidents - moving off from rest

In this scenario, the HGV is stationary, often at traffic lights but sometimes at a junction or in a queue of traffic. A pedestrian crosses the road in front of the HGV in relatively close-proximity so that they cannot be seen by the driver. Before the pedestrian has moved past the path of the vehicle the lights turn to green (or the traffic allows the vehicle to move) and because the driver cannot see the VRU, he or she pulls away from rest and collides with the pedestrian. In fatal cases, the pedestrian is usually run over by the vehicle. Some pedal cyclists are killed in a similar situation (Knight, et al., 2017).

A breakdown of the pedestrian fatalities recorded in STATS19 in London during the period 2008-2017 (Figure 4-4) shows that incidents where the pedestrian hit the front of the HGV accounted for 71% of all pedestrian fatalities that occurred in collisions with an HGV (>7.5t GVW) where the HGV was moving off from rest. Furthermore, in 73% of these cases, the vehicle’s blind spot was coded as a potential contributory factor. The driver failing to look properly was also coded as a contributory factor in 50% of these cases.

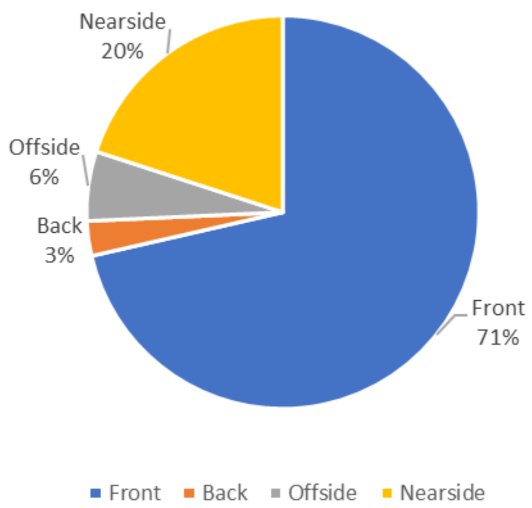


Figure 4-4: Proportion of pedestrian fatalities in London from collisions with an HGV (>7.5t GVW) moving off from rest, by impact location

An analysis of similar scenarios from the Heavy Vehicle Crash Injury Study (HVCIS) database also showed that improving the forward field of vision was coded as a potential countermeasure in 46 of the 50 cases (92%) where an HGV was moving off from rest.

In the HVCIS database, countermeasures are assigned to each accident with a probability of preventing a fatality of "Definitely", "Probably" or "Maybe". The probability is based on consideration of the wide range of evidence in the source police file and guidelines about each measure. However, it inevitably involves a degree of subjective judgement on behalf of the coder. When analysing the countermeasures, the number of fatalities potentially prevented are weighted by a probability of prevention, i.e. "Definite" are multiplied by 1.0, "Probable" by 0.75 and "Maybe" by 0.25. Using these weightings, it was estimated that 23 of the 50 pedestrian fatalities (46%) could have been prevented from improving the forward field of vision in incidents where an HGV was moving off from rest.

The accident data did not contain any information on the typical distance between the front of the HGV and the path of the pedestrian crossing in front of the vehicle. (Knight, et al., 2017) highlighted that the forward position of a pedestrian is highly relevant to the range required of any sensing system intended to prevent crashes. (Summerskill, et al., 2015) evaluated the field of view from a wide range of goods vehicles from different sectors. In terms of forward vision, they measured the furthest forward position at which a 50th percentile male pedestrian (1.75m tall) just remained invisible (through direct vision) to a 50th percentile male driver, in a standardised seating position. They found that the distance ranged from zero to 1.5m in front. This distance would be extended if a smaller person, such as a 5th percentile female, were considered.

4.4 HGV-VRU incidents - turning left

The typical crash type involves an HGV turning from a main road into a side road and colliding with a pedal cycle positioned to its nearside, normally one that was intending to travel straight on (Knight, et al., 2017). However, (Robinson, et al., 2016) studied in-depth crash data and analyses of this crash type, particularly the analyses of (Jia, 2015) and (Jia & Cebon, 2015). It was found that a wide range of manoeuvres, relative velocities, positions and impact points could be involved. They grouped these diverse types into three sub-manoeuvres of the left turn problem:

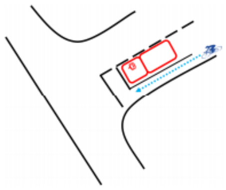
1. <u>The pedal cycle moves up the nearside of an HGV stationary at traffic lights</u>. This was the most common scenario. Impact points are typically at the nearside front, around the area of the front and second axles of a traditional 4 axle tipper. However, at the time when the driver would need to react to avoid a collision the cycle can be positioned further back, up to around 5 or 6m rear of the front of the vehicle.

2. <u>Both vehicles are stationary before moving off from rest together</u>. The cycle is sometimes initially positioned ahead of the vehicle with the HGV, then overtaking slightly in the moments before collision. Other times the HGV is initially ahead with the pedal cycle undertaking slightly before the collision. Impact points are typically at the nearside front of the vehicle, typically around the position of the front axle.

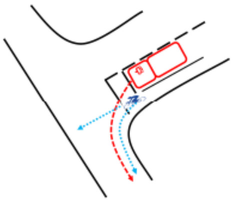
3. <u>Both vehicles moving</u>. Impact positions vary along the length of the side of the vehicle from the front to the position of the rear axle. Thus, the position of the cyclist at the critical moment for detection could be anywhere from the nearside front corner to quite close to the rear of the vehicle, around 8.5m rear of the front of a rigid tipper but potentially much further rearward for an articulated vehicle.

(Knight, et al., 2017) considered scenario 1 to be the most important in respect of blind spot sensors because the evidence suggests it is the most frequent mechanism in fatal collisions (40% of the (Jia, 2015) sample, with approximately 30% each for scenario 2 and 3), and because the rapidly changing relative position will mean the mirrors that the cyclist appears in will change rapidly and the perceived threat level will depend very much on the exact instant the HGV driver chooses to look in that particular mirror.

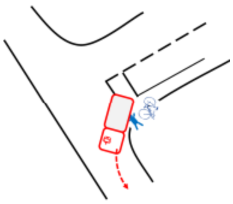
(Thomas, et al., 2015) also highlighted the typical sequence of events prior to a collision between a cyclist and a large vehicle and suggested that the conflict that leads to the collision typically occurs when the lorry driver is unable to perceive the presence of the cyclist and the cyclist does not recognise that the lorry is about to turn left.



The cyclist moves towards a lorry that is moving slowly or stopped at a junction and decides to pass on the left side, dedicated cycle paths or the availability of an advanced stop line may encourage the cyclist. The lorry driver intends to turn left but is either not indicating or the indicators are not visible to the cyclist.



The cyclist moves to a zone around the front left corner of the lorry, either to the left side front or the front left. The cyclist intends to continue ahead or to turn left but is not observed by the lorry driver who steers the lorry around the corner, being a long vehicle, the front end takes a wider curve than the rear which moves close to the curb.



The bicycle is struck at slow speed as the lorry moves away, the cyclist falls to the ground and passes underneath any side underrun guards to be run over by the following wheel either on a second front or a rear axle.

(Schreck & Seiniger, 2014) studied collisions in Germany during the development of a proposed test procedure for collision warnings in turning manoeuvres. They proposed testing at a low lateral separation of 1.5m between the side of the HGV and the VRU. UK collision data did not contain objective information on the lateral separation between HGVs and cyclists killed in left turn conditions in the UK.

(Knight, et al., 2017) highlighted that typical UK lane widths are around 3.5m and most HGVs in excess of 7.5 tonnes are 2.5m wide. This means that an HGV positioned at the far right of a lane would leave a gap of just 1m up the inside. Thus, depending on the position and type of bicycle, lateral separations between the two participants could be as little as around 300mm.

In Germany (Schreck & Seiniger, 2014) found that accidents could involve a distance of up to 5m between the side of the HGV and the cyclist prior to the HGV making the turn, which is in excess of a full UK lane width. However, the larger lateral separations could be associated with collisions that occurred as HGVs turned across separated cycle lanes (Figure 4-5), which were common in Berlin where much of the collision data came from.

Figure 4-5: Examples of separated cycle lanes in Germany. Source (Schreck & Seiniger, 2014)

Using the longitude and latitude co-ordinated recording for each incident in STATS19, a visual analysis of the accident location was undertaken using the measurement tool within Google Earth Pro. The 22 incidents resulting in a cyclist fatality in London between 2008 and 2017 where the HGV involved was making a left turn (as shown in Table 4-1) were analysed. In most cases the location was comprised of a normal traffic lane (3.0 – 3.5m in width), without any cycle or bus lane to the nearside. In these cases, and assuming the HGV was positioned in the centre of the lane closest to the nearside kerb, a lateral distance of between 0.25m and 1.0m was typically observed. If a driver had positioned the vehicle with the right had side of the vehicle over the centre line of the carriageway, to provide the additional space to make the left turn, then the lateral distance between the nearside of the HGV and the kerb was typically abut 2m and could be as high as 4m.

Seven cases were identified where a cycle/bus lane was located to the nearside of the normal traffic lane, and in two of these cases the cycle lane was also separated from the traffic lane by a raised kerb/pavement (Figure 4-6).

Figure 4-6: Examples of separated cycle lanes in London where a fatal cyclist to turning HGV collision has occurred. Source: (Google Maps, 2018)

This analysis suggests that lateral separations of up to 5m, as observed by (Schreck & Seiniger, 2014), do happen in London but are not that common. However, the use of such cycle lanes has the potential to increase. TfL design guidance highlights the potential of segregated lanes and states that the greater the width of the separation, the greater the degree of protection.

A breakdown of the cyclist fatalities recorded in STATS19 in London during the period 2008-2017 (Figure 4-7) shows that incidents where the cyclist hit the nearside of the HGV as the HGV was turning left accounted for 73% of all cyclist fatalities that occurred in collisions with an HGV (>7.5t GVW) where the HGV was turning left. In 57% of these cases, the vehicle's blind spot was coded as a potential contributory factor.

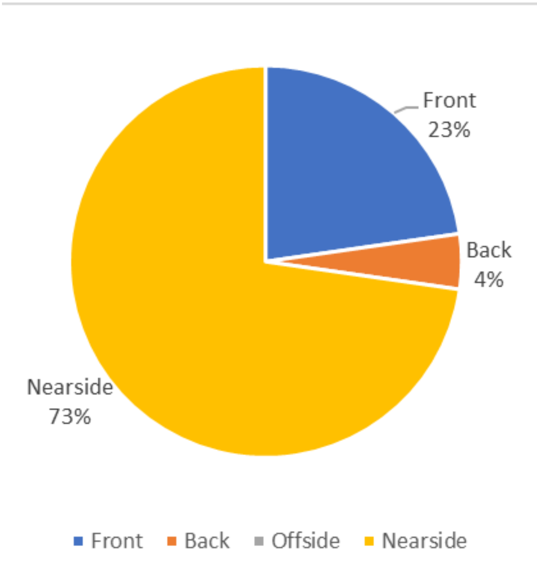


Figure 4-7: Proportion of cyclist fatalities in London from collisions with an HGV (>7.5t GVW), by HGV impact location

(Thomas, et al., 2015) reported a similar pattern, showing that the most common manoeuvre involved the large vehicle turning left resulting in a low speed interaction with the cyclist. Generally, impacts occurred to the front left side or left front side of the truck (24 cases, 89%). Insufficient direct vision of the cyclist was a factor in all these cases with additional risks associated with driver attention and mirror limitations. The availability of Class V side and Class VI front mirrors did not prevent all fatalities.

An analysis of similar scenarios from the Heavy Vehicle Crash Injury Study (HVCIS) database also showed that improving the side field of vision was coded as a potential countermeasure in 46 of the 66 cases (70%) where an HGV was moving off from rest. Improving the forward field of vision was coded as a potential countermeasure in 14 of the 66 cases (21%). In most cases improvements to the forward field of vision were also coded in addition to improvements to the side vision. However, if these two measures were combined and the countermeasure with the greatest probability of preventing a casualty selected, a total of 49 of the 66 cases (74%) could have been affected, preventing an estimated 20 fatalities (30%).

4.5 Annual variation in casualty numbers

(Robinson, et al., 2016) reported that STATS19 data for the period 2005-2014 showed that vulnerable road users (mainly pedal cyclists) killed by the nearside of an HGV turning left represented the largest group of HGV collisions where the vulnerable road user was likely to have been in close-proximity to the HGV in the seconds immediately prior to the collision (Table 4-4).

Table 4-4: London VRU fatalities by manoeuvre group and impact point. Source: STATS19 database – 2005-2014

<table>
<tr><th rowspan="3">VRU Type</th><th rowspan="3">HGV manoeuvre</th><th colspan="4">10 year annual average (2005-14)</th></tr>
<tr><th colspan="3">1st point of impact (HGV)</th><th rowspan="2">Total</th></tr>
<tr><th>Nearside</th><th>Front</th><th>Offside</th></tr>
<tr><td rowspan="4">Pedestrian</td><td>Moving off</td><td>0.4</td><td>2.1</td><td>0.1</td><td rowspan="3">3.6</td></tr>
<tr><td>Turning left</td><td>0.5</td><td>0.2</td><td>0.1</td></tr>
<tr><td>Turning right</td><td>0</td><td>0.1</td><td>0.1</td></tr>
<tr><td>Other</td><td>0.9</td><td>2.5</td><td>0.3</td><td>3.7</td></tr>
<tr><td rowspan="4">Cyclist</td><td>Moving off</td><td>0.4</td><td>0.2</td><td>0.1</td><td rowspan="3">3.3</td></tr>
<tr><td>Turning left</td><td>2.2</td><td>0.1</td><td>0.1</td></tr>
<tr><td>Turning right</td><td>0</td><td>0.1</td><td>0.1</td></tr>
<tr><td>Other</td><td>0.8</td><td>0.2</td><td>0</td><td>1</td></tr>
<tr><td rowspan="3">All</td><td>Vision relevant</td><td>3.5</td><td>2.8</td><td>0.6</td><td>6.9</td></tr>
<tr><td>Not Vision relevant</td><td>1.7</td><td>2.7</td><td>0.3</td><td>4.7</td></tr>
<tr><td>Impact point distribution</td><td>50.7%</td><td>40.6%</td><td>8.7%</td><td>100.0%</td></tr>
</table>

The availability of STATS19 data for 2015-2017 now shows a small change in this distribution with VRU fatalities from where the front of the HGV collides with a VRU now showing as the largest group Table 4-5).

Table 4-5: London VRU fatalities by manoeuvre group and impact point. Source: STATS19 database – 2008-2017

<table>
<tr><th rowspan="3">VRU Type</th><th rowspan="3">HGV manoeuvre</th><th colspan="4">10 year annual average (2008-17)</th></tr>
<tr><th colspan="3">1st point of impact (HGV)</th><th rowspan="2">Total</th></tr>
<tr><th>Nearside</th><th>Front</th><th>Offside</th></tr>
<tr><td rowspan="4">Pedestrian</td><td>5 - Moving off</td><td>0.7</td><td>2.5</td><td>0.2</td><td rowspan="3">4.5</td></tr>
<tr><td>7 - Turning left</td><td>0.5</td><td>0.3</td><td>0.1</td></tr>
<tr><td>9 - Turning right</td><td>0</td><td>0</td><td>0.2</td></tr>
<tr><td>Other</td><td>1</td><td>2.4</td><td>0.3</td><td>3.7</td></tr>
<tr><td rowspan="4">Cyclist</td><td>5 - Moving off</td><td>0.2</td><td>0.2</td><td>0.1</td><td rowspan="3">2.8</td></tr>
<tr><td>7 - Turning left</td><td>1.6</td><td>0.5</td><td>0</td></tr>
<tr><td>9 - Turning right</td><td>0</td><td>0.1</td><td>0.1</td></tr>
<tr><td>Other</td><td>1</td><td>0.2</td><td>0</td><td>1.2</td></tr>
<tr><td rowspan="3">All</td><td>Vision relevant</td><td>3</td><td>3.6</td><td>0.7</td><td>7.3</td></tr>
<tr><td>Not Vision relevant</td><td>2</td><td>2.6</td><td>0.3</td><td>4.9</td></tr>
<tr><td>Impact point distribution</td><td>41.1%</td><td>49.3%</td><td>9.6%</td><td>100.0%</td></tr>
</table>

The change is mainly due to the change in distribution of cyclist fatalities. For the period 2005-14, cyclist collisions with the nearside and front account for 79% and 12% of cyclist fatalities respectively. Whereas for the period 2008-2017 this distribution had changed to 64% and 29% for the nearside and front.

As a percentage the difference looks quite substantial but the absolute numbers of casualties each year are relatively low and are therefore quite sensitive to small year-to-year changes. For example, whilst there is a slight downward trend in the number of cyclist fatalities from impacts to the nearside of an HGV, the main reason for the difference between the 2005-14 and 2008-17 datasets is because there were no fatalities recorded for this scenario during 2016 and 2017. Similarly, four fatalities in 2017 from collisions with the front of an HGV represent the first cases reported since 2008.

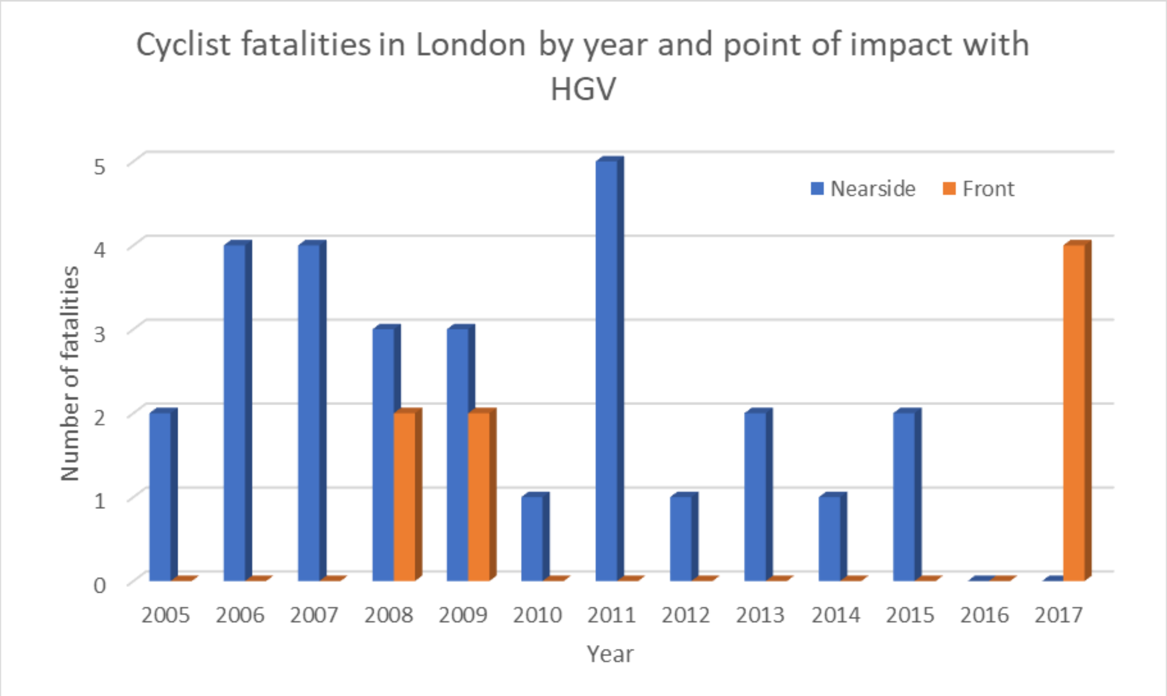


Figure 4-8: London cyclist fatalities by year from impacts with an HGV (>7.5t) where the HGV was going ahead or turning and the impact point was front or nearside. Source: STATS19 database

5 Mirrors

5.1 Fundamental Concept

The results of collision data, such as that summarised in section 4, have remained consistent for many years and vehicle blind spots have long been identified as a key contributor to close proximity collisions involving HGVs. Historically, survey data has also shown concern with the view in a range of other traffic situations and the existence of blind spots on HGVs was easily confirmed, see for example (Southall, et al., 1998). At the time, class II, class IV and class V mirrors were mandatory for the largest goods vehicles but the size of the view from each was smaller than it is today and class VI (frontal blind spot) mirrors were not required. Mirrors clearly do allow the driver to physically see into blind spots and improvement to mirrors represented the path of least resistance. Directive 2003/97/EC substantially increased the size of the minimum field of view from mirrors required in order to gain European Type Approval for a new HGV. Effectively, all new vehicles sold in the EU from January 2007 would have had to comply with these new requirements.

In addition to this, Directive 2007/38/EC required that the class V blind spot mirror at the nearside, as defined by Directive 2003/97/EC, should be retrofitted to most existing HGVs on the road that were not already equipped. This retrofitting exercise had to be completed by the year 2009. The exceptions to the retrofit requirement were vehicles first registered before 1 Jan 2000, vehicles that had mirrors that came very close to meeting the new requirements and, where for technical or economic reasons a vehicle could not be made to fully comply with the Directive, alternative solutions could be defined.

In 2015, TfL’s Safer Lorry Scheme required that all vehicles more than 3.5 tonnes entering London had to be equipped with class V mirrors (as per the mandatory requirement but without restriction by age of vehicle etc) and extending the requirement to include class VI frontal blind spot mirrors as well. This rule also contained some exemptions allowing a small number of specific vehicle models to continue operation without fitment and any vehicle where it was impossible to ensure the mirror was mounted more than 2m from the ground.

Continuing improvements to indirect vision from HGVs have been implemented in type approval through UNECE Regulation 46 with an additional change to blind spot mirror requirements coming into force in 2016 to increase the size of the required ground plane view.

The FORS Silver requirements have been that blind spots around the vehicle must be minimised and operators must demonstrate that they have ensured appropriate vision aids are fitted to both front left and rear of vehicles. Vision aids can be mirrors or camera monitor systems. However, the most recent version of the standard (V5) has amended the requirement such that the vision aids must include a camera monitor system with no specific mention of solutions without cameras, except as a possible alternative for older vehicles in specific circumstances.

Thus, two basic concepts for including mirrors in the HGV Safety Permit can be considered:

- Simple incorporation of the existing Safer Lorry Scheme requirements within the HGV Safety Permit such that only one legal instrument is required

- Extension of the Safer Lorry Scheme requirements to recognise, where appropriate, efforts of FORS silver operators to minimise blind spots using additional blind spot mirrors or similar passive vision aids (not cameras)

5.2 Regulatory minimum field of view from mirrors

UNECE Regulation 46 defines 4 fields of view that must be visible via indirect vision for category N2/N3 vehicles, as illustrated in Figure 5-1, below.

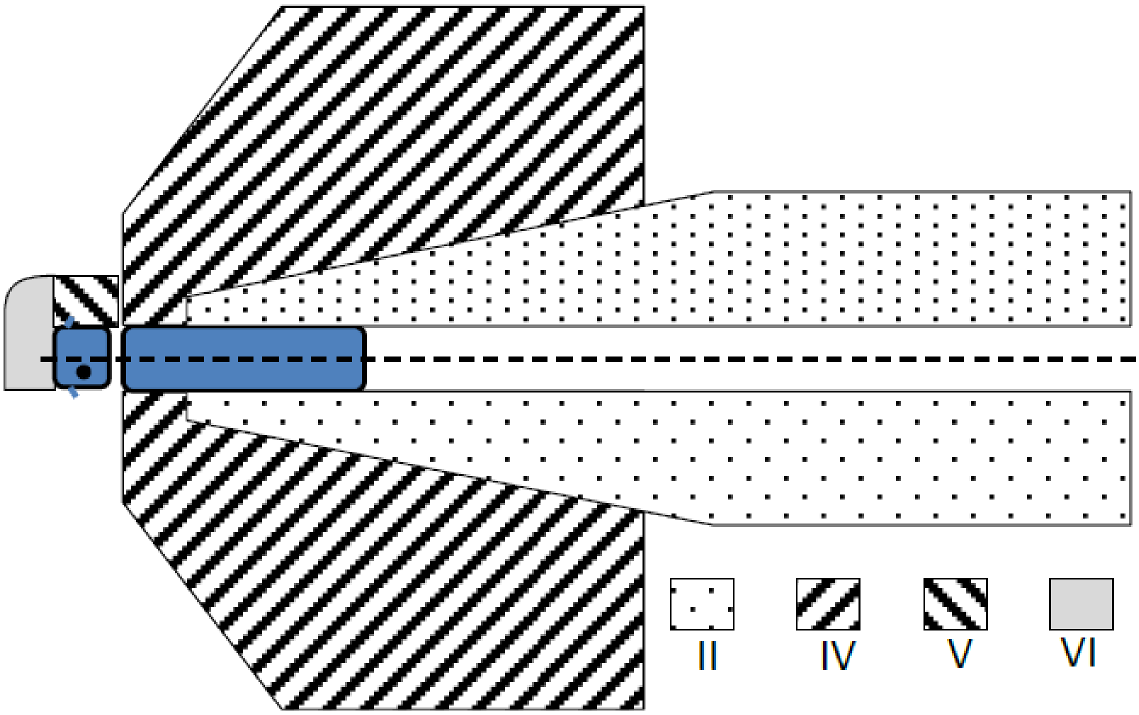


Figure 5-1: Areas of the ground plane that must be visible via indirect vision from an HGV as defined by UNECE Regulation 46 (note this is for a left-hand drive EU vehicle). Source: (Martin, et al., 2017)

The class V view measures 4.5m wide and extends 3m forward of the driver's eye point and 1.75m rearwards. The class VI view must extend 2m forward of the vehicle and extend to the same width as the class V view, although this may be curved towards the nearside of the zone. The regulation aims to be flexible in how these views are achieved. For example, if the class V view can be achieved with a combination of a class IV and a class VI mirror then a separate mirror is not required for the class V view. Similarly, any of the fields of view can be achieved using a camera monitor system, provided it meets minimum design and performance standards.

5.3 How recognisable are vulnerable road users in mirrors?

Identifying the answer to this question requires consideration of how human drivers use vision to detect and recognise objects. (Terzis, 2016) described human optical perception as being divided into foveal (central) and peripheral vision. The central area of vision is the only area that provides a sharp focussed view. However, it is very small (less than around 0.1% of total human field of view) and relatively slow to process vision, needing at least 200ms before identifying the content of a particular view. Typically, the duration for which a driver fixes their vision in one spot is between 200ms and 800ms with an average of around 300-400ms (Terzis, 2016). Information in central vision cannot be processed in parallel. The driver must fixate on a given view for long enough to process the image and only then can it move on to another view and fixate on that for long enough to process the image. Thus, scanning the view around the vehicle is a sequential series of eye movements, known as saccades, followed by fixations on a single point. The saccades happen very quickly of the order of 20-80ms, though figures vary somewhat in the literature. It is an oversimplification to say that humans cannot see during the saccades, but vision and consequently object recognition, is substantially reduced. Thus, the time taken to scan 6 different mirrors is likely to be between around 1.9 and 2.9 seconds[2] on average, assuming that the gaze does not fixate on any other areas of the view in between the different tasks. Even travelling at a low speed of 10 mile/h in manoeuvring, this translates to moving a distance of between around 8.5m and 13m during the process of scanning each mirror. Vulnerable road users in close proximity to the vehicle are also likely to be moving at the same time, which if in the same direction, will reduce the relative difference in position but if in different directions can increase the change in the position of the VRU relative to the driver. Thus, it is quite possible that a VRU will appear in one mirror, while the driver is looking in another, and then move from the original mirror by the time the driver has scanned to it.

Peripheral vision works differently. In peripheral vision there is much lower visual acuity and limited colour perception. Effectively the images seen in peripheral vision are compressed for fast delivery in a manner that priorities motion stimuli. (Terzis, 2016) suggests this results in very fast but blurred vision which is particularly sensitive to movement direction and velocity. (Terzis, 2016) states that human perception utilises the advantages of each type of vision such that objects are detected in peripheral vision, particularly where the object is moving, and this attracts the attention such that the gaze is directed at the object in order for foveal (central) vision to be used to identify the object and understand its significance.

The use of mirrors does not work very well with this theory. In a mirror of fixed and relatively small dimensions (compared to the total of human peripheral vision) the object the driver needs to detect is a small image and the amount by which that image can move across the mirror is also small. Thus, it is less likely to attract the attention of the driver in the same way as it would if it was visible at life size in a direct field of view where it would move across a much larger proportion of the peripheral view. For mirrors to be effective, then the driver must have a conscious, trained, strategy of scanning the mirrors with their central (foveal) vision at key moments and, as discussed above, this takes a finite amount of time.

(Schmidt, et al., 2015) states that when using mirrors, it can be difficult for drivers to accurately estimate distance and speed and that high speeds are typically underestimated but slow speeds typically overestimated. The estimation of speed and distance relies on the depth perception of the driver. Depth perception is often associated with the use of two eyes (binocular vision) but in fact some features are derived from seeing the same object with two eyes and others are associated with features that are apparent even in one eye (monocular vision) (Terzis, 2016). Binocular depth perception relies on differences between the angles that each eye need to be looking at to see objects at different

[2] Estimated from the figures published in (Terzis, 2016) as 6 fixations at 300-400ms each plus 6 saccades at 20-80ms each. Lower value (6*300)+(6*20)=1920ms or 1.92s. Upper value (6*400)+(6*80)=2880ms or 2.88s

distances. The image in a mirror is always at the same distance from the eyes and so at the same 'depth of vision' such that this binocular measurement of distance always gives the same answer regardless of how far away the object in the mirror is.

Binocular depth of vision is strongly limited by the distance between the eyes and their resolution such that it can only play one part in depth perception (Terzis, 2016). Monocular depth perception relies on different cues, including the image size, how that size changes as the object moves and parallel perspective (e.g. the apparent narrowing of a road of equal width as it extends into the distance). Mirrors are still capable of showing these features and so the element of depth perception that uses monocular vision can still be effective. However, the images in mirrors are small compared with the same object seen in direct vision and the variation in size of image with distance from the mirror will also be smaller. Thus, the monocular depth of vision cues are more limited in mirror view than direct view.

Thus, the ability to ability to show depth of vision in mirrors is limited. The human brain can learn to compensate for this (Schmidt, et al., 2015) but the visual cues that enable this compensation will also be complicated by the visual distortion that comes from a curved mirror. In these circumstances, the brain must work harder to compensate for the curvature. Thus Regulation 46 has evolved to limit the curvature of mirrors, to maximise image size and minimise distortion.

The physical and biological limitations are in general consistent with the findings of more observational studies of the use of mirrors. For example, (Milner & Western-Williams, 2016) found that reflected objects tended to be overlooked in comparison to directly viewed objects and that driver recognition rates were compromised towards the edges of mirrors.

5.4 Additional blind spot mirrors available

Additional mirrors, or different designs of mirrors, could extend the field of view further. (Dodd, 2009) tested several such devices including the 'dobli' mirror, a supplementary mirror from BDS and a Fresnel lens. An image from the test vehicle is shown in Figure 5-2.

Figure 5-2: Image of a test vehicle equipped with two additional blind spot mirrors and a Fresnel lens

It can be seen that a car parked next to the vehicle is only just visible in direct vision through the passenger window and is not clearly visible in the mandatory mirrors. It is partly visible in the two additional blind spot mirrors and fully visible in the Fresnel lens. In fact, the Fresnel lens was found to give the largest increase in field of view of all the indirect vision aids tested by (Dodd, 2009).

However, although an extreme example (it is unlikely a vehicle would be fitted with two additional mirrors and a Fresnel lens), this picture is also an excellent example of the problems referred to in sections 5.3 and 5.5 associated with the ability of the driver to quickly view and understand all the available fields of view, recognise a collision threat and respond appropriately.

This image can also relate to the processing required to understand a view. For example, the image of the car in the Fresnel lens is clearly recognisable as a car, that is, it is sufficiently large and free from distortion. However, its position in the nearside window is where you might expect a car that is further away from the vehicle to be positioned. Examining the different road surfaces shows the discontinuities created between direct and indirect vision that could also require additional brain processing to correctly understand. The area just beyond where the car is positioned is also effectively obscured from the direct vision as well, so solving one blind spot problem has the potential to create a new one.

5.5 Adjustment and usage

Mirrors are by necessity adjustable such that they can provide the correct field of view for drivers of different statures and in different seating positions. However, this also leaves the opportunity for mirrors to be poorly adjusted such that they do not provide the field of view that they are supposed to. For example, (Fenn, et al., 2005) cited research showing that less than half of 2,000 lorries surveyed had correctly adjusted mirrors and (Schoon, 2009) showed that in 37% of blind spot collisions mirrors were poorly adjusted. A small sample of fatal collisions studied in-depth by (Fenn, et al., 2005) also produced one where the class V blind spot mirror was significantly poorly adjusted, and this may have been a contributory factor in the cause of the collision.

Not only must drivers adjust their mirrors correctly before starting their journey (at least any time the vehicle has been driven by someone else since their last use of it), they must also use them correctly, scanning each of them at all the correct times during normal driving and low speed manoeuvring. (Fenn, et al., 2005) showed that in a stated preference survey, most drivers self-reported that they did use close proximity mirrors for their intended purpose most of the time. However, a significant minority admitted to rarely or never adjusting them when they got in the cab (11%) and to rarely or never using the mirrors to check for cyclists or pedestrians by the nearside door when undertaking low speed manoeuvring (14%).

5.6 Evidence of effectiveness

5.6.1 Experimental evidence

Many studies have measured the physical view from vehicles and have found that adding mirrors can substantially increase the view and reduce blind spots.

However, no experimental evidence has been identified that attempts to realistically correlate the size and quality of mirror view with correct observation, detection and collision avoidance in the way that (Milner & Western-Williams, 2016) did for direct vision.

5.6.2 Post hoc statistical studies

In terms of the field of view from mirrors, the main limitations to post hoc statistical studies is the ability to accurately identify in collision and exposure data the field of view that was available from any given vehicle. The regulations define different minima, but these may well be exceeded in practice where, for example, a vehicle variant with a cab height at the high end of the range uses a standard class V mirror component that is capable of meeting the minimum view from the lowest possible cab height for that model. However, the view can also be worse than the regulatory minimum in service because of poor adjustment. The closest proxy is identifying vehicles that were subject to the different regulatory criteria by their registration age.

No studies were identified that undertook a full statistical study of the effects of the mirror changes, while properly controlling for potential confounding factors.

A number of simplistic studies were identified that compared basic measures of collision frequency and severity over time and related this to the introduction of improved mirror requirements.

(Schoon, 2009) recorded a 43% reduction in the number of relevant deaths in the 2 years after implementing an additional blind spot mirror requirement (at the start of 2002) but this largely disappeared again by 2004.

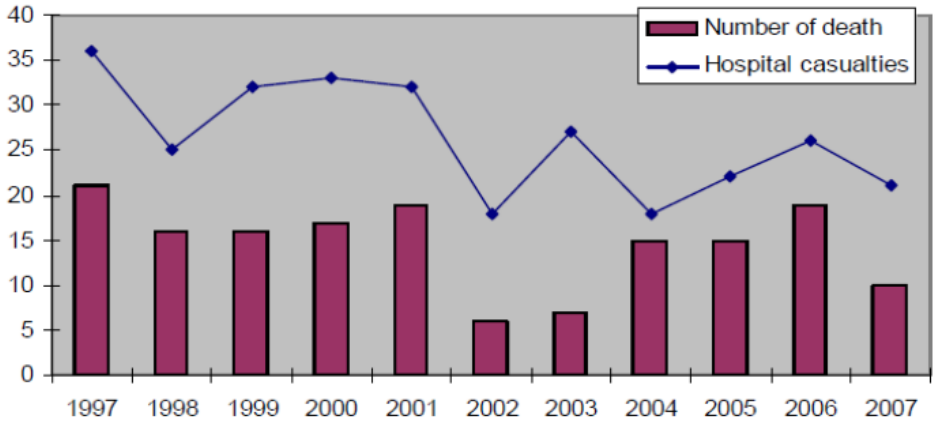


Figure 5-3: Number of cyclist deaths and casualties in collision

The technical requirement imposed in The Netherlands was to use a specific additional mirror that effectively brought forward in time a large part of the increase in mirror field of view that was required for new vehicles from 2007 by Directive 2003/97/EC, as shown in Figure 5-4, below.

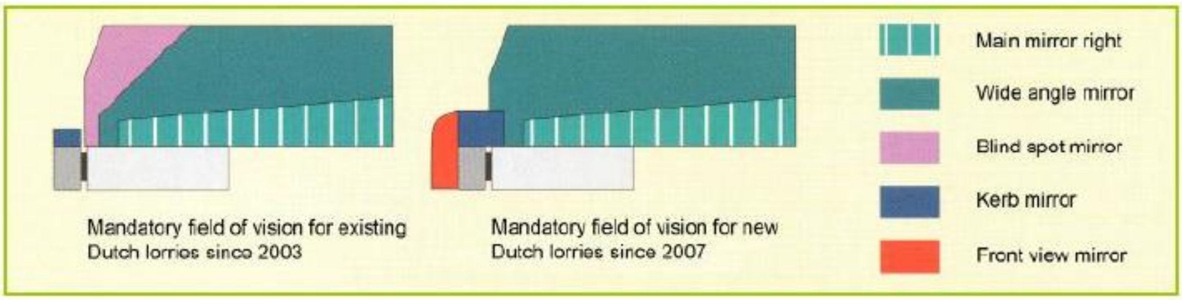


Figure 5-4: Field of view requirements in the Netherlands. Source: (Schoon, 2009)

([redacted] 2011) analysed CARE data and showed that there was a generally reducing trend for left turn collisions involving vulnerable road users over the time period that the new Directives were introduced. However, it also showed collisions of all types reduced by a comparable amount in the same time period and that the reduction in left (right in mainland EU) turn collision was small compared to a much bigger reduction in collisions when the HGV was moving straight ahead. Thus, the proportion of all VRU fatalities from collisions involving HGVs had actually increased from 16% to 24%. The conclusion of the study was that the falls in casualty numbers seen exceeded predictions of the effect of the retrofit directive but that there was little evidence to prove that the retrofit of blind spot mirrors had caused this fall, or even part of it.

5.6.3 Causation studies

[redacted], 2015) found that of 27 London HGV-cyclist collisions studied in detail, mostly involving left turn collisions, all collisions involving a cyclist positioned in a zone relevant to class V mirrors were equipped with class V mirrors. This does not prove that such mirrors are ineffective, they may have been effective in other near collisions that did not occur as a result of the mirror. However, it does prove that they do not eliminate collisions. For collisions where cyclists were in a position relevant to the class VI frontal mirror, slightly more than half of the vehicles were not equipped with the frontal mirror. This does allow the possibility of a greater effect for frontal mirrors but may also be a simple function of exposure: that is, at the time of the collisions far fewer HGVs were equipped with class VI mirrors than class V.

No definitive reason was found for the failure of the driver to see and react to the cyclist in those cases where mirrors should have provided a view. Observations identified from witness statements and analyses included drivers citing the demands of a busy traffic environment, looking at the mirrors but failing to see the cyclist, relative movement of the cyclist combined with mirror curvature meaning the cyclist would only have been visible in the mirror for a short time, incorrect mirror adjustment and incorrect understanding of the purpose of the mirrors.

5.6.4 Predictive studies

[redacted] et al., 2005) studied collisions in the HVCIS fatal accident database for HGVs. This involved detailed study of police fatal collision reports for more than half of UK collisions involving HGVs and the routine coding of countermeasures based on a probability scale, subjectively assessed by the coder. This study predicted that as many as 55% of those cyclists killed in collision with an HGV turning left could be prevented. However, it should be noted that the terms of this study were actually an assessment of improved field of view generally rather than particular design of mirror specifically. As such, coders would have effectively assumed that the 'improvement' in vision would have been sufficient to make the cyclist available to be seen and then the probability of avoidance would have depended on whether the evidence suggested the driver involved had properly adjusted their mirror, was or was not paying proper attention at the time left turn. Coders would not have had sufficient information to be able to fully assess the likelihood of detection based on the interaction of mirror properties and human visual behaviour, driver workload etc.

5.7 Costs of implementation

The cost of mirrors would vary strongly based on whether it was an additional mirror fitted on a new vehicle, a replacement of an existing mirror, or an additional mirror fitted to an existing vehicle. The cost of retrofitting blind spot mirrors was quantified in line with the decision to retrofit class V mirrors across the EU and to retrofit class VI mirrors in Ireland.

(RSA, 2011) estimated the cost of fitting a class VI mirror to an existing HGV to be between €135 and €200 per vehicle. FORS online resources suggest around £85 to £170 per vehicle.

Internet sources[3] suggest that the parts only price of a class V or VI mirror was between around £28 to £75.

5.8 Gap analysis

The evidence around the effectiveness of mirrors is somewhat ambiguous and no rigorous post-hoc statistical studies are available to prove effectiveness, likely because of limitations in the available data. The predicted benefits of blind spot mirrors were substantial, and theory suggests that mirrors should give an advantage. However, available theoretical evidence also suggests that the extent of that advantage is limited by the nature of the human vision system and issues of driver workload. Post-hoc examination of overall collision trends over a time when significant changes to mirror technical standards were made has shown some reductions in casualties but there is

[3] See for example https://www.bisonparts.co.uk/daf/blind-spot-mirrors

considerable doubt as to whether the effects observed were attributable to mirror fitment or to other factors influencing collisions at the same time and there was evidence that cyclists colliding with HGVs turning left now represent a larger proportion of a smaller overall HGV safety problem.

Table 5-1: Evidence identified for effectiveness of mirrors

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical		X	
Causation	X		
Predictive	X	X	
Experimental: Physical	X		
Experimental: Behavioural			
Survey: Observed			
Survey: Stated			
x = Limited/weak evidence; X = Stronger evidence			

Gaps can clearly be seen in the evidence base for mirrors:

- **Post-Hoc statistical studies** – only data reviewing basic trends is available, no proper statistical analysis accounting for exposure, different levels of view and confounding factors. However, at present the data does not exist to undertake such a study, detailed information on actual mirror view by individual vehicle and in collision data is not available. Proxy information could be based on regulatory changes but would be considerable less accurate. Sample size would remain a problem.
- **Experimental and/or observational studies** of driver behaviour with different mirror views: This would help to establish the net balance of effect between the additional physical view with the theory regarding limitations with respect to effectiveness of peripheral vision, depth of vision and driver workload. It would involve a study similar in nature to that of (Milner & Western-Williams, 2016) but comparing different levels of mirror view with a baseline of no mirrors, rather than comparing different levels of direct vision with a single mirror view baseline.

5.9 Candidate policy options

The possible policy options with respect to mirrors are as follows:

- **Do not include mirrors within Safety Permit requirements:** Most vehicles would continue to operate with class V and VI blind spot mirrors as required by regulation. Some vehicles exempt from requirements for those mirrors may not replace them after breakages etc[4] slightly reducing the fitment of these mirrors over time. Given that the safety effect of fitting them is not clearly proven, it cannot

[4] Assuming the requirements of the existing safer lorry scheme would lapse on commencement of the Safety Permit Scheme.

be definitively stated that this would reduce safety, but it is clearly also not proven that it would be safe to remove them.

- **Use requirements from Safer Lorry Scheme:** This would maintain the status quo with respect to mirror fitment and consequent safety during manoeuvring
- **Include requirements for additional mirror view(s):** This may reflect the efforts of FORS Silver operators who might have chosen to fit additional blind spot mirrors to meet the obligation to minimise blind spots, going over and above the requirements for UNECE Regulation 46. The safety benefit of such a move is not clear given the lack of post hoc statistical evidence of the effectiveness of blind spot mirrors and the human factors evidence highlighting limitations in how mirrors work with human vision and driver workload concerns. The chances of effectiveness would be likely to depend strongly on technical requirements to limit excessive curvature and in terms of mirror placement to ensure workload and new obstructions to direct vision were minimised.

6 Direct Vision

6.1 Fundamental concept

Mirrors still leave some blind spots with many HGV cabs, as shown in Figure 6-1, below shows this effect on the ground plane blind spots.

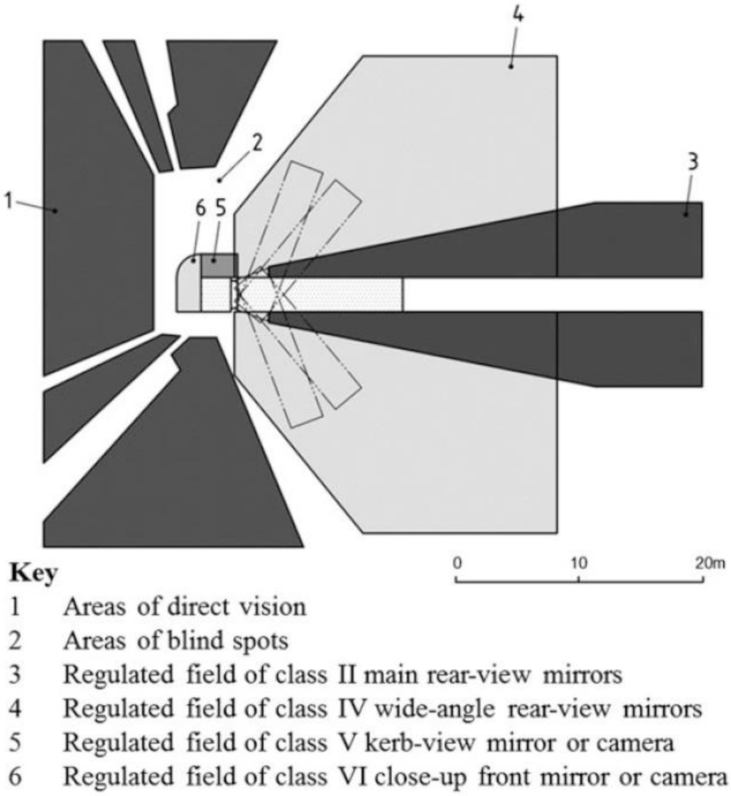


Figure 6-1: Visible ground plane area from combined direct and indirect vision. Source: (Terzis, 2016)

This is perhaps even more graphically demonstrated in a profile view, as shown in Figure 6-2, below.

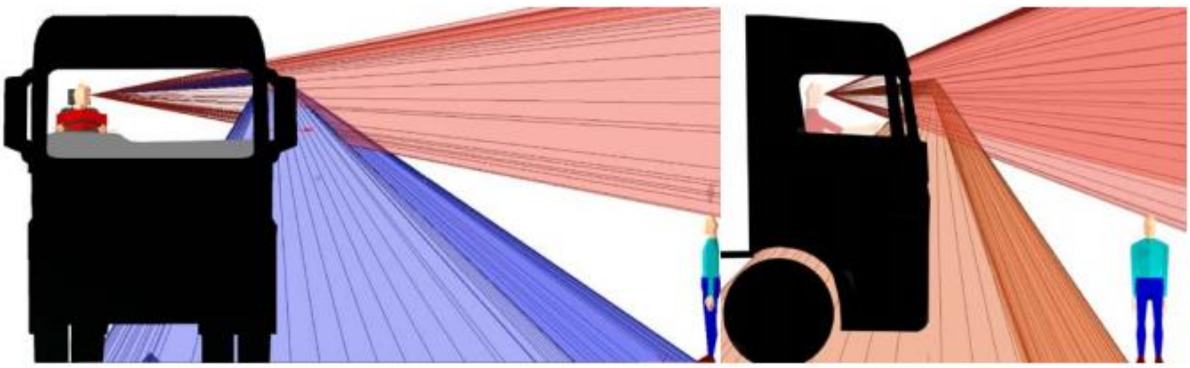


Figure 6-2: Illustration of direct and indirect views from the side and front of an HGV cab where a 5th percentile Italian female is not at all visible in either view. Source: (Summerskill, et al., 2017)

Thus, the fundamental concept with direct vision is that these continuing blind spots needed to be seen and the limits were being reached as to what was feasible with mirrors without creating excessive driver workload, additional mirror obstruction to direct vision and/or introducing more distortion of view in mirrors. In addition to this, the theory was put forward that direct vision would likely be more effective than indirect vision and so should be extended into areas already covered with a mirror view wherever possible in order to maximise the chances of the driver correctly detecting and recognising vulnerable road users around the cab.

6.2 Object recognition and driver workload

Seeing objects around the cab directly, at life size, in the full range of motion, allows the human vision system as described in section 5.3 to work in the way nature intended, without forcing the brain to compensate for abnormalities in the view. Thus, the full capabilities of both peripheral vision, depth perception and spatial awareness can be used.

Where better direct vision is achieved simply by moving the existing cab design closer to the ground, there is no additional area of windscreen to scan by the driver, so an increase in workload is not possible. Where it is achieved by increasing the glazed area of the windows, for example, by lowering their bottom edge, then potentially there is a wider area of glass to scan, which can take finite time. However, any vulnerable road user whose position is changing relative to the driver's eye point will trigger the motion perception part of peripheral vision, naturally drawing the driver's attention to the relevant area. Thus, an active scanning strategy is less necessary to enable drivers to detect the objects and even the additional windscreen area is less likely to increase the driver workload.

When the drivers central vision is focussed on a vulnerable road user, then in direct vision it will always be a larger image than in a mirror, will be free from distortion in most circumstances and will always be oriented in a realistic fashion (whereas mirror views from top down and strongly curved mirrors may show vulnerable road users at unnatural angles). Thus, the ability to recognise the object quickly should be enhanced.

6.3 Evidence of effectiveness

6.3.1 Post-hoc statistical studies

A comparison of collision rates per vehicle divided by the TfL DVS rating for that vehicle was attempted as part of the analysis reported by (Knight, et al., 2017). However, severe limitations in the data, particularly in terms of identifying the exact heights of the very small number of vehicle models involved in collisions for which DVS data was available, meant that no consistent effect was observed. The authors concluded that this represented a continued absence of evidence about the effect, rather than evidence of the absence of the expected effect.

6.3.2 Experimental studies

(Milner & Western-Williams, 2016) reported on both survey and experimental studies to assess the effectiveness of direct vision. In experiments where subjects in a stationary vehicle were asked to react to the presence of stimuli in the view, their reaction time did not differ when the vehicle was stationary. However, their driving simulator study found that viewing a pedestrian, while driving, through direct vision resulted in reaction times on average approximately 0.7 seconds quicker than when viewed in indirect vision. This is consistent with the theory presented in section 5.3 where in a stationary situation there will be no movement cues to stimulate peripheral vision and no problems with depth perception in mirrors. In a simulated route designed to be challenging then this finding translated to the observation that 27% of drivers collided with a pedestrian when in a traditional cab, compared with just 3% of those driving a low entry cab. When drivers were asked to undertake a more demanding cognitive task (simulating a heavy driver workload) at the same time as driving then around 52% of drivers in a traditional cab collided with a pedestrian, compared to around 12% in a low entry cab.

(Future Thinking, 2016) reported on driver and operator views of high visibility (low entry) cab vehicles based on in-service operation of a selection of trial vehicles. It was found that before driving the vehicles, drivers tended to be sceptical but that once the vehicles had been driven the view improved considerably and drivers felt that they were more aware of vulnerable road users. Managers considered these vehicles the best available for urban operation. However, both drivers and managers had concerns about their suitability for use on some sites, particularly where there was soft ground instead of hard standing.

6.3.3 Surveys of effectiveness

A survey of how 37 truck drivers used different areas of direct vision was reported in (Terzis, 2016) and this was separated by drivers of long haul and distribution vehicles and is reproduced in Figure 6-3 and Figure 6-4, below.

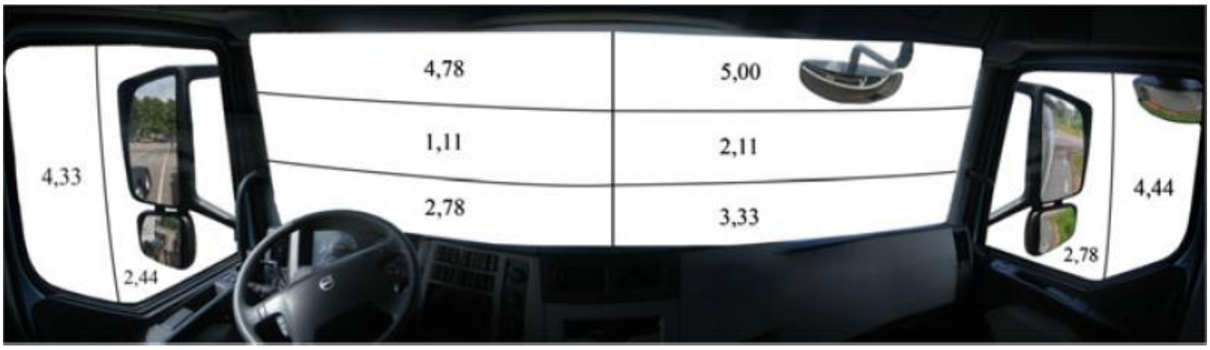


Figure 6-3: Importance of different window areas in the case of a long haul truck (1 means used most often, 5 means used most rarely). Source: (Terzis, 2016)

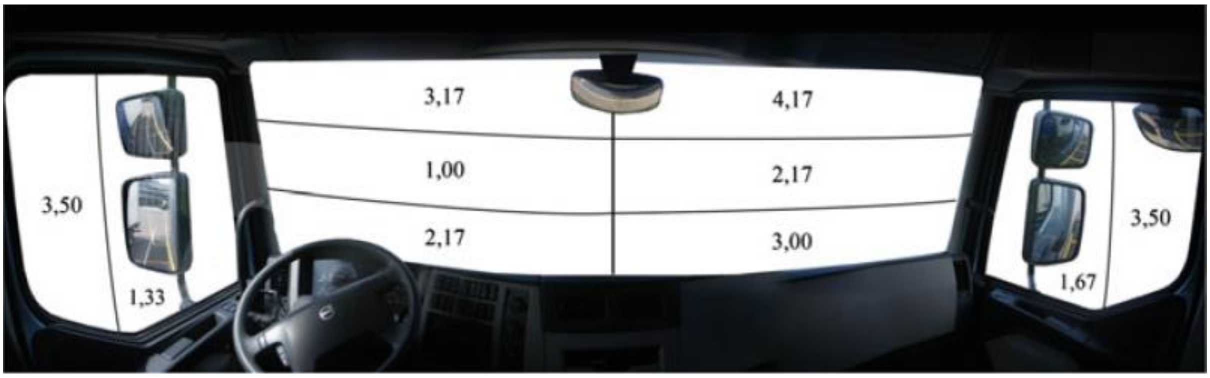


Figure 6-4: Importance of different window areas in the case of a distribution truck (1 means used most often, 5 means used most rarely). Source: (Terzis, 2016)

Results show that distribution drivers use the side windows much more and the lower portions of the front windscreen more than long haul drivers do. If they are using these areas at the right times, then it bodes well for the effectiveness of improved direct vision. However, how the driver of a long-haul vehicle might adapt their use of the screen when occasionally taking their larger vehicle into an urban area was not covered by the survey. If they do not adapt their behaviour in such circumstances, it may represent a risk that improved direct vision was less effective for them.

Survey evidence from (Milner & Western-Williams, 2016) also showed that vulnerable road users considered that direct vision would give them more confidence that they had been seen when moving around a large vehicle.

6.3.4 Predictive studies

[redacted], et al., 2017) collated comprehensive causation data concerning the number of collisions where blind spots were considered a potential contributory factor in close proximity manoeuvring collisions between HGVs and vulnerable road users in London. A simple percentage effectiveness was derived based on the experimentation by (Milner & Western-Williams, 2016) and summarised above. In scenarios where the HGV was moving off from rest, a 0-star vehicle was considered equivalent to the current fleet (o% effectiveness) and a 5-star vehicle was estimated to represent a 77% to 88% effective. For left turn collisions the effectiveness of a 5 star vehicle was considered to be 19% to 22%. The effectiveness of 1 to 4-star vehicles was calculated based on linear interpolation between the two extreme cases. The reason for the lower effectiveness in left turns is because:

- the in-depth collision data reported in section 4 showed that a substantial proportion of cyclist collisions where at the moment the driver needs to take avoidance action, the cyclist is significantly behind the cab and therefore not in a position where improved direct vison can offer a benefit
- driver workload may be quite high with competing demands for attention in several different directions

([redacted] et al., 2017) undertook a wide-ranging study of the likely casualty reduction effectiveness of a range of 24 measures that were candidates for inclusion as part of the European Commission’s proposed revision of the General Safety Regulation and Pedestrian Safety Regulation. Improved Direct Vision was one of those measures. In order to evaluate the effectiveness of direct vision a case by case analysis was undertaken based on a sample of in-depth collision data from the Road Accident In-Depth Study (RAIDS) database. Two standards of direct vision were considered:

- Best in class: This assumed ‘removal of the highest chassis and adoption of new cabs with improved direct vision through windshield, passenger door and side windows’. However, it was not specifically linked to either TfLs proposed direct vision rating or any specific objective measure such as distance at which a certain size pedestrian would be visible, so it is unclear how this relates to the technical standards proposed by TfL
- High direct vision: This is described as ‘a low forward position cab with much improved direct vision’. This was also not directly linked to objective measurements but seems likely to relate to 5-star vision as defined by TfL and based on low entry cab designs such as the Dennis Eagle Elite or Mercedes Econic.

Whether each standard of vision would prove effective at either avoiding the collision or mitigating its consequences was assessed subjectively by the coder, considering the evidence in the file about the quality of vision from the vehicle, the traffic situation and the attentiveness of the driver. The coders were asked to give their opinion in each case as to whether they had high, medium, low or zero confidence in whether the measure would be effective. Indicative probabilities of avoidance were:

- Low: 1% - 33%
- Medium: 34% – 66%
- High: 67% - 100%

The full range of results of the study are, therefore, obtained by considering a lower estimate where only cases with high confidence are counted and an upper estimate where all cases where the coders had at least some confidence that it might have an effect. This produces a range of effect from 1% to 36% for 'best in class' vision and 1% to 48% for low entry cabs. (Barrow, et al., 2017) provide a central estimate (their 'prediction') based on counting all cases with high or medium confidence, which produces an effectiveness estimate of 3% for the best in class cab and 27% for the best in class cab.

The predicted estimates (Barrow, et al., 2017) for the overall performance of the high vision cab (27%) are slightly higher than predicted for left turns only (19%-22%) by (Knight, et al., 2017) but substantially lower than predicted for moving off from rest (77%-88%) (Knight, et al., 2017). Given a relatively even distribution of these two collision types in London at least then the overall equivalent value based on the study by (Knight, et al., 2017) might be expected to be in the region of 50%, almost double the estimate by (Barrow, et al., 2017). The best in class value is not easily comparable because of the lack of technical definition of the size of view implied by this in (Barrow, et al., 2017).

The target population for pedestrians was defined (according to table 5 in (Barrow, et al., 2017)) as being all pedestrians in collision with the front or side of an HGV in a single vehicle collision where the HGV manoeuvre was not stationary, reversing, undertaking a U-turn or unknown. For pedal cyclists, it was a 2 vehicle collision with no pedestrian involvement where the cyclist hit the front or side of an HGV and the HGV was undertaking the same manoeuvres as defined for pedestrian above. It should be noted that this is quite a wide definition of target population for close proximity blind spot collisions. It restricts it to the road users typically injured in such collisions and the typical impact point for those collisions but does little to restrict it to collisions actually involving a blind spot.

(Knight, et al., 2017) restricted the target population more tightly considering both restricting manoeuvres to left turns and moving off from rest, where blind spot was a contributory factor, but also including corrections for under-reporting. As such it was a smaller target population much more focussed on specific blind spot collisions. The collision type forming the main difference between the two is where a pedestrian is hit by the front of a vehicle 'going ahead other' which is typically taken to be where a pedestrian crosses the road in front of an HGV moving at normal traffic speeds. Data varies based on the time period studied, (Robinson, et al., 2016) showed that pedestrian fatalities from this type of collision in London were equal in number to moving off from rest, (Knight, et al., 2017) showed that it was about half the number killed when moving off from rest. Time series produced for this report showed that both are correct it is just that the numbers in London are subject to considerable year on year variation, as evidenced by the STATS19 analysis shown in section 4.5.

If both studies had found the same absolute number of cases where direct vision was effective and then expressed that effectiveness as a percent of the target population, then (Barrow, et al., 2017) would provide a percentage around half that of (Knight, et al., 2017). However, this difference is only presentational and would not affect a full calculation of costs and benefits because the absolute number prevented would be the same.

The detailed sample of data extracted for case by case analysis in (Barrow, et al., 2017) was based on the same criteria as the target population. Fifty two percent of cases were recorded as having no influence of blind spot, which is broadly consistent with the difference in target population, based on the analyses of (Knight, et al., 2017). The analysis was based on a sample of 26 collisions, 14 of which involved an N3 vehicle and 12 an N2 vehicle. Collisions covered all injury severities but were biased to fatal and serious. Also, the RAIDS study area[5] is not a dense urban environment like London and 35% of collisions were classified as occurring in a non-built up area. Only 17% of those vehicles in sample were tipper or skip carrier, and most of those were skip carriers. (Knight, et al., 2017) found that 27% of the target population of collisions were with Tipper bodied vehicles. Thus, there are a number of differences in the sample definition that may be a function either of different definition of the target population, different geographical area of study or simply the fact that the samples are small and random chance has a strong influence on the detailed distribution. Extrapolations to larger geographical areas from both studies must, therefore, be treated with extreme caution.

It should also be noted that the result for 'best in class' (Barrow, et al., 2017) is mostly dependant on the confidence level expressed by the coders. The difference in the range of results between best in class and low entry cab is not particularly big (1-36 vs 1-48). However, the difference in 'predicted' value is substantial (3% vs 27%). This is highly subjective and can also be analysed in different ways. Figure 6-5 shows the how the coders in (Barrow, et al., 2017) assessed the confidence in different circumstances.

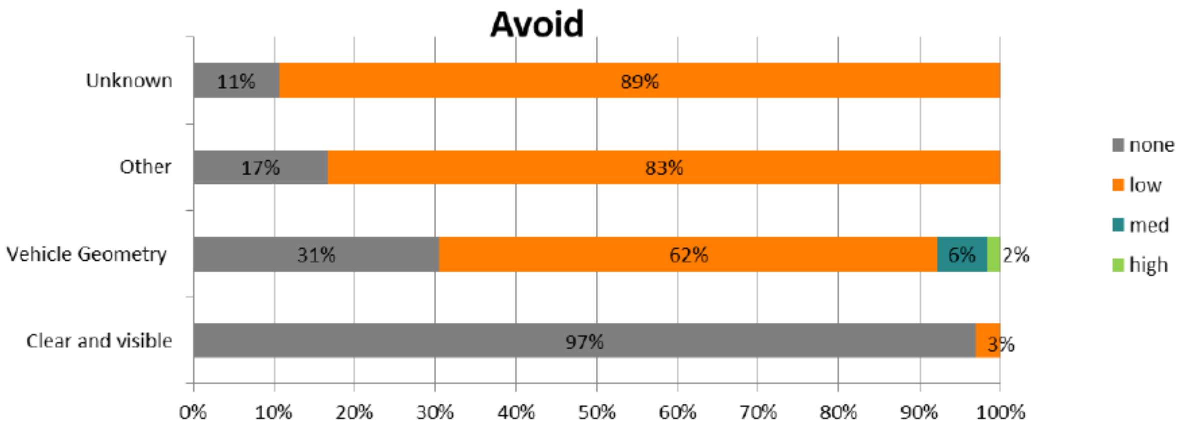


Figure 6-5: Confidence with which coders considered best in class direct vision would have avoided collision, divided by an assessment of the actual presence. Source: (Barrow, et al., 2017)

In cases where it was unknown whether a vehicle blind spot contributed to the collision or whether the obstruction was something other than vehicle geometry, it is understandable that the confidence will always be low. This will reflect a lack of available evidence on which to base a judgement. Where there was no impediment to view it is equally obvious that improving the view would have no effect. Thus, the main category of interest is the 40% of cases where vehicle geometry caused an impediment to view. In only 31% of these cases were the coders confident that improved direct vision would have no effect. In 2% to 69% there is at least some chance that best in class direct vision would have an

[5] The RAIDS study areas are based on a radius that can be reached in a reasonable response time from TRL in Crowthorne, near Reading in Berkshire and Loughborough University.

effect. In effect, this is a reflection of a different target population, considering only those collisions where a blind spot was known to be a contributory factor. Looked at this way, the central estimate based on a count of high and medium confidence estimates would become 8% instead of the quoted 3%.

In addition to this, counting the estimates at different levels of confidence is not the only way of generating a central estimate. It is at least equally valid to assess the different confidence levels based on assigning a mathematical probability to each level. Coders were instructed that low was a confidence of 1-33%, medium 34-66% and high 67%+. If a probability value at the centre of each range is applied then it can be estimated that 16.5% of low confidence cases will actually result in avoidance, 50% of medium confidence cases and 83.5% of high confidence estimates. Applying this to the percentages for cases where vehicle geometry was a factor (see Figure 6-5 above) makes a central estimate of 14.9% for the best in class cab. So, the same data considered differently can produce a central estimate of effectiveness from 8% to 15%. Given the range of possible answers from the same small set of data it would be technically inappropriate to select only a single value as 'the result' of this study for use in policy decisions. A sensible range balancing the technical uncertainty and the need for the conclusion to be informative would be a more appropriate route.

The data used to produce the results reported by (Knight, et al., 2017) calculates an equivalent effectiveness of mandating 1 star direct vision of approximately 0% to 13%, which is broadly comparable to the range from (Barrow, et al., 2017), if a range was based on their method of deriving a central estimate and the revised method of producing a central estimate from the same data proposed above.

6.4 Cost of implementation

(Cheung, 2017) studied the cost of implementing a direct vision standard in London. The study considered switching to vehicles of at least 1 star in 2020 and 3-star in 2024. This level of DVS performance was achievable without radical redesigns such as those for low entry cabs. Designs at this level were already in the market place. It was, therefore, considered that with like for like features there would be no premium in cost for upgrading to a higher standard of direct vision as far as the operator is concerned. However, vehicles are purchased with a view to a significant operational life. For that reason, many operators in London using vehicles of less than 3-star DVS would be forced to replace their vehicles ahead of schedule. Depending on vehicle type new vehicles were estimated to cost between £60k and £170k per vehicle, it was estimated that the average residual value of vehicles sold would be 30% of cost price and the proportions of the existing fleet that would be likely to need to replace vehicles were estimated based on survey responses. The analysis found that if the standard was implemented as an outright restriction it could cost in the region of £571million to £728million.

It was this very high cost of implementation that led to consideration of alternative options, including the concept of the Safety Permit that is the subject of this study.

6.5 Gap analysis

The effectiveness of direct vision is very well backed by the scientific and engineering theory and this is supported by survey findings suggesting that drivers do regularly use the relevant areas of direct vision as well as experimental findings showing both improved reaction times when viewing hazards in direct vision compared with mirrors and in terms of reduced collision frequencies in simulated driving through difficult scenarios with high collision risks. However, there are no known studies available quantifying a measured reduction in collision frequency and linking this to particular technical standards of vision.

Table 6-1: Evidence identified for effectiveness of direct vision

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical	x		
Causation	X		
Predictive	X	X	
Experimental: Physical	X	X	
Experimental: Behavioural	X		
Survey: Observed			
Survey: Stated		X	
x = Limited/weak evidence; X = Stronger evidence			

The main gap in evidence in relation to direct vision is a rigorous post-hoc statistical analysis of the collision involvement rate of vehicles with different DVS ratings. This may become more feasible in future if, as part of the Safety Permit implementation, TfL is able to record the DVS rating of specific vehicles, that is, attributable to a specific number plate. This must account accurately for the specific cab height of that vehicle. If this can be done in a way that allows a link to the collision data recorded in Stats 19, then it may be possible to compare the number of relevant and irrelevant collisions involving each DVS level to the number of vehicles in use in London at those levels. Such an analysis is not currently feasible, and even if it becomes feasible it will be limited by the relatively small number of collisions that occur in London.

6.6 Candidate policy options

Currently only one candidate policy option is considered for Direct Vision. The requirement will be for at least one-star direct vision in 2020, or the other requirements of the Safety Permit will become mandatory.

7 Camera Monitor Systems (CMS)

7.1 Fundamental concept

According to UNECE Regulation 46, a Camera Monitor Systems (CMS) is defined as a device which represents the field of vision obtained by means of a camera-monitor combination to the driver. Camera-monitor systems are used in vehicles to provide the driver with information on a specific field of vision (usually the rear view). The most common applications include:

- **Supplementary indirect vision**: CMS as an indirect view over and above those defined by UNECE Regulation 46: Some views, such as the view immediately behind an HGV, are almost impossible to see with mirrors. Others are difficult without increasing size of mirrors or their curvature, each of which have significant disadvantages.
- **Mirror replacement**: CMS replacing one or more of the indirect views required by UNECE Regulation 46: Replacing mirrors with cameras can reduce obstructions to direct vision, reduce aerodynamic drag and reduce the cost of frequent damage to mirrors as well as occasional injuries where mirrors collide with pedestrians.
- **360-degree birds eye view CMS**: Where the views from multiple cameras are synthesised into a single plan view image of the vehicle and objects around it.

Using cameras rather than mirrors means that the external object can be smaller and, without the need for direct line of sight between the driver's eyes and the mirror, the camera can be optimally positioned to provide the best coverage. Similarly, the monitor used by the driver can also be in the most intuitive position and/or to minimise any blind spot behind it.

Digital image processing can also offer possibilities for viewing that are not feasible with mirrors. Thus, the aim is that the extent of blind spots can be reduced without some of the disadvantages of mirrors.

7.2 Field of view

The extent of the field of view from camera monitor systems is in theory unlimited. However, in practice it will be limited by the number and size of monitors required to display the view in a meaningful form to the driver.

The mandatory minimum required field of view from different classes of mirrors are defined within UNECE Regulation 46 (see section 5.2). However, through head movement in combination with the movement of the upper body, a driver can expand the mandatory field of view from mirrors for special driving situations such as merging lanes on a motorway (Terzis, 2016). Thus, requirements for camera monitor systems should ideally compensate for this, for example by detecting the type of manoeuvre in which a larger view may be required and panning the view or changing magnification to compensate, or even by sensing driver head movement and replicating the same behaviour as mirrors.

7.3 Quality of view

(Milner & Western-Williams, 2016) reviewed literature and found that there were several risks related to using monitors aimed at extending HGV vision while driving:

- Increased periods of off-road glances
- Drivers take longer to acquire critical information when returning their gaze to the road
- Image resolution sensitive to environmental conditions
- Limited resolution and colour range, minimal time delay
- Additional workload to process additional visual information
- Processing the spatial location of the visual information received (e.g. where is a pedestrian seen in a monitor in relation to the vehicle).

In turn this could risk:

- Reduced hazard detection
- Abrupt steering wheel movements
- Impaired lane keeping

Although perfectly valid findings, it can be argued that many of these risks are clearly dependant on controllable factors such as the number and position of mirrors/displays competing for the driver's attention and could therefore be overcome with an appropriate design.

A driver's ability to understand the camera views is strongly influenced by camera positions. Views that are significantly different to the viewpoints of existing mirrors may be hard to interpret (Terzis, 2016). This could be considered a risk in relation to 360-degree camera systems stitching images into a 'birds eye' view of the vehicle and its surroundings from above. However, no specific research quantifying this was identified.

(Schmidt, et al., 2015) and (Terzis, 2016) highlighted several technical aspects that need to be considered when comparing the performance of a CMS and a traditional mirror, including:

Direct Sunlight/Low Sun: This can cause blooming of the image and a problem where dynamic range of the camera is not sufficient such that either areas of lower light are under exposed (black) or areas of too much light are over exposed (white). The camera can miss the detail from the rear area of the image but has the advantage of not causing glare on the driver's eyes.

Field of View: It was found that blind spots could be reduced but the estimation of the distance and speed of objects is more difficult in this aspherical section of the monitor (left).

Depending on the design, it is possible to receive more information about the rear space from a CMS than is possible with mirror systems.

Light/Dark Transition: It was found that when entering a tunnel, the image on the monitor first turns dark, as the camera sensor is underexposed for a moment but adjusts in under 1 seconds. When leaving a tunnel the reverse happens, with an initial overexposure results in a blooming effect

Rain: In light/normal rain, the protected position of the CMS meant it was better than a mirror which suffered from drops and water streaks on the window. Heavy rain results in more a difficult detection of point light sources in the CMS. Both the mirror and CMS are heavily impaired by splashing and rain drops, however, the colour rendering is more realistic in the CMS due to the better contrast ratio.

Night driving: Individual head lamps of other vehicles can be recognised both in the mirror and in the CMS. CMS Shows some light flare around the head lamps.

Rain can make it harder to identify vehicles and estimate speed.

Snow/fog: At a low ambient luminance including fogged up side windows and / or droplets on the side mirror, the CMS showed an image that was hardly affected by the weather.

With increased snow fall and higher ambient luminance a vehicle with the dipped headlights turned on, merges with the background making CMS worse.

Dropouts/interference: Dropouts should not occur. A radio with a 446 mhz frequency caused flickering and dropout, though a mobile phone did not. It is very important to design the individual components of the CMS with appropriate measures that ensure compatibility with electromagnetic influences.

(Schmidt, et al., 2015) highlighted that camera image changes are depicted with a very short time delay, whereas in the mirror, changes are reflected in real-time. It was also noted that a CMS requires time to initially 'boot up' and that the change from mirrors to CMS requires a certain period of familiarisation. However, this period is relatively short and does not necessarily result in safety-critical situations.

7.4 Usage and workload and potential for distraction

A key consideration for the fitment of CMS is whether it makes it easier or harder for driver to scan surroundings and identify threats. CMS fitted in addition to mandatory mirrors has the potential to increase a driver's workload, simply by creating additional areas that must be scanned. However, poor quality images would also increase the time required to process and understand them. Conversely a well-designed system replacing mirrors with monitors in intuitive locations offering clear and easily interpreted images could have the opposite effect and reduce a driver's workload.

(Terzis, 2016) highlighted that it is important that a changed view doesn't surprise the driver and that positioning of monitors inside the vehicle needs to consider

- Need for eye movements while monitoring vision views
- Obstruction of direct vision
- Sensitivity to incoming light
- Risk of glare and other disturbances in dark conditions

(Lundin & Zaimovic, 2015) undertook tests in a driving simulator to consider the best arrangements of the monitors and found that the best arrangement was for an A-pillar mounted monitor on the driver's side, but a monitor mounted in the instrument panel on the right side. (Figure 7-1, right). They also found that two A-pillar monitors (Figure 7-1, left) was popular with the drivers and might make it suitable for use in a transition period as drivers got used to using monitors instead of mirrors.

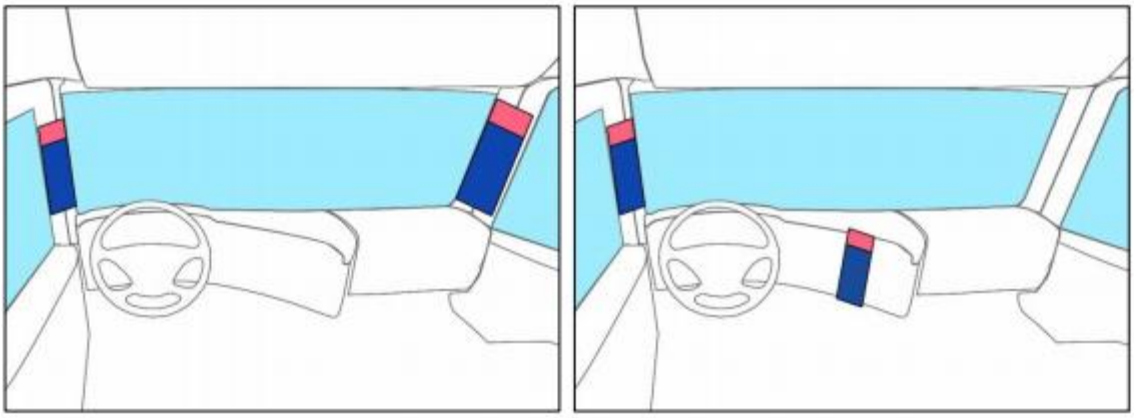


**Figure 7-1: Monitor locations used during simulator trials.
Source: Lundin & Zaimovic, 2015**

Simulator studies by (Large, et al., 2016) also found that drivers preferred monitor locations as close as possible to where they would expect mirrors to be. (Murata & Kohno, 2018) by contrast found that a centrally mounted screen was more effective than side mirrors based on the reaction time of the driver. They also found that an 8-inch screen was more effective than a 6-inch screen. If monitors need to be larger to be beneficial then this could make integration with the cab more difficult.

(Terzis, 2016) highlighted the importance of avoiding distraction and being able to adapt the brightness of monitor in relation to ambient light. They also highlighted that drivers with multi-focal lenses might find it advantageous to have the displays mounted lower to facilitate the readability. This conflicts with the common theory concerning the need to reduce the driver's workload by reducing the number of different locations that need to be checked.

Opportunities do exist for enhancing CMS, with the possibility of adapting and optimising views depending on different driving situations. For example, (Terzis, 2016) suggested that image processing algorithms can be used to recognize dangerous situations and objects such as quickly approaching vehicles and give the driver an early warning and an optimized field of view (including graphical overlays) for this situation. This could make CMS a fundamental technology for the development of other advanced driver assistance systems.

With direct vision and to a lesser extent a conventional side mirror, eye contact between the driver and the VRU offers a communication channel between the parties, offering reassurance that one is aware of the presence or intend of the other. (Terzis, 2016) highlighted that this possibility does not exist in the case of CMS.

7.5 Regulatory requirements

(Terzis, 2016) states that CMS used in addition to mandatory mirrors are not regulated in Europe. Examination shows that UNECE Regulation 46, the regulation defining minimum standards of indirect vision in European type approval, defines camera monitor systems as devices for enabling the six defined vision areas (class I to VI) to be seen. That is, there are effectively defined as mirror replacement CMS. Regulation 46 was, in 2016 at least, the only Regulation worldwide allowing mandatory mirrors to be replaced by camera monitor systems (Terzis, 2016).

The Regulation does also define ‘surveillance camera monitor recording devices’ as a separate system for allowing views other than the six defined by the regulation to be seen and/or as a security device. However, these are not subject to the technical requirements of mirror-replacement CMS. Similarly, where there are problems with blind spot mirrors being able to see the defined views, it is permissible to use a ‘vision support system’ to enable the driver to detect and/or see objects in the area adjacent to the vehicle. This could be a camera monitor system but could also be a sensor/detection system. In either case, the only technical requirement applied to it is a definition of an object that must be detected.

For mirror replacement CMS, UNECE Regulation 46 builds on ISO 16505 requirements to provide comprehensive definition of the field of view that must be visible but also a range of parameters relevant to the quality of the monitor image and the ergonomics around the ability of the driver to see the image in a range of conditions. These include requirements around the contrast and blooming experienced under direct sunlight, low light performance and the ability to view the screen in different light conditions and at different angles.

In the main wording of UNECE Regulation 46, camera monitor systems are defined as devices to enable one or more of the defined views (Class I-VI) to be seen. In that sense, a device intended to view a blind spot left after the mandatory views are achieved would not be deemed a camera monitor system.

However, Regulation 46 also allows devices to be approved as components. This means that the component supplier must show that the device meets all the quality requirements and would be capable of seeing one of the defined views if installed in the correct way. Components meeting these requirements must display the international approval mark consisting of a circle surrounding the letter ‘E’ followed by the distinguishing number of the country in which the approval has been granted. This allows component suppliers to sell a single approved product to multiple vehicle manufacturers. The vehicle manufacturer is then responsible for ensuring that the installation is correct such that the vehicle as a whole can be approved to UNECE Regulation 46. It also enables an aftermarket device to gain an approval to R46. The operator would then be responsible for ensuring that the system was installed in such a way that it met UK Construction and Use Regulations (1986) as amended, though there would not be a requirement for any test or certification to prove that it did.

In the USA rear view cameras are mandatory and subject to a range of technical requirements governing their field of view and the quality of the image. Quality includes minimum standards for the image size, requirements that it only activates on selection of reverse, for the speed of response to selecting or de-selecting reverse, and durability of the system in the presence of temperature cycles etc.

Four of five suppliers of camera monitor systems that responded to the survey stated that they offered CMS as a mirror replacement. However, only one confirmed that their system complied with UNECE Regulation 46, which is mandatory if the CMS replaces a mandatory mirror. This suggests that respondents may have misunderstood the question. Another respondent confirmed compliance with UNECE R10 (electromagnetic compatibility) and one more simply stated that their produce was ‘e-marked’ which implies compliance with at least one UNECE Regulation. Compliance with the field of view requirements of regulation 46 is dependent on the vehicle to which the system is installed and its installed location. So, it is presumed that the reference refers to compliance with the quality requirements of the Regulation via a component approval.

Although the Traffic Regulation Order (TRO) for the Safer Lorry Scheme in London is worded to require all vehicles within the scope of the TRO to be fitted with Class V and Class VI mirrors, CMS are permitted through an exemption clause[6] where doing so is permitted by UNECE Regulation 46 (Figure 7-2)

> **Exemption:**
> A Class N2 or N3 goods vehicle is an ‘exempted vehicle’ if the vehicle is fitted with any combination of direct view and/or indirect vision devices as permitted by UNECE Regulation 46 as an alternative to fitting a Class V or Class VI mirror.

Figure 7-2: Safer Lorry Scheme exemption clause that permits CMS instead of Class V/VI mirrors.

7.6 Systems fitted

The survey of technology suppliers identified five respondents stating that they supplied CMS, all but one of them as replacements for one or more mandatory mirrors. All systems record and store their images.

The system that does not replace mirrors was described as having a single in-cab monitor *“with 4 channels usually positioned on the dash, below the dashboard line, in the peripheral vision of the driver when checking his mirrors”*.

The mirror replacement systems varied, with one, for example, offering a single, 360° view, another having multiple, “triggered” views, e.g. near-side view on left turn indicator

[6] http://content.tfl.gov.uk/exemption-for-hgvs-with-indirect-vision-devices.pdf

activation, and another integrated with collision warning systems such as forward collision warning, headway monitoring, lane departure warning and VRU collision warning.

A brief review of suppliers advertising on the internet identified a company called Orlaco marketing a range of CMS for trucks and buses. The main system is marketed at OEMs and can replace all mirror views. However, they also claim to be the first CMS to get a component approval to UNECE Regulation 46 for market the Cornereye® system[7] to replace both Class V and VI mirrors. It was not 100% clear if these were available as an aftermarket fitment or only for OEMs. An example of their installation is shown in Figure 7-3 below.

Figure 7-3: Example of Orlaco Cornereye® installation

Brigade Backeye®360 has also achieved UNECE Regulation 46 compliance[8], Continental offer the ProViu®ASL360 cameras in a variety of formats including as a 360° birds eye view[9] but do not mention UNECE Regulation 46 compliance and Vision Techniques[10] produce a camera monitor systems that is integrated with a blind spot warning such that overlays appear on screen to highlight VRUs at risk. Again, compliance with UNECE Regulation 46 is not mentioned.

The above is a far from exhaustive list but serves to illustrate there are a variety of products readily available in the marketplace.

7.7 Future developments

(Jager, et al., 2018) showed the development of an integrated CMS and blind spot warning system using overlays on the monitor image to highlight objects causing a hazard. The Vision Techniques system above already does this to at least some extent.

Survey respondents suggested that improvements should include:

- 360° views and collision detection

[7] https://www.orlaco.com/cornereye

[8] http://transportoperator.co.uk/2016/11/22/brigade-camera-monitoring-systems-can-replace-class-vvi-mirrors/

[9] https://www.continental-automotive.com/en-gl/Trucks-Buses/Vehicle-Chassis-Body/Advanced-Driver-Assistance-Systems/Camera-Based-Systems/ProViu-360

[10] http://www.vision-techniques.com/turnsafe/turnaware

- Fitment by OEMs as factory standard
- Cost reductions
- Rigorous system testing
- Requiring camera system only to avoid too much driver distraction (i.e. no mirrors)
- Need sensors/cameras at front, not just side
- Evolve to 360° systems at later stage
- Multiple cameras, wirelessly linked
- Self-cleaning cameras

7.8 Evidence of effectiveness

7.8.1 Post-hoc statistical studies

There are very few vehicles on the road with mirror replacement camera monitor systems and, as such, no statistical evidence in relation to their effect on collision involvement yet exists. Supplementary CMS providing views in addition to mirrors are on vehicles in significant numbers but still no statistical analyses have been identified in relation to heavy vehicles.

However, (Cicchino, 2017) assessed the effectiveness of rear view cameras fitted to passenger cars in preventing police reported reversing collisions. Collision rates of four vehicles equipped with reversing cameras were compared to the same models where the option of a reversing camera was not taken. It was found that on average, reversing collisions were reduced by 17% when the cameras were present. The system had a much higher effect for older drivers over 70 (36%), though the difference was not statistically significant. Reversing will place different demands on driver workloads and may well be less complex than a left turn manoeuvre in busy London traffic. The degree to which results from reversing can be transferred across to apply to similar systems working in left turn collisions is, therefore, open to question.

7.8.2 Experimental evidence

(Schmidt, et al., 2015) completed an experiment with 42 drivers assessing when it was safe to make a lane change. Figure 7-4 shows that use of the CMS typically resulted in greater safety distance being employed compared with an external mirror, although this was not statistically significant. The tests were completed in a passenger car and not in urban traffic, so the circumstance may not be directly applicable to the scope of this study.

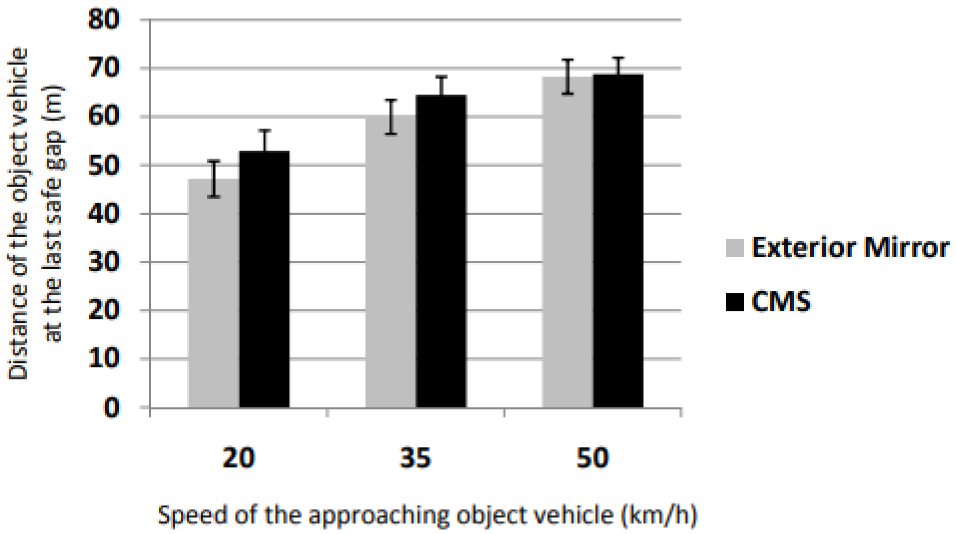


Figure 7-4: Comparison of perceived safe distance using external mirrors and CMS. Source: Schmidt, et al., 2015

Measured by the number and duration of glances some systems provoked more driver effort than a mirror, but one system required less driver effort.

A trial by (Schmidt, et al., 2015) using cars found that speed and distance estimation were carried out more conservatively with the CMS than with mirrors, i.e. subjects waited for slightly larger gaps before pulling out.

(Schmidt, et al., 2015) also assessed CMS on trucks. Results showed that CMS displayed the wide-angle image more clearly than mirrors, due to lack of concavity and distortion in the image. Additionally, it was found that a reversing task was performed more easily with the CMS. On average drivers estimated distance better than with mirrors but 60% rated the ability to recognise distant objects as worse.

(Lin, et al., 2010) evaluated the potential of a side view camera to reduce blind spots at the side of city buses using a controlled road trial with 28 drivers. They found that the camera field of view was much larger than with a mirror and that the drivers involved did not struggle with depth perception and were positive about benefits in lane change situations. They adapted quickly to the system, generally liked it and valued the benefits. They found it to be more effective than mirrors in both dark and rainy conditions.

(Fitch, et al., 2011) undertook a controlled 4-month road trial with 12 drivers of HGVs equipped with camera monitoring systems. Two systems were tested. For each driver and system, the vehicle was driven for one month with the system disabled and three months with it enabled. The 'advanced system' involved the fitment of three monitors, one at each A-pillar near the roof line and one at the centre of the screen near the roof. The second system was a 'standard' commercially available system with one camera each side looking rearward and two in-cab monitors placed on the dashboard either side of the steering wheel. In all cases the test vehicle retained its standard mirrors. Unsurprisingly, in a four-month trial, no collisions were encountered. The researchers instead defined 'safety critical events' but found that the use of the monitors did not reduce the number of safety critical events experienced. A concern based on earlier literature was that the monitors would take attention away from the road. However, it was also found that the amount of time the driver spent looking forward at the road did not change. The authors did find that glances at the CMS were of shorter duration than for convex mirrors, suggesting that the driver extracted the required information from the mirrors more quickly than from convex mirrors.

(Large, et al., 2016) studied the effects of mirror replacement CMS in a simulator trial and found that driver performance improved in terms of reduced decision times for drivers, though they cautioned that this may at least be partly down to limitations in the experimental design.

7.9 Cost of implementation

Operators responding to the survey provided a wide range of installed cost varying between £500 and £3,500, with £2,000 - £2,500 being the most commonly quoted figures. Warranties tend to be 1-2 years typically, though a minority (15%) of operators have 2-5-year warranties. Very few operators pay extra for these longer warranties.

7.10 Gap analysis

High quality CMS was well backed by theory, human factors experiments and limited road trials. However, no evidence was identified, positive or negative in relation to predictions of casualty effects.

No statistical information and little if any on the effectiveness of stitching multiple views into a single panoramic view was available.

Table 7-1: Evidence identified for effectiveness of CMS

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical			x
Causation	X	X	
Predictive			
Experimental: Physical		X	X
Experimental: Behavioural		X	X
Survey: Observed			
Survey: Stated			

x = Limited/weak evidence; X = Stronger evidence

7.11 Candidate policy options

The literature identified a wide range of parameters that seem to be important to the likely effectiveness of camera monitor systems whether used as a supplementary view or as a replacement of an existing mirror view.

Theory strongly suggests that further increases in the number of discrete mirror and/or camera locations that the driver must actively scan and monitor will at least reduce the effectiveness offered by a reduction in blind spots and has the potential to be counterproductive. However, at least one trial showed that with two or three monitors in addition to mirrors there was no change in the frequency or severity of safety critical events. This might suggest that at this level any benefit from decreased blind spot is neutralised by workload problems, though the same study found no reduction in the time spent looking forward.

For rear view cameras, most literature found that they should be activated only in reverse, though some studies did find benefits to the rear-view camera on a truck in forward driving.

Glare from monitors at night time was found to be a concern wherever screens were not adjustable in brightness.

Screen size and location was found to be important. Most research agreed that a bigger image was better and that drivers preferred screens close to the location of existing mirrors. However, studies considering objective measures of performance were sometimes at variance with this suggesting in one case that a single screen directly in front of the driver was better or where the driver's side view was on an a-pillar with the passenger side view in the instrument panel to the right of the steering.

The quality of the display was also considered important in terms of its ability to seamlessly integrate different views into one image. Restrictions around the response to direct sunlight on the camera, on the monitor, different viewing angles, brightness and contrast were all important.

Most of these requirements are covered by UNECE Regulation 46 but this only applies directly to whole vehicles where at least one of the mandatory fields of view are provided by camera monitor systems as a replacement for mirrors. The US Regulation (FMVSS 111) also provides minimum standards for reversing cameras and covers some common areas with UNECE Regulation 46. Compliance with the technical quality requirements of either of these regulations would provide more confidence that any system had been well implemented and would be likely to be effective.

This leads to a range of possible CMS options for technical requirements:

- **FORS Silver**: a full view of the nearside blind spot and a system monitoring the rear blind spot (front and offside are optional). No technical requirements on quality, location of installation etc.
- **Side, front and rear view**: Add a frontal view to the mandatory requirement. Collisions at the front of the vehicle when moving off from rest are equally important as those when the vehicle is turning left.
- **Restrict number of locations:** Such that the driver needs to view a maximum of 6 mirrors plus 2 monitors
- **Restrict monitor location:** Monitors to be positioned close to a window edge or existing mirror location, to minimise the time a driver needs to scan the monitor(s).
- **Allow CMS to replace mirror views**: This could reduce the number of locations needing scanning. If this is undertaken it must be proved compliant with UNECE Regulation 46, as per the exemption clause of London's Safer Lorry Scheme.
- **CMS as a supplement to mirrors:** Require CMS used as a supplement to mirrors to gain a component approval in accordance with UNECE Regulation 46
- **CMS as a replacement to mirrors:** Require CMS to replace all mandatory mirrors such that all mandatory views can be achieved in three monitors, substantially reducing the number of locations the driver needs to scan. Include requirements for views that adapt to circumstances

- **Integrated CMS:** Require an integrated CMS and warning system such that visual warnings occur around or within the display showing the detected hazard, with supplementary warnings if there is an imminent collision risk.

8 Blind Spot Information, Warning & Intervention systems

8.1 Fundamental concept

The use of sensing systems to detect the presence of vulnerable road users and warn drivers can have several advantages:

- Small unobtrusive sensors can see a wide field of view and can fill blind spots left between direct and indirect vision
- Warnings can draw the attention of a driver to a problem even if the driver is not looking in the right direction
- Sensors can monitor different areas of view simultaneously, which humans cannot do with mirror views and only partially via peripheral vision for direct views through the windscreen.

Thus, blind spot information, warning and intervention systems can be of benefit in terms of eliminating blind spots but also in terms of improving the chances of a driver detecting the presence of a vulnerable road user in positions where they may already be available to be seen in direct or indirect vision. This is particularly true in highly dynamic collision types where, for example, a cyclist might be technically available to be seen but is at a substantial distance when a driver initially checks the mirror but then have rapidly moved forward such that when the driver next scans they may be moving between visibility in rear view mirrors, class V blind spot mirrors and direct vision, spending only a short time in each. The driver may be attentive but just unlucky to look at the wrong place at the wrong time. A good warning system can, therefore, substitute to some extent for poor vision but can also complement and enhance good vision by acting as an aid to the driver in difficult traffic situations.

Even a good warning system still relies on the driver to react quickly and appropriately and so the possibility for collisions remains. In certain circumstances it may be possible for the vehicle to intervene on behalf of the driver to prevent a collision that a driver has not reacted appropriately to, despite the warning.

8.2 System activation and warning strategy

8.2.1 Defining true and false positives

The aim of the systems within scope of the HGV Safety Permit is to prevent the same type of collisions thought to be caused by blind spots that the vision measures are intended to prevent. Thus, the situations that are considered desirable for the system to activate include, for example, when a pedestrian walks across the front of a stationary HGV at a time when the HGV intended to move off from rest, or when a cyclist is positioned on the inside of the HGV that is turning left and is on a collision course. If the system does indeed activate in such a situation, it is referred to as a ‘true positive’. However, it is also possible to have ‘false positives’ and both true and false negatives. A basic definition of the concept is shown in Table 8-1, below

Table 8-1: Basic classification of system actions. Adapted from (Martinez & Martinez, 2008) as cited by (Lubbe, 2014)

		Does the system activate?	
		Yes	**No**
Will a collision happen in the absence of intervention?	**Yes**	True Positive	False Negative
	No	False Positive	True Negative

In the most basic form, then true positives and true negatives are always desirable and false positives or negatives are always undesirable. If this is considered in the context of this study, then the system should only activate if the HGV is on an active collision course with a VRU such that a collision would happen in the absence of intervention. However, there is often a trade-off between the objectives of minimising false negatives and false positives (see for example (Nadler, et al., 2017). Where a system activates and there is no plausible risk of collision, then it is clearly a false positive. Several authors, see for example (Parasuraman, et al., 1997) (Naujoks, et al., 2016), have shown that false positives where a driver cannot see a plausible reason for a warning undermines trust in the system and results in drivers complying with the warning less frequently.

However, where the driver does see a risk of collision, the definitions are open to interpretation in terms mainly of timing. A driver might consider that he or she can see a risk of collision, but the warning came too early at a time when they had perceived the risk but not yet deemed it necessary to act. It might be timely, or it might also be perceived as arriving too late to help avoid a collision.

Whether any individual driver considers a warning premature will depend on their own individual driving characteristics. An aggressive driver who regularly brakes harshly and is used to avoiding hazards relatively late, will have a different interpretation of what is premature compared to an overly cautious driver who rarely brakes hard and typically maintains large gaps to vehicles. Similarly, there is a wide range in human emergency braking performance. For example, (Dodd & Knight, 2007) reported on a driving simulator trial with a group of normal drivers. The simulated vehicle was capable of a deceleration of 10 m/s^2 but in emergency events on average the subjects only achieved mean decelerations of 7.5 m/s^2 with a standard deviation of 10%. On average, drivers took 0.93 seconds from first touching the brake to achieving 90% of their peak deceleration. In this measure the standard deviation was 35% of the mean. This means that some drivers will need to brake earlier than others to avoid a collision in the same situation. Once braking some drivers will need a much higher peak brake force to avoid collision because they took longer to reach it, which will affect their perception of how severe an emergency was.

This variation in driver perception leads to the consideration of whether a classically defined false positive is always undesirable. (Lubbe, 2014) cites (Kallhammer, 2011) who argues that activations should be assessed in terms of their usefulness, not in terms of true and false. (Kallhammer, 2011) argues that if a true positive alarm is technically very accurate, it will be very rare because collisions are very rare. Drivers with no experience of such a rare event will not have learned how to react efficiently to it, such that the alert will have no value. (Abe & Richardson, 2006) also studied the timing of forward collision warnings and found that alarms that were activated after the driver had already initiated braking were considered late and that typically drivers expected alarms to be activated before they instigated braking. The authors found that when this does not happen, driver trust in the system is substantially decreased. This means that a true negative that is highly technically accurate (not activating unless a collision is certain in the absence of system intervention) can also be undesirable and undermine trust in the system.

These factors in combination led (Lubbe, 2014) to propose the following classification system.

System activation			
Yes	No		
True Positive (TP)	False Negative (FN)	Yes	Collision certain without system activation?
Desired False positive (DFP)	Desired True Negative (DTN)	No	
Undesired False positive (UFP)	Undesired True Negative (UTN)		

Figure 8-1: Enhanced Activation classification proposed by (Lubbe, 2014)

(Naujoks, et al., 2016) found that warnings that were not strictly necessary but where the driver could see the rationale for the alarm did not result in reduced compliance with the warning. It should be noted that these results were based on driving a simulator through 12 critical and 12 non-critical situations over a 45-minute drive, so excludes any long term effects. (Maltz & Shinar, 2004) goes further showing evidence from a simulator trial that a collision warning system intended to operate in front to rear shunt collisions that activated prematurely became a kind of headway monitoring system that allowed drivers to better judge the right distance to leave to the vehicle in front and reducing collisions as a consequence of being better at avoiding getting into situations where an accurate collision warning would be needed. This was recently confirmed by (IIHS, 2018) in a road trial of an aftermarket collision warning system (by Mobileye) and is consistent with the headline outputs of a trial of the same system applied to a London bus[11].

8.2.2 Urgency and criticality

A wide range of research has identified that the most effective type of warning, bearing in mind the need to effectively alert drivers while also minimising the potential for annoyance, depends on the criticality and urgency of the driving situation. This has led to definitions of the criticality and urgency of warnings in ISO standards, for example (ISO, 2004) (ISO, 2005). In considering the wide variety of evidence and standards in existence, international regulators produced guidance for regulators establishing requirements for high priority warning signals (UNECE, 2011). The key parts are (Knight, et al., 2017) that in international standards, four levels of criticality have been defined, based on road user injury and vehicle damage (ISO, 2004). The four levels are:

[11] https://www.abellio.co.uk/news/abellio-launches-mobileye-bus-safety-technology-trial/

Criticality Level 3

- Severe or fatal injury to occupants

Criticality Level 2

- Severe or possible injury to occupants

Criticality Level 1

- No injury to occupants but with damage to any vehicle

Criticality Level 0

- Neither injury to occupant nor damage to any vehicle

The urgency has been defined based on the time within which the driver action or decision has to be taken if the benefit intended by the system is to be derived from the signal (ISO, 2004):

Urgency Level 3

- Respond immediately (0 - 3 sec)

Urgency Level 2

- Respond within a few seconds (3 - 10 sec)

Urgency Level 1

- Response preparation (take action or decision within 10 sec - 2 min)

Urgency Level 0

- Information only

Many collision warning systems are designed to work in situations where severe injury or fatality are possible outcomes. (UNECE, 2011) simplifies the above based mainly on the urgency of the warning:

High-level

- warning requires the driver to take immediate action or decision (0 to around 2 seconds) to avoid a potential crash that could result in serious injuries or fatalities

Mid-level

- requires action or decision within around 2 to 10 seconds; may escalate to high-level warning if not acted upon

Low-level

- driver prepares action or decision within 10 seconds to 2 minutes; may escalate to a higher level if not acted upon

Research, for example, (Baldwin & Lewis, 2014) has shown that within any given type of warnings, there are variable parameters that can affect the balance between how effective the warning is at alerting drivers, versus how annoying it is. In general, increasing effectiveness was correlated with increasing annoyance. However, the extent to which annoyance increased with effectiveness varied between different types of warning. In general, the research showed that:

- Visual warnings of a simple colour or written message were least alerting and least annoying and that at their best, they could be as alerting as tactile and audible warnings at the lower end of their range.
- Flashing visual warnings were more alerting but could also be substantially more annoying.
- Audible warnings were among the most alerting but also the most annoying
- Tactile warnings could buck the trend to some degree, with the best versions being as alerting as the best audible warnings while being less annoying than those

(Naujoks, et al., 2016) and others have shown that driver response to warnings is also affected by how the warning is presented, for example responding more quickly to combined audio-visual warnings than audible alone.

Consideration of speech warnings is mixed in the literature and strongly related to urgency and criticality of the situation and the duration and clarity of the message. The theory is that tones can alert a driver but are generic and don't convey the content of what the alarm is. Speech can convey that content but takes a finite time to deliver and comprehend. (McKeown & Isherwood, 2007) looked at different types of audible messages within vehicles in relation to non-critical driving events, such as 'exceeding speed limit' and found that speech messages outperformed abstract tones in terms of identification time and accuracy. They were also perceived as more pleasant and less urgent than tonal messages. A range of research studies, for example (Politis, 2016) (Baldwin & Lewis, 2014), have found that a speech message alone does not perform well in urgent and critical situations. However, (Politis, 2016) cited other works that found that combining short speech messages with other more urgent modalities improved effectiveness and their own test results showed that using elements of speech in an enhanced multi-modal tactile warning could be effective.

In combination this type of research has led to the development of a range of ISO standards defining the types of warning that should be used in different situations and these were reviewed by (Knight, et al., 2017). The findings can be summarised as below.

In general, drivers must make a lot of decisions all the time during driving, but collisions are rare. Thus, low-level situations as defined by (UNECE, 2011) above are likely to occur very frequently. High level situations requiring action within 2 seconds will be relatively rare. Thus, it makes sense for the least alerting and least annoying warning modes to be used for the frequent, low urgency incidents. Thus, audible (tones) and multiple mode warnings should not be used for low urgency events. Conversely, the most urgent events demand the most alerting techniques. Thus, speech should not be used for urgent warnings. The fact that they are rarely issued means that although they are individually more annoying and intrusive, the cumulative level of annoyance during driving over a substantial period will remain low.

8.2.3 Supporting driver perception and response

(UNECE, 2011) defines the driver perception-response sequence as:

- **Detection**: Driver attention
- **Identification**: Understanding
- **Decision**: Choosing response
- **Response**: Taking action

If an urgent warning, defined in the preceding section as 'high-level', is issued then as long as an effective presentation of the warning is chosen, it could be very effective at alerting the driver to the presence of a hazard; **detection** in the four phases of perception-response described above. However, this realisation that a problem exists does not help the driver to **identify or understand** the exact nature of the problem. Without fully understanding the nature of the problem, it may be hard for the driver to **choose** the correct response and promptly **take action.**

A good warning system can help to support the driver not just with detection but also with the remaining phases of the perception response. Based on (UNECE, 2011) and ISO reports and standards (ISO, 2004) (ISO, 2005), (Knight, et al., 2017) defined 10 principles that the warnings should follow. Of relevance to supporting the understanding and decision elements of perception-response, were requirements that warnings should provide spatial cues to the hazard location, elicit timely responses, inform the driver of the proximity of the hazard, and minimise the chances of unintended consequences of activation.

In short, this can be taken to mean that the warning needs to draw the drivers attention in the direction of the hazard such that he or she can quickly gain sufficient situational awareness to make the right choice of avoidance action and implement that action quickly. Thus, the test method developed by (Knight, et al., 2017) rewarded systems that had directional warnings and staged approaches of increasing urgency as a collision became more likely. This could have been implemented by early warnings using speech to locate the hazard, or visual warnings adjacent to where the VRU was most likely to be seen, for example a warning lamp adjacent to the A-pillar/nearside mirror for a cyclist at the side of the HGV. This might be combined with later multi-mode warnings when a collision became imminent.

(Terzis, 2016) cites the future potential to integrate Camera Monitor Systems with blind spot information and warning systems such that visual warnings can be displayed in the monitors used as substitutes for mirrors to draw the attention of the driver directly to the view that they need to see. Further development could include the use of screen overlays to enhance the visibility of a detected hazard combined with audible warnings when collisions were imminent. These have the potential for improving the perception-response process over, for example, those with simple visual or audible warnings.

Vision Techniques produces a "turn detection system"[12] which uses a camera and monitor system in combination with "motion sensors" to achieve a system where the hazard can be seen on a monitor and visual overlays combined with audible warnings are applied to warn drivers of a hazard.

8.2.4 Intervention on behalf of the driver

At least one truck on the market is available with an automated emergency brake (AEB) system that will detect pedestrians and react to apply the brakes in collisions where a pedestrian crosses the road in front of a moving HGV. These systems have the advantage of being able to react more quickly than the average human driver in such situations and TfL has developed standards intended to encourage the adoption of AEB on its fleet of buses[13]. The collision data do show that there would be similar significant potential for such systems on HGVs in London but it is clear that the system will not be available on sufficient vehicles to be economically viable for implementation in the Safety Permit in 2020. In addition to this, the group of casualties expected to benefit from such a system are not a group that are adversely affected by blind spots. In So, AEB would not be a direct substitute for direct vision in the way that other measures considered here would be.

There are, therefore, no automated intervention systems available on the market now that would benefit the same group of casualties as improving direct vision to the front of the vehicle. However, (Knight, et al., 2017) proposed including such a system within a proposed rating scheme for blind spot safety devices because it was considered that it was technically relatively straightforward and low risk (compared to AEB for example) to develop one and it was considered desirable to incentivise such a development. The test procedure was designed to reward fitment of a system that would either apply the brakes or disable the throttle in a situation where sensors detected that the vehicle was stationary, and a vulnerable road user was positioned in close-proximity to the front of the vehicle. The test procedure permitted the driver to manually over-ride the system to avoid the possibility of a false positive or defect leaving the vehicle stranded and unable to move but only if a collision warning was sounded throughout any initial movement.

8.2.5 Application of principles to systems in use

The survey results show that a large proportion of blind spot warning systems currently on the market, or in use by operators, do not fit well with the principles defined above.

[12] http://www.vision-techniques.com/turnsafe/turnaware

[13] https://trl.co.uk/sites/default/files/articles/Bus%20Safety%20Standard%20-%20Executive%20Summary%20-%20TRL-TfL.pdf

Almost all operators responding to the survey believed that the system they used warned anytime a hazard is detected in close-proximity to the vehicle, rather than acting only when sensors detect that a collision is imminent. All but one technology suppliers confirmed that their system also warned based on proximity rather than collision risk. This type of system may, therefore, issue a warning while an HGV is stationary at the lights and a cyclist is stationary adjacent to the vehicle. If that cyclist is in a blind spot or the driver is not paying sufficient attention, then it is a valid piece of additional information that can help the driver to do the right thing. If the cyclist is visible in either direct vision or mirrors at that time and the driver has looked and seen that they are there, the warning becomes unnecessary. In either case, it can be a significant amount of time before the vehicles even begin to move and even then, if for example there is adequate room and the HGV is proceeding straight ahead or both vehicles are turning left such that they are never on a collision course. Thus, the urgency is at most mid-level and may quite frequently be low-level.

Thus, the evidence suggests that for this type of systems, the warning should be issued as a visual, haptic or spoken word warning of relatively low urgency. However, the survey evidence suggests that most systems in existence today use audible warnings of the tonal variety, which they evidence suggests are highly alerting but also highly annoying.

All respondents to the relevant section of the technology suppliers survey stated that their system would warn for a pedal or motor cyclist and 6 of 7 would warn for a standing pedestrian (the one that would not, manufactured a system specifically for left turns targeting only cyclists). However, 2 of 7 respondents said their system would warn in response to roadside furniture such as a road sign, lamp post or pedestrian railing. In a situation where the vehicle is on a collision course with that roadside object, the evidence suggests this would be considered by most drivers a valid warning. However, 5 of 7 respondents indicated that their systems are based on warning whenever a detected object is within a defined distance of the vehicle not only when it is on a collision course. Thus, it is quite possible that a stationary vehicle at traffic lights will issue a warning just because the vehicle is within a short distance of the traffic light pole itself or some other roadside furniture adjacent to the road. In this situation, there is genuinely no risk that the driver is likely to consider plausible and so it will often be perceived as a false positive. The scientific evidence suggests that this will reduce compliance with the warnings. Extrapolating the evidence also strongly suggests that the annoyance factor would be considerably worse if it was an urgent warning (e.g. audible/tonal) and the survey suggests that most of them are. This may reduce compliance further.

The HGV operators and drivers responding to the survey generally thought their systems worked reasonably well but, warning too frequently, warning in relation to roadside furniture and drivers becoming immune to warnings were all regularly mentioned as negative aspects of the systems.

In a stakeholder meeting ahead of the start of this project, attendees flagged the need to define the appropriate range for the systems. The context discussed was in terms of tuning the range to balance the warning effectiveness of the system against the potential negative effects of ‘false positives’ and ‘over-exposure’. The systems are not usually driver adjustable but, when purchasing the system, it is possible for the operator to choose from different detection ranges. For example, one operator sells systems covering the whole side of a vehicle with a lateral range selectable as either 1m or 1.5m, or simpler systems covering only part of the side or the corner of the vehicle, with a range selectable as either

0.6m or 1m. For each of these, the brochure states two levels of detection sensitivity but this is not further defined. Another manufacturers website described a 3-stage warning:

- 1st stage: Triggered when the hazard was 0.6m from the vehicle,
- 2nd Stage: Triggered when the hazard was 0.45m from it, and
- 3rd Stage: Triggered when the hazard was 0.3m from the vehicle.

Responses to the survey completed as part of this project highlighted that proximity sensors were able to detect objects typically within 1 – 2.5 m of the vehicle.

TfL's Direct Vision Standard assesses the direct vision performance at up to 4.5m from the side of the vehicle, based on the principle that a 5th percentile Italian female should be visible when stood at the extreme edge of the mandatory view from the class V mirror. Earlier research in direct view had (Robinson, et al., 2016) had suggested that the zone of relevance for direct vision extend 3.5m laterally to the nearside of the vehicle. This was based on the geometry of infrastructure in London where this would allow an HGV turning left from lane 2 to see a cyclist positioned at the inside of lane 1. (Schreck & Seiniger, 2014) proposed the development of a test procedure for blind spot warnings for HGVs and proposed a maximum lateral separation of 4.5m based on observed separations on collisions investigated in Berlin. However, what led to this conclusion was a significant proportion of collisions occurring where the HGV was turning across the path of a cyclist travelling on a cycle lane separated from the main road by a substantial distance, often also incorporation trees. This form of infrastructure is relatively rare in London as illustrated in Figure 8-2 below.

Figure 8-2: Examples of separated cycle lanes with potential line of sight obstruction in Germany. Source London on left (Knight, 2017) & Berlin on right (Schreck & Seiniger, 2014).

Direct vision is a passive system and there is no disadvantage to offering more vision. Thus, the only potential problem with including a wider field of view is that if all, or nearly all, vehicles can see the extremities of the zone, the test procedure will be less sensitive to small changes to field of view closer to the vehicle which may have more value to safety. However, when proximity warnings are considered (those that activate whenever an object is within a defined range), particularly those that activate in response to any object not just vulnerable road users, there are potential disadvantages. If a vehicle was driving in a position similar to that on the left of Figure 8-2 above and was equipped with a system with a range of 4.5m, then it would warn the drivers of vulnerable road users and potentially buildings up to around 3.5m on the pavement side of the kerb edge. The driver of such a vehicle would very likely not see the presence of these objects as plausible safety risks and thus a warning could undermine driver trust in the system and create significant annoyance and reduce compliance with the warnings.

Based on the evidence, there is, therefore a case for the existing systems offering detection ranges that are smaller than the zones defined for the assessment of direct vision. However, it is equally apparent that at the lower end of the range offered (c.0.6m) that a vehicle in the situation depicted on the left of Figure 8-2 above could fail to detect a cyclist positioned immediately next to the kerb. Thus, at the lower end of the range, the effectiveness in true positive situations, where the warning is needed, is likely to be much lower. Consideration of why a supplier or operator may see it as beneficial to specify a range as low as this comes back to the activation strategy and the urgency of the warning. Most of the systems operating in this way activate:

- whenever an object is in detection range not just when a collision is imminent,
- in response to fixed objects as well as vulnerable road users, and
- use a relatively high urgency, high intrusion, audible warning.

Thus, even at relatively modest lateral ranges, a considerable number of activations can occur, and the high urgency warning mode can create driver annoyance and poor compliance.

Thus, changing the activation strategy and warning urgency to better match the recommendations from the experimental evidence could allow improved effectiveness by allowing an increased detection range, while also improving driver compliance with the warnings. There are examples of individual systems that operate in a way more closely aligned with this approach. For example, Fusion Processing supply a system (CycleEye®)[14] that remains a proximity warning only but does separately identify cyclists and roadside furniture such that it will only warn for cyclists, not other objects. It uses a spoken word warning consistent with the low-med urgency of a proximity warning in most encounters with cyclists. Unfortunately, it currently only works for cyclists at the side of the vehicle and not pedestrians or cyclists at the front of the vehicle, though it is understood that future systems are under development.

Two respondents to the technology supplier surveys indicated that they have, or are working on a motion inhibit system, as included in the test procedure developed by (Knight, et al., 2017) to prevent the vehicle moving off from rest when a VRU is positioned in front of it. Further dialogue with one of those suppliers shows that this is a working prototype that can be demonstrated now but is not yet ready for production.

Two respondents to the survey produce a range of camera driven warning systems based on tracking and classifying objects. As such it can tell the difference between vulnerable road users, other vehicles and roadside furniture and adapt its warning strategy to suit. A range of systems are available including basic warnings whenever the headway to a vehicle ahead is below a threshold value, genuine forward collision warning where a collision would occur if no action was taken and collision warnings for vulnerable road users positioned at the sides and corner of the vehicles during turns.

Experience with one such system suggests that it was only active when the vehicle is moving, such that it would not warn of the presence of a pedestrian in the forward blind spot when the vehicle is stationary before a moving off from rest collision. Another possible limitation is that although a true collision warning they are often set to warn relatively

[14] http://www.fusionproc.com/products/

early. For example, (Reagan, 2018) found that in a road trial a system of this type issued forward collision warnings at an average rate of between around 1 and 5 per 100 miles depending on whether the warning was live (actually issued to drivers or in a disconnected mode where the warning was recorded by not connected to the buzzer) and by location. Given that in the UK passenger car traffic totals 253 billion vehicle miles, then it is clear that each activation does not correspond to a collision avoided. It is expected that warnings should activate in many situations that would be near misses and that near misses might number an order of magnitude more than actual collisions. However, the activation rate still implies another order of magnitude more collisions than are actually recorded. This implies that the system evaluated does issue a significant number of warnings that are at least premature or unnecessary, if not fully false.

The Vision Techniques "turnaware" system is promoted[15] as a hybrid camera monitor system and warning system that activates the warning elements based on a proxy for detection of an imminent collision. That is, it claims to ignore hazards moving away from the vehicle and warns only when a hazard is moving towards the vehicle. It implies that it might react only to vulnerable road users not other objects but this is not 100% clear.

It should be noted that none of the systems above have been independently tested as part of this research.

8.3 Future regulation and standards

In October 2018, the UNECE adopted a new draft regulation relating to blind spot information systems for the detection of bicycles (UNECE, 2018). This regulation is intended to reduce the frequency of low speed collisions between trucks turning right in mainland Europe, left in the UK, and cyclists positioned to the side of the vehicle. They refer to the same principles of urgency of the warning as discussed earlier in this report but conclude that because the time available between the probability of a collision becoming high and the moment of impact is low, that a low urgency "information signal" should be provided at a time when the cyclist is in a position of risk alongside the vehicle but before the vehicle has commenced turning while the probability of a collision remains low (most encounters between cyclists and trucks that have not commenced a turn do not result in collision). Effectively, this is equivalent to the terminology of a 'proximity warning' used in this research and defined in a draft performance test derived by (Knight, et al., 2017). The information signal, or proximity warning, will be issued any time that a hazard is detected in the area defined, regardless of whether the participants are on a collision course or not.

The European Commission has published proposals to implement this UNECE Regulation in EU type approval as part of the General Safety Regulation[16] by 2020[17] for new types of HGV and by 2022 for all new HGVs sold. Although technically, Brexit would mean that the UK could change approval requirements on a national basis, there has been no suggestion from the UK Government that this is likely, and the UK will remain a member of the UNECE and, therefore, able to adopt the UNECE Regulation independently.

The main requirements of the regulation are that:

[15] http://www.vision-techniques.com/turnsafe/turnaware
[16] https://eur-lex.europa.eu/resource.html?uri=cellar:f7e29905-59b7-11e8-ab41-01aa75ed71a1.0003.02/DOC_2&format=PDF
[17] http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/625192/EPRS_BRI(2018)625192_EN.pdf

- An information signal (proximity warning) is mandatory and must be issued at a time before a vehicle commences the turn that would then result in collision. Information signals must be optical.
- The BSIS shall warn the driver when the risk of collision increases (i.e. collision warning). Thus, a 2-stage warning is required. The warning can be optical, acoustic, haptic or any combination of these. However, it must differ from the information signal, for example in mode or activation. The warning must not be issued before the vehicle has commenced towards the cyclist.
- The system must operate at all speeds from standstill to 30 km/h but there is no requirement to prevent it being operative at speeds above 30 km/h
- It must operate in ambient light conditions above 15 lux, approximately equivalent to streetlit night time conditions.
- The system must issue the information signal in response to cyclists travelling at between 5 and 20 km/h at a lateral separation of between 0.9 and 4.25m. When the cyclist is forward of the front axle the lateral separation is reduced to 0.25m.
- The vehicle manufacturer is obliged to ensure that the number of false positive warnings due to the detection of static non-VRU objects such as cones traffic signs and parked cars shall be minimised. An information signal (proximity warning) is permitted in response to such items if a collision is imminent.
- The system must operate when the direction indicators are not activated.
- A test procedure to prove compliance is defined. This involves tests:
  - with a stationary vehicle and a cyclist moving up the inside of the vehicle at a lateral separation of 2.75m: the information signal must activate at least by the time that the cyclist is 7.77m to the rear of the front of the vehicle
  - with a stationary vehicle and a cyclist moving perpendicular to the vehicle on a path 1.15m in front of the vehicle: the information signal must activate before the cyclist reaches a point 2m from the nearside edge of the vehicle.
  - With a cyclist and vehicle moving in the same direction at different speeds and lateral separations. The information signal must activate a margin before the point where a theoretical application of steering would result in a collision between cyclist and a point on the vehicle less than 6m rear of the front of the vehicle. The test authority selects the test case from a matrix of 7 possible configurations spanning vehicle/bicycle speeds from 10-20 km/h, lateral separations from 1.25 to 4.25m and geometric parameters relating to impact positions from front to 6m back with turn radii of between 5 and 25m.
  - The moving cyclist and vehicle test also includes a requirement not to activate when passing a standard traffic sign. The regulation does not explicitly define the lateral separation between traffic sign and the edge of the vehicle. It states that it must be positioned at the entrance to a defined test corridor and the corridor is defined as being 1m wider than the test vehicle. It makes sense that the sign is positioned longitudinally at the start of the test corridor, but it is possible that it also means that it shall be aligned laterally with the test corridor which would result in a lateral separation of nominally 0.5m but in reality, between 0 and 1m.

  - No test is defined that actually proves that the collision warning function works. Nor are there explicit requirements in the tests above that the collision warning must not activate, though it is implied by the overall requirement not to activate before steering commences.

Based on the information generated from literature and surveys, very few systems currently on the market and used in the London fleet would be likely to pass this regulatory minimum standard.

(Knight, et al., 2017) also developed a test procedure for blind spot warning systems. This was intended as a consumer information test and as such it graded performance into 6 easy to understand performance bands and did not mandate or prohibit any system. In the intent and technical principles, it was broadly similar to the proposed regulation but it went further in some aspects. The main differences were:

- The test procedure assessed performance in a turning manoeuvre and when moving off from rest when the vulnerable road user was in front of the vehicle.
- It assessed performance for proximity warnings (information signals), collision warnings, blind spot aids (e.g. camera monitor systems), and for an intervention system defined as 'motion inhibit' to prevent a driver pulling away from rest while a VRU was present in front of the vehicle
- In left turn manoeuvres it assessed lateral separations of 0.6 to 1.5m, instead of 0.9m to 4.25
- Specific tests were included to assess for activation in response to a range of different roadside clutter (advertising hoardings, posts, railings) and to assess whether collision warnings activated when simply passing cyclists.
- While the HMI followed the same basic principles (low intrusiveness signals for less urgent situations, highly intrusive for high collision probability urgent situations), the evaluation went further. Proximity warnings could be visual or speech, rather than just speech. Additional points were awarded for warnings giving cues to the location of the hazard, collision warnings that were issues over multiple modes and where warnings have specific properties, for example, for speech warnings less than 6 words, for visual warnings the use of correct colour codes (e.g. amber for less urgent, red for urgent) etc.
- The manoeuvres were all subject to test both true and false positive scenarios and the test itself took the vehicles right up to just before the point of collision, significantly after the initiation of a left turn. This is important to enable a valid test of a collision warning system but does create risk of damage to expensive test equipment.

Based on the principles outlined in previous sections, a system scoring full marks in the test defined by (Knight, et al., 2017) would be likely to have a considerably greater collision reduction potential than a system just passing the proposed regulation in its current form (UNECE, 2018) and a greater potential than one that just meets the proposed requirement not yet drafted to extend the regulation to collisions involving moving off from rest. This is unsurprising because Regulation is intended to represent a minimum standard for the whole market and the procedure of (Knight, et al., 2017) was defined as a means of trying to shift the market toward best practice. Although not tested formally, it seems likely that a system just meeting the proposed regulatory requirements would score as band 3 of 6 (6 being the best) in the procedure defined by (Knight, et al., 2017) whereas most systems on the market currently would fall into bands 1 or 2.

The procedure by (Knight, et al., 2017) was defined before the Geneva process defining the draft regulation commenced and before some of the other research cited in this report was completed. These developments highlight some areas where the procedure by (Knight, et al., 2017) could be improved (e.g. testing at greater lateral separation) and other areas where simplification of the tests may be possible (e.g. false positives and testing of proximity only warnings only in a straight line condition). The latter would substantially reduce the cost of executing the tests.

8.4 Evidence of effectiveness

Table 4-1 showed that, between 2008 and 2017, 37 pedestrians were killed in collision with an HGV moving off from rest in London, representing 41% of the 90 pedestrians killed in total. Buses have excellent direct vision to the front of the vehicle and the moving off from rest collision type is thought to be relatively simple to prevent because the vehicle is initially stationary. However, data analysed as part of TfL's bus safety standard project showed that 29 pedestrians were killed by a bus moving off from rest, representing 27% of the 108 pedestrian fatalities that occurred in collision with a bus. So, although the proportion killed in these circumstances is lower for buses, the problem has not been eliminated. Thus, systems to attract the driver's attention to the risk and/or to intervene do still have significant potential.

8.4.1 Statistical studies

(Cicchino, 2016) analysed the effectiveness of forward collision warnings (FCW) intended to prevent front to rear shunt collisions when fitted to passenger cars. She found that vehicles fitted with FCW had on average 23% fewer police reported collisions where the equipped vehicle struck the rear of another vehicle and this was statistically significant. When only front to rear collisions involving injury were considered the reductions from FCW were only around 6% and were not statistically significant. When FCW was combined with automated emergency braking (AEB) then collision involvement was reduced by 39% and collisions with injuries by 42%.

Abellio Group operates buses in London and trialled the use of an aftermarket forward collision warning, headway monitoring, speed limit indicator and lane departure warning system. Sixty-six buses were equipped with the system in normal service for more than a year. Interim results suggested a reduction in all collisions of 30% and a reduction in injuries of 60%[18]. Additional consultation with the operator suggests that the collision reduction was based on a substantial number of collisions in the 'control' group, though the injury reduction was based on a single figure sample in the control group such that there was considerably more uncertainty in the injury figure. The study was a before and after fitment study and as such, it would measure the combined effect of all changes that occurred in the same time frame rather than specifically the effect only of the measure. However, Abellio had controlled for that as far as possible by restricting the trial to operation out of one depot where no other safety related changes were made during the trial period. Results were also compared to trends at other depots over the same period which supported the finding of a strong reduction. It should be noted that this system used a forward facing camera only and so did not warn in situations of cyclists on the inside of

[18] https://www.businesswire.com/news/home/20181114005196/en/Abellio-London-Achieves-Significant-Reductions-Collisions-Injuries

a vehicle turning left and only one incident in case or control groups involved a pedestrian that would have been in the camera view before collision such that the sample was not large enough to prove or disprove any effect of the system on pedestrian collisions.

8.4.2 Experimental evidence

(Naujoks, et al., 2016) found that drivers reacted significantly more quickly to hazards with a collision warning system even when that system was not perfectly reliable and gave some false or unnecessary warnings. (Maltz & Shinar, 2004) also found that even 'imperfect' collision warnings could aid drivers in the form of a training aid. That is, a frequently issued warning tended to encourage drivers to drive more defensively so that they triggered the warning less frequently, and this was supported by (Reagan, 2018). Many other authors have found in simulator studies and road trials that correctly delivered warnings could improve driver responses in hazardous situations, for example (Abe & Richardson, 2006) (Baldwin & Lewis, 2014) (Kallhammer, 2011) (Parasuraman, et al., 1997) (Politis, 2016).

8.4.3 Predictive studies

(Barrow, et al., 2017) studied 'VRU detection systems' and 'AEB PCD' alongside direct vision in a predictive study of effectiveness based on case by case analysis. The vision analysis was reviewed in section 6.3.4. and included quite detailed information on the results. VRU detection systems were defined as systems that warned of the presence of a Vulnerable road user (VRU) ahead of the vehicle or at the side. VRU AEB was defined as a system that would detect a VRU ahead of the vehicle or at the side, warn the driver and automatically brake. The definition asserts that both systems were considered to:

- be less dependent [than direct vision] on driver actions;
- offer additional benefit in higher speed traffic scenarios
- Include crossing pedestrians
- Cover all speeds including pulling away from stationary and very low speeds.

It should be noted that very few current HGVs offer a production AEB system that is functional in situations where the vehicle is travelling at speed and a pedestrian crosses on a collision course. To the best of the authors knowledge, there is no production HGV offering an AEB system effective for vulnerable road users at the side of the vehicle. (Knight & Dodd, 2019) tested a prototype AEB for a city bus that could detect forward collisions with crossing pedestrians and cyclists travelling ahead of the vehicle and found that it was not functional at speeds below around 7 km/h so would not be effective at moving off from rest. Prior experience of the authors with AEB systems for trucks and passenger cars suggests this is typical.

The target population identified by (Barrow, et al., 2017) was the same as that for direct vision so excluded collisions involving an impact at the rear of the HGV and excluded manoeuvres including parked, reversing, U-turn, waiting to turn left or right and where manoeuvre was unknown. Critically, therefore, it included collisions that occurred where the vehicle was 'going ahead' either on a left or right-hand bend or in a straight line and would, therefore include the substantial proportion of VRU collisions that occur with a vehicle travelling at significant speed where limitations to close-proximity vision is not a common contributory cause. Similarly, the same small (26) sample of in-depth cases was used and this was acknowledged to not be representative of the national collision database. The same technique of case by case review was used with subjective assessment of whether the collision would definitely, probably, or possibly be avoided by the two different technologies.

The study found that in total the ability of VRU detection systems at the front and side to avoid collisions was between 6% and 47%, based on considering only cases where coders had 'high' confidence of avoidance and considering all cases where coders considered it at least possible that avoidance would occur even if confidence was 'low'. The 'predicted' value was 40%. This implies that the effectiveness is considerably higher than even the high direct vision cab (equivalent to a low entry cab such as Dennis Eagle Elite or Mercedes Econic). For direct vision, the results were broken down by whether collision causes were affected by vehicle blind spots (see Figure 6-5 shown in the direct vision section). This allowed the differences in the definition of target population between (Barrow, et al., 2017) and (Knight, et al., 2017) to be accounted for. The equivalent data was not published by (Barrow, et al., 2017) in relation to detection systems so the same analyses was not possible.

It was however, possible to account for the possibility of using probability to produce a different 'prediction' from the same base data. If a probability value at the centre of each range indicated by (Barrow, et al., 2017) is applied then it can be estimated that 16.5% of low confidence cases will actually result in avoidance, 50% of medium confidence cases and 83.5% of high confidence estimates. This would translate to a prediction of 23% effectiveness rather than 40%. This compares to an estimate for a high direct vision cab, calculated on the same basis, of 17% for a high direct vision cab and 7% for a 'best in class' minimum standard for direct vision (on a like for like basis related to the larger target population defined by (Barrow, et al., 2017)). This still suggests that detection systems are more effective than direct vision, it is just that the margin is considerably reduced (7% direct vision to 23% detection/warning, rather than the original 3% to 40%).

(Barrow, et al., 2017) also assessed the ability of AEB to work in the same cases and quoted the 'predicted' value as 44%, only 4% greater than the 'predicted' value for detection and warning only. This small margin is in stark contrast to the difference between warning and AEB observed in post-hoc statistical studies on passenger cars, where AEB was found to be around twice as effective as forward collision warning. If the AEB results are adapted for the different method of producing the central 'predicted' estimate, then the central estimate becomes 35% effectiveness. Thus, on this probability basis, the collision detection and warning system is 23% compared to AEB 35%, which is much closer to the typical margin found between forward collision warning and AEB in passenger cars.

(Knight, et al., 2017) also made estimates of the effectiveness of blind spot information, warning and intervention systems alongside direct vision. However, these were based on a more tightly defined target population such that for the same casualties saved, the percentage figure would appear higher. The estimates were based on comparison to statistical post-hoc studies evaluating the effect of blind spot information systems on cars (IIHS, 2011), the test procedure for HGVs developed by (Knight, et al., 2017) and estimates of effectiveness found by (Martin, et al., 2017). (IIHS, 2011) found that passenger car BLIS was reducing injury claims by approximately 15-24%. Based on functionality it was considered that passenger car BLIS was approximately equivalent to a system rated in band 3 or 4 (on a scale from 1 to 6 where 6 is the best) according to (Knight, et al., 2017). (Martin, et al., 2017) derived an estimate of effectiveness for ultrasonic systems informing drivers of the proximity of hazards of between 26% and 46% based on an assumption that the sensors would cover all relevant areas at the front and side and other cited research suggesting that the warnings would be correctly issued between 42% and 58% of the time and that the human driver would respond correctly and be able to avoid the collision 80% of the time. (Martin, et al., 2017) did not explicitly consider the quality of the HMI or whether the alerts would be issued in response to all objects or just VRUs, which the theory suggests will strongly influence the response of the driver.

This resulted in estimates by (Knight, et al., 2017) that the effectiveness of blind spot information, intervention and warning systems would be 0% to 16% for a band 2 system; 30%-62% for a band 4 system and 58% to 70% for a band 6 system. It should be noted that a band 2 system might only be active at front or side rather than both and a band 6 system would have to include both front and side detection, would discriminate between VRUs and roadside furniture, would contain both a proximity information signal and a true collision warning and a 'motion inhibit' system designed to intervene to prevent a driver pulling off from rest while a VRU is in front of the vehicle. Based on survey results, most of the systems currently fitted to HGVs would be likely to attract band 1 or 2 ratings in the procedure proposed by (Knight, et al., 2017). Systems compliant with the forthcoming regulatory standard would discriminate between VRUs and objects at least to some extent and are more likely to have correct HMI and should include true collision warnings, though with little definition of quality. Requirements are expected to be phased in from 2020 to 2022 for systems fitted at the side of the vehicle and from 2022-2024 for systems fitted at the front of the vehicle. As such, in the test procedure proposed by (Knight, et al., 2017), they would be likely to attract ratings at band 3 in the first phase and band 4 or 5 in the second phase.

Not accounting for the difference in target population, the estimate of effectiveness of warnings by (Barrow, et al., 2017) implies a band-4 effectiveness, which is broadly consistent with the second phase of implementation of the regulation in 2022/24 where the system assumed by (Barrow, et al., 2017) covers the front as well as the side. However, it is possible that when the different definition of target population is accounted for the effectiveness found by (Barrow, et al., 2017) would be more consistent with that of a band 5 system as defined by (Knight, et al., 2017), which represents the top end of likely technical performance..

In consideration of both studies, there is considerable uncertainty in the estimates as a consequence of small sample sizes and difficulties with clear links to the technical requirements as well as simplified consideration of the human element in the equation. In particular, it should be noted that the higher estimates of effectiveness for high quality systems all imply a casualty reduction that is greater than post hoc statistical studies suggest is actually being achieved for different types of collision warning systems in passenger cars.

8.5 Cost of implementation

Stakeholder responses to the survey completed within this project showed that installation costs quoted vary from £150 up to £5,000, though the more expensive are thought likely to include a variety of other safety elements.

The clear majority are fitted by the supplier or their approved installer and come with 1-2 years warranties. About 10% of operators have longer warranties, though only one pays extra.

8.6 Gap analysis

Blind spot information, warning and intervention systems were strongly supported by theory, experimental evidence and predictive casualty analysis. Even imperfect systems had some evidence of effectiveness and predictions were that very high-quality systems had the potential to be more effective than direct vision, particularly in the more dynamic variants of left turn manoeuvres where the cyclist is positioned behind the drivers cab at the moment the driver needs to see them to avoid collision. However, the survey evidence also suggested that most of the systems currently fitted to vehicles were at the basic end of the spectrum of different performance levels. Forthcoming regulation would be expected to drive improvements quite quickly from 2020.

Table 8-2: Evidence identified for the effectiveness of blind spot information, warning and intervention systems

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical	X		X
Causation	X	X	
Predictive	X	X	X
Experimental: Physical			
Experimental: Behavioural		X	
Survey: Observed			
Survey: Stated			
x = Limited/weak evidence; X = Stronger evidence			

8.7 Candidate policy options

The design and function of blind spot information, warning and intervention systems is very flexible and there are many different ways of implementing them. As such a wide variety of candidates for technical requirements can be considered:

- **FORS Silver:** Requires an audible warning system to alert the driver that other road users are present in the nearside blind spot. No technical criteria are defined so systems informing the driver of the presence of other road users without considering whether they are on a collision course are acceptable. Similarly, nothing is present to stop systems activating in response to the presence of stationary parked vehicles or roadside furniture. Twenty six percent of respondents to the survey were not FORS members so this would increase the quantity of vehicles in London with the safety systems fitted.
- **FORS Silver plus frontal system:** Extend the FORS silver requirement to cover the blind spot at the front of the vehicle as well, based on the class VI mirror zone. Fatalities from the moving off manoeuvre are of comparable frequency to those from turning left.
- **Lateral range of detection:** Define that the lateral range for detection of vulnerable road users is at least 2.5m. This lateral range shall be maintained at least from front of the vehicle to the greater of 6m rear of the front of the vehicle

or 1m forward of the rear of the vehicle. This will increase the proportion of collisions where the VRU will be detected but should only be considered in combination with measures to reduce false positives and annoyance from warnings.

- **Introduce HMI requirements:** Require that warning HMI is in compliance with the principles outlined in UNECE guidance and ISO documentation. This means that in situations that are of medium or low urgency, warnings should be of a less alerting, less intrusive nature defined as being issued over a single mode only and using either visual or speech warning. Situations where there is a hazard in the blind spot area but it is not on a collision course (e.g vehicles running parallel or one or both vehicles stationary) will be low or medium urgency situations. Situations where the vehicles are moving towards each other such that in the absence of intervention a collision will occur in less than around 2 seconds are high urgency situations. In these situations, the warning shall be issued over more than one mode and shall not involve a speech coded warning. This should reduce the annoyance from frequent proximity warnings while retaining and enhancing the urgency of collision warnings.
- **Roadside furniture and stationary vehicles:** Prohibiting activation of the proximity warning in relation to roadside furniture or stationary vehicles would substantially reduce the frequency of warnings that most drivers would consider false. A reduction in false positives would increase trust in, and compliance with, the warnings.
- **Require collision warnings:** Collision warnings without proximity warnings would be issued much less frequently than proximity warnings, reducing alerts considered by drivers to be false or unnecessary. This would be likely to improve trust in, and compliance with, the warnings. When combined with proximity warnings it produces a 2 stage warning system likely to be more effective than proximity warning alone in a critical situation. Most systems currently in use on operators fleets are not capable of this, though systems are available in the market.
- **Functionality in dark street-lit conditions:** This would increase the proportion of collisions in which the systems might be effective from the 87% of pedestrians and 95% of cyclist fatalities that occur in daytime to the 99% of all relevant fatalities that occur either in daylight or in street-lit conditions. However, this may prohibit some camera-based systems that are more effective in the greater proportion of daytime collisions than ultrasonic or radar systems unaffected by light levels. So, it is not guaranteed to improve overall effectiveness.
- **Direction indicators:** Assuming that in some collisions, the driver fails to indicate left before the turn, then a system that does not require the indicators to be activated to issue a warning to the driver will be effective in a broader range of collisions. Where drivers find the warnings annoying, deactivating the system when the direction indicators are not activated can introduce a perverse incentive to drivers not to use the indicators, which would increase risk. However, many systems currently in the market are known to be active only when the direction indicators are set.
- **Compliance with forthcoming Regulation**: Compliance with the proposed Regulation relating to blind spot information systems for the detection of bicycles (UNECE, 2018) will be mandatory for new vehicles from 2020 will effectively integrate many of the technical requirements above but only for the turning left

manoeuvre not moving off from rest. Requiring all existing vehicles to meet this is likely to mean most vehicles already equipped with blind spot warnings would need to replace them, at least in the side. Proving compliance with the requirements may not be straightforward because the proposed regulation does not make provision for approval of a component, only a whole vehicle.

- **Integration with CMS:** From an HMI perspective the ideal situation is where a warning attracts the attention of the driver to a location where the hazard can be clearly seen and identified, thus allowing the perception-response to be optimised. This can potentially be achieved by having a visual proximity warning attached to the monitor of the CMS in which the hazard can be seen and potentially enhancing the view of the hazard on the screen using graphical overlays or other enhancements. This can be supplemented with an audible or tactile warning for collision warnings. At least one system exists in the market currently but the vast majority of vehicles with warning equipment do not have integrated systems.
- **Require Motion Inhibit systems:** Evidence shows that some moving off from rest collisions occur even with city buses that have excellent direct vision and that not all warnings are complied with. Thus, intervening to prevent moving off when a pedestrian is in front of the vehicle will extend the benefits of systems to even more collisions. One survey respondent suggested a system was available now and another confirmed a prototype system was available for demonstration now.

9 Warning of intended manoeuvre

9.1 Fundamental Concept

A substantial proportion of the HGV-cyclist fatalities that occur in London, where blind spots are thought to be a contributory factor, occur when the HGV turns left across the path of a cyclist that was intending to travel straight on. Thus, another contributory factor in these cases would be the lack of awareness of the cyclist of the intention of the HGV to turn left, at least until it was too late to take avoiding action. There could be a number of reasons for this failure, including but not limited to one or more of the following:

- HGV driver did not indicate left
- HGV driver did indicate left but cyclist did not see it, either because of their position relative to the HGV or because of distraction or some other reason.
- HGV path suggested the opposite of a left turn – i.e. it first swung out to the right before quickly turning left, a path that is necessary in many tight turns to avoid running over the kerb with the rear wheels.

The concept of the warning of intended manoeuvre is to more effectively warn vulnerable road users around the vehicle that it is turning left, therefore enabling them to take earlier and more effective avoidance action. The existing direction indicators mandatory on all road vehicles are, therefore, a warning of intended manoeuvre. The aim here is to supplement that visual warning with a warning that attracts the attention and provokes the correct response from vulnerable road users more effectively.

9.2 Definitions

This section refers extensively to measurements of noise. These measurements are complex and not particularly intuitive so, some basic definitions have been included in Appendix B to help the understanding of the following sections.

9.3 Audible warnings: Noise level

A stakeholder meeting undertaken prior to the initiation of this research identified concerns over the sound level that external warnings of intended manoeuvre should issue. Stakeholders identified that if they were very loud they could cause considerable noise nuisance, particularly where multiple vehicles were queued at a junction, where the ambient noise level was low and at night. However, other stakeholders also noted that if they were insufficiently loud, they may not be heard, particularly where ambient noise levels were high and/or vulnerable road users wore any head gear covering the ears (hats, scarfs or particularly headphones for phone conversations or music).

(Pecheux, et al., 2015) confirmed in their trials and surveys that identifying the correct volume for the systems was a problem throughout the duration of the demonstration. At the start of the trial, feedback was that the volume was too high and so it was adjusted down. This reduced the quantity of feedback complaining about excess noise but increased levels of feedback that they were now too quiet to be effective. (Pecheux, et al., 2015) also found that there were differences in the findings between surveys of operators, surveys of pedestrians and participants in focus groups as well as between systems that warned via a spoken message and those that warned via a tonal (beeping) alert.

Vehicle operators generally found that the systems were both too quiet to be effective and too loud to prevent annoyance. They considered that the margin by which the system was “too loud” was greater for the spoken warning system compared to the tonal beeping. By contrast, most pedestrians surveyed about the system did not find the warnings intrusive on the environment. However, those that did find them intrusive were similar to the operators in more often finding the spoken message warnings too loud compared to the beeping warnings. Pedestrians participating in a focus group found the opposite; that once adjusted, the spoken warning volume was acceptable but the beeping warning remained too loud. However, the authors noted that the focus group participants had also complained about the frequency and repetition of the warning, which was related to the methods of activation.

Four respondents provided answers in the survey about the sound output from the devices they manufactured. The sound outputs stated were between 65 dB and 120 dB. By way of comparison, sound emitters designed to ensure that an electrically powered vehicle has a sound output equivalent to a combustion engine vehicle when travelling at low speed, known as Acoustic Vehicle Alerting Systems (AVAS) are required by Regulation 138 to have a sound output no greater than 75 dB(A). In order to stand out and be detectable on a combustion engine vehicle, then an audible warning of intended manoeuvre would need to be louder than the combustion engine vehicle and any other ambient noise level.

Measurements made during the development of TfLs bus safety standard of ambient noise at 4 sites in London found that ambient noise levels ranged between 65.5 and 73.8 LA_{90}.

Table 9-1: Traffic noise levels. London sites

	LA_{90}	(L_{Aeq})
Site 1	73.8	82.7
Site 2	67.6	74.2
Site 3	65.5	73.8
Site 4	69.4	74.4

(JASIC, 2018) described background noise as defined in Table 9-2, below.

Table 9-2: Description of traffic noise levels. Source: (JASIC, 2018)

Background Noise Level (L_{Aeq})	Traffic Noise	Real World situation
65	Noisy	Nearby railway
55	Normal	Shopping district
45	Slightly quiet	Residential area
35	Quiet	Residential area at dawn

It can be seen that the recent measurements in London are very substantially noisier than the descriptions of noisy near a railway in Japan (JASIC, 2018).

In general, it seems likely that most people would find the activation of a vehicle’s horn every time a truck was turning left would be excessively noisy. UNECE Regulation 28 requires that a horn for vehicles should have a sound pressure level measured 2m from the source of between 105 and 118 dB(A).

The centre for disease control and prevention have produced the following graphic relating typical sounds to their intensity, which provides a further guide to how different levels of noise are perceived.

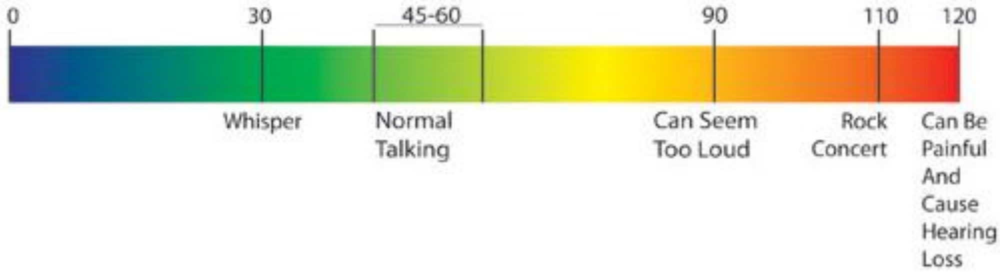


Figure 9-1: Intensity of common sounds, measured in decibels (dB). Source: CDC[19]

This implies people will start to consider things too loud from around 90 dB(A).

(JASIC, 2018) undertook a range of experiments with human subjects in an anechoic chamber in order to assess how noticeable and how acceptable different sounds were at different sound intensities. They varied background noise between 35 and 65 dB and a reversing alarm at a distance of 7m from the participant between 40 and 90 dB. They found that, once distance was accounted for, sounds could be heard moderately well as soon as the intensity exceeded the background level but that substantial improvements could still be seen when levels increased well above the background level, showing signs that detectability levelled off around 90dB. Sounds were considered at least moderately noisy when they exceeded the background level by around 7dB, and were considered very noisy when at 90dB, even though the source was 7m away.

9.4 Activation and Warning Strategies

As extensively discussed in section 8.2 research on collision warnings for drivers has found that if a driver perceives a warning to be false then it will reduce compliance with the warning, undermine trust in the system and cause annoyance. Similarly, it has been found that to increase compliance and minimise annoyance, the urgency and intrusiveness of the warning should relate to the urgency and criticality of the driving situation the vehicle is in. Although the warning of intended manoeuvre is aimed at the vulnerable road user rather than a driver, they remain human and it is likely that the same principles apply.

(Pecheux, et al., 2015) evaluated 4 external audible warnings to pedestrians of a turning vehicle, in this case fitted to city buses: They noted several different strategies for activating the warnings:

- Activating any time that the steering angle exceeded a defined threshold AND the speed was below a defined threshold.
- Activating when the direction indicators are activated with or without a maximum speed threshold

Survey responses suggest that most, if not all, left turn systems in use in London will activate based on activation of the direction indicators, while reversing systems will be

[19] https://www.cdc.gov/ncbddd/hearingloss/sound.html

activated by selection of reverse gear. Reversing alarms will typically activate when reverse gear is selected and the vehicle is in motion.

(Pecheux, et al., 2015) found that systems activating based on speed and steering angle suffered false positives and activated in sharper curves, lane changes and parking situations. The system was active at speeds of up to 25 mile/h in the trial and after the trial they concluded 15 mile/h would have been more appropriate.

Systems activating on turn signals also activated at bus stops pulling in and out drivers and pedestrians tended to agree that activation at bus stops was important. This may not be as relevant in truck operation.

(Pecheux, et al., 2015) surveys of operators and pedestrians showed some consensus and some disagreement around warnings. Operators were divided over warning type, some preferring spoken, some preferring tonal. Pedestrians were less divided and tended to prefer spoken. There was consensus about the differences in messages used that 'caution, bus is turning' was better. Both groups recommended considering a message that combined a sound with a spoken warning. Concerns were expressed that if warnings occurred all the time they would become ubiquitous and blend into the background. This led to proposals to be more selective about when and where the warnings were issued.

The appropriateness of a warning strategy aimed at vulnerable road users would be expected to conform to the same principles outlined for warnings intended for the driver. There is general correlation between how alerting a warning is and how annoying it can be for drivers when it is activated frequently, particularly if those activations are false or unnecessary.

When considered in light of a reversing warning or a warning of a vehicle turning, then the warning will be activated every time the direction indicators are applied, or the vehicle is reversed. In a substantial proportion of these activations, there will be no vulnerable road user or other hazard present in the area at risk. All such activations can be considered false positives. In another major proportion of activations, a vulnerable road user will be present but both driver and vulnerable road users will be aware of one another having seen them in direct or indirect vision systems, such that the risk is low. The driver and/VRU is likely to consider these unnecessary warnings. Only where both driver and VRU are unaware of each other is there a genuine true positive situation. Actions to minimise false positive activations are, therefore, likely to be beneficial in terms of both people heeding the warning and in terms of minimising annoyance as a consequence of the warning.

Once activated, the ideal type of warning is also related to the urgency and criticality of the warning. In a reversing context, the situation becomes critical when a hazard is in the path of the reversing vehicle and the time to collision is less than 2 seconds or so. This might approximate to where a pedestrian is positioned less than 5 or 10 metres from the rear of the vehicle. In these circumstances an audible warning (tonal or broadband) is appropriate. If a pedestrian is further away than that, or is walking out of the path of the vehicle, then the urgency is at most medium and quite possibly low. In these situations, non-urgent warnings such as visual or speech should be used according to guidelines. At present, an inadvertent visual warning of reversing is presented by a reversing light in many situations but this may not be very effective as a warning and not consistently applied.

The analysis is similar for left turns. While stationary at lights for example, there is no imminent risk. Also, there is no risk if there is no vulnerable road user and a low risk if both parties have seen each other. Only where one or more parties have not seen each other, the vehicle is moving, and the turn has commenced does the situation start to meet the high urgency definition of avoiding action being required within two seconds. In most situations, a visual warning is the appropriate intervention, though it could also be a speech warning. Such a visual warning already exists in the form of mandatory direction indicators, though potentially this could be enhanced (see section 9.5). An activation strategy that restricted the use of the audible (tonal or broadband) noise to truly high urgency situations would be expected to improve compliance with the warning and reduce annoyance from it.

Several papers were identified considering what type of audible warning was most effective in terms of balancing the degree to which it alerted vulnerable road users and minimised environmental noise. These have been published in specific relation to reversing alarms and acoustic vehicle alerting systems for quiet vehicles and have, therefore, been considered separately to those aimed at assessing the effectiveness of different warnings intended for drivers.

One of the main differences between warnings to people outside of the vehicle will be the different volume and character of ambient noise around them. As part of the development of the bus safety standard for London, ambient noise levels were measured at several locations in London. It was found that, measured in the same way as (JASIC, 2018), the results were between 74 LA_{EQ} and 83 LA_{EQ}. On the basic noise level analysis reported above, it is likely that the alarms would need to be louder than this in order to be heard. However, the loudness or sound intensity is not the only factor affecting whether or not a sound can be detected against the background. The frequency at which that sound is issued is also important.

Most background noise will have a wide variety of different sound frequencies within it, a typical example is shown for road traffic noise below.

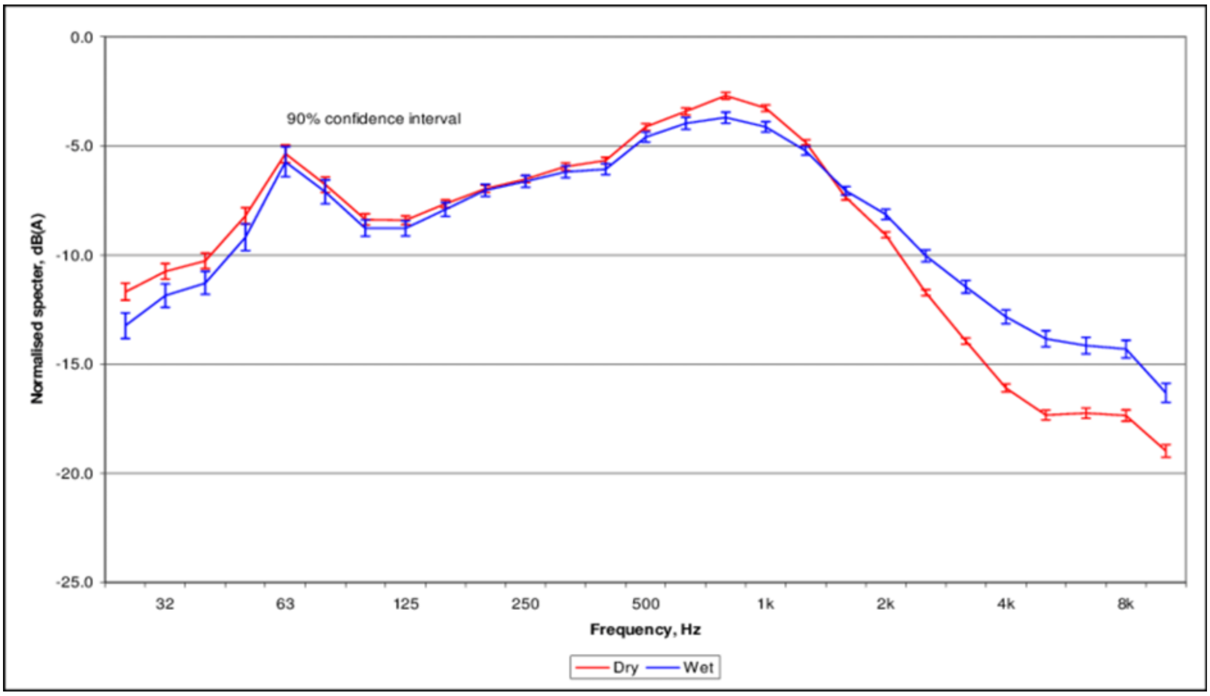


Figure 9-2: Typical spectrum for road traffic noise. Source: (GJestland, 2008)

So, another way of making a warning sound stand out from the background is to give it a significantly different frequency spectrum to the background.

Tonal sounds comprise of sound concentrated around one particular frequency. So, these can stand out from background noise as long as they are louder than the background noise at the same frequency. The highest intensities of background sounds are in the area around 1 kHz, so a tonal warning would stand out most at frequencies of less than 500 Hz or more than around 1500 Hz.

All of the suppliers of warnings of left turns that responded to the survey stated that they included speech (e.g. 'warning, vehicle turning left') as part of their warning. Speech contains a mix of frequencies, with vowels tending to have low frequencies in the range of 250 to 1,000 Hz and consonants having higher frequencies of 1500 to 6,000 Hz. A typical male speech spectrum is shown below.

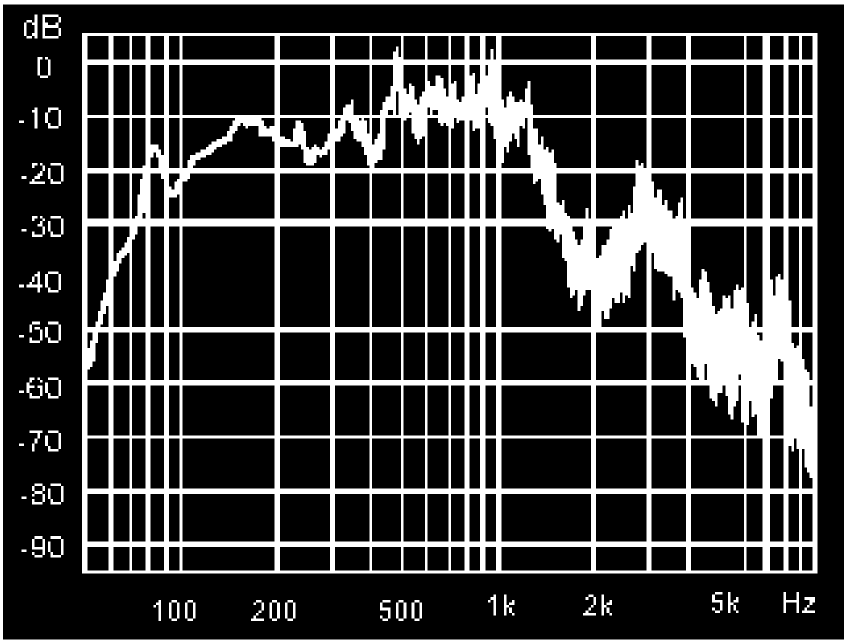


Figure 9-3: Typical spectrum from male speech[20]

It can be seen that the shape of the curve is not dissimilar to that shown in Figure 9-2 for traffic noise. Thus, normal speech may be hard to separate from the background noise.

Three of the four suppliers responding to the survey stated that their left turn alarms used 'white noise' in addition to speech. White noise is technically referred to as a broadband sound and is defined as a sound that has equal intensity at all frequencies. A practical implementation of this is shown by comparing a tonal and broadband sound with the same total sound intensity as illustrated below.

[20] http://www.bnoack.com/index.html?http&&&www.bnoack.com/audio/speech-level.html

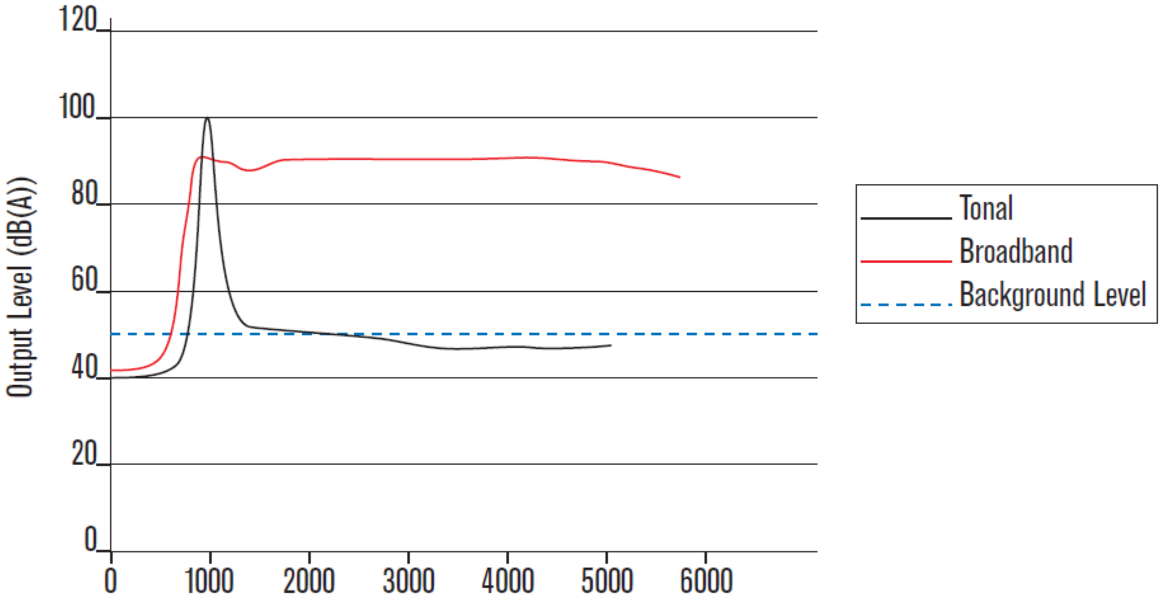


Figure 9-4: Comparison of a tonal and broadband sound spectrum. Source: (Brigade, 2009)

The frequency spectrum for broadband is also clearly different to background noise and so can stand out from that background. It can be seen that for the same overall sound intensity, the peak intensity at anyone frequency is lower than for a tonal sound.

(Ainge & Morgan, 2018) studied the potential for an Acoustic Vehicle Alerting Sound (AVAS) to compensate for the lower noise emitted by electric vehicles compared with traditional ones when moving at low speed. Regulations for such devices already exist and define the type of sound in a more complex fashion considering maximum and minimum levels at a range of individual frequency bands known as 1/3 Octave Bands.

The rationale behind proposals for this type of approach was that much of the background noise is at frequencies of around 1,000 Hz. Minimising the sound at this frequency will help to avoid adding to the peak sound intensity. People with 'normal' hearing remain very sensitive to sounds in the range of 1600 Hz to 2400 Hz so boosting the sound in this area should result in something very detectable to them. However, those with impaired hearing can be substantially less sensitive to those frequencies while still being sensitive to lower frequencies in the range of 600 to 800 Hz. Having high sound intensities at these levels can, therefore, help to make the sound more detectable for the hard of hearing, while making it less sensitive to barriers such as clothing or headphones (lower frequencies penetrate solid objects better than higher frequencies).

The approach described would lead to a spectrum similar to that indicated by that marked as the draft NHTSA spec (orange trace) in Figure 9-5, below.

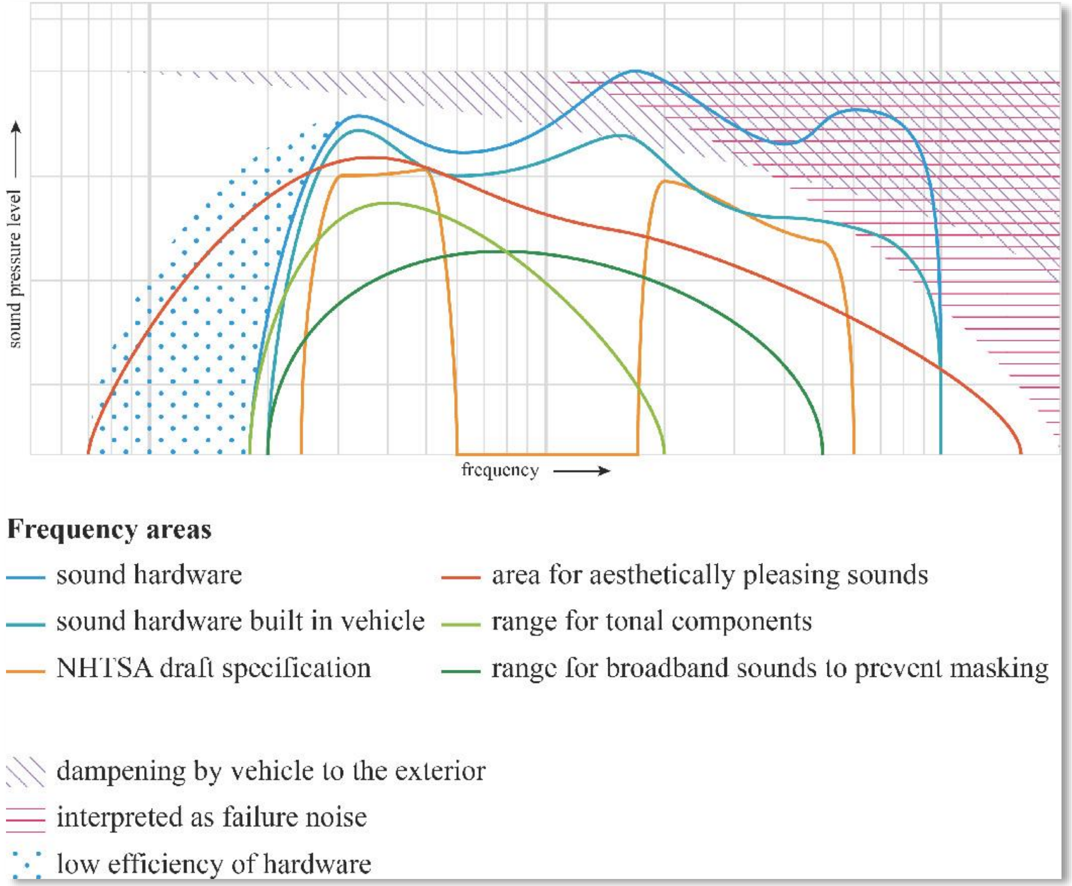


Figure 9-5: Concept of frequencies for added sound. Source (Vegt, 2016)

It should be noted that the restrictions suggested do not mean that speech cannot be used. A speech signal could be modified to fit the spectral curve suggested, it would just sound slightly different to normal.

Supporting the perception -response of the VRU to get the correct action as quick as possible. Not only does the warning need to be detected by the VRU to be effective but they need to be able to quickly understand what it means and what reaction is needed. Provided the warning is not time critical, then speech can be very good at this because the content of the message can clearly warn of the specific hazard.

The sound needs to be locatable. The VRU needs to know that the sound is coming from a specific vehicle relevant to them. (Brigade, 2009) states that human hearing uses different techniques to identify the direction that a sound is coming from depending on whether it is low, medium or high frequency. A tonal sound is only likely to use one of those mechanisms and if it is the low frequency mechanism in particular then confusion can remain. A broadband sound or a 1/3 Octave approach with a sufficiently broad frequency content can trigger all three mechanisms, increasing the chances of correctly locating the source.

The sound also should be minimised outside the area of risk, to avoid warnings considered, false or unnecessary for people not directly at risk. The rate at which sound decreases with distance travelled through the air also varies with higher frequencies attenuating faster than lower ones.

Thus, this theory suggests that broadband sounds ought to be more detectable and less annoying than 1/3 octave sounds. However, (JASIC, 2018) undertook experiments with different alarm sounds in the presence of background noise and found that overall the participants in the trial found the tonal sounds more alerting and more acceptable. The authors suggested that may at least partly because broadband alarms were rarely used in japan and so would have seemed very different to the expectation of the participants. This raises another important consideration around cultural and trained expectations. For example, as a consequence of its prevalence in reversing alarms, broadband sound might be more acceptable in the UK. However, it may also have become strongly associated with the reversing manoeuvre, such that its use in left turns may introduce some confusion.

(UNECE, 2018) provides a first draft of a regulation on reversing alarms. This has combined experience in a range of countries with available research on detectability and nuisance from alarms to propose noise limits expected to still produce effective systems while minimising noise pollution. The requirements are only draft but at the time of writing it is proposed that the regulation allows for approval of components or whole vehicles and allows tonal alarms, broadband alarms or those based on more complex 1/3 Octave band approaches. It defines that the alarms as a minimum should be manually adjustable in 3 levels (low medium high) to allow for use in different levels of ambient noise. Upper and Lower sound intensity limits are then applied differentially, depending on which sound type is used. Provisions are also made then for systems that automatically adjust their output level in relation to the ambient background noise. This basically defines a set decibel level (different for each sound type) by which the system can exceed the background noise level but only within defined limits of background noise. This ensures that the alarm cannot issue an excessively loud signal, that might for example damage hearing, even if the background noise is already very loud.

9.5 The potential for visual warning

Several survey respondents identified the problem that the cyclists intended to benefit from a warning of intended manoeuvre were unlikely to be visually impaired but may be hearing impaired and/or may be wearing clothing or headphones that reduced their ability to hear a warning. It is obvious to state that all road legal motor vehicles are equipped with a visual warning of intended turn manoeuvre in the form of direction indicators. The installation of direction indicators is governed by UNECE Regulation 48. All trucks of category N2 and n3 are required to have direction indicators at each side front and rear and must have a side repeater indicator within 1.8m of the front of the vehicle.

Side marker lights are mandatory on all vehicles over 6m and optional on all other vehicles. There must be a side marker in the middle third and one no more than 3m from the front of the vehicle. The distance between adjacent markers shall not exceed 3m (4m if impossible due to design) and the distance to rear is 1m

Depending on interpretation of the requirement for a lamp in the middle third then a rigid 6m long vehicle will require 2 or 3 side marker lights, one longer than 6m but 10m or less will require 3 side markers, a vehicle of 10-12m length will require at least 4 side markers. These side markers may be flashed with the turn signal provided they are amber in colour (the rear side marker can be red if not flashing).

So, it is possible that a long HGV in London may be able to have only one direction indicator at the side of the vehicle. However, others may have an additional 3 or 4 side marker lights that also flash with the direction indicators. It is logical to assume that these might increase the chances of being detected by a cyclist positioned at the side of the vehicle or moving up the inside of it from behind. However, no evidence was identified examining this potential or quantifying it.

Similarly, it would be technically straightforward to used LED strip lights connected to the direction indicators to further enhance the visibility of direction indicators to cyclists. However, no research quantifying the effect of this was identified and no information considering the legality of this within existing lighting regulations.

9.6 Regulation and test procedures.

In the UK, audible warnings must comply with the Road Vehicles Construction and Use Regulations (1986) as amended. Regulation 37 defines a reversing alarm and other audible warning types and prohibits certain sounds. In terms of technical requirements, the main requirement is that a reversing alarm "shall not be strident". Regulation 99 governs the use of audible warnings and states that nobody shall use 'any horn, gong, bell, or siren' at any time for stationary vehicles and between the hours of 23:30 at night and 07:00 hours the following morning for vehicles in motion.

Currently no other technical requirements exist in the UK. However, other countries have national standard for reversing alarms and there is currently a draft UNECE Regulation on reversing warnings under development. It is intended that this should be adopted during 2020 (UNECE, 2018)

9.7 Evidence of effectiveness

9.7.1 Experimental evidence of effectiveness

(Ainge & Morgan, 2018) evaluated a technology known as Acoustic Vehicle Alerting Systems (AVAS). This is designed to enhance the acoustic conspicuity of vehicles (in this case buses) that use electric or hybrid electric drivetrains which can be much quieter than conventional diesel vehicles. The study acknowledged that many collisions occur where a VRU has failed to correctly observe and judge the collision risk associated with an approaching diesel vehicle. Thus, achieving the equivalent acoustic conspicuity of a diesel vehicle is only a part of the solution.

When investigating the effectiveness of such a system IRIS data was used to estimate that a pedestrian/cyclist is approximately 15% more likely to have a collision with an electric bus than a conventional bus, assuming that the only difference between the two bus types was the absence of any audible alerting cues. The casualty benefits of an AVAS system was assumed to be 15% (with a tolerance of ±5% for best/worst cases), such that it would make the rate of collisions per bus-km the same for both electric and diesel buses.

9.7.2 Survey evidence: stated opinion

(Pecheux, et al., 2015) undertook extensive surveys of bus operators and the general public during a trial of devices on city buses. They asked for opinions on effectiveness generally but also asked the subjects about the noise levels experienced. The volume of devices was reduced during the trial and surveys repeated at intervals and, as might be expected, reducing the volume resulted in people saying they were too noisy but also reduced their perception of effectiveness. Subjects were also asked about whether tonal or speech warnings were better but preferences were split.

9.7.3 Survey evidence: observed behaviours

(Pecheux, et al., 2015) undertook observational studies via a video survey at four intersections over 80 hours. This resulted in observations of 894 bus turning events. 124 of these involved a bus equipped with the warning and 109 involved pedestrian interaction. In 13 of these pedestrian interactions (12%) then the pedestrian made some form of visible reaction to the warning. There were 663 interactions between pedestrians and a bus not equipped with the warning of intended manoeuvre and in only one of those cases (0.15%) did the pedestrian make a similar visible reaction to the presence of the bus. Typical reactions to the warning were to see a head movement in the direction of the bus at the time the warning sounded or for pedestrians crossing a road into which the bus was turning to speed up/break into a run to complete the cross more quickly.

(Ponziani, 2012) observed 12,000 vehicle manoeuvres in the Ohio area in the US and found that in 25% of turning situations and 48% of lane changes, drivers did not use the direction indicators. If a comparable rate were found for London HGV drivers, this would cap the maximum effectiveness of this measure at around 75% because it is wholly dependent on operation of the direction indicators.

9.8 Cost of implementation

Responses to the stakeholder survey showed that the installation costs for stand-alone systems are typically £200 - £500. Most operators were found to use systems fitted by the supplier or their approved installer, with a small minority opting to fit themselves. Warranties are typically 1 or 2 years (less than 10% of operators have longer warranties) and installation costs for stand-alone systems are typically £200 - £500.

9.9 Gap analysis

Warnings of intended manoeuvre had the least directly relevant evidence of effect. Studies of the effect of electric vehicles on low speed collision with vulnerable road users show that electric vehicles are more likely to be involved in incidents than conventional diesel vehicles. Experimental evidence shows that acoustic warnings could restore a VRUs ability to detect the vehicle to the level of an internal combustion engine vehicle. Trials of warnings of left turn manoeuvres on buses showed an increase in the number of pedestrians that visibly reacted to the presence of a turning bus. Human factors experiments show that people found that reversing alarms made vehicles more noticeable.

Table 9-3: Evidence identified for the effectiveness of warning of intended manoeuvre systems

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical			X
Causation			
Predictive			
Experimental: Physical			
Experimental: Behavioural			X
Survey: Observed		X	X

Survey: Stated			x
x = Limited/weak evidence; X = Stronger evidence			

9.10 Candidate policy options

The main concerns about warnings of intended manoeuvre have centred around a possible trade-off between being sufficiently loud to be effective in busy and noisy London streets, while being sufficiently quiet not to add excessively to that noise level or to cause excessive nuisance in quieter situations or at night. This is potentially exacerbated given that a proportion of the vulnerable road users that this measure is intended to influence will have impaired hearing either naturally or because of clothing worn around the ears or the use of headphones.

Options for the technical policies to be applied in respect of this system that have been identified are:

- **FORS Silver:** requires audible warnings that alert other road users to left turn and reversing manoeuvres. No technical requirements are applied.
- **Enhanced visual warning of turn:** Few cyclists will be visually impaired, but they may fail to see existing direction indicators if, for example, a single side repeater is dirty or the cyclist is ahead of that position and the front indicator is in-board of the very edge of the vehicle such that it can't be seen. Requiring side marker lights connected to the indicators may improve detection where indicators are applied. Similarly, further enhanced LED displays (along length of vehicle or vertically up the height of the vehicle) would be technically straightforward but effectiveness and legality remain unknown.
- **Control volume of audible warning:** Sound output measured 2 m from the sounder shall be between 65 and 88 dB(A) based on draft regulation for reversing alarms
- **Minimise noise at night:** Require manual or, preferably automatic, adjustment of the sound level at night such that the maximum night time level is 68 dB(A). This can be achieved by switching the system off at night.
- **Operating speed range:** Devices shall not activate when the vehicle is stationary or travelling at speeds in excess of 20 mile/h.
- **Content of audible warning:** Audible warning shall incorporate either a Broadband sound (white noise) or 1/3 Octave Band Sound in between 400 Hz and 4kHz which may include speech. The audible warning shall not include tonal signals. The levels are based on relevant proposals in the draft regulation for reversing alarms
    - Broadband sounds (Daytime) shall be between 70 and 84 dB(A)
    - Broadband sounds (Night) shall be no more than 64 dB(A)
    - 1/3Octave sounds (Daytime) shall be between 65 and 81 dB(A)
    - 1/3 Octave sounds (Night) shall be no more than 61 dB(A).
- **Adaption to time of day and surroundings:** Warnings shall be adapted automatically in relation to time of day and the ambient noise level actually measured by the vehicle, within ranges as follows

  - for broadband sound from 400 Hz to 10 kHz + 5 dB(A) ± 1 compared to the ambient sound emission between [60 to 95] dB(A). Variation subject to a night time maximum of 64 dB
  - for 1/3 Octave Band Sound in between 400 Hz and 4 kHz + 1 dB(A) ± 5 to the ambient sound emission between 55 to 93 dB(A). Variation subject to a night time maximum of 61 dB

- **Control activation and warning urgency strategy:** Current systems issue the same audible warning any time the direction indicators are applied. This means the same warning is issued regardless of whether a VRU is there to hear it or not and regardless of whether a collision risk exists. This represents a high false positive rate: A variety of sub-options exist to reduce the false positive rate and bring the approach into line with UNECE guidelines. However, none of these are yet thought to be in the market:
  - Activate the warning based on applied steering angle and/or yaw rate: In this way the alarm would act more as a collision warning than a proximity warning, only applying once collision probability increases because a turn has commenced. However, if the steering threshold is too small, many false positives may occur. If it is too large, then the warning may come too late to be effective in many situations.
  - Activate a two-stage warning based on direction indicators and steering angle: Apply a less intrusive but less alerting warning when the indicators are applied but the vehicle is stationary or travelling in a straight line. Change to a more alerting, more intrusive warning when steering is applied.
  - Integrate the warning of intended manoeuvre for VRUs with the blind spot information and warning signals to the driver. Only activate the warning of intended manoeuvre when the blind spot sensors detect that a VRU is present and the indicators are applied. Implement a second stage warning based on the collision warning phase of the on-board system.

10 Side under-run protection

10.1 Fundamental concept

In general terms, side guards are lightweight structures that are intended to fill the gap between the front and rear axles of goods vehicles with a gross vehicle weight (GVW) greater than 3.5t. They can consist of rails or panels or a combination of these, but the lower surface must be at most 550mm from the ground (Robinson & Cuerdon, 2014). Community Directive 89/297/EEC sets out the type approval requirements for the lateral protection (side guards) of vehicles falling into categories N2, N3, O3 or O4.

Sideguards are intended to provide protection for VRUs that are involved in impacts with the side of an HGV in the area in front of the rear axle(s) when the HGV is overtaking. The primary aim is to prevent them being run over by the rear wheels.

Figure 10-1: Example of HGV side guard.
Source: (Nationwide Trailer Parts, 2018)

10.2 Evidence of effectiveness

(Thomas, et al., 2015) studied 23 cyclist fatalities in collision with an HGV in London, mostly involving a left turning HGV, where sideguard fitment was known. They found that 11 were exempt from the requirement. However, in all of these cases the cyclist was on the ground before any sideguard interaction could have occurred and, therefore, sideguards were not effective in left turns.

(Riley, et al., 1985) undertook research into the effectiveness of sideguards based on full scale tests with trucks and dummies of pedal cycles. Tests involving a truck fitted with a side guard just complying with the legal minimum in the UK were found to prevent run over in 4 out of 10 cases. Differences in the speed or configuration of the collision did identify the possibility of more violent collisions with projections such as load hooks, the leading edge of the side guard or the rear wheel. It was suggested that such problems could be improved by fitting stronger guards flush with the outside of the vehicle.

(Walz, et al., 1990) and (de Coo, et al., 1994) restricted their analysis to VRUs being overtaken by an HGV, but the found similar findings to (Riley, et al., 1985).

(Knight, et al., 2005) investigated the effectiveness of sideguards at preventing serious injury to cyclists and pedestrians when the HGV they were fitted to was travelling in a straight line and when it was turning left. The analysis suggested that sideguards were effective at reducing the severity of cyclist accidents involving a passing HGV, but not when the HGV had been turning left. The reduced effectiveness during the left turn manoeuvres was thought to be a result of the accident mechanism, whereby the initial contact with the cyclist typically occurs near the front, knocking the cyclist to the floor as the HGV continues the manoeuvres. The prone cyclist is then run over by the rear wheels because the person passes under the sideguard. (Knight, et al., 2005) suggested modest additional benefits could be possible if exemptions to regulations were ended and/or if the technical requirements were enhanced.

(Keigan, et al., 2009) and (Cookson & Knight, 2010) both suggested that there is some chance that improved sideguard design, primarily by lowering the bottom edge, could potentially improve injury outcomes for cyclists in collisions with an HGV turning left, although considerable uncertainty was acknowledged in this suggestion.

10.3 Cost of implementation

Literature describing the likely costs of installing side underrun guards was not identified. However, a review of several websites identified the following costs. Full side underrun kits, consisting of rails, end caps, brackets and fixings that care cut to size for a specific vehicle were identified to retail for £400 - £510 (excl. VAT) (Thompsons E Parts, 2018). Other sites also sold individual component parts with a 3m rail typically costing around £50, and brackets, legs and other components ranging between £25 and £50 (KUDA Automotive, 2018), (Nationwide Trailer Parts, 2018)

10.4 Gap analysis

Several studies have shown the benefits of side underrun guards in specific conditions. Guards are now widely fitted across the fleet.

Table 10-1: Evidence identified for the effectiveness of side underrun guards

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical		x	
Causation			
Predictive	X	X	
Experimental: Physical		X	
Experimental: Behavioural			
Survey: Observed			
Survey: Stated			
x = Limited/weak evidence; X = Stronger evidence			

10.5 Candidate policy options

Currently only one candidate policy option is considered for Direct Vision. The requirement will be to harmonise with TfL's Safer Lorry Scheme that requires vehicles over 3.5t GVW to be fitted with sideguards.

11 Driver Training

11.1 Fundamental concept

In-depth collision data analysis has consistently found over many years and many studies that human error contributes at least in part to almost all road collisions, with 90% to 95% commonly quoted. As such, the obvious response to this finding is that training drivers, and other road users, so that they are better able to avoid making those errors will reduce the frequency of collisions.

However, the effectiveness of training will depend very strongly on factors such as what the drivers are trained to do, how that message is communicated to drivers and the extent to which the message is reinforced over time. In addition to that, human beings are highly variable in the personalities and behaviours and will, therefore, respond differently to any given approach. In short, designing effective driver training is a complex and difficult field.

TfL provide truck drivers on the cross-rail project with special cycle awareness training, provide free cycle skills training and undertake 'exchanging places' events where cyclists and HGV drivers get to swap places so that they can become more aware of each other and the limits of what can and can't be seen from a truck. Several training providers also provide both cycle specific training for HGV drivers and cycle skills training.

11.2 Evidence of effectiveness

There is a considerable body of research related to the effectiveness of training. Much of this relates to the training provided to learner drivers and the effectiveness of the driving test. (Helman, 2013) reviewed the evidence of whether driver behaviour interventions of different types worked, and the methods needed to actually reliably measure effectiveness. (Helman, 2013) proposed the use of objective measurements strongly related to the risk that the measure was intended to mitigate with proper statistical analysis of a case control methodology, usually implemented as a before and after study. This essentially describes a study similar to that classed as a post-hoc statistical study of a vehicle safety intervention in this report.

Based on that level of evidence, (Helman, 2013) found that the evidence for a direct safety benefit from traditional driver training and education for new drivers is almost non-existent. Similarly, there was no evidence for an overall effect for post-license training, either remedial or advanced, focussed on provision of driving skills. It is worth noting that many training interventions are simply not evaluated such that a part of these findings can be considered an absence of evidence about the effect, rather than evidence that there is an absence of effect. However, (Helman, 2013) found that in some cases the opposite effect occurred. For example, research by (Katila, 1996) was cited and said to show that skid training was found to increase collisions experienced by young, particularly male, drivers.

However, other training interventions showed promise. (Helman, 2013) found strong evidence that there was a direct safety benefit for graduated driver licensing, evidence that hazard perception testing resulted in 11% fewer collisions for new drivers, that 'resilience training' may lower collision risks in new drivers and that some fleet safety interventions performed better than a control group.

Training specific to solving problems of HGV and cyclist interaction is much more niche and there is relatively little evidence available that has studied the effect. (Future Thinking,

2016) surveyed a wide range of operators and drivers who had been through HGV specific training including cycle specific elements and generally found that they thought it was well delivered and improved their awareness. Similarly, (Sherriff, 2017) surveyed HGV drivers that had participated in a safer urban driving course, which included a practical element of riding a bike in the urban environment. (Sherriff, 2017) also found that the training was generally well received and positively influence driver attitudes and self-reported behaviour. However, neither study attempted to measure the actual effect of the training on collision rates.

11.3 Cost of implementation

HGV drivers are obliged by the requirements of the Driver Certificate of Professional Competence to undertake regular training and fleet operators may choose to go above and beyond this minimum standard voluntarily. Provided cycle specific training can count towards these mandatory hours the marginal cost of requiring it will be small and relate only to any difference in price between different training courses.

However, where a requirement adds to the total quantity of training required, the cost can be considerable. The costs of a 5-day training course might be in the region of £500 per driver plus the driver’s employment costs for those 5 days.

11.4 Gap analysis

The evidence picture for training is mixed with strong evidence of effectiveness for some interventions, a substantial absence of evidence for others and active evidence or disbenefits in some cases. When cycle specific evidence is considered, there is some survey-based evidence that it positively influences attitudes but no evidence in terms of collision risk.

Table 11-1: Evidence identified for the effectiveness of driver training

Type of evidence	Direction and indicative magnitude of effect based on studies of		
	London HGV market	HGV market elsewhere	Other vehicle types
Post-hoc Statistical		X	
Causation			
Predictive			
Experimental: Physical			
Experimental: Behavioural			
Survey: Observed		X	
Survey: Stated		X	
x = Limited/weak evidence; X = Stronger evidence			

11.5 Candidate policy options

TfL’s baseline is that driver training would be encouraged as part of the HGV Safety Permit but is not a mandatory requirement.

It could be envisaged that this requirement is made mandatory. However, the evidence that existing cycle safety training reduces blind spot related collisions is relatively weak, based on self-reported attitudes only. The evidence suggests it would also be important to ensure the training syllabus was well controlled, to avoid possible unintended consequences and adverse effects on collision risks as has been identified for at least one other, unrelated, training intervention.

12 Membership of FORS Silver

The Fleet Operator Recognition Scheme (FORS) is a voluntary accreditation scheme for fleet operators which aims to raise the level of quality within fleet operations, and to demonstrate which operators are achieving exemplary levels of best practice in safety, efficiency, and environmental protection (FORS, 2018).

FORS accreditation can be attained via:

- A Single Operating Centre Accreditation (SOCA)
- A Multi-Operating Centre Accreditation (MOCA)
- Whole Fleet Accreditation (WFA)

There are three levels of FORS accreditation which a fleet operator can be granted. These are as follows:

Bronze – a legally compliant operator that is following good practice - this is the entry level of accreditation

Silver – high quality operator, committed to becoming safer, greener and more efficient – this is the intermediate level of accreditation.

To apply for Silver accreditation, the operator must be FORS Bronze accredited with at least 45 calendar days before its expiry date

Gold – exceptional operator that has met specific targets and is continuing to improve – this is the highest level of accreditation.

To apply for Gold accreditation, the operator must be FORS Bronze and Silver accredited with at least 45 calendar days before its expiry date.

There are four key areas to the FORS Standard:

MANAGEMENT	VEHICLES	DRIVERS	OPERATIONS
Responsibilities & authority	Road worthiness	Training and assessment	Routing and scheduling
Competent Person	Insurance	Driving at work	Transport control
Communication	Fleet performance	Fitness and health	Fines and charges

For Bronze accreditation there are many specific requirements within each of the above areas. There are then additional requirements for an operator to achieve Silver and Gold accreditations. Requirements related to vehicle safety equipment and the protection of vulnerable road users are part of the "Vehicles" area. Table 12-1 shows the individual vehicle safety equipment requirements for Bronze and Silver levels.

Table 12-1: Safety equipment requirements for Bronze and Silver levels in FORS

<table>
<tr><th>Requirement</th><th>Scope</th><th colspan="2">Level</th></tr>
<tr><td>Blind Spot Warning signage fitted to the rear of the vehicle</td><td>HGVs > 3.5t GVW and PSVs > 16 passengers</td><td rowspan="4">Bronze</td><td rowspan="7">Silver</td></tr>
<tr><td>Side underrun protection to both sides of the vehicle</td><td>HGVs > 3.5t GVW</td></tr>
<tr><td>Class V and Vi close-proximity mirrors</td><td>HGVs > 3.5t GVW</td></tr>
<tr><td>Achieve at least 1-Star rating against HGV Direct Vision Standard (DVS) or be fitted with safety equipment in accordance with Silver FORS requirements</td><td>HGVs > 12t GVW (operating in London)</td></tr>
<tr><td>Blind-spot vision aids that provide a full view of the nearside vehicle blind spot</td><td>HGVs > 3.5t GVW</td><td rowspan="3"></td></tr>
<tr><td>Audible warning system that alerts other road users of left-turn and reversing manoeuvres</td><td>HGVs > 3.5t GVW</td></tr>
<tr><td>Camera system that monitors the rear vehicle blind spot. The ability to cover front and offside blind spots and to digitally record incidents is also recommended but not required.</td><td>Rigid HGVs > 7.5t GVW</td></tr>
</table>

13 Assessing the policy options

13.1 Rationalising and categorising candidate technical requirements

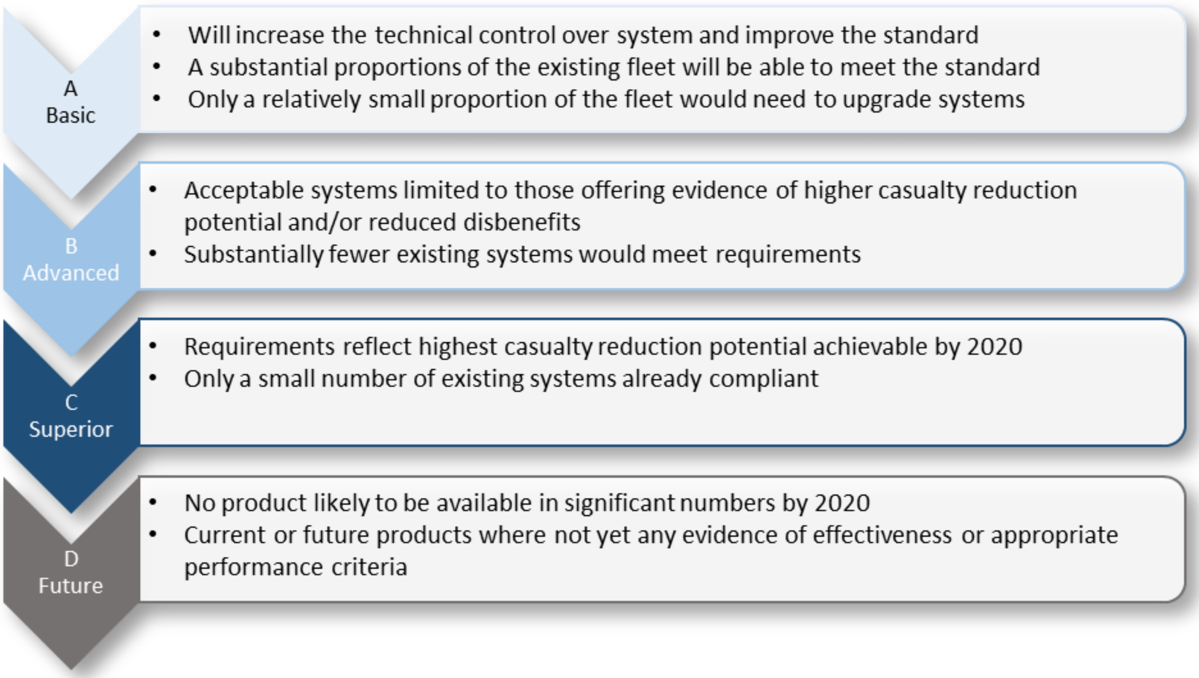
For each individual measure up to 11 candidate technical requirements were identified. In addition to these, there are further options that apply across all the other potential requirements:

- **Impose maximum speed**: warnings and CMS providing supplementary views, are intended to be effective in low speed manoeuvres. Disabling them at speeds above 20mph would be likely to reduce the incidence of warnings the drivers considered false or unnecessary and/or to reduce the risk of distraction or glare during higher speed driving.
- **Apply different requirements for vehicles registered before and after a relevant cut-off date**: If requirements are applied uniformly then the cost imposed on industry could be quite high if technical requirements are such that vehicles already equipped with CMS, blind spot warnings or warnings of intended manoeuvre are forced to replace them with a higher standard system. In this case, the whole cost of the higher spec system will be attributable to this policy decision. If higher specifications are applied only to new registrations, then the higher specification can be fitted from the start such that the cost attributable to the policy is only the price difference between the higher specification system and the lower specification system that would otherwise have been fitted. This, therefore creates a compromise between a lower cost, lower effectiveness approach and a higher cost, higher effectiveness approach. However, it does not match the approach to direct vision, where all vehicles must comply regardless of age.

If all these options were fully independent, which is true for most but not all of them, then this would lead to a total matrix of more than 22,000 discrete possible options. Clearly there is a need to rationalise these many permutations into a manageable set of options that allow TfL to make an informed choice of approach.

The baseline condition is considered to be implementing the equivalent of the FORS Silver scheme directly into the HGV Safety Permit, without amendment. For requirements that go beyond this baseline then the aim has been, for each individual safety measure, to group them into four simple bands as described below, based on adapting the descriptions from IIHS classifications of the performance of AEB[21]:

[21] https://www.iihs.org/iihs/ratings/ratings-info/front-crash-prevention-tests



For this initial implementation of the HGV Safety Permit, systems falling into Category D (Future) cannot, by definition, be a viable option. Therefore, they have not been considered policy options but have been put on the roadmap for consideration as part of future developments of the standards.

The classification and rationale are presented for each technical measure in the sub-sections below. Requirements in each band should be considered additional to requirements at the lower band.

13.1.1 Mirrors

For mirrors, there are clear benefits in terms of the field of view provided but the evidence of how past changes have influenced collisions is ambiguous and far from conclusive. Some evidence does suggest an improvement, but other evidence suggests that there may have been relatively little change directly attributable to those changes. There is sound human factors evidence that can explain why the benefits of mirrors may be limited, especially where there are larger numbers of mirrors, curved mirrors and mirrors showing views in an unnatural orientation. There are concerns that increasing mirror numbers, convexity or size could all have adverse effects. However, there is no evidence to suggest that removing existing requirements would not have adverse effects. Thus, options to remove mirror requirements or extend them have not been considered further.

Therefore, the single option considered is whether or not to transfer the mirror requirement from the safer lorry scheme to the HGV Safety Permit or not. This would simplify administrative arrangements and it is assumed that this would be considered part of the baseline option.

13.1.2 Camera Monitor Systems

For camera monitor systems there was clear theory and experimental evidence to show that the quality of the system was critical to its performance. Implemented poorly then CMS could create distraction from other important views and slow the recognition parts of the perception response process if images are poor. This could offset or even reverse the benefit of being able to see into the blind spot. However, implemented well CMS has the potential to reduce driver workload and better support the perception response process than mirrors, while allowing the blind spot to be seen.

The baseline position is as for FORS Silver which requires fitment at the nearside but does not control the technical quality of the device.

Pedestrians killed in the frontal blind spot while an HGV moves off from rest are as frequent if not more frequent than cyclists killed when an HGV turns left and so should get the same level of safety equipment. The addition of this view creates three camera views in addition to the six mandatory mirror views. The effect on the number of locations the driver must scan should be limited, in effect requiring the views to change dynamically (e.g. rear view replaces front view when reverse selected) or to share space on one screen.). The amount by which the driver needs to move his or her gaze away from the road or other important views should be minimised.

Requirements proposed for Band A are as follows:

A
Basic

- Add front view CMS
- Maximum two monitors
- Monitors positioned close to a window edge or existing mirror location
- Mirrors for low speed manoeuvring shall be switched off over 20mph

UNECE Regulation 46 imposes significant requirements on the quality of view from the monitor and so ensures a good standard of view. It is not mandatory for CMS that are not used as an alternative to mirrors for viewing the mandatory indirect vision areas (Class I – VI) to meet these requirements but component approval is possible.

Requirements proposed for Band B are in addition to Band A and include:

B
Advanced

- CMS used as a supplement to existing mirrors
- CMS to gain a component approval in accordance with UNECE Regulation 46 requirements for mirror replacement CMS

Replacing all mandatory mirrors with a CMS will substantially reduce the number of locations the driver needs to scan and provides opportunities for manufacturers to provide views that adapt to driving circumstances. For example, a large nearside monitor attached to the A-pillar might normally use 2/3rds of its screen to show a Class II rear view and 1/3 to show a Class V nearside blind spot view. This ratio could reverse at low speeds etc.

Requirement for Band C is additive to Band A and effectively replaces the need for and B:

C Superior

- CMS replaces all mandatory mirrors
- All mandatory views and residual blind spots achieved with 3 monitors
- Systems shall comply with all requirements of UNECE Regulation 46

This leaves one candidate technical requirement, the integration of CMS and warnings to be considered as a Band D potential future requirement.

D Future

- Integrate CMS and blind spot warnings

Technically, one such system is available now in the after-market, but the survey responses did not identify many equipped vehicles. In addition to this, very limited information was available about the technical performance of this system and the warning standards in existence have not been defined with that type of system in mind such that it is hard to define technical standards at this time.

13.1.3 Blind spot information, warning and intervention systems for the HGV driver

Extensive behavioural research and experimentation exists to show that warnings can work, and this is backed by predictive collision data and post-hoc statistical studies of systems fitted to passenger cars. However, the evidence also agrees that the design and performance of the system will very strongly influence the effectiveness.

The baseline position is that of FORS Silver, which requires systems at the nearside but does not control the design or performance of the system.

Moving off from rest manoeuvres cause a comparable number of fatalities to turning left and should benefit from the same level of safety equipment

A Basic

- Extend requirements for proximity warning to cover frontal blind spot
- This shall cover the are defined for a Class VI mirror by UNECE Regulation 46
- A nearside system shall have a longitudinal range of detection extending from the foremost point of the vehicle to the greater of:
  - 6m rearward of the foremost point of the vehicle
  - 1m forward of the rearmost point of the vehicle

The introduction of audible warnings that are speech based, not tonal or haptic, and visual warnings that are not red or flashing would substantially reduce the frequency of warnings that most drivers would consider false. A reduction in false positives would increase trust in, and compliance with, the warnings. The HMI requirements would also reduce driver annoyance with any remaining false activations and those that are not false but where the driver considers it unnecessary because they have already seen the hazard. More intrusive collision warnings, if provided, would improve responses of drivers. This improvement in response to both true and false positives would allow an increase in range and the removal of the condition of only operating when the direction indicators are applied. This would increase the population of collisions in scope to those with greater lateral separations and where drivers did not apply the indicators.

Band B requirements are in addition to Band A and include:

B
Advanced

- Proximity warnings
  - Audible warning shall be speech based
  - No haptic warnings
  - Visual warnings shall not be red and shall not flash
  - Shall not activate for roadside furniture or static vehicles
- Collision warnings (if provided)
  - Should differ significantly from proximity warnings
  - Audible warnings shall NOT be speech based
- Systems shall switch of over 20mph
- Systems shall operate independent of the use of direction indicators
- Lateral range of detection is at least 2.5m covering the longitudinal range in Band A

Although the proposed Regulation relating to blind spot information systems for the detection of bicycles (UNECE, 2018) will not come into force on new vehicles until 2020, compliant systems covering the nearside may be available before that time with at least one supplier suggesting they have a compliant system in prototype form currently.

Band C requirements are in addition to band A and B requirements

C
Superior

- Require compliance with forthcoming regulation

Thus, three requirements have been considered only feasible in future.

D
Future

- Collision warning functionality
- Function in the dark
- Motion inhibit systems

Systems that claim to do collision warnings are available in the market and the test defined by (Knight, et al., 2017) can in theory be used to prove that it is effective. However, no systems have actually been tested so the procedure proposed can only be considered 'draft' and the performance of the existing systems are unknown. The proposed regulation also does not require a collision warning because it is considered technically difficult.

Function in the dark is quite possible now. However, collisions that occur in the dark are a very small proportion of the total and it is possible that this condition would rule out some camera-based systems that may be more effective in the much greater number of daylight collisions than systems that work in the dark. Thus, this should not be prohibited until that can be established. The introduction of the regulation in 2020 will require performance in the dark but will not apply to existing vehicles, unless TfL enforce it as part of the Permit.

Motion inhibit systems are certainly not established in the market yet. One survey respondent stated that they offered a camera-based system but no technical details have yet been identified. Another respondent stated that they have a prototype system available for immediate demonstration such that it could be moved to production standard relatively quickly.

13.1.4 Warning of intended manoeuvre

The baseline consideration for warnings of intended manoeuvre is as for FORS Silver; inclusion of a warning for reversing and for left turns. However, stakeholder input prior to this research identified a risk balance considering the effect of such systems on safety but also on wider noise pollution, such that it was considered that removing the requirement for a left turn warning should be considered as an option. The research has supported the existence of this trade-off but it has identified some limited evidence of effectiveness and has identified a range of technical requirements that could help manage this trade-off and even buck the trend to produce a warning that is both more effective and less polluting in terms of environmental noise. For that reason, an option to remove the left turn component has not been included as part of the following groups. The requirements below apply to both reversing and left turn alarms.

Requirements considered for band A are shown below. Complying with these requirements should ensure the systems are audible, at least close to the speaker, in most London ambient noise conditions, while limiting the extent to which they cause noise pollution and irritation. The numbers for daytime are based on the full range for different sound types at 'normal level' as proposed at the time of writing in the draft UNECE Regulation for reversing alarms, as applied to individual components not installed on a vehicle. As such it should be measured when not fitted to the vehicle 1m from the speaker. The night time maximum is based on the maximum for any sound type proposed for 'low level' warnings in the proposed draft UNECE Regulation for reversing alarms. The requirement not to activate when stationary is to ensure compliance with Construction and Use Regulations.

A
Basic

- Control volume of audible warning.
    - Output measured 1m from sounder shall be between 65 dB(A) and 88 dB(A)
- Minimise noise at night
    - Manual or automatic adjustment to a maximum night lime level of 68 dB(A)
    - Can be achieved by switching system off
- Shall not activate when vehicle is stationary or when travelling over 20mph

Research has shown that white noise can be more alerting because it includes substantial frequency content that is different and distinguishable from ambient background noise. It is also found to be relatively directional and for the same level of alert it can be issued at a lower overall volume. Research into AVAS has suggested sounds tuned to increase levels at specific frequency bands and decrease it at ambient frequencies can be even more effective, allowing reduced overall volume.

Requirements considered for band B:

B Advanced

- Audible warning shall include broadband sound (white noise) and not include tonal signals
- Audible warning may include speech or 1/3 Octave Band Sound between 400Hz and 4kHz
- Volume of audible warning
  - Broadband sound (daytime): Between 70 dB(A) and 84 dB(A)
  - Broadband sound (night): No more than 64 dB(A)
  - 1/3 Octave Band Sound (daytime): Between 65 dB(A) and 81 dB(A)
  - 1/3 Octave Band Sound (night): No more than 61 dB(A)

By adapting the sound level relative to ambient it is possible to allow a louder sound to be more effective in very noisy environments, without the adverse consequences in quieter conditions. The values selected are those proposed at the time of writing in the draft UNECE regulation for reversing alarms.

Requirements proposed for band C:

C Superior

- Warning shall automatically adapt in relation to the time of day
- Ambient noise shall be measured by the vehicle
  - Broadband sound: 400Hz to 10kHz +5 dB(A) ±1 compared to ambient sound emission between 60 dB(A) and 95 dB(A)
  - 1/3 Octave Band Sound: 400Hz and 4kHz +1dB(A) ±5 compared to ambient sound emission between 55 dB(A) and 93 dB(A)
- Variation subject to a night time maximum of 64 dB(A)

Further technical requirements could enhance the performance of these systems in future. This could include:

D Future

- Measurement of the sounds as installed
- Cap maximum sound level in directions where warning is not intended to influence behaviour
- Refine sound signature to optimise detectability against noise nuisance
- Improve activation strategy to minimise false/unnecessary warnings
  - Incorporation of steering into the activation
  - Allow activation when direction indicators not used
  - Enable two-stage proximity/collision warning approach
  - Integration with blind spot warning
- Enhanced visual warning for 'proximity' stage of two-stage warning

13.1.5 Summary

The requirements are summarised in Table 13-1, below.

Table 13-1: Summary of banded requirements by type of safety system

	A: Basic	B: Advanced	C: Superior
Mirrors	Permit mirrors replacement CMS	-	-
Camera Monitor Systems (CMS)	Nearside, rear and front view using a max of 2 monitors, positioned close to existing view direction Define min. length of nearside detection zone	Require supplementary CMS to be approved to UNECE Reg 46	Require mirror replacement for CMS reducing 6 mirror views to 3 monitor views in accordance with UNECE Reg 46
Blind spot information, warning and intervention for the driver	Extend requirements to front blind spot based on Class VI view Define min. length of nearside detection zone	Introduce HMI requirements Prohibit proximity warning for roadside furniture and stationary vehicles Disable over 20mile/h Lateral range ≥ 2.5m Operation without direction indicators	Nearside systems comply with UNECE Regulation
Warning of intended manoeuvre for VRU	Limit sound levels for day and night conditions No activation when stationary or above 20mile/h	Prohibit tonal sounds Lower sound limits, and divide by sound type	Systems that adapt volume relative to background noise level

13.2 Indicative benefits and costs

A formal cost benefit analysis suitable for use in impact assessments was not within the scope of this study however simplistic indications of casualty reduction effectiveness have been made where sufficient data has permitted. Where necessary, pragmatic adjustments have been made to the ranges presented. The assumptions and adjustments made are listed below in the relevant section.

For each technology, the literature review presented earlier in this report included a summary of evidence that had sought to estimate the effect that the technology would have in reducing road user casualties. The details of the studies mean that most of the estimated effects do not align exactly with the different levels of implementation presented in section 13.1 (e.g. A, B, C). Therefore, some assumptions have been made as to which implementation level each of the studies might be most aligned with.

13.2.1 Summary of VRU casualties in London

Based on the STATS19 analysis, reported in section 4, Table 13-2 shows the average number of pedestrian and cyclist casualties in London each year resulting from collisions with an HGV > 7.5t GVW, where the HGV was moving away from rest or turning left.

Table 13-2: Average number of pedestrian and cyclist casualties in London each year resulting from collisions with an HGV > 7.5t GVW, where the HGV was moving away from rest or turning left. Source: STATS19 database 2008-2017.

Accident Scenario	Fatal	Serious	Slight

Moving Off v Pedestrian	3.7	2.5	3.8
Moving Off v Cyclist	0.5	0.5	3.2
Moving Off Total	**4.2**	**3**	**7**
Turning Left v Pedestrian	1.2	2.4	4.6
Turning Left v Cyclist	2.2	4.2	8.9
Turning Left Total	**3.4**	**6.6**	**13.5**

These figures have been used as the target population against which the estimated casualty savings from the identified literature have been applied. It should be noted that these figures do not take account of under-reporting of collisions involving some construction HGVs such as tippers and cement mixers in STATS19. This occurs when such vehicles are mis-coded as 'other motor vehicles'. (Knight, et al., 2017) found that on average this problem meant that there were 21% more pedestrian fatalities and 30% more cyclist fatalities than found when only considering vehicles recorded as HGVs>7.5 tonnes.

13.2.2 Camera monitoring systems

There are very few vehicles on the road with mirror replacement camera monitor systems and, as such, no statistical evidence in relation to their effect on collision involvement yet exists.

(Cicchino, 2017) and (Schmidt, et al., 2015) reported on studies where camera systems were fitted to passenger cars. These showed 17% fewer reversing collisions occurred and that a greater safety distance was employed.

Several studies provided qualitative evidence that the field of view and/or quality of the image was just as good as a mirror. (Fitch, et al., 2011) found that glances at the CMS were of shorter duration than for convex mirrors, suggesting that the driver extracted the required information from the mirrors more quickly than from convex mirrors.

Despite the above studies there remains a lack of data that could be used to estimate the potential effectiveness of a CMS system. Therefore, for this study, a target population that could be influenced by the fitment of CMS has been estimated instead.

CMS can be installed to monitor the frontal blind spot with a monitor positioned in a place that is easier to see than the class VI mirror, which tends to be up high at the top of the windscreen. The pedestrian will typically be in front of the vehicle for a time before the vehicle moves and the driver only needs to abort the decision to move. It was, therefore assumed that all moving off from rest collisions would be in scope, though of course effectiveness will depend on how often the driver correctly uses the CMS and correctly responds to what they see.

Based on collision data published by (Jia, 2015) and (Jia & Cebon, 2015), (Robinson, et al., 2016) grouped left turn incidents involving cyclists into three categories:

1. The pedal cycle moves up the nearside of an HGV stationary at traffic lights,
2. Both vehicles (cyclist and HGV) are stationary before moving off from rest together,
3. Both vehicles (cyclist and HGV) moving.

Scenario 2 could be considered most relevant to fitment of CMS since, in such cases, the VRU is positioned towards the front nearside corner of the HGV where a genuine blind spot often exists and drivers will have time to scan all views. For Scenario 3 the VRU could be positioned anywhere alongside the HGV and so in many cases will already be visible in mirrors. It was therefore assumed that only a proportion of these could be considered relevant to CMS. In scenario 1, the situation starts with the cyclist visible in rear view mirrors but with the moving quite quickly such that they will spend little time visible in a purely blind spot CMS and at a moment very close to the moment of impact. It was, therefore assumed CMS would not have an effect in these situations.

Table 13-2 shows the average number of cyclist casualties each year resulting from incidents involving an HGV turning left. Based on data by (Jia, 2015), (Knight, et al., 2017) showed that for fatal incidents where both the cyclist and HGV moved off from rest together (Scenario 2) accounted for approx. 30% of cyclist fatalities, with a further 30% happening when both vehicles were already moving (Scenario 3).

If it were assumed that fatalities from Scenario 2 were all applicable to the fitment of CMS and 50% of the fatalities from Scenario 3 were relevant to the fitment of CMS, then this would mean that the target population for CMS would be 45% of the cyclist casualties per year resulting from incidents involving an HGV turning left. It was also assumed that the collisions involving pedestrians and left turns occurred in the same distribution and effect. Based the DfTs average value of casualty prevention[22] this would give a monetised value of £12.36m per year (Table 13-3).

This value should be considered as a substantial overestimate since there would inevitably be many cases within this target population in which the driver would not properly use the system or where it would not offer any additional benefit for some other reason. It also does not account for the fact that some of the reported collisions may have involved a vehicle already equipped with CMS.

Table 13-3: Estimated maximum monetised casualty benefit for the target population of incidents relevant to fitment of CMS

Scenario	Proportion VRU casualties	VRU casualties (Table 13-2)			Assumed relevance to CMS	Monetised Value
		Fatal	Serious	Slight		
Move off	100%	4.2	3	7	100%	£8.72m
Left turn 1	40%	1.36	2.64	5.4	0%	£0.00m
Left turn 2	30%	1.02	1.98	4.05	100%	£2.42m
Left turn 3	30%	1.02	1.98	4.05	50%	£1.21m
Total		**7.6**	**9.6**	**20.5**		**£12.36m**

13.2.3 VRU detection systems

(Cicchino, 2016) found that vehicles fitted with FCW had on average 6% fewer police reported collisions where the equipped vehicle struck the rear of another vehicle, and the collision resulted in an injury. When FCW was combined with automated emergency braking (AEB) then collision involvement was reduced by 42% for collisions with injuries. For this analysis it has been assumed that the FCW system is equivalent to Implementation Level A, and FCW in combination with AEB represents Level C, since very few current HGVs offer a production AEB system that is functional for low speed VRU collisions.

[22] https://www.gov.uk/government/statistical-data-sets/ras60-average-value-of-preventing-road-accidents

(Barrow, et al., 2017) found that in total the ability of VRU detection systems at the front and side to avoid collisions was between 6% and 47%, with a predicted value of 40%. However, accounting for the possibility of using probability to produce a different 'prediction' from the same base data, the predicted value was recalculated by the authors to produce a prediction of 23%. The specification of the system evaluated was not defined however, the approach seems to correlate broadly with the minimum standard for future regulations if that was also applied to moving off from rest collisions. Therefore, it has been assumed that such a system represents Implementation Level B. The upper prediction of 47% has also be assumed equivalent to Implementation Level C because it exceeds the results of the post-hoc statistical study by (Cicchino, 2016).

(IIHS, 2011) found that passenger car BLIS was reducing injury claims by approximately 15-24%. Based on functionality it was considered that passenger car BLIS was approximately equivalent to a band-4 system according to (Knight, et al., 2017) and so it has been assumed that this corresponds to Implementation Level B for this study

(Knight, et al., 2017) estimated that the effectiveness of blind spot information, intervention and warning systems would be 0% to 16% for a 1-star system; 30%-62% for a 3-star system and 58% to 70% for a 5-star systems. These have been translated in Level A, B, C systems respectively.

Table 13-4 shows a summary of the above estimates aligned with the assumed levels of implementation.

Table 13-4: Estimated casualty effectiveness of blind spot warning systems based on identified literature.

Implementation Level	Study				Overall Range
	Cicchino, 2016	Barrow, et al., 2017	IIHS, 2011	Knight, et al., 2017	
A	6%			0% - 16%	0% - 16%
B		23% - 40%	15% - 24%	30% - 62%	15% - 62%
C	42%	43%		58% - 70%	42% - 70%

By using the lower and upper limits of the overall range for each system with the annual number of VRU casualties, shown in Table 13-2, and applying the DfTs average value of casualty prevention[23], Table 13-5 shows that an estimated casualty benefit of up to £11.8m has been estimated. Given that this does factor in the estimates of true effectiveness it should be considered a more realistic range and is not, therefore, directly comparable to the 'target population' figure expressed for CMS. However, it still does not account for the proportion of vehicles already equipped with systems and that some collisions in the data may have occurred with vehicles that already had systems.

Table 13-5: Estimated casualty benefit of blind spot warning systems on target population

Implementation Level	Fatal		Serious		Slight		Total	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
A	0.0 m	2.3 m	0.0 m	0.3 m	0.0 m	0.1 m	0.0 m	2.7 m
B	2.2 m	8.9 m	0.3 m	1.3 m	0.1 m	0.2 m	2.5 m	10.4 m

[23] https://www.gov.uk/government/statistical-data-sets/ras60-average-value-of-preventing-road-accidents

C	6.1 m	10.1 m	0.9 m	1.4 m	0.1 m	0.2 m	7.1 m	11.8 m

13.2.4 Warning of intended manoeuvre systems

(Ainge & Morgan, 2018) evaluated a technology known as Acoustic Vehicle Alerting Systems (AVAS) and estimated that a pedestrian/cyclist is approximately 15% more likely to have a collision with an electric bus than a conventional bus, assuming that the only difference between the two bus types was the absence of any audible alerting cues. The casualty benefits of an AVAS system was assumed to be 15% (with a tolerance of ±5% for best/worst cases), such that it would make the rate of collisions per bus-km the same for both electric and diesel buses.

(Pecheux, et al., 2015) undertook observational studies via a video survey at four intersections over 80 hours. From 109 events where a pedestrian was present as a test bus (fitted with an audible warning) made a turn, 12% of pedestrians made some form of visible reaction to the warning, compared to 0.15% when other buses (without the warning system) made similar turns.

(Ponziani, 2012) observed 12,000 vehicle manoeuvres in the Ohio area in the US and found that in 25% of turning situations and 48% of lane changes, drivers did not use the direction indicators. This would limit the effectiveness of the system since it relies on the operation of the direction indicators

Although the studies above produced similar estimates for the potential number of cases that could be affected by a warning system (12% - 15%), this is only a very limited base of evidence on which to base any potential casualty savings.

For this study it has been assumed that the 12%-15% range represent the upper limit of potential casualty benefits for Implementation Level B, which would be reduced if direction indicators were only used in a subset of cases, as suggested by Ponziani.

For Implementation Level A, it has been assumed that the more basic functionality of the system, would reduce the number of circumstances in which it is effective, such that it would be effective in 0%-10% of cases. For Implementation Level C, it has been assumed that improved volume and directional control of the warning coupled with a more optimised sound signature may increase the effectiveness of the system to work in 15%-20% of cases. It is important to note that these assumptions are unproven and have been proposed as a means to provide an indication of the order of magnitude of any possible benefits.

Table 13-6 shows to combined effect of considering the number of cases that a warning system might be effective in, and the proportion of cases in which a direction indictor is used.

Table 13-6: Effect of direction indicator use on proportion of incidents affected by warning of intended manoeuvre system

Implementation Level	Incidents affected	Turn indicator usage	Combined range
A	0% - 10%	52% - 75%	0% - 7.5%
B	12% - 15%	52% - 75%	6.2% - 11.2%

C	15% - 20%	52% - 75%	7.8% - 15%

Table 13-7 shows the result of applying the overall range to the target population numbers (Table 13-2), which in this case are turn left incidents involving either a pedestrian or cyclist. Again, the figures do not account for the fact that some vehicles will already be equipped with the systems.

Table 13-7: Estimated casualty benefit of warning of intended manoeuvre systems on target population

Implementation Level	Fatal		Serious		Slight		Total	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
A	0.0 m	0.5 m	0.0 m	0.1 m	0.00 m	0.02 m	0.0 m	0.6 m
B	0.4 m	0.7 m	0.1 m	0.2 m	0.01 m	0.02 m	0.5 m	0.9 m
C	0.5 m	1.0 m	0.1 m	0.2 m	0.02 m	0.03 m	0.6 m	1.2 m

13.3 Defining Policy options

Even with the rationalised set of technical requirements described in section 13.1 a range of policy options are possible. Three options have been defined, as described below, though the third could be considered to have several sub-options:

13.3.1 Option 1: BASIC

This option makes compliance with all Band A technical requirements mandatory to gain the Safety Permit. This will substantially increase the number of collisions that will fall into scope of the vehicle safety measures compared with the baseline FORS Silver compliance, by requiring systems to be active at the front as well as the side (encouraged as part of FORS but not mandatory). It will also apply some very basic technical standards that will prevent very low standard systems from qualifying. However, most systems on the market will already comply with the technical requirements such that few operators would be required to replace a system that they had already fitted in accordance with FORS guidance in good faith.

It should be noted that each type of system has examples of poor implementation in the market which could have an adverse impact on the effectiveness of the system and/or nuisance effects of the systems. Making it mandatory to fit all three systems with only basic technical requirements could have the effect of increasing the number of poorly implemented systems in the fleet. This might occur if, for example, the industry responded by complying at minimum cost.

13.3.2 Option 2: ADVANCED

This option makes compliance with Band B technical requirements, in addition to Band A, mandatory. It significantly increases the stringency of the technical requirements compared with Band A and this would be expected to significantly increase the casualty reduction potential and/or reduce the chances of adverse consequences of the technologies. However, a much greater number of existing systems already fitted to vehicles in accordance with FORS would need to be replaced with new systems.

13.3.3 Option 3: FLEXIBLE

The flexible option allows both manufacturers and operators much more choice and control over the approach that they think best suits their operation and the status of their existing vehicles. It recognises that the performance level of systems already available in the market place is highly variable and the evidence does suggest that effectiveness will be highly dependent on that performance. Some operators may have chosen to invest additional funds on one high performance system rather than a lesser total investment in three basic systems. The evidence suggests that it is quite possible that such an approach may well result in greater safety benefits. Thus, systems would be awarded 1 point for a system meeting the Band A requirement, 2 points for a system meeting the Band B requirement and 3 points for a system meeting the Band C requirement.

The Safety Permit would, therefore, require vehicles to achieve a certain minimum point score to be achieved rather than mandating requirements more specifically. Sub-options exist based on what the minimum point score should be:

- **Minimum 3 points:** A vehicle could achieve the permit by fitting three 'Basic' systems, by fitting one 'Basic' system and one 'Advanced' system or by fitting one 'Superior' system only.
- **Minimum 4 points:** Three 'Basic' systems would no longer qualify. Compliance would require a minimum of one 'Advanced' system and two 'Basic' systems, or one 'Superior' system and one 'Basic' one. Thus, at least two of three systems are required but these could both be aids to the driver with nothing for the vulnerable road user. Many survey respondents highlighted the need to target measures at the vulnerable road users as well
- **Minimum 4 points with restriction:** As per the option for a minimum 4 points but with the added restriction that at least one system must aim to help the vulnerable road user and at least one must aim to help the driver.
- **Minimum 5 points:** Would require at least two 'Advanced' systems and one 'Basic', or one 'Superior' and one 'Advanced'.
- **Minimum 6 points:** approximately equivalent to *Option 2: ADVANCED* in requiring three 'Advanced' systems but with the flexibility to have one 'Superior' one 'Advanced' and one 'Basic' instead.

Clearly the minimum point score could go on to a minimum of 9. However, in 2020 the Safety Permit is intended to make a vehicle that achieves 0-star direct vision be as close as possible to an equivalent level of safety as a 1-star vehicle. It is very difficult to objectively and accurately draw that comparison, but it is considered highly likely that requiring higher technical standards than that offered by a 6-point score in the flexible option (or compliance with Option 2: ADVANCED above) is highly likely to be a higher standard than a 1-star direct vision.

The advantages of the flexible option over the two preceding ones is that it is likely to allow the trade-off between the technical standard required and the cost of implementation to be avoided, at least to some degree. It also helps avoid providing an incentive for the market to design down to the minimum standard (compliance at minimum cost) by ensuring that manufacturers of higher specification products can provide a cost justification for choosing that approach as well as a safety one. This is likely to be an advantage for those operators that have already voluntarily invested in higher specification equipment and who have had the capacity to analyse their collisions and risks and identify single solutions that they believe work well for them.

However, the disadvantage is that it requires operators to make choices about their approach. Some operators, particularly smaller ones that do not have large quantities of collision data to analyse to help inform their choices, may prefer to be told more simply exactly what they must do to comply.

14 An Initial Roadmap towards 2024

TfL have committed to upgrading the requirements of the Safety Permit in 2024 at which point the direct vision standard will also become more demanding, requiring vehicles to have at least 3-star performance. The start of 2024 is only five years from the time of writing of this report. DfT vehicle licensing statistics[24] show that approximately half of all licensed HGVs at any one time are six or more years old. Although replacement cycles may be shorter than this for the first buyer of vehicles, it will not be long before fleet buyers will want to know the specification of vehicle that they should buy in order for it to have a good chance to be compliant with standards that will come into force during its life, or at least the life with that first buyer.

Thus, the costs of new safety rules can be minimised by applying them only to new vehicles, as is done with most safety regulations applied through the type approval scheme and/or by providing the industry with good forward guidance on what is expected to be included in future rules so that the industry can adapt to them ahead of time. The Euro NCAP programme for assessing the safety of new passenger cars operates on this principle and regularly issues ‘roadmaps’ describing the plans it has for upgrading requirements over the following five years.

The main aim of this research was to quantify the evidence available to support the 2020 HGV Safety Permit and to consider appropriate technical requirements for it. It was not to develop a roadmap for 2024. However, the information reviewed inevitably identified some technical development paths of the technologies already considered in scope as well as some that were not in scope. These could not be included in 2020 either because they were not available, or in the market in sufficient numbers, or because there was, currently, limited evidence of their effect or details of appropriate technical requirements. This section, therefore summarises those potential future developments and outlines what additional evidence might be needed to further assess their suitability for inclusion in a future development of the HGV Safety Permit.

14.1 Blind Spot Information, Warning and Intervention systems

At present, the research identified only three systems already in the market that claimed to provide a true collision warning based on calculation of the trajectory of the HGV and cyclist and thus issuing warnings only when a collision was imminent. None of these had been subject to independent testing to assess their effectiveness. In addition to this, the survey responses suggested that these systems would currently represent only a small market share. However, the theory suggests that an accurate collision warning should be more effective than proximity warning alone such that requiring this would provide additional safety benefits in 2024.

Draft test methods for such systems do already exist (Knight, et al., 2017) but would benefit from validation using several systems spanning the range of technical performance covered. An experimental trial, similar to that undertaken for direct vision, would also help to confirm whether systems scoring more highly in those tests did in fact result in better responses to the warnings in the specific situations most relevant in London.

At present, the effectiveness of specific systems already in the market are not well known and most have not been tested. Based only on characteristics advertised by manufacturers and survey responses, there is a possibility that in daylight some camera-based systems

[24] Table veh0507 available from https://www.gov.uk/government/statistical-data-sets/veh05-licensed-heavy-goods-vehicles

may be more effective than some ultrasonic based systems. However, this may be reversed in the dark. Ideally systems would be highly effective in both daylight and dark but street-lit conditions. A future regulation will require function in the dark and it is likely systems will evolve that way such that the requirement can be added in future without the risk of adverse effects. Undertaking specific testing according to either the proposed regulatory or the draft procedures proposed by (Knight, et al., 2017) in both light and dark with different systems would allow this to be better quantified.

One survey response claimed that a motion inhibit system was already in production and another stated that a prototype was available for immediate demonstration. If effectiveness of such systems can be demonstrated in tests, then committing to a future requirement would incentivise the market to develop the system (where needed) and to fit it to vehicles ahead of deadlines.

Automated Emergency Braking (AEB) is required on trucks for front to rear collisions with vehicles directly ahead. However, the collision data (Table 4-1) shows that a comparable number of pedestrians are killed when the HGV is going ahead as are killed when moving off from rest. These collisions are mainly those where a pedestrian crosses the road in front of an HGV moving at normal traffic speed. Mercedes already market an AEB system that functions in this type of situation[25] and (Knight & Dodd, 2019) described tests of a prototype systems effective in this situation applied to a city bus and developed a performance test and rating. Minimal adaptation would be required to amend this procedure to be suitable for HGVs. Testing of one or more HGV systems would assess how the effectiveness might differ from passenger cars or the prototype bus.

There is a suggestion in some of Mercedes literature that the pedestrian AEB also works when the vehicle is turning but no detail is provided, and no information of independent test has been found. However, it is known that a turning AEB is under development by at least one tier-one supplier. If accurate and well-engineered, then such systems would be expected to further reduce casualties though independent testing to confirm functions would be beneficial. The procedures developed for warning systems by (Knight, et al., 2017) would require minimal adaptation to apply to AEB in turning situations.

14.2 Warnings of Intended manoeuvre

The requirements proposed for 2020 are all based on measuring the sounds from the speaker in isolation (lab testing). Where the system is installed, how many speakers are used etc will affect the sound reaching the ears of a VRU in the real world. Thus, requirements could be improved if the sound was measured in the 'as installed' condition. Similarly, the maximum sound level in directions where warning is not intended to influence behaviour (e.g. to the right of the vehicle when turning left, ahead of the vehicle, up in the air) could be capped to minimise noise pollution effects.

The evidence so far showed that there was a wide range of ways of optimising the sound signature to better balance detectability against noise nuisance. This would be likely to require some experimental research to develop and prove a more effective sound but could then become a future requirement. It is worth noting that as part of the bus safety standard, TfL are considering the development of a similarly optimised sound for use as an alerting system for quiet (e.g. electric) vehicles.

[25] https://www.mercedes-benz.co.uk/content/unitedkingdom/mpc/mpc_unitedkingdom_website/en/home_mpc/truck/home/roadefficiency/greater-safety.html

There may be opportunities for considerable improvements in left turn warnings from integrating steering into the activation and warning strategy. A two-stage warning could be developed that allowed a non-urgent, non-intrusive/annoying warning to be issued when indicators are activated but vehicle remains in a straight line. This could be escalated to a louder more intrusive collision warning when steering was activated, and a collision became more likely. Research to identify the optimum activation strategies might be required as well as observational studies to assess how it changed VRU behaviour around vehicles.

14.3 System Integration

The evidence reviewed has identified several benefits of integrating systems. For example, warning a driver and then drawing his or her attention to where the hazard can clearly be seen is an evidence good practice. Thus, integration of visual and audible warnings within camera monitor systems have clear potential, though further experimental validation would be beneficial in the specific circumstances relevant to this work.

Similarly, integration of warnings with the warning of a left turn would be considerably beneficial in reducing ‘false positive’ activations of the warning when no VRU is present.

14.4 Supporting analyses

One of the main gaps for most of the measures analysed in this report, is that very little in the way of rigorous post-hoc analyses of the effect of the measures on casualty rates is available. This is one of the most convincing forms of evidence of effect. For measures confined only to London, the numbers of vehicles and collisions will always limit the statistical power of such analyses. However, at present they are not possible at all, mainly because the fitment or performance of systems in the fleet and in the collision data population are not known.

It is at least theoretically possible that the process of applying for a Safety Permit would allow TfL to collect information on the safety equipment fitted to specific vehicles and from there to link it to measures of exposure (e.g. traffic levels from ANPR cameras) and to collisions. If this were to be possible, it would allow such post-hoc statistical analyses to be attempted and may offer the opportunity to provide more robust evidence of safety effects in future.

14.5 Harmonisation of technical standards

While the HGV Safety Permit can enforce minimum standards in London, it is limited by the technology available to operators. Higher standards of technology can be driven if the market for the technology is larger. Development costs can be spread over larger quantities of sales and so better systems can also be cheaper. The HGV Safety Permit approach may not be possible in all cities because legal constraints and powers may vary. However, if a common technical standard was agreed across a much wider demographic (e.g. UK or EU wide) then manufacturers could see that complying with it would reach a much larger potential market. Individual cities or authorities could require or incentivise compliance with it in whatever way they saw fit locally. In effect, such a harmonised scheme could become analogous to a Euro NCAP for HGVs and, in fact, such a possibility has been acknowledged in the latest Euro NCAP roadmap document[26].

[26] https://www.euroncap.com/en/for-engineers/technical-papers/

15 Conclusions

1. The fundamental problems associated with HGVs involved in close-proximity manoeuvring collisions has been reviewed. It has confirmed that blind spots are a significant contributor to collisions and the key manoeuvres are turning left (mainly affecting cyclists) and moving off from rest (mainly affecting pedestrians). Further information showing that the area of risk at the nearside may be greater than thought based on subjective impressions of London infrastructure.
2. Studies of human visual behaviour confirm that complexity of manoeuvre and the need to scan multiple views can be a contributory factor to collisions even when vulnerable road users are not in blind spots.
3. There is clear evidence that mirrors can substantially reduce blind spots but the evidence that this translates to casualty reductions is much more ambiguous. Evidence in relation to human visual behaviour relating to the size of image, the lack of relative motion to trigger peripheral vision, the need to consciously scan the mirrors and the time taken to do so, and the additional perception response difficulty associated with curved mirrors, distorted images or images presented in unnatural orientations all provide likely explanations of the limitations in effectiveness of further mirror development.
4. The same evidence provides strong support for why direct vision is expected to be more effective than mirrors and this is strongly backed by experimental evidence.
5. The behavioural evidence suggests that camera monitor systems can potentially have adverse effects but can also offer significant advantages over mirrors. They are capable of overcoming physical limitations of mirrors in order to be able to see blind spots that mirrors cannot do. However, the net effects are very strongly dependent on the design and performance of the system:
    a. CMS used in addition to mirrors with poor quality screens, poorly located can add to driver workload, taking attention away from other important views, and increasing perception-response difficulties, offsetting or even reversing the benefits of increased area of view.
    b. CMS used to replace mirrors with high quality components and well-located monitors can potentially reduce blind spots, reduce driver workload, improve driver perception response and may in fact give better images than mirrors in several adverse weather conditions by using sophisticated image processing and enhancement techniques. Adaptive displays that prioritise views based on the driving situation are also possible.
6. The behavioural evidence studied suggests that collision warnings generally can have significant benefits, even when imperfectly implemented. However, there was also a considerably body of evidence that was broadly in consensus that those with higher technical standards, particularly those minimising false positives and matching the urgency of the warning to the urgency and criticality of the driving situation, would substantially improve compliance with the warnings and reduce the extent to which drivers might find them annoying.
7. Warnings to VRUs of the intended manoeuvre of the vehicle followed similar principles to those intended to benefit drivers but with a particularly pronounced trade off between the effect in the hazardous situation and contribution to noise

pollution. Again, the importance of the technical standard in terms of false positives and warning strategies was found to be critical.

8. In terms of the casualty reduction effectiveness of the systems, none could be supported by the highest standard of evidence: statistical studies demonstrating the vehicles with the feature had fewer and/or less severe collisions than those without the feature. This is likely due to relatively low numbers of commercial vehicle incidents and a lack of information about what systems are fitted to vehicles will limit the ability to successfully produce that type of evidence. At least some evidence was found to support the likelihood of effectiveness for all systems, though the confidence in that evidence varied considerably:
    a. Direct vision was strongly supported by theory, experimental evidence, survey evidence and predictive casualty analyses, all suggesting strong potential benefits in the relevant manoeuvres, particularly moving off from rest.
    b. Blind spot information, warning and intervention systems were strongly supported by theory, experimental evidence and predictive casualty analysis. Even imperfect systems had some evidence of effectiveness and predictions were that very high-quality systems had the potential to be more effective than direct vision, particularly in the more dynamic variants of left turn manoeuvres where the cyclist is positioned behind the drivers cab at the moment the driver needs to see them to avoid collision. However, the survey evidence also suggested that most of the systems currently fitted to vehicles were at the basic end of the spectrum of different performance levels. Forthcoming regulation would be expected to drive improvements quite quickly from 2020.
    c. High quality CMS was well backed by theory, human factors experiments and limited road trials. However, no evidence was identified, positive or negative in relation to predictions of casualty effects.
    d. Warnings of intended manoeuvre had the least directly relevant evidence of effect. Studies show that electric vehicles are more likely than combustion engine vehicles to have low speed collisions with vulnerable road users. Experimental evidence shows that acoustic warnings can restore a VRUs ability to detect the vehicle to the level of an internal combustion engine vehicle. Trials of warnings of left turn manoeuvres on buses showed an increase in the number of pedestrians that visibly reacted to the presence of a turning bus. Human factors experiments show that people found that reversing alarms made vehicles more noticeable.
9. A huge range of potential technical requirements were identified that would improve the standard of each type of system over the baseline level of the requirements of FORS Silver (v5). This range of candidate requirements was rationalised to three technical levels: Basic, Advanced, and Superior.
10. Three main policy options were identified:
    a. **Basic:** requires all three systems with technical requirements at the basic level, providing significant improvements over baseline while minimising the number of vehicles voluntarily fitted with existing systems that would be forced to replace those systems prematurely. There would be a risk of driving the market down to the minimum standard

b. **Advanced:** requires all three systems with considerably more stringent technical requirements that are feasible in the time frame but would require a considerably larger number of vehicles already fitted with systems to replace those systems with higher specification ones, at significant cost.

c. **Flexible:** defines a points system awarding 1 point for a basic system, 2 points for advanced and 3 points for a superior system. Requires that all vehicles score a minimum number of points between 3 and 6 that would allow operators and manufacturers much greater flexibility in the systems they chose to achieve comparable safety levels potentially at lower cost or in the way most suited to their existing fleet.

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Appendix A Summary of Survey Responses

A.1 Survey approach

A set of four separate on-line surveys was developed and distributed to:

- Technology Suppliers
- HGV Operators
- HGV Drivers
- VRU Groups and road safety experts

The surveys were used to generate mainly qualitative information about what types of blind-spot safety systems are typically fitted/supplied, their capabilities, limitations and costs, and to seek stakeholders' views on a potential minimum standard in London.

Links to the surveys were distributed by TfL and the research team by email, and recipients were further encouraged to forward the links on to their contacts. In total, over 200 individuals and organisations contributed responses to one or other of the surveys, mostly HGV operators and drivers. Given the technical nature of many of the questions, this is considered a very good response rate.

The following sections describe in more detail the questions in each survey and summarize the responses of most usefulness in supplementing and complementing the other evidence gathered for this research.

A.2 Survey of technology suppliers

Seven organisations supplying Camera Monitor Systems, VRU Detection Systems and/or Intended Manoeuvre Warning Systems responded to the survey, as did two organisations who supply Fresnel lenses or passenger door windows. All these respondents stated they had been active in the market for at least 5 years and four of them for over 10 years.

A.2.1 CMS suppliers

Five respondents supply CMS, all but one of them as replacements for one or more mandatory mirrors. All systems record and store their images.

The system that does not replace mirrors was described as having a single in-cab monitor *"with 4 channels usually positioned on the dash, below the dashboard line, in the peripheral vision of the driver when checking his mirrors"*.

The mirror replacement systems varied, with one, for example, offering a single, 360° view, another having multiple, "triggered" views, e.g. near-side view on left turn indicator activation, and another integrated with collision warning systems such as forward collision warning, headway monitoring, lane departure warning and VRU collision warning. Only one system, however, was specifically described as UNECE Regulation 46 approved. Follow-up conversations with the CMS suppliers found two potential reasons for this apparent anomaly:

- Systems are not currently fitted as mirror replacements (they are in addition to the mirrors) so suppliers have not yet needed to formally go through the Regulation 46 approval procedure, though they believe their systems would comply

- Systems may be adopted as standard or optional fit by OEMs to replace mirrors, and they would handle the Regulation 46 approval

In response to a question about how their systems were likely to be more effective at helping to prevent VRU collisions than those of their competitors, the following points were made:

- Video analytics used to provide driver alerts only when a VRU is approaching the vehicle, eliminating the propensity for proximity sensors to issue too many false alerts, e.g. detecting street furniture
- Single view/monitor useful in reducing driver distraction
- Night vision cameras
- Multiple cameras covering vehicle side, passenger door area, front and back

Systems tend to be offered with 1-2 years warranty, fitted by approved installers or the suppliers themselves, and cost between £700 and £3,000 depending on the exact specification, e.g. whether recording is used. The more expensive systems tend to be more comprehensive, however, than just CMS, with detection systems and manoeuvre warnings included as a complete package.

Respondents further emphasised the importance of proper fitment, versatility for different vehicle types (e.g. a 360° view not being appropriate for articulated vehicles), image and camera quality, and after-sales support.

Next-generation CMS were felt by respondents likely to include more extensive use of Artificial Intelligence to identify genuinely hazardous situations, better imaging, data transfer and storage capabilities and integration of separate systems to reduce costs and reduce driver distraction.

A.2.2 VRU detection system suppliers

Six respondents supply VRU detection systems, all covering the vehicle near-side and five (all the CMS suppliers) also able to cover the vehicle front.

All suppliers stated their systems would detect pedal and motor cyclists as a minimum, with all but one also able to detect pedestrians (adult and child). Most also stated their systems would detect other vehicles, wheelchairs and pushchairs but only one stated their systems would also detect roadside furniture such as lamp-posts and railings.

Most of the detection systems were stated to work using ultrasonic sensors, but many also mentioned camera sensors. Only one supplier mentioned the use of LIDAR sensors and two others did so for RADAR. Proximity sensors were stated to be able to detect objects typically within 1 – 2.5 m of the vehicle. Most of the systems alert whenever an object is within the detection range, with one system only warning when the system “has determined that a collision will incur if no action is taken” and another warning under both scenarios but using different warnings for each. All systems provide both visual and audible warnings, with one also claimed to provide autonomous braking. A follow-up conversation with that supplier, however, revealed that this autonomous braking capability only applies to their reversing sensors, presumably designed more to prevent damage around loading bays than collisions with VRUs.

In response to a question about how their systems were likely to be more effective at helping to prevent VRU collisions than those of their competitors, the following points were made:

- Reduced false alarms, reducing driver distraction and improving driver behaviour
- Integration with CMS
- Fusion of radar and camera data
- "traffic light" visual aid in cab

Systems tend to be offered with 1-2 years warranty, extendable to 5 years, fitted by approved installers or the suppliers themselves, and cost between £300 and £3,500 depending on the exact specification, e.g. whether they are just proximity sensors or have more advanced features. The more expensive systems tend to be more comprehensive, however, than just detection systems, with CMS and manoeuvre warnings included as a complete package.

Respondents further emphasised the importance of avoiding driver distractions and cognitive overload through use of spoken word warnings and the need for systems to work in all weather conditions.

Next-generation detection systems were felt by respondents likely to include more extensive use of Artificial Intelligence to identify genuinely hazardous situations rather than just detect objects and integration of separate systems to reduce costs.

A.2.3 Intended manoeuvre warning system suppliers

Four respondents supply manoeuvre warning systems, with one only catering for left turns but the others also covering reversing, activated by the indicator or reverse gear selection.

All suppliers stated their systems would provide a spoken word VRU warning, e.g. "warning, vehicle turning left", while all but one also provides buzzer/beeper warnings or white noise. Stated volumes ranged from 65 – 120 dB via one, two or three speakers depending on the number of manoeuvres.

In response to a question about how their systems were likely to be more effective at helping to prevent VRU collisions than their competitors', the following points were made:

- Directional, multi-frequency noise signature to aid detection for both the visually and hearing impaired. Quiet mark certificate and approved by Noise Abatement Society for use at night.
- Loud enough to be heard over traffic noise
- Robust, waterproof housing
- Customisable to any vehicle or environment
- Can be fitted with optional warning lights

Fitment is usually by the supplier or their approved installers and costs range from £80 - £200. Future improvements mentioned include further combining both auditory and visual warnings and using AI to activate the warnings when necessary even if the indicator or reverse gear is not selected.

A.2.4 FORS Silver as a potential minimum standard

All suppliers were asked for their views on the likely effectiveness in reducing HGV-VRU collisions of the FORS Silver (v5) requirements on blind-spot safety system fitment. Most respondents felt that the use of those requirements had the potential to help prevent most collisions, though several others felt they would only influence a small proportion.

When asked how the requirements could/should be changed or improved, respondents made various suggestions, including:

- Include a lower passenger door window requirement
- Include a Fresnel lens requirement for passenger door window
- Improved lighting and warning of blind-spots
- Encourage better visual manoeuvre warnings
- Recording systems would encourage correct usage and aid accident investigation
- Driver training

A.3 Survey of HGV operators

Responses were received from 150 HGV operators, 51 of whom (34%) had either never used blind-spot safety systems or had only done so for less than 2 years, 49 of whom (33%) had used systems for between 2 and 5 years, and the remainder (50, 33%) had used them for 5 years or more (see Figure 16-1).

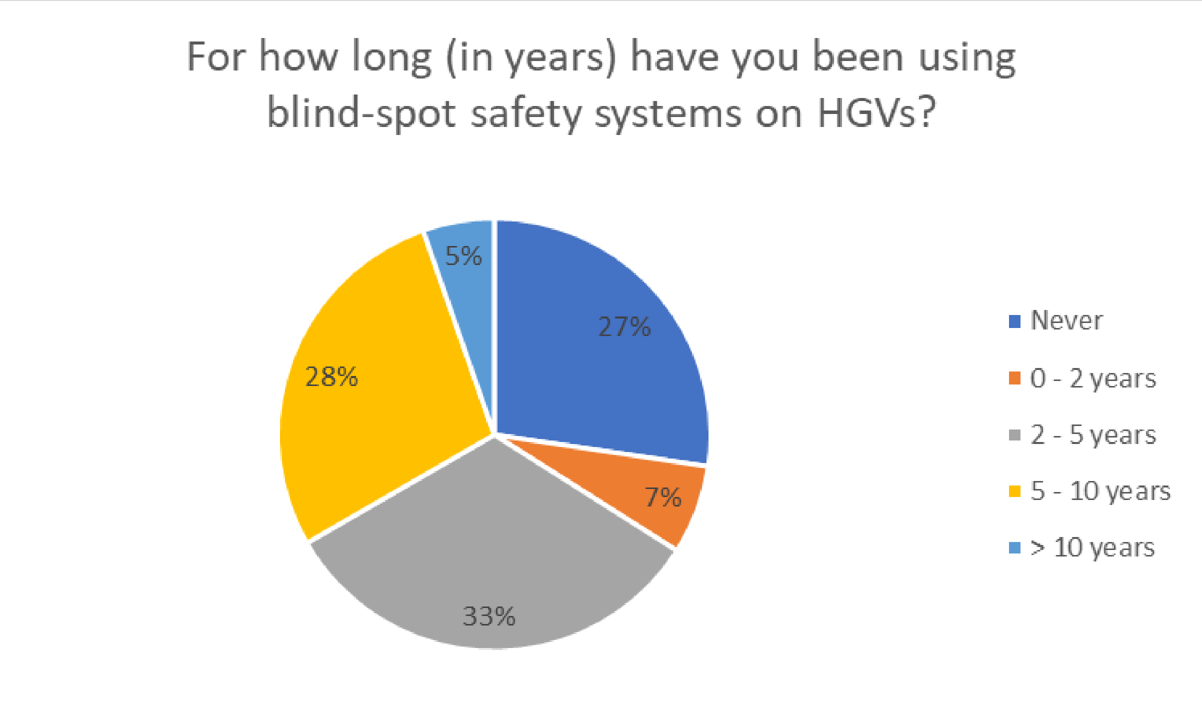

Figure 16-1. HGV Operator experience of blind-spot safety system usage

The following sections describe in more detail the responses from these operators, split by the level of experience as either "experienced in system usage", defined as anyone with at least two years' experience, or "inexperienced in system usage", defined as those with less than 2 years' experience or no experience at all.

A.3.1 HGV operators experienced in system usage

Of the 99 experienced operators, 12 are not FORS registered, 36 are FORS Bronze, 28 are FORS Silver and 23 are FORS Gold. Almost half (46) use or have used all three safety systems in combination (cameras, VRU detection and intended manoeuvre warnings). Table 16-1 shows a more detailed breakdown of the numbers of experienced operators fitting the various combinations of safety systems being assessed. Note that five operators who said they were experienced in safety system usage reported not using or having used any of the three systems.

Table 16-1. Distribution of blind-spot safety system usage amongst experienced operators

System								Totals
Camera Monitor System	✓	✗	✗	✓	✓	✗	✓	85
VRU Detection	✗	✓	✗	✓	✗	✓	✓	70
Intended Manoeuvre Warning	✗	✗	✓	✗	✓	✓	✓	64
Number of operators	7	5	3	18	14	1	46	94

A.3.1.1 CMS users

A large majority of these 99 experienced operators (85, 86%) use or have used camera monitor systems. A little less than half of these (36) use a multi-camera, single monitor with multiple images set-up, while 20 others have an otherwise similar set up but with only a single image at any one time, depending on the manoeuvre. Seven operators have both multiple cameras and monitors, while ten use just a single camera and monitor and nine have a 360° camera view with a single monitor. All but eight of these operators have CMS that record images.

Only about a third of the CMS users reported that they had had no major issues with reliability or system performance. Issues commonly cited by the remainder include:

- Wiring problems, e.g. water ingress and fraying
- Recording system issues, e.g. faulty SD cards
- Camera faults and dirt on lenses
- Unusable in poor weather or low sun

Around 80% of the operators have their CMS fitted by the supplier or their approved installer, with most of the remainder fitting them themselves. The numbers involved are too small for firm conclusions to be drawn but it is potentially noteworthy that all those operators who mentioned issues with water ingress also fit systems themselves.

Warranties tend to be 1 – 2 years typically, though a minority (15%) of operators have 2 – 5-year warranties. Very few operators pay extra for these longer warranties. Installation costs are stated as being anything between £500 and £3,500, with £2,000 - £2,500 being the most commonly quoted figures.

A.3.1.2 VRU detection system users

Seventy (71%) of the experienced operators use or have used VRU detection systems. Of these, almost half have systems that detect VRUs both at the near-side and front of the vehicle, with half of those also having motion inhibit and/or autonomous braking, too. Most of the remaining operators have system that detect VRUs at the near-side only, with just three operators using systems that detect VRUs only at the vehicle front.

Almost all the operators believe their systems detect all objects (VRUs, other vehicles and roadside furniture). Ultrasonic sensors are the most commonly mentioned technology, followed by camera sensors, with about one-fifth of respondents saying their systems use both together. Only a very small number of operators mention other technologies such as infra-red or LIDAR.

Operators tend to think the systems they use prevent HGV-VRU collisions quite well or, in some cases, very well, but many respondents highlight issues with their effectiveness, including:

- False alarms when detecting street furniture
- Systems can’t prevent reckless or inappropriate behaviour of the VRUs
- Alerts going off too often to have an impact on the driver
- Effectiveness depends on attentiveness of the driver

Most operators report that their systems work well in all weather conditions, though some note issues in heavy rain, particularly with a higher number of false alarms. The alerts are most frequently both visual and audible, usually combining both buzzers/beeps and spoken word warnings, with the remainder being typically audible only (fairly evenly split between buzzers/beeps only and those with spoken word, too).

Less than 10% of the operators use systems that sense and warn when a collision is imminent with the remainder using proximity sensors only.

Only a handful of operators state they can adjust the performance of the systems they use; either the in-cab volume or the sensor detection distance. The vast majority are fitted by the supplier or their approved installer and come with 1-2 year warranties. About 10% of operators have longer warranties, though only one pays extra. Installation costs quoted vary from £150 up to £5,000, though the more expensive are likely to include a variety of other safety elements.

A.3.1.3 Intended manoeuvre warning system users

Around two-thirds (64, 65%) of the experienced operators use or have used manoeuvre warning systems. Of these, most turn warnings are activated simply by the indicator, though some operators mention maximum activation speeds of 10 – 20 mph.

The warnings are most often spoken word (47 respondents), with only fourteen operators using buzzers or beepers. Most (42) do not permit the systems to be de-activated by the driver, while eleven allow this only at certain times (e.g. at night). Only nine respondents allow their drivers to de-activate the warnings at any time.

The vast majority of operators use systems fitted by the supplier or their approved installer, with a small minority opting to fit themselves. Warranties are typically 1 or 2 years (less than 10% of operators have longer warranties) and installation costs for stand-alone systems are typically £200 - £500.

A.3.1.4 FORS Silver as a potential minimum standard

The operators were also asked for their general thoughts on blind-spot safety system effectiveness and development, as well as on the potential usefulness and enhancement of the FORS Silver requirements.

When specifying safety, the operators mentioned various key considerations, including:

- System safety effectiveness
- Reliability, brand identity and supplier back-up
- Quality, especially of in-cab monitor views and audible warnings
- Ease of use
- Drivers not able to tamper/de-activate

The features they felt were most likely to help avoid HGV-VRU collisions included:

- Cameras preferred as detection systems go off too often and VRU's ignore warnings
- Clear audible warnings
- 360° views and collision detection
- Systems that reliably detect VRUs and not roadside furniture

Suggestions for future improvements included:

- Common standards for inter-operability
- Better accuracy of VRU detection
- Visual VRU warnings, e.g. side repeater lamps flashing, rather than audible
- Fitment by OEMs as factory standard
- Cost reductions
- Rigorous system testing
- Head up display of warnings

Several respondents also highlighted their desire for more to be done to train and educate VRUs, for more stringent enforcement of safe practice and greater segregation between HGVs and VRUs.

When asked about the potential effectiveness of the FORS Silver requirements, almost half the respondents (43, 46%, excluding those who responded "don't know") felt they would help to prevent only a small proportion of collisions or be totally ineffective (8 of those). Ten respondents (11%) felt they would be likely to prevent about half of all collisions, while most of the remainder (34, 36%) thought they would prevent most collisions. The remainder (7, 7%) felt the requirements had the potential to eliminate all HGV-VRU collisions.

Respondents suggested several potential improvements to the requirements, including:

- Removing the allowance of a manual switch to de-activate the manoeuvre warnings
- Requiring camera system only to avoid too much driver distraction
- Visual warnings for VRUs should be more strongly encouraged
- Require autonomous braking capability
- Audible warnings for drivers should be preferred to visual displays
- Should specify direct vision panels on passenger door
- Need sensors/cameras at front, not just side
- Evolve to 360° systems at later stage
- Mandatory driver training

- Target construction vehicles such as tippers, mixers and skip carriers

A.3.2 HGV operators inexperienced in system usage

Of the 51 inexperienced operators, most (41) had no experience of using blind-spot safety systems, while the remaining ten operators had used them for no more than 2 years. Half (three) of these operators use or have used a combination of all three safety systems, while the remainder use some other combination of one or two systems.

A.3.2.1 CMS users

Six of the inexperienced operators (12%) use or have used camera monitor systems. Three of these use a multi-camera, single monitor with multiple images set-up, two use just a single camera and monitor and one has a 360° camera view with a single monitor. All these operators have CMS that record images.

None of these CMS users reported any major issues with reliability or system performance.

Four of the six operators have their CMS fitted by the supplier or their approved installer, with the remainder fitting them themselves.

Installation costs of around £500 are the most frequently quoted figures amongst these operators.

A.3.2.2 VRU detection system users

Five of the inexperienced operators use or have used VRU detection systems. All of these operators have/had systems that detect VRUs at the near-side only, using ultrasonic sensors, cameras or both.

Four respondents highlight issues with their effectiveness, including:

- Too many false alarms, e.g. street furniture detected
- Systems can’t prevent reckless or inappropriate behaviour of the VRUs
- Doesn’t fully eliminate blind spots
- Ineffective in bad weather

The alerts are most frequently both visual and audible, activating whenever an object is detected (proximity sensors).

None of the operators state they can adjust the performance of the systems they use and all are fitted by the supplier or their approved installer.

A.3.2.3 Intended manoeuvre warning system users

Six of the inexperienced operators use or have used manoeuvre warning systems.

The warnings are most often spoken word (five respondents), with only one operator using buzzers or beepers. Most (four) do not permit the systems to be de-activated by the driver, while the other two allow their drivers to de-activate the warnings at any time.

Four operators use systems fitted by the supplier or their approved installer, two opting to fit themselves.

A.3.2.4 FORS Silver as a potential minimum standard

All the inexperienced operators were also asked for their general thoughts on blind-spot safety system effectiveness and development, as well as on the potential usefulness and enhancement of the FORS Silver requirements.

When specifying systems, the operators mentioned various key considerations, including:

- System safety effectiveness
- Reliability and supplier back-up
- Cost
- Ease of use
- FORS Compliance

The features they felt were most likely to help avoid HGV-VRU collisions included:

- Clear audible manoeuvre warnings
- Good quality cameras and sensors
- Reliability

Suggestions for future improvements included:

- Fewer error messages
- Audible warnings for drivers in preference to reliance on visual checking of multiple mirrors and monitors
- Reducing potential for driver distraction
- OEM fitment
- Cameras replacing mirrors
- Use of warning lights

Some respondents also highlighted their desire for more to be done to train and educate VRUs.

When asked about the potential effectiveness of the FORS Silver requirements, four of the respondents felt they would help to prevent only a small proportion of collisions. Two respondents felt they would be likely to prevent about half of all collisions and another two thought they would prevent most collisions. The remaining two felt the requirements had the potential to eliminate all HGV-VRU collisions.

A.4 Survey of HGV drivers

Responses were received from 43 HGV drivers, 19 of whom had never used blind-spot safety systems. Three had only done so for less than 2 years, twelve had used systems for between 2 and 5 years, and the remainder (nine) had used them for 5 years or more.

Almost all the 24 drivers who had at least some experience had experience of using all three safety systems under consideration (CMS, VRU detection and intended manoeuvre warning).

When asked which type(s) of system they had found to be most helpful to them in avoiding collisions with VRUs, several drivers mentioned camera systems and proximity sensors and some mentioned Fresnel lenses and/or mirrors. Only one mentioned manoeuvre warnings.

Drivers echoed the feedback from operators in stating that systems were generally not adjustable and confirmed that systems are generally reliable but prone to some issues in service, such as:

- False alarms from street furniture, especially in bad weather
- Sensors prone to malfunction when dirty

Drivers felt systems could/should be improved by:

- Better placement of monitors in the cab
- OEM fitment
- Better sensor accuracy, e.g. via thermal imaging
- Sensors more robust
- Autonomous braking
- External microphones
- Use of Fresnel lenses
- Multiple cameras, wirelessly linked
- Self-cleaning cameras

A.4.1 FORS Silver as a potential minimum standard

All the drivers were also asked for their general thoughts on the potential usefulness and enhancement of the FORS Silver requirements.

Two of the respondents felt they would be totally ineffective in preventing VRU-HGV collisions, and five felt they would be likely to help prevent only a small proportion of collisions. Three respondents felt they would be likely to prevent about half of all collisions and a further nine drivers thought they would prevent most collisions. The remaining three drivers felt the requirements had the potential to eliminate all HGV-VRU collisions.

Suggestions for improvements to the requirements included:

- Not allowing de-activation of manoeuvre alarms at night
- Rear-view cameras positioned away from spray
- Visual manoeuvre warnings in addition to (or instead of) audible
- Should apply to all commercial vehicles
- Include Fresnel lens requirement
- Collision detection system preferred over proximity sensors

A.5 Survey of VRU Groups and road safety experts

Only two responses were received from this group of stakeholders, one a general road safety organisation, the other a cycling body.

Both respondents felt that Camera Monitor Systems had the potential to become an added distraction to drivers unless they replaced mirrors.

One also raised driver distraction as a key issue for VRU detection systems, if based on proximity sensors as they would tend to go off all the time, while the other felt they could be useful in providing some "vision" of areas not covered by mirrors or direct vision.

The effectiveness of audible manoeuvre warnings was questioned by the road safety organisation, particularly in light of many cyclists wearing head/earphones, but the cycling group pointed to their usefulness in circumstances where the indicator is obscured or not visible. The cycling group also mentioned their preference for indicators to cover the entire side of the vehicle, e.g. via an LED strip with the road safety organisation making a similar suggestion for more (and lower) side indicator lamps.

Linking VRU detection to collision sensing and autonomous braking was also suggested as a key technology for avoiding collisions, as was driver monitoring systems/cameras.

The FORS requirements were felt to have the potential to help prevent no more than half of all HGV-VRU collisions at best. Suggested improvements include making it time limited to encourage the uptake of safer vehicles with good direct vision and encouraging systems (e.g. cameras) to be fitted to a wider set of HGVs, even those with quite good direct vision. Systems such as smartphone apps that help drivers identify and report any system faults immediately, and repair action to be taken promptly, were also mentioned. The road safety organisation echoed the sentiment of many of the HGV operators and drivers surveyed that greater attention should also be paid to the training/behaviour of VRUs as part of any comprehensive approach to tackling the problem.

Appendix B Definitions related to noise measurement

Section 9 refers extensively to measurements of noise. These measurements are complex and not particularly intuitive so, some basic definitions have been included in this Appendix to help the understanding of the following sections.

B.1 Sound intensity

Sound Intensity is defined as the power carried by sound waves per unit area in a direction perpendicular to that area. Its standard unit is the watt per square metre. Clearly this is a complex measurement involving multiple units and the range of sound intensity can be very large. Thus, sound intensity is usually measured in Decibels (dB).

Decibels are effectively a logarithmic ratio of sound intensity relative to a threshold level of 0 dB. Zero dB is the quietest sound audible to a healthy human ear. From there, every increase of 3dB represents a doubling of the sound intensity.

B.2 Sound pressure

Sound pressure is related to sound intensity and is the difference between ambient air pressure and the peak pressure caused by the sound wave and is measured in units of Pascal. Hearing is directly sensitive to sound pressure.

B.3 Perceived loudness

Perceived loudness is a subjective psychological phenomenon and will vary considerably between different people, so cannot be measured objectively. As a rule of thumb, most people are considered to perceive one sound to be twice as loud as another when the sound intensity is measured as 10 dB different. An example of how measurements in decibels relate to changes in sound intensity and perceived loudness is shown in Table B-16-2, below.

Table B-16-2: Relative difference in sound intensity and typically perceived loudness at different decibel levels (baseline 60 dB)[27].

Sound Level	Index relative to 60 dB (60 dB=1)	
	Sound Intensity	Perceived Loudness
60 dB	1	1
70 dB	10	2
80 dB	100	4

This can be thought of as follows. If one reversing alarm speaker registered 60 dB then 10 identical reversing alarm speakers would register 70 dB and it would take 100 such speakers to register 80dB. However, 100 speakers going off at once would only be perceived (typically) as around 4 times as loud as just one speaker. An important consideration is that the risk of hearing damage is related to sound intensity and not perceived loudness, which is why hearing damage can occur without people realising there is a problem.

[27] Adapted from https://www.noisehelp.com/decibel-scale.html

In reality, sound intensity is spread out across a wide range of frequencies. However, the human ear is not as good at hearing very high or very low frequencies as it is those in the mid range. The standard decibel scale treats all frequencies equally and is referred to variously as flat, linear or Z weighted. An A-weighted decibel scale (dB(A) has been developed that weights sound intensities at lower and higher frequencies differently so it more closely represents a human response to sound at relatively low levels. A C-weighting scale has also been developed in order to correlate better with human response to peak or impact noise levels such as gunfire. These are illustrated in Figure B-2, below.

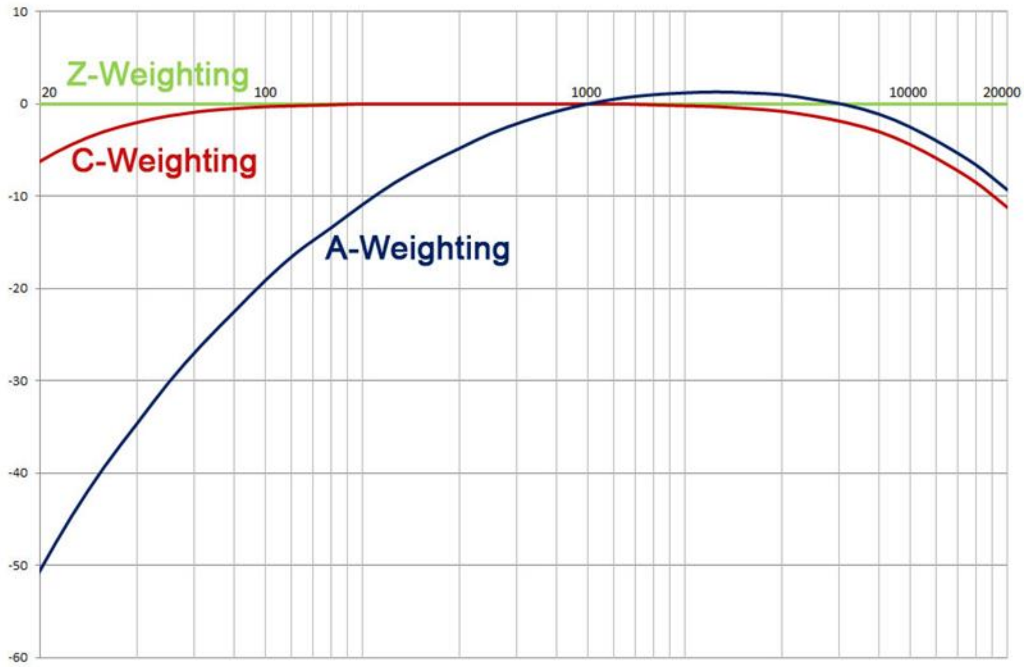

Figure B-2: Different weighting curves applied to decibel levels at different frequencies.

So, if a piece of music included a modest sound intensity at 1000 Hz but included a very high sound intensity at 20 Hz, then in a flat or Z-weighted dB measure it would have a high intensity. However, the A-weighting would dramatically reduce the degree to which the 20hz component influenced the overall measure of sound intensity because the human ear is not very good at hearing sounds at 20 Hz.

The intensity of sound changes with increasing distance from the source according to an inverse square law. Simply put, every time the distance from the source doubles, then the sound intensity drops by 6 dB. So, if an alarm registers 90 dB at a distance of 1m, it will register 84dB at 2m, 78dB at 4m, 72dB at 8m and so on.

When specifically considering a measurement of background noise, then an important consideration is that background noise will usually comprise of multiple different sounds from sources near and far and will often vary continuously. Two common measures of background noise are LA_{EQ} and LA_{90}. LA_{EQ} is the A-weighted equivalent sound level. That is the constant sound level that would give the same cumulative sound intensity as the varying sound over the period, in effect a form of average sound level. LA_{90} is the threshold sound level that the actual measured sound exceeded for 90% of the measurement time.