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The Transport for London Bus Safety Standard: Visual Conspicuity

Evaluation of Safety Measure

Stephen Skippon, Tom Hyatt, Emily Castiaux, David Jenkins, Alix Edwards, Phil Martin, and Shaun Helman

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Version	Date	Description	Editor	Technical Reviewer
1.1	31/07/2022	Corrections to Table 1 & Figure 3 Added reference to TfL for latest specification in the executive summary and recommendations	AE	PSM & DH

Executive Summary

Bus Safety Standard (BSS)

The Mayor of London's Transport Strategy sets out a commitment to vision zero: no deaths or serious injuries from any collisions on the roads of the capital by 2041, and no fatalities involving a London bus by 2030. The BSS is focussed on the contribution that vehicle safety features can make towards these challenging targets.

To develop the standard a large body of research and technical input was needed, so Transport for London (TfL) commissioned TRL (the Transport Research Laboratory) to deliver the research and consult with the bus industry. The delivery team has included a mix of engineers and human factors experts, to provide the balance of research required.

All TfL buses conform to regulatory requirements. TfL already uses a more demanding specification when contracting services and this requires higher standards in areas including environmental and noise emissions, accessibility, construction, operational requirements, and more. Many safety aspects are covered in the specification such as fire suppression systems, door and fittings safety, handrails, daytime running lights, and others. However, the new BSS goes further with a range of additional requirements developed by TRL and their partners and peer-reviewed by independent safety experts. Accompanying the specification there are guidance notes to help inform the bus operators and manufacturers of what the specification is aiming to achieve and some practical tips on how to meet the requirements.

For each safety measure considered, a thorough review was completed covering the current regulations and standards, the specification of the current bus fleet and available solutions.

Full-scale trials and testing were also carried out with the following objectives. Firstly, the tests were used to evaluate the solutions in a realistic environment to ensure that a safety improvement was feasible. Secondly, the testing was used to inform the development of objective test and assessment protocols. These protocols will allow repeatable testing according to precise instructions so that the results are comparable. The assessment protocol provides instructions for how to interpret the test data for a bus or system, which can be a simple pass/fail check, or something more complex intended to encourage best practice levels of performance. These assessment protocols will allow TfL to judge how well each bus performs against the BSS and will allow a fair comparison in terms of safety if they have a choice between models for a given route.

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

This research was completed in 2018. The detailed specification, assessment procedures and guidance notes have been incorporated into the Transport for London specification for buses, which is a continuously updated document to keep pace with the latest technological and research developments. This report is not the specification for a bus and should not be used as such. Bus operators, manufacturers, and their supply chain should consult with TfL for the specification.

Visual Conspicuity

The annual number of bus-pedestrian collisions in London is slightly over 340, of which around 120 result in the pedestrian being killed or seriously injured. The visual conspicuity of a bus may potentially play a role in some of these collisions with pedestrians, particularly the 49% in which the pedestrian is struck by the front of the bus. While many such collisions can be attributed to distracted walking on the part of pedestrians, it may be possible to mitigate against some collisions, where the pedestrian looks but fails to see (LBFTS) the bus, or misjudges the time-to-collision (TTC). Improvements to the visual conspicuity of the front face of buses might help reduce the number of such collisions.

The scope for improving frontal visual conspicuity is restricted by UNECE Regulation 48 (for new build) and the Road Vehicle Lighting Regulations 1989 (for retrofit). Thus, only a limited number of options are possible. The following were tested:

- Additional pair of end-outline marker lights
- Reflective tape outlining as far as possible the front edges of bus
- Additional pair of end-outline marker lights PLUS reflective tape

All three were tested for their effectiveness at reducing the likelihood of LBFTS and TTC errors compared to a baseline condition with neither additional lights nor reflective tape. Since both LBFTS and TTC errors are errors of pedestrian perception, the tests both involved human participants. LBFTS errors are essentially failures of visual search, so the effectiveness of the counter-measures were tested in a controlled laboratory test the measured how quickly participants were able to identify the presence of a bus in their visual field. Testing TTC requires an object moving appropriately, at traffic speed, so the effectiveness of the counter-measures was tested in a controlled test-track trial that measured the interval between the time when a participant judged it was no longer safe to cross in front of an approaching bus and the time the bus passed the participant's position.

The tests found no significant differences in the time it took for participants to identify a bus, or in participants' time-to-collision estimates, (using the conventional $p < 0.05$ criterion) between any of the counter-measures and baseline, in either day or night conditions.

Thus, none of the proposed counter-measures was effective with respect either to LBFTS or TTC errors in adults in optimum conditions. A plausible explanation for this is that buses are large, conspicuous objects that are easy to see, and the proposed countermeasures, in being consistent with UNECE R48 (additional end-outline marker lights) or the Road Vehicle Lighting Regulations 1989 (retrofitted reflective tape), added little to their conspicuity. Since testing was carried out with adults with normal unimpaired vision, it is possible that the countermeasures might yet be effective for children, the elderly, people with partial sight, or those whose visual perception is impaired through mental fatigue, alcohol intoxication, drug use, etc.

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1 Introduction to the Bus Safety Standard (BSS)

1.1 Bus Safety Standard

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

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

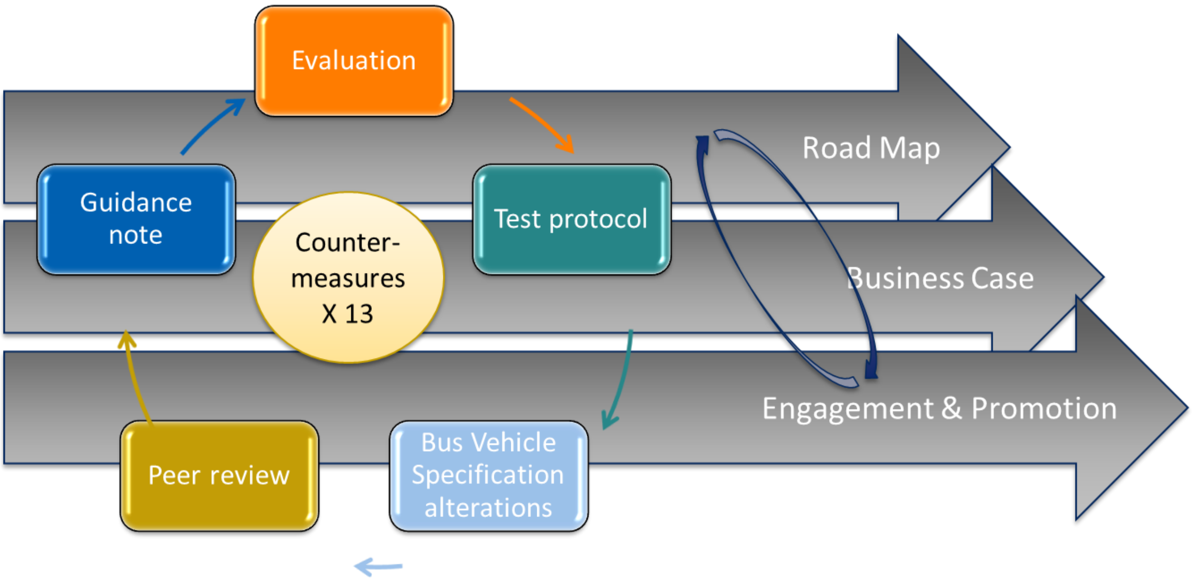

Figure 1: Summary of the BSS research programme

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

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

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

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

1.2 Bus Safety Measures

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

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

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

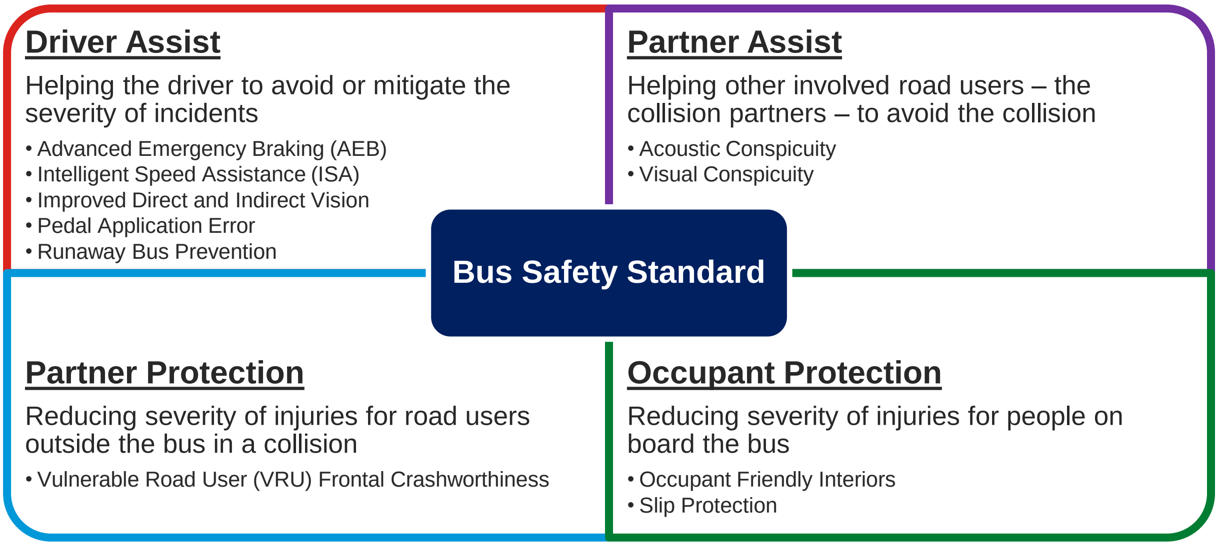

Figure 2: Bus safety measures

1.3 Visual Conspicuity

The annual number of bus-pedestrian collisions in London is slightly over 340, of which around 120 result in the pedestrian being killed or seriously injured. The *visual conspicuity* of a bus may potentially play a role in some of these collisions with pedestrians, particularly the 49% in which the pedestrian is struck by the front of the bus. Visual conspicuity refers to how easily an object stands out from its surroundings (Lesley, 1995, cited in Langham & Moberly, 2003). Several factors influence conspicuity, with size and contrast being two important factors; large objects with high contrast with their background tend to be more conspicuous than small objects with low contrast.

Buses are large, visually distinctive objects that are relatively easy to see when compared with other road vehicles such as cars, vans, and especially motorcycles or bicycles. However further improving their visual conspicuity could potentially mitigate the risk of some types of bus-pedestrian collisions, particularly those in which the pedestrian looks in the direction of the bus but fails to see it, and those in which the pedestrian sees an approaching bus but misjudges its speed.

2 Defining the Problem

2.1 Casualty priorities for TfL

Transport for London’s aim in implementing the bus safety standard is to assist in achieving ‘vision zero’ on the principle that no loss of life is acceptable or inevitable. Thus, the largest focus is on incidents resulting in death or serious injury. However, they recognise the disruption and cost that minor collisions can have for bus operators and the travelling public alike. Thus, safety features that can reduce the high frequencies of incidents of damage only and/or minor injury are also included within the scope. The high-level matrix below in Table 1 categorises and prioritises the casualties based on past data for London derived from the GB National collision database.

Table 1 shows that over the past decade the highest priority casualty group in terms of death and serious injury from collisions involving buses in London has been pedestrians severely injured in collisions where the bus was coded as going ahead, without negotiating a bend, overtaking, starting or stopping, etc.

2.2 Bus collisions with pedestrians

An analysis of ACCSTATS data (Shepherd, Wallbank, Hammond & Sharp, 2018) indicates that over the three-year period 2015-2017 there were 1,064 collisions in London involving both a bus and pedestrian; of these, 1,029 involved a pedestrian being struck by a bus (the others being largely attributable to multi-vehicle collisions in which the pedestrian was struck by one of the other vehicles). In around 35% of these the pedestrian was killed or seriously injured. The annual number of bus-pedestrian collisions, based on this analysis, is slightly over 340, of which around 120 result in the pedestrian being killed or seriously injured.

Figure 3 shows the breakdown of bus-pedestrian collisions in terms of the movement of the bus. A majority of bus-pedestrian collisions (85%) involved a pedestrian crossing the road when the bus was moving ahead, either slowly or at traffic speed.

Table 1: Casualty prevention value attributed to different collision types; London STATS19 data from 2006-15 (%)

Casualty Type	Collision type	Fatal	Serious	Slight	KSI	Total
Bus Passenger	Injured in non-collision incidents - standing passenger	4.2%	17.1%	23.3%	11.9%	15.2%
	Injured in non-collision incidents - seated passenger	0.5%	6.4%	13.0%	4.0%	6.6%
	Injured in non-collision incidents - boarding/alighting/other	1.6%	7.6%	5.3%	5.2%	5.2%
	Injured in collision with a car	0.5%	4.6%	10.1%	2.9%	5.0%
	Injured in collision with another vehicle	0.0%	3.1%	5.0%	1.8%	2.8%
	Total	6.9%	38.7%	56.7%	25.9%	34.8%
Pedestrian	Injured in a collision while crossing the road with a bus travelling straight ahead	30.7%	20.0%	7.0%	24.3%	19.3%
	Injured in a collision, not while crossing the road, with a bus travelling straight ahead	10.6%	7.9%	4.6%	9.0%	7.7%
	Injured in a collision with a bus turning left or right	12.2%	3.1%	1.2%	6.8%	5.2%
	Injured in other collision with a bus	2.1%	1.4%	0.7%	1.7%	1.4%
	Total	55.6%	32.5%	13.6%	41.8%	33.6%
Car Occupant	Injured when front of bus hits front of car	6.3%	1.9%	0.9%	3.7%	2.9%
	Injured when front of bus hits rear of car	1.6%	0.8%	2.8%	1.1%	1.6%
	Injured when front of bus hits side of car	1.1%	1.1%	1.8%	1.1%	1.3%
	Injured in side impact collision with a bus	2.6%	1.9%	3.9%	2.2%	2.7%
	Injured in other collision with a bus	2.1%	1.0%	1.4%	1.5%	1.4%
	Total	13.8%	6.6%	10.8%	9.5%	9.9%
Cyclist	Injured in a collision with the front of a bus travelling straight ahead	2.1%	1.2%	0.9%	1.5%	1.4%
	Injured in a collision with another part of a bus travelling straight ahead	0.0%	2.6%	1.5%	1.6%	1.6%
	Injured in a collision with the nearside of a bus which is turning	1.6%	0.8%	0.4%	1.1%	0.9%
	Injured in other collision with a bus	0.5%	3.1%	2.1%	2.1%	2.1%

Casualty Type	Collision type	Fatal	Serious	Slight	KSI	Total
	Total	4.2%	7.8%	5.0%	6.4%	6.0%
Powered Two Wheeler (PTW)	Injured in a collision with a bus travelling straight ahead	2.6%	1.3%	0.7%	1.9%	1.5%
	Injured in a collision with a bus turning left or right	0.5%	1.0%	0.7%	0.8%	0.8%
	Injured in other collision with a bus	0.5%	1.0%	0.9%	0.8%	0.8%
	Total	3.7%	3.4%	2.3%	3.5%	3.2%
Bus Driver	Injured in collision with a car	0.0%	1.5%	2.5%	0.9%	1.4%
	Injured in non-collision incidents	0.0%	0.5%	0.5%	0.3%	0.4%
	Injured in collision with another vehicle	0.5%	1.2%	1.5%	1.0%	1.1%
	Total	0.5%	3.2%	4.5%	2.1%	2.8%
Other	**Total**	**15.3%**	**7.9%**	**7.1%**	**10.9%**	**9.8%**
Casualties Total		**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

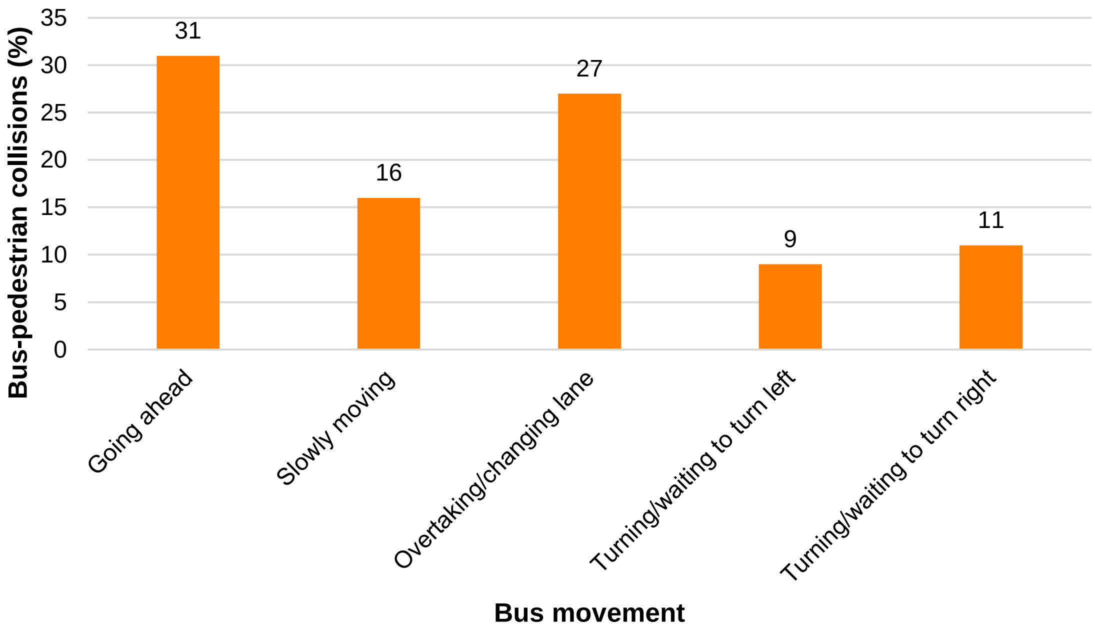

Figure 3: Bus movement in bus-pedestrian collisions (ACCSTATS, 2015-17)

Figure 4 shows the breakdown of bus-pedestrian collisions in terms of the first point of impact with the bus. The pedestrian was struck by the front of the bus in 49% of bus-pedestrian collisions, and by the nearside of the bus in 39%. The visual conspicuity of the front of the bus may have played a role in the 49% that involved frontal impacts. Visual conspicuity is considered less likely to be relevant to collisions where the impact was on the side of the bus, in most of which cases the impact is on the nearside. Viewed from the side, especially close up (pedestrian on the pavement adjacent to the bus), a bus is a very large object that fills much of a person’s visual field. It seems likely that many of these collisions involve the pedestrian simply not looking at all before stepping into the road. These cases might be better addressed through acoustic measures to capture attention. This report therefore focuses on the 49% of bus-pedestrian collisions where a pedestrian is struck by the front of the bus.

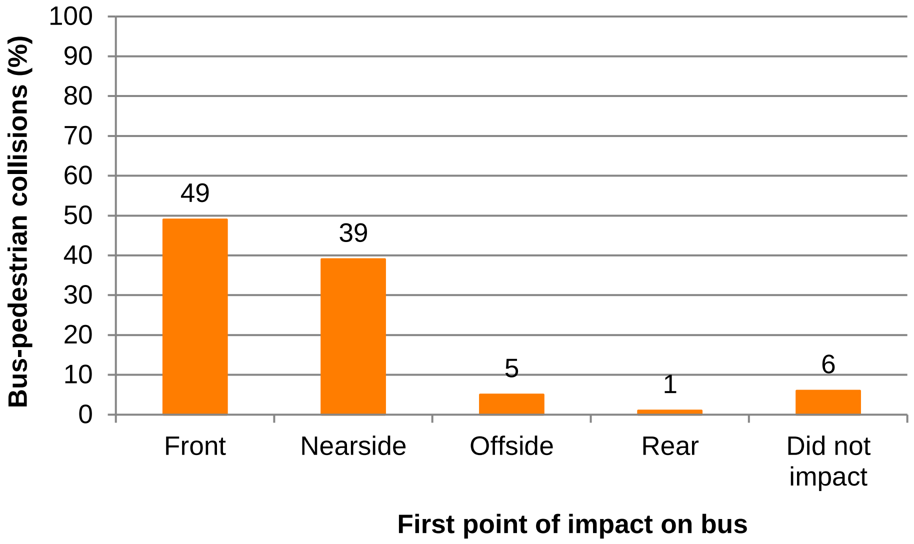

Figure 4: First point of impact with bus in bus-pedestrian collisions (ACCSTATS, 2015-17)

ACCSTATS also records Contributory Factors (CFs) for those collisions attended by the police (88% of collisions involving buses, and 86% of collisions involving VRUs; Shepherd *et al.*, 2018). CFs record the attending police officer's opinion of the factors that contributed to the collision. According to Shepherd *et al.* (2018), among collisions involving a bus and a pedestrian, in 64% of cases at least one contributory factor was attributed to the pedestrian without any being attributed to the bus, and in 25% of cases at least one contributory factor was assigned to each[1]. Thus according to these figures, in the opinion of police officers present, pedestrians contributed in some way in 89% of bus-pedestrian collisions. The most common CFs for pedestrians are shown in Figure 5. They include 'failed to look properly' (71%), 'careless/reckless/in a hurry' (62%), and 'failed to judge vehicle's path or speed' (28%).

Many of these contributory factors on the part of the pedestrian involve either a total failure to search the carriageway before entering it, or a partial failure, such as allowing insufficient time for a visual search or searching whilst cognitive functioning is impaired by alcohol. Improved visual conspicuity is very unlikely to help in these incidents. In other cases, the bus was seen, but the pedestrian failed to judge the bus's path or the Time-to-Collision (TTC). The risk of these collisions could potentially be reduced by improving the visual conspicuity of the front of the bus.

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[1] More than one CF can be attributed to a pedestrian or a bus involved in a collision

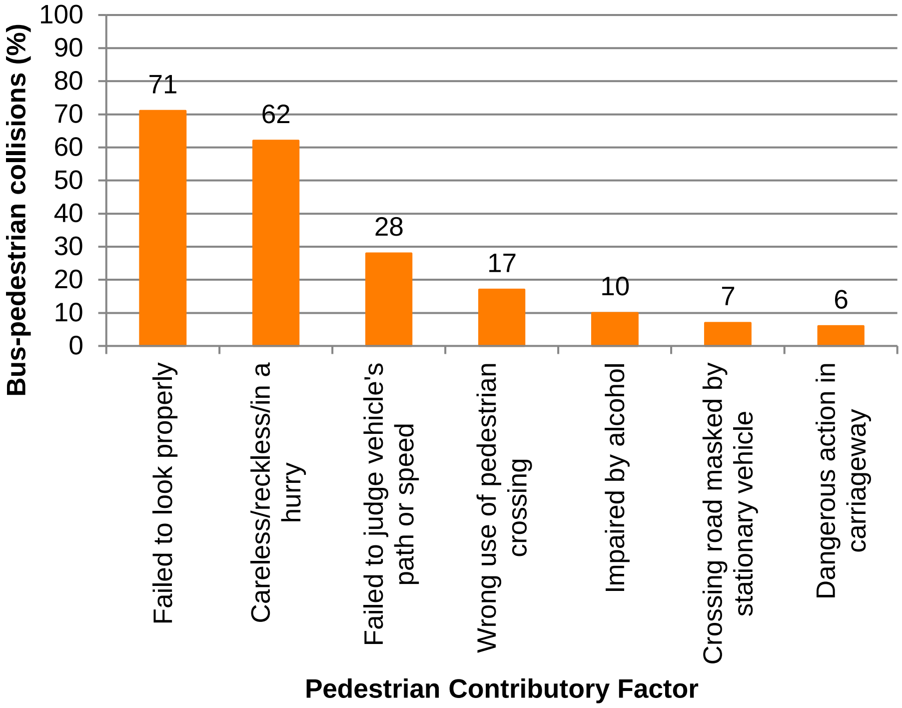

Figure 5: Most common pedestrian Contributory Factors in bus-pedestrian collisions (ACCSTATS, 2015-17)

Figure 6 shows that the highest proportion of bus-pedestrian casualties was in the 25-59 years age category (56%), with males accounting for 35% and females 21% (Shepherd *et al.*, 2018).

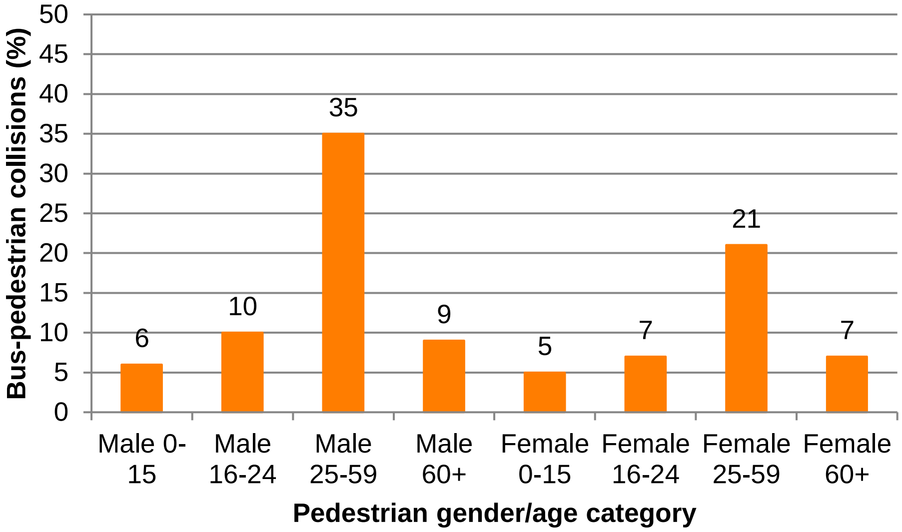

Figure 6: Pedestrian casualties in collisions with buses by age and gender (ACCSTATS 2013-15)

Shepherd *et al.* (2018) also reviewed the technical literature in relation to bus collisions. The review found strong evidence supporting the conclusion that unsafe pedestrian behaviour, particularly entering the carriageway without due care, is a major contributor to collisions in which the pedestrian is killed (Arrifin, Jawi, Isa, Kassim & Wong, 2010; Edwards, Barrow, O'Connell, Krishnamurthy, Khatry, Hylands *et al.*, 2017). Pedestrian behaviours at bus stops have also been reported as contributing to increased risk of collision, for example chasing buses into the road when they are pulling out from bus stops, stepping into the road due to overcrowding at the bus stop when buses are slowing to enter it (Pecheux, Bauer, Miller, Rephlo, Saporta, Erickson *et al.*, 2008), passenger unloading, and pedestrians crossing in front of the bus near bus stops (Cafiso, Di Graziano & Pappalardo, 2013a; Cafiso, Di Graziano & Pappalardo, 2013b).

There is some evidence in the literature that the risk of bus collisions increases during the evening and night due to poor visibility, particularly related to pedestrian conspicuity (Feng, Li, Ci & Zhang, 2016). Innamaa, Norros, & Pilli-Sihvola (2014) demonstrate that this risk is particularly high in the early hours of the morning (particularly around 4am). While this literature tends to focus on pedestrian conspicuity, in at least some of these cases it again seems plausible that the risk of collisions could potentially be reduced by improving the visual conspicuity of the front of the bus.

In the ACCSTATS data for 2015-17, the majority of bus-pedestrian collisions (46%) were reported to have happened between the hours of 10:00 and 15:59, closely followed by the 16:00-18:59 (20%) and 07:00-09:59 (15%) periods (Figure 7: Shepherd *et al.*, 2018). The 10:00 to 15:59 period is daylight throughout the year, but the latter two periods are dark for a portion of the year (as well as corresponding to the morning and evening 'rush hours'). This suggests that it is important to consider bus visual conspicuity in both daytime and night-time conditions.

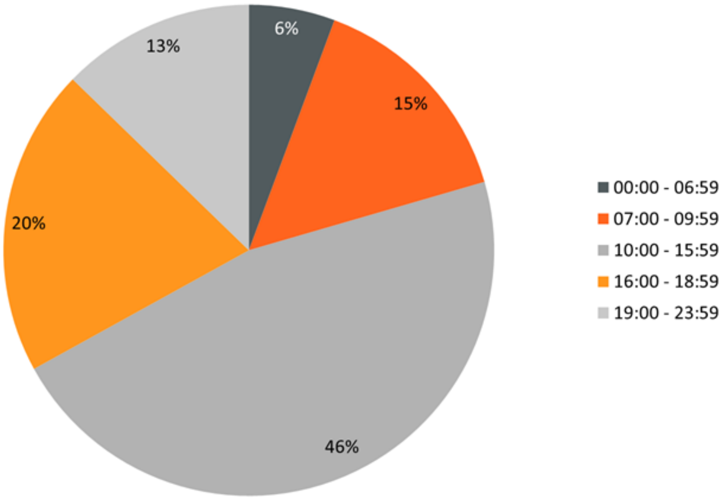

Figure 7: Distribution of collisions involving a bus passenger injury by time of day (IRIS, 2014/15 – 2016/17)

The literature also identifies ‘distracted walking,’ in which pedestrians using electronic devices such as smart phones, approach and cross the road with their attention on their device rather than the traffic, and so are unaware of the danger around them (Ehrlichman, 2012; Palamara & Broughton, 2013). Distracted walking may be be linked to the CFs ‘failed to look properly’ and careless/reckless/in a hurry’ mentioned above (Figure 5). In such cases, improving the visual conspicuity of the front of the bus is unlikely to mitigate the collision risk because the pedestrian is not looking in its direction.

To summarise, ACCSTATS data for 2015-2017 indicates that there are approximately 340 bus-pedestrian collisions per year in London. Of these, 49% (~167) involve the pedestrian being struck by the front of the bus. The risk of these collisions could potentially be mitigated by improvements in the visual conspicuity of the front face of the bus. It is not possible however to distinguish between those collisions where the pedestrian looked in the direction of the bus, and either failed to see it or failed to correctly judge the TTC, and those collisions where the pedestrian was distracted and did not look in the direction of the bus. Therefore we can set an upper limit of around 167 collisions per year that could potentially be mitigated by improved visual conspicuity of the bus, recognising that this figure is an over-estimate because some of them, potentially a large fraction, will be the result of pedestrians (for whatever reason) simply not looking at all before stepping into the road.

2.3 Bus collisions with cyclists

Analysis of ACCSTATS data (Shepherd *et al.*, 2018) indicates that over the three-year period 2015-2017 there were 380 collisions in London involving both a bus and cyclist; in 13% of these the cyclist was killed or seriously injured. The annual number of bus-cyclist collisions, based on this analysis, is around 127, of which around 17 result in the cyclist being killed or seriously injured.

Figure 8 shows the breakdown of bus-cyclist collisions in terms of the movement of the bus. A much smaller percentage of bus-cyclist collisions (47%) occurred when the bus was moving ahead (either slowly or at traffic speed) than in the case of bus-pedestrian collisions. 27% occurred when the bus was overtaking or changing lanes, and 20% when the bus was turning or waiting to turn.

Figure 9 shows the first point of impact with the bus in bus-cyclist collisions. In contrast to bus-pedestrian collisions, the first point of contact was with the front of the bus in only 24% of bus-cyclist collisions. The first point of contact was more frequently with the sides of the bus (47% nearside, 12% offside). It is unlikely that visual conspicuity of the bus is a factor in collisions between a cyclist and either side of a bus.

These data indicate first that there are fewer bus-cyclist collisions than bus-pedestrian collisions, second that fewer bus-cyclist collisions result in the cyclist being killed or seriously injured than is the case for bus-pedestrian collisions, and third that fewer bus-cyclist collisions could potentially be mitigated by improvements to the visual conspicuity of the bus. Accordingly this report focusses on bus-pedestrian collisions.

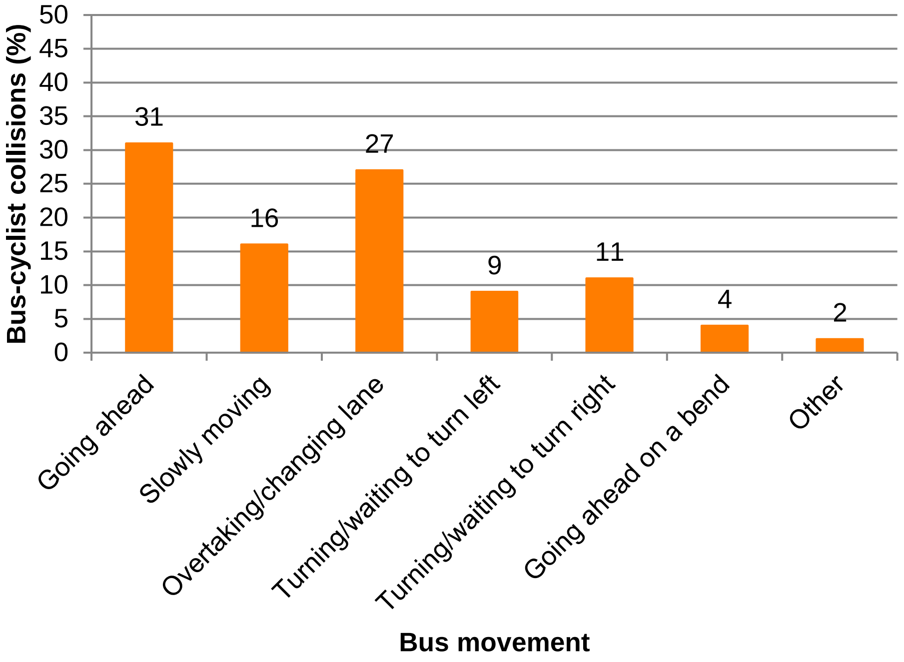

Figure 8: Bus movement in bus-cyclist collisions (ACCSTATS, 2015-17)

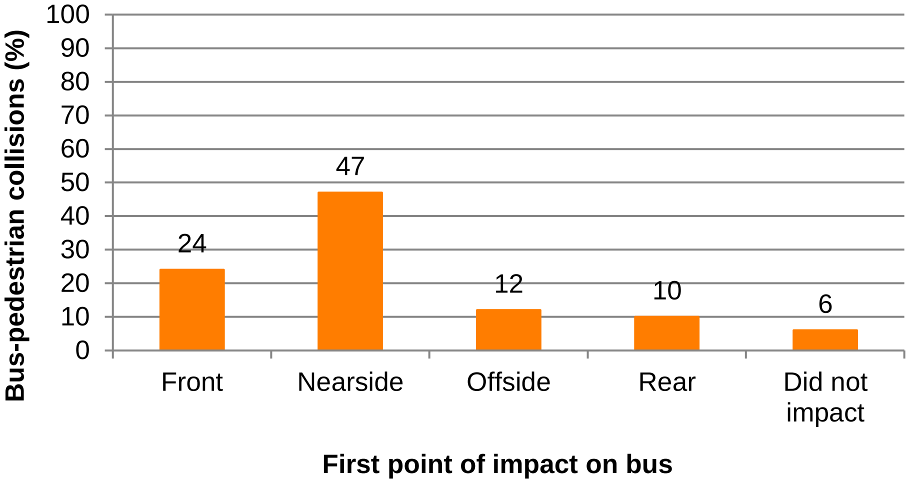

Figure 9: First point of impact with bus in bus-cyclist collisions (ACCSTATS, 2015-17)

2.4 Perceptual errors by pedestrians

2.4.1 Types of error

The bus-collisions where CFs were attributed to the pedestrian that have been discussed above appear to arise from one or more of three types of perceptual error on the part of the pedestrian:

1) Pedestrian not attending to the traffic situation: in particular not visually attending to the direction of oncoming traffic (i.e. looking to the right when beginning to cross a road, but could include looking in a variety of directions when crossing at intersections). This is often attributed to distraction resulting from the use of mobile devices, particularly smartphone displays, although in principle it could also be attributed to other sources of distraction such as interacting with other people.
2) Failure to identify oncoming vehicle: often referred to as 'Looked But Failed To See' (LBFTS), this refers to the situation where the pedestrian looks in the direction of oncoming traffic, but fails to identify the presence of a bus; it is a failure of search. It may be the result of insufficient search (e.g. a glance that is too short in duration to enable the scene to be fully processed so that object recognition is reliable). A search that is insufficient may occur, for instance, in cases where the CF of 'careless/reckless/in a hurry' is attributed to the pedestrian. Alternatively an LBFTS error may occur if the bus cannot readily be visually distinguished from the background even with a careful search of the scene. The latter possibility is more likely in low light conditions, poor visibility (e.g. in fog or rain) or reduced contrast (also in fog, rain, etc.).
3) Failure to estimate time to collision (TTC): this refers to the situation where the pedestrian is aware of the presence of the bus but incorrectly estimates the time available to cross the road before it arrives.

2.4.2 Development and Impairment of visual perception

Visual perception develops in the early years of life, but recent research (Kovacs, 2005) has shown that visual integration, necessary for object recognition, develops gradually across childhood. Thus the ability to recognise an object in the visual scene is lower in children than in adults, making child pedestrians potentially more likely to make LBFTS errors. The evidence on impacts of ageing on visual perception is more complex (Faubert, 2002), suggesting that a number of visual perceptual abilities diminish with age while others do not. Perceptual deficits due to ageing become more evident when the cognitive load is high, for instance when processing complex scenes.

Alcohol intoxication is also known to impair visual perception. For example Calhoun *et al.* (2003) found that alcohol caused a decrease in activation over much of the visual perceptual network in an fMRI imaging study, the effect increasing with dose. Moskowicz and Robinson (1988) in a review of alcohol impairment in driving, concluded that divided attention, visual functions, and visual tracking were all impaired at blood alcohol concentrations of 0.01 to 0.02 grams/decilitre. Drugs likewise impair accuracy and response time for visual stimuli (West, Hernandez, & Appel, 1982).

Visual perception is also impaired by mental fatigue. It results in an increase in reaction times, failure to respond to visual stimuli, and reduction of goal-directed attention (Boksem, Meijman, & Lorist, 2005).

It is possible that improved visual conspicuity may have larger effects when visual perception is under-developed or impaired. However to test the effectiveness of proposed countermeasures at reducing LBFTS and/or TTC errors among people with all various the forms of impairment would require a large scale study with many participants and is beyond the scope of the present study.

2.4.3 Potential for mitigation

The first of the errors listed in section 3.3.1 cannot be addressed with visual conspicuity measures, since these rely on the pedestrian looking in the direction of the bus. These errors could, however, potentially be addressed through acoustic conspicuity measures (if applied to all types of bus moving at traffic speeds, rather than restricted to quiet vehicles (electric and hybrid) running at lower speeds) and advanced emergency braking (AEB).

LBFTS and TTC errors could potentially be addressed through measures to improve the visual conspicuity of the front of the bus, so these are the focus.

3 Improving visual conspicuity: potential solutions

3.1 Regulatory requirements for additional lights and light-signalling devices

Additional lights could potentially improve the visual conspicuity of a bus, particularly at night and when visibility is poor. In particular, lights positioned to mark the outer edges of the front of the bus could potentially reduce both LBFTS and TTC errors. However the fitting of additional lights is constrained by regulations. The following section reviews those constraints.

3.1.1 Requirements for lighting and light signalling devices at the front of new M3 category buses

The requirements for the type approval of vehicles with regards to the installation of light and light signalling devices are provided in United Nations Economic Commission for Europe (UNECE) Regulation 48. The applicable revisions are shown in Table 2.

Table 2: Applicable revisions of UNECE Regulation 48

National Small Series Type Approval	**Regulation 48.03**
EC Whole Vehicle Type Approval	Regulation 48.05
Latest published revision	Regulation 48.06, Supplement 8

The requirements for vehicle light or light signalling devices (e.g. retro-reflectors) varies by vehicle category and installation location. Certain devices are mandatory, some are optional, and some are prohibited in particular installation locations. Light and light signalling device requirements relating to the front of new M3 category buses are summarised in Table 3.

All mandatory and optional light and light signalling devices must be installed in accordance with the applicable requirements for that type of device in terms of location, visibility and operation. Lighting devices that are not covered by the Regulation are not permitted. Each light or light signalling device must be type approved to the applicable UNECE Regulation (e.g. Regulation 7 for end-outline marker lamps).

In addition to the requirements below, only white light is allowed to be emitted at the front of the vehicle, with the exception of direction indicators which must be amber and front fog lamps which can be yellow. Full or partial conspicuity markings (reflective tape) are not permitted on the front of M3 category buses.

As shown in Table 3, additional devices beyond the mandatory number are permitted for main beam headlamps; end-outline marker lamps; and front retro-reflectors. The rules and limitations governing these additional devices are provided within the regulation, but an overview is shown in Table 4.

Table 3: M3 category buses: light and light-signalling device requirements relating to the front of the vehicle

Light / light signalling device (UNECE R48 Reference)	Mandatory	Optional	Additional devices permitted
Main beam headlamp (6.1)	Two	No	Two
Dipped beam headlamp (6.2)	Two	No	None
Front fog lamp (6.3)	No	Two	None
Direction indicator (6.5)	Two	No	None
Hazard warning lamps (6.6)	Two (flashing direction indicators)	No	None
Front position lamp (6.9)	Two	No	None
End-outline marker lamp (6.13)	Two (vehicles >2.1m wide)	No	Two
Front retro-reflector (6.16)	Only if all other lamps are concealable	Two	Unlimited
Daytime running lamp (6.19)	Two (optional in R43.03)	No (optional in R43.03)	None
Cornering lamp (6.20)	No	Two	None
Adaptive front lighting system (6.22)	No	One	None

Table 4: Rules and limitations governing additional light and light signalling devices.

Light / light signalling device (UNECE R48 Reference)	Approval Table marking	Location / Visibility	Other
Main beam headlamp (6.1)	UNECE R98 / R112	Front of vehicle	The aggregate maximum intensity of the main beam headlamps which can be switched on simultaneously shall not exceed 225.000 cd.
End-outline marker lamp (6.13)	UNECE R7; A or AM	Position: >200mm from position lamp, <400mm from vehicle edge, above windscreen. Visibility: 80º outwards, 5º upwards and 20º downwards.	
Front retro-reflector (6.16)	UNECE R3; Class IA or IB	Position: <400mm from vehicle edge, height >250mm and <900mm. Visibility: 30º inwards and outwards, 10º upwards and 10º downwards.	Additional retro-reflecting devices and materials (including two retro-reflectors not complying with positioning requirements), are permitted providing they do not impair the effectiveness of the mandatory lighting and light-signalling devices.

3.1.2 Lights projecting in front of buses

New vehicle types under EC Whole Vehicle Type Approval can only be fitted with the light and light signalling devices permitted and installed in accordance with the requirements of UNECE Regulation 48.06. Additional lamps fitted pre-registration that are not listed as mandatory or permitted as optional are prohibited. There is no reference in the Regulation to lighting devices which project light patterns, warnings or symbols onto the road to the front or side of the vehicle which are intended to draw the attention of VRUs. Cornering lamps which provide supplementary illumination to part of the road, which is located near the forward corner of the vehicle at the side towards which the vehicle is going to turn are permitted as optional under the Regulation. These lamps are activated when the vehicle is at speeds below 40kph and the indicator is activated or steering angle changed. It is not the intention of these lamps to warn VRUs.

Additional lamps fitted to registered vehicles within Great Britain must be compliant with the requirements of the Road Vehicles Lighting Regulations. The Regulations do not specifically include or exclude the use of lighting devices which project light patterns, warnings or symbols onto the road to the front or side of the vehicle which are intended to draw the attention of VRUs. The fitment of such lighting devices would have to align with one of the categories within the Regulations. The inference from this is that such lighting devices would not be permitted. The Regulation does include a general requirement that any lamp fitted must not be used so as to cause undue dazzle or discomfort to other persons using the road.

3.1.3 Aftermarket and retrofitting of lights and light signalling devices

UNECE R48 is applicable for new vehicles requiring type approval. The requirements for aftermarket or retrofitting of lights or light signalling devices differ as they are based on older standards. The requirements in Great Britain are provided in the Road Vehicle Lighting Regulations 1989. These permit any number of additional end-outline marker lamps to be fitted to the front (they must be white and must not flash). They make no reference to reflective conspicuity material on the front of a vehicle (the regulation is understood to pre-date conspicuity tape). Small white retroreflectors are permitted in any number.

3.2 Potential improvements to bus frontal visual conspicuity

UNECE R48 is restrictive in terms of what additional lights and/or light-signalling devices are permitted on new build vehicles and prior to vehicle registration. Thus, only a limited number of options are possible. Flashing lights, while potentially effective as a conspicuity measure, are not permitted either by UNECE R48 (for new build vehicles) or the Road Vehicle Lighting Regulations 1989 (for retrofitting).

Perception of TTC is based on the rate of change of angular size of an object in the visual field. To maximise perception of TTC, the edges of the object must be readily detected. In daylight this is hardly an issue for the front face of a bus; but at night or in poor visibility such detection depends to an extent on how far the edges of the front face are delineated by lights. Ideally lights would be located in the corners of the front face, supported by additional lights at intervals along the edges. UNECE R48 does not permit such configurations, but it does permit certain additional lights.

3.2.1 Additional pair of main beam headlights

One additional pair of main beam headlights is permitted provided the total light output from both pairs does not exceed the specified 225,000 cd. The output restriction limits how much they might improve visual conspicuity, and the need for them to be co-located with the existing pair of main beam headlights means that they could not serve as an additional cue to TTC.

3.2.2 Daylight running lights

Daylight running lights are discussed in the literature as potential improvements to visual conspicuity (e.g. Sivak, Flannagan, Traube, & Miyokawa, 1999). However, our understanding is that these are already in use on London buses.

3.2.3 Additional pair of end-outline marker lights

One additional pair of end-outline marker lights is permitted. Inspection of buses in operation indicates that on some models (of double-deck buses) the existing lights are positioned above the lower windscreen, while on others they are positioned above the upper windscreen, close to the upper corners of the front face. In either case, an additional pair could be located above either the lower or upper windscreen as necessary to ensure that both positions are equipped with end-outline marker lights. In conjunction with the main beam headlights, these would then act to mark out most of the area of the front face of the bus at night or in poor visibility. Potentially this could act as an improved cue to TTC. This configuration was therefore selected for testing. Figure 10 shows test buses equipped with an additional pair of end-outline marker lights in the top corners.

3.2.4 Retrofitted white reflective tape outlining edges of front face of bus

As discussed in section 3.1, the fitting of an additional pair of front retro-reflectors is permitted under UNECE R48, and these were considered. An unlimited number of white retro-reflectors is permitted as a retrofit under the Road Vehicle Lighting Regulations 1989, so in principle it would be possible to use a number of these to mark out as far as possible, the outline of the front of the bus. However a potentially more effective way to do this is the use of reflective tape to mark out, as far as possible, the outline of the front of the bus. There is an analogy with the use of red reflective tape to mark out the outline of the rear of Heavy Goods Vehicles (HGVs) to following traffic, which is an established measure for reducing rear-end vehicle-to-vehicle collisions with HGVs (Ferrone, 1995; Richardson & Lawton, 2005). Use of reflective tape as a retrofit is not specifically disallowed under the Road Vehicle Lighting Regulations 1989 (although it is not allowed under UNECE R48). Clearly its effectiveness would be limited to night-time and only when illuminated by the headlights of oncoming traffic or other light sources such as street lighting, but it is relatively easy to apply and inexpensive as an after-market measure. The addition of white reflective tape to mark out the outline of the front of the bus was therefore selected for testing. The test bus on the right in Figure 10 is so equipped; the tape was only applied to appropriate bodywork surfaces and not to windows.

Figure 10: Test buses: Both buses are equipped with an additional pair of end-outline marker lights in the top corners (existing lights are just above the 'Not in Service' display); the bus on the right is additionally equipped with white reflective tape

3.2.5 Alterations to paintwork

Alterations to paintwork on frontal body panels was considered but not selected as a conspicuity measure. It was considered unlikely to be effective since painted body panels make up a small fraction of the frontal area of a bus, and its effectiveness would be limited at night.

3.2.6 Changes to the colour and/or brightness of saloon lights

In darkness the internal saloon lights, viewed through the front windscreens of a bus, contribute to its overall visual conspicuity. Changes to the colour and/or brightness of saloon lights could therefore potentially increase visual conspicuity. Such changes could also potentially impact on passenger experience, so testing their effectiveness would require measurements of acceptability to passengers as well as effectiveness as conspicuity measures. They were not included in this research, but could be the subject of a follow-on study.

4 System performance

The performance of the solutions described (i.e. their effectiveness at reducing the frequency of bus-pedestrian collisions) could not be tested directly. Testing was undertaken, described in section 5, to quantify their effectiveness at reducing LBFTS and TTC errors.

5 Development Testing for the BSS

The two selected counter-measures, additional end-outline marker lights and reflective tape, were tested for their effectiveness at reducing the likelihood of LBFTS and TTC errors. Since both LBFTS and TTC errors are errors of pedestrian perception, the tests both involved human participants.

LBFTS errors are essentially failures of visual search, so the effectiveness of the counter-measures were tested in a controlled laboratory test the measured how quickly participants were able to identify the presence of a bus in their visual field. Testing TTC requires an object moving appropriately, at traffic speed, so the effectiveness of the counter-measures was tested in a controlled test-track trial that measured the interval between the time when a participant judged it was no longer safe to cross in front of an approaching bus and the time when the bus passed the participant’s position.

5.1 Looked-But-Failed-To-See errors

The effect of each of the proposed counter-measures on the time taken to identify a bus in the visual scene was investigated in a laboratory experiment. Participants were presented with a series of photographs of a London street scene on a computer monitor and asked to press a key on the computer keyboard if a bus was present in the scene, and a different key if a bus was not present in the scene. Half of the images showed daytime scenes, half showed night-time scenes. In those images where a bus was present in the scene, the bus either did or did not have additional marker lights, and either did or did not have reflective tape. The position of the bus in the scene, when present, varied from image to image to ensure participants had to conduct a visual search to determine whether a bus was present. The time interval from initial presentation of the image to the participant’s response (pressing one of the keys) was recorded.

The experiment tested three hypotheses:

> H1: Additional marker lights would cause a decrease in response time (i.e. faster detection)
>
> H2: Reflective tape would cause a decrease in response time (i.e. faster detection)
>
> H3: Participants would respond more quickly to daytime images than to night-time images

5.1.1 Method

5.1.1.1 Experimental design

The test used a within-participants design with three independent variables:

- background (2 levels: day, night)
- reflective tape (2 levels: with tape, without tape)
- additional marker lights (2 levels: with lights, without lights)

There was one dependent variable:

- response time

In addition, accuracy of response was measured to enable checking that each participant had fully engaged with the task.

5.1.1.2 Participants

There were 30 adult participants, a representative mix of age and gender, all with normal or fully corrected eyesight. They were recruited from the TRL participant pool of around 3000 people living in the area around TRL in Wokingham, Berkshire who have given their prior consent to being contacted as potential participants in transport-related research. Participants were paid £20 in compensation for their time and travel costs. An adult sample was used as adults (aged 25-59) are involved in a majority of bus-pedestrian collisions (Figure 6). Comparisons between age groups (e.g. including children and older adults) or between fully and partially sighted people would require substantially larger samples, beyond the present scope.

5.1.1.3 Equipment and software

The experiment was conducted using a computer monitor and keyboard. The monitor had a refresh time of 1ms to ensure accurate timing data could be gathered. It was programmed using the E-Prime experimental software.

Participants were seated at a distance from the monitor such that the angular size of buses in the images displayed on the monitor was the same as the angular size of buses at the camera position when the images were taken. This distance D was determined according to Equation 1:

$$\boldsymbol{D = \frac{BH_{image}}{BH_{actual}} \times D_{road}} \qquad \textbf{(Equation 1)}$$

Where D_{road} was the distance from the camera position to the bus when the image was captured (40m), BH_{image} was the height of the bus in the image as displayed on the monitor, and BH_{actual} was the actual height of the test bus that was photographed (4.95m).

5.1.1.4 Images

Experimental images were created from photographs of the two test buses shown in Figure 10, recorded on Goldhawk Road, part of the A402 in West London. The specific location was on the south-side of Goldhawk Road between the junction with Brading Terrace and the Paddenswick Road bus stop (bus stop SH towards Acton Green or Chiswick). The location featured a bus lane, allowing the test buses to be photographed at an appropriate distance without the front of the bus being obstructed by other traffic between bus and camera. This was an important experimental control, without which the experiment would have had uncontrolled variations in the extent to which the front of the bus was obscured by intervening traffic. Note that there were still uncontrolled traffic variations shown in other parts of the scene, as realistic to the environment. There were two bus routes passing the location (bus 94 and bus 237; only double deck buses were observed). Photographs were not included when any bus other than the test buses appeared in the scene.

As it approached the camera position, the test bus maintained a constant speed of 30mph. Photographs were taken when the front of the bus was 40m from the camera position. The 40m distance corresponded approximately to the distance at which a pedestrian could cross a standard-width lane (3.65m) at a walking speed of 3mph (1.34ms^{-1}) before a bus traveling at 30mph (13.4ms^{-1}), reached them. The time to cross the lane at 1.34ms^{-1} is 2.72 seconds; a bus travels 36.4m at 13.4ms^{-1} in this time. This is rounded up to 40m to allow a small safety margin (0.27 seconds).

The two test buses shown in Figure 10 were used. Both of these had additional marker lights that could be switched on and off by the driver. One of the test buses had reflective tape, the other did not. Images were recorded in daylight (afternoon) and night-time (evening) of the tests buses with/without additional marker lights and with/without reflective tape. Saloon lights were switched off in daytime conditions and on in night-time conditions. Additional photographs were taken in both daytime and night-time conditions with neither test bus (nor any other buses) present in the scene.

Eight photographs with the test buses present were selected – one for each experimental condition. From each of these, three experimental images were produced by cropping the original photograph: one with the bus positioned centrally, one with the bus positioned towards the right hand side of the image, and one with the bus positioned towards the left hand side of the image. The same aspect ratio was maintained as far as possible for all the cropped images. Varying the position of the buses in the images ensured that the task involved a genuine degree of visual search each time an image was presented to the participant.

Eight photographs without test buses present were also selected, and three experimental images were produced from each of these by cropping in a way equivalent to the cropping of the with-bus images.

Figure 11 shows sample with-bus images showing all eight conditions and all three bus positions in the image. Figure 12 shows a selection of equivalent images without a test bus.

Figure 11: Experimental images with bus, in all eight experimental conditions (day/night, with/without additional marker lights, with/without reflective tape)

Figure 12: Experimental images without bus, daytime and night-time

5.1.1.5 Procedure

Prior to starting the experiment participants read the Participant Information Sheet (Appendix A), and read and signed the Consent Form. They were then seated at the experimental station. The position of the keyboard was adjusted as necessary so that they were comfortable and ready to begin. They were told that the experiment would take approximately 15-20 minutes.

Participants were initially presented with on-screen instructions on how to proceed. Once they had read the instructions they pressed a key to begin a practice session. In the practice session they were presented with eight images, four of which had a bus present, and four of which did not. These were different images from those used in the main session: half showed daytime and half night-time scenes, and the four bus images included each of the different combinations of with/without lights and with/without tape. Presentation of each image was preceded by a visual fixation screen consisting of a black + sign in the centre of a white background, presented for 0.5s. This controlled for variations in the initial direction of participants' gaze.

When a participant had completed the practice session, a screen indicated that they could initiate the main session by pressing a key.

Participants were instructed to view each image, pressing a YES key (marked on the keyboard with a sticker) when they had identified a bus in the image, or a NO key if they had not identified a bus. Presentation of each image was preceded by a visual fixation screen consisting of a black + sign in the centre of a white background, presented for 0.5s. Images were presented for up to 5s. Response time (the interval between the image appearing and a key being pressed) was recorded. The relevant experimental condition for the image presented (day/night, with/without lights, with/without tape) was also recorded.

After the participant pressed either the YES or NO key, or after 5s had elapsed with no response, a new screen was presented for 1s, indicating that a new image would now be presented; the next image then followed. Participants were presented with 48 images in total, 24 of which included a bus and 24 of which did not. The order of presentation of the images was randomized for each participant.

The YES and NO keys were located on different sides of the keyboard (e.g. keys '\' and '?'). For half of the participants, the YES key was on the right hand side of the keyboard and the NO key on the left. For the other half this positioning was reversed. This controlled for handedness of participants.

On completion, participants were provided with a short debrief sheet explaining the purpose of the experiment. Participants then received their compensation for participation.

5.1.2 Data cleaning

Data was inspected to exclude invalid data where participants did not comply with the test instructions. Data was excluded where participants:

- Responded in less than 100ms (suggesting an immediate response without looking at the scene)
- Responded incorrectly (YES, when no bus in scene; NO, when bus was present in scene)

Where a participant made only a few invalid responses, only these data points were excluded. Had a participant's data indicated a pattern of invalid responses (e.g. a sequence of very quick responses, suggesting the participant had disengaged) all data from that participant would have been excluded; this did not occur.

5.1.3 Analysis

Two Analyses of Variance (ANOVAs) were carried out on the response time data. ANOVA 1 compared mean response times for day/night and with bus/without bus conditions, using all the data. ANOVA 2 compared mean response times for the three independent variables (day/night, with/without lights, with/without tape) using only the data from those images where a bus was present.

A proposed additional analysis comparing the accuracy of responses was not carried out, after inspection of the data revealed very few incorrect responses.

5.1.4 Results

5.1.4.1 *ANOVA 1: Comparison of response times when bus was present vs. when no bus was present, daytime and night-time*

Figure 13 shows the mean response times when a bus was present in the image compared with when it was not, for daytime and night-time images. Response times were generally quicker when a bus was present than when it was not, and were also generally quicker in the daytime than at night.

Formally, there was a statistically significant main effect on response time depending on whether the scene was viewed in the daytime or at night (Day/Night) (F(1,29) = 46.58, p < 0.001): response times were quicker in the daytime conditions. There was also a significant main effect of whether a bus was present in the image or not (F(1,29) = 7.014, p = 0.013): participants responded more quickly when a bus was present in the image than when it was not. The interaction between day/night and bus/no bus conditions was not significant (F(1, 29) = 2.295, p = 0.141).

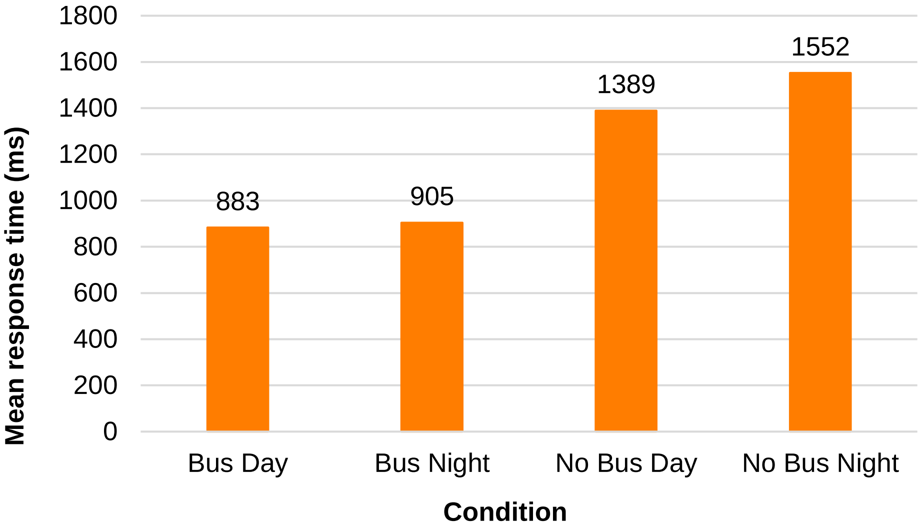

Figure 13: Mean response times when a bus was present in the image compared to when it was not, daytime and night-time (numbers above columns indicate mean response time (ms) for that condition)

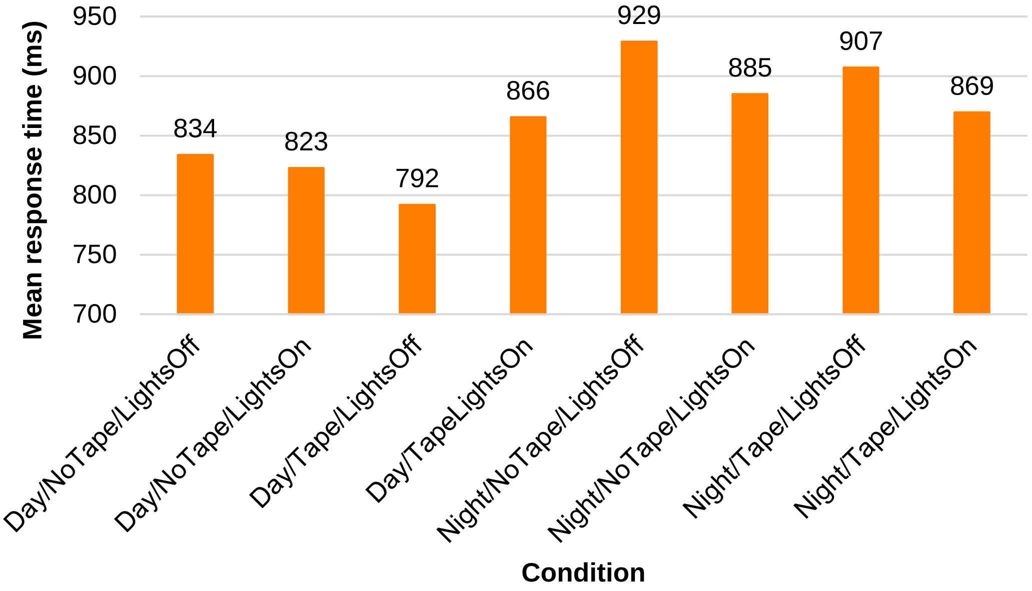

Figure 14: Mean response times for each condition: day/night, with/without reflective tape, with/without additional marker lights (numbers above columns indicate mean response time (ms) for that condition)

5.1.4.2 ANOVA 2: Comparison of response times with/without counter-measures, daytime and night-time

Figure 15 shows the mean response times for each condition (day/night, with/without reflective tape, with/without additional marker lights). Response times were generally quicker in the daytime than at night. However there was little difference between response times with or without additional marker lights on, and with or without reflective tape, either in the daytime or at night.

Formally, there was a significant main effect on response time depending on whether the scene was viewed in the daytime or at night (Day/Night) ($F(1,29) = 16.40$, $p < 0.001$): response times were quicker in the daytime conditions. The main effect of Reflective tape was not significant ($F(1,29) = 0.18$, $p = 0.674$); neither was the main effect of additional marker lights ($F(1,29) = 0.031$, $p = 0.861$). None of the interaction terms was significant.

5.1.5 Discussion

The finding that response time was substantially quicker for images where a bus was present than for images where it was not confirms that a visual search (Cole & Hughes, 1984; Palmer, 1999) occurred in the task. The findings can be interpreted as indicating that if a bus was perceived, then the search terminated, but when a bus was not perceived, the search continued for longer. The findings also indicate that it was marginally quicker to identify a bus in the daytime than at night, though the difference, whilst statistically significant, was small.

The key finding of this test however is that neither of the proposed counter-measures, additional end-outline marker lights nor reflective tape, made a statistically significant difference to response time for adults in optimal conditions. It can therefore be concluded that neither is likely to be an effective counter-measure for LBFTS errors in situations where a participant is searching for a bus[2].

5.2 Time-To-Collision errors

The effect of each of the proposed counter-measures on the ability of a person at the roadside to estimate time-to-collision was investigated in a test track experiment. Participants were positioned by the roadside at the noise test facility at the Millbrook Proving Ground (Figure 15) where they were approached by a test bus. They were asked to press a button at the last moment they judged they could safely walk across the road in front of the bus. The time at which the button was pressed was logged, as was the time at which the bus interrupted a light beam that crossed the track at the participant’s position. The time interval between these two signals was a measure of the participant’s estimate of TTC; the size of gap participants were willing to accept is believed to be based at least partly on TTC judgement, and previous work in field experiments has shown that lighting interventions such as those tested here can influence this measure (e.g. Helman, Palmer, Haines & Reeves, 2013). Each participant experienced four conditions, the bus approaching with/without additional marker lights and with/without reflective tape. Participants experienced these conditions either in the daytime (afternoon) or night-time (evening).

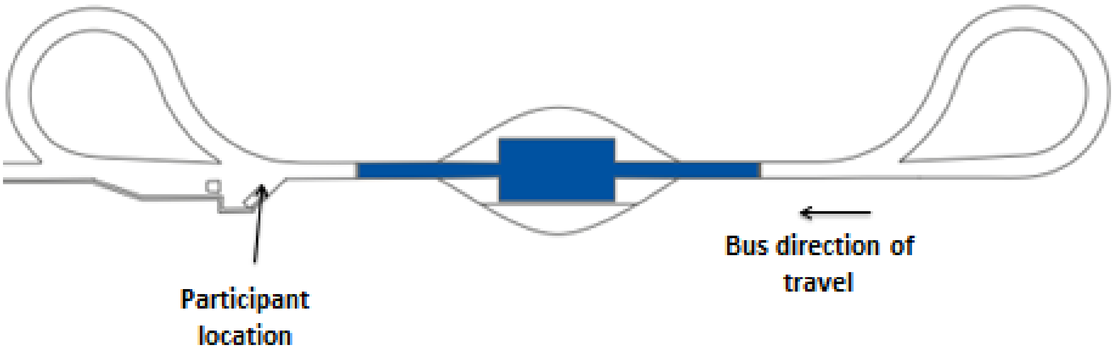

Figure 15: The Noise Site at Millbrook Proving Ground

The experiment tested four hypotheses:

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[2] The effect of these countermeasures on situations in which a pedestrian glances slightly in the direction of an approaching bus but stops short of actively searching for it would need to be tested using a different method. So-called ‘attention conspicuity’ (Cole & Hughes, 1984) refers to the ability of an object to ‘grab’ attention even in the absence of effortful visual search.

H1: There would be a difference in mean gap accepted when additional marker lights were displayed compared with when they were not.

H2: There would be a difference in mean gap accepted when the test bus had reflective tape compared with when it did not.

H3: There would be an interaction between whether additional marker lights were displayed or not and day/night condition.

H4: There would be an interaction between presence of absence of reflective tape and day/night condition.

5.2.1 Method

5.2.1.1 Experimental design

The experiment used a 2 x 2 x 2 mixed factorial design with three independent variables:

- Ambient light condition (2 levels: afternoon, evening): between-participants
- Additional marker lights (2 levels: with/without): within-participants
- Reflective tape (2 levels: with/without): within-participants

Saloon lights were switched off in daytime conditions and on in night-time conditions.

There was one dependent variable (gap accepted, operationalized as time interval between participant’s release of the button and the bus’ interruption of the light beam).

The mixed design was required to avoid having participants waiting for an extended period between daytime and night-time conditions. Ambient light condition was a between-participants variable, with different participants for the daytime and night-time conditions.

For logistic reasons participants were taken to the Noise Site in groups of four. The order of conditions was not randomized but a partially counter-balanced design was used:

Group 1, Participants 1 & 2 (afternoon): Blue – Green – Red – Yellow
Group 1, Participants 3 & 4 (afternoon): Green – Blue – Yellow – Red
Group 2, Participants 1 & 2 (afternoon): Red – Green – Blue – Yellow
Group 2, Participants 3 & 4 (afternoon): Yellow – Blue – Green – Red
Group 3, Participants 1 & 2 (afternoon): Blue – Yellow – Red – Green
Group 3, Participants 3 & 4 (afternoon): Blue – Red – Yellow – Green
Group 4, Participants 1 & 2 (evening): Red – Yellow – Green – Blue
Group 4, Participants 3 & 4 (evening): Red – Yellow – Blue – Green
Group 5, Participants 1 & 2 (evening): Green – Blue – Red – Yellow

Group 5, Participants 3 & 4 (evening): Green – Blue – Yellow – Red
Group 6, Participants 1 & 2 (evening): Yellow – Red – Blue – Green
Group 6, Participants 3 & 4 (evening): Yellow – Red – Green – Blue

Where:

Red: Without reflective tape, without additional marker lights
Yellow: Without reflective tape, with additional marker lights
Green: With reflective tape, without additional marker lights
Blue: With reflective tape, with additional marker lights

In this scheme each condition occupied 1st, 2nd, 3rd, and 4th place three times. The first two participants within each group experienced the conspicuity conditions in one order, the second two in a different order. For four of the groups, this was achieved simply by switching additional marker lights on/off on the same test bus. For the remaining two groups, the test bus was switched after the first and third runs/participants. These two groups (2 and 3) were scheduled for the afternoon session so that the evening sessions involved the less complex condition swaps.

5.2.1.2 Participants

There were 24 participants, a mix of ages and gender, all with normal or fully corrected eyesight. Participants were recruited from among Millbrook staff.

5.2.1.3 Equipment

Two test buses were modified and supplied by Operator C. Each was equipped with additional end-outline marker lights in the top corners that could be switched on/off independently of the other lights on the bus by a switch accessible to the driver. One test bus also fitted with reflective tape.

The following additional equipment was used:

- Light beam transmitter/receiver pair, with the beam spanning the track at the participant's position
- Hand-held button, used by participant: the button was held down while the participant judged it safe to cross in front of the bus, and released when the participant judged it unsafe to cross
- Laptop computer and data logger
- Cable connecting light beam receiver to data logger
- Cable connecting hand-held button to data logger
- Track position marker (traffic cone) 134m from the participant's position, representing the point from where the bus would reach the participant's position in 10s at constant speed (30mph).

Electrical power was provided via a portacabin at the participant location on the Noise Site.

5.2.1.4 *Procedure*

1) Prior to starting the experiment participants read the Participant Information Sheet, and read and signed the Consent Form. They were then taken to the trackside by minibus in groups of four.
2) Participants received a briefing at the trackside and were familiarised with the equipment.
3) Participants waited in the portacabin for their turn at the trackside; each test run involved one participant.
4) The participant took position beside the track (close to the portacabin, behind a barrier separating them from the track). The participant was initially positioned facing away from the direction from which the bus would approach.
5) The test bus accelerated to its target speed (30mph) in the run-up zone.
6) As the bus passed the track position marker (positioned at the point from where the bus would reach the participant's position in 10s at constant 30mph) the researcher instructed the participant to look at the bus and hold down the button (Figure 16). They were instructed at step 2 of this procedure to hold the button down until the last moment that they could safely cross the road in front of the bus (their instructions did not specify at what crossing speed they might attempt this, recognising that in reality pedestrians vary in crossing speeds and this source of variation should be accounted for in the test).
7) The participant continued to hold down the button until the last point where they judged that they could safely cross the road in front of the bus. At this point, the participant released the button. The time of release was recorded by the datalogger.
8) As the bus passed the participant's position it interrupted the light beam causing its output to switch. The time of this switch was recorded by the datalogger.
9) The bus continued round the end loop and either returned to the start loop (right hand loop in Figure 15) or was replaced with the other test bus, as necessary for the run schedule.
10) When all runs for all participants were completed, participants were transported from the Noise Site by minibus.

Figure 16: View from participant position towards approaching test point. The bus has passed the track position marker and the participant is looking in its direction, holding the button

5.2.1.5 Analysis

The gap accepted was calculated from the time interval between the participant releasing the button and the bus interrupting the light beam.

Data was inspected and obvious outliers (e.g. button not released) were excluded.

A 2 x 2 x 2 mixed factorial Analysis of Variance was used to compare means between the eight experimental conditions.

5.2.2 Results

Figure 17 shows the mean time differences for each condition (day/night, with/without reflective tape, with/without additional marker lights). Time difference is the gap accepted divided by the speed of the bus. The latter was measured, and transmitted to the datalogger by radio; unfortunately this data was missing for several runs. Therefore, time difference is reported rather than gap acceptance, to avoid having to use an estimate of speed for those runs[3]. Although there appear to be differences in the means (e.g. suggesting smaller time differences with additional marker lights than without), the variances within each condition were substantial so none of the differences was statistically significant.

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[3] This made negligible difference to the analysis and interpretation of the results, since the variance in speed was small.

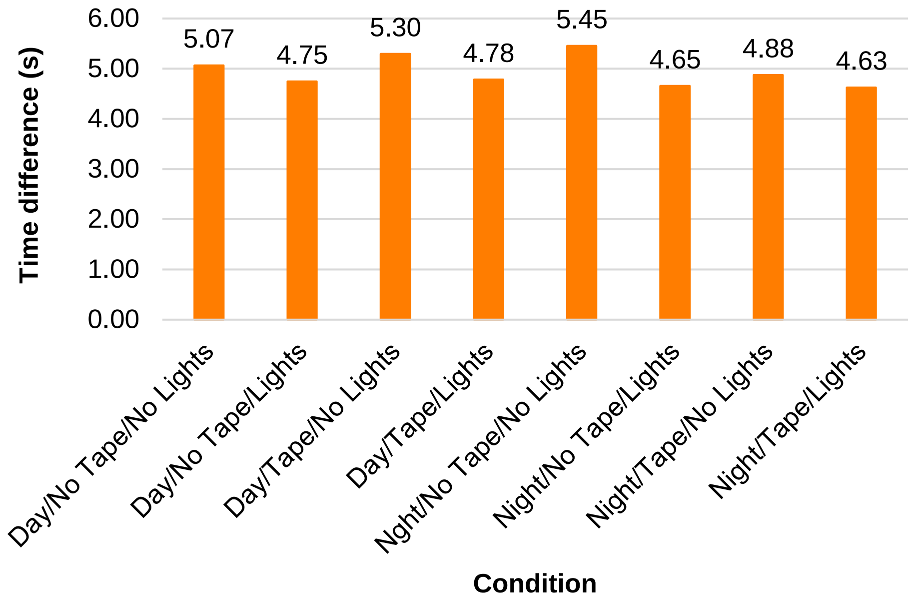

Figure 17: Mean time differences for each condition: day/night, with/without reflective tape, with/without additional marker lights (numbers above columns indicate mean time difference (s) for that condition)

Formally, none of the main effects of day/night (F(1, 22) = 3.22, p = 0.087), reflective tape (F(1, 22) = 0.072, p = 0.791), or additional marker lights (F(1, 22) = 0.141, p = 0.711) were statistically significant using the conventional p =0.05 criterion. None of the interaction terms was statistically significant.

5.2.3 Discussion

The key finding of this test was that neither of the proposed counter-measures, additional end-outline marker lights nor reflective tape, made a statistically significant difference to minimum gap accepted, for adults in optimal conditions. It can therefore be concluded that neither is likely to be an effective counter-measure for TTC errors.

6 Cost-benefit analysis

6.1 Target population

The annual target population in 2018 estimated for all outcome severities (fatal, serious and slight casualties) relevant to the visual conspicuity measure is presented in Table 5 below. Target populations were considered to be equivalent between the different visual conspicuity safety measure solutions. Target populations were calculated for pedestrians, as this is the population primarily affected by improvements in the visual conspicuity of buses. The selection of appropriate target populations was performed to include the average annual number of bus-pedestrian collisions in London where the pedestrian was first struck by the front of the bus and where the pedestrian either failed to look properly or failed to judge the path/speed of the bus (see Section 2 for further information on target population calculations). Casualty data was abstracted from the UK STATS19 road safety database; the proportion first struck by the front of the bus was abstracted from ACCSTATS.

Table 5: Estimated average annual target population in 2018 for the visual conspicuity [VCO] safety measure solutions

Safety Measure Solution	Outcome Severity		
	Fatal Casualties	Serious Casualties	Slight Casualties
Reflective Tape	5.0	33.8	97.1
Extra Marker Lights	5.0	33.8	97.1
Marker Lights & Reflective Tape	5.0	33.8	97.1

6.2 Estimates of effectiveness

The overall effectiveness values estimated for all outcome severities relevant to the visual conspicuity safety measure (fatal, serious and slight casualties) are presented in Table 6 below. Effectiveness of the proposed countermeasures was evaluated in the laboratory test described in Section 5.1 (pedestrian LBFTS perceptual errors) and Section 5.2 (pedestrian TTC perceptual errors). None of the proposed countermeasures was effective in either test.

Table 6: Estimated overall effectiveness ranges casualties prevented and casualties mitigated for the visual conspicuity safety measure solutions

Safety Measure Solution	Casualties Prevented			Casualties Mitigated		
	Fatal Casualties	Serious Casualties	Slight Casualties	Fatal to Serious	Fatal to Slight	Serious to Slight
Reflective Tape	0%	0%	0%	0%	0%	0%
Extra Marker Lights	0%	0%	0%	0%	0%	0%
Marker Lights & Reflective Tape	0%	0%	0%	0%	0%	0%

6.3 Fleet fitment and implementation timescales

Timescales were determined for both the retrofit and new build visual conspicuity measure solutions to develop fleet fitment and policy implementation roadmaps for each solution (Table 7). These timescales were determined based on stakeholder consultations with bus manufacturers for first-to-market timescales and TfL for the proposed timescales for policy implementation. Bus operators and suppliers contributed to establishing the estimates for current levels fleet fitment and expected years to full fleet fitment after implementation for each solution. Please see the associated stakeholder consultation report for further details on stakeholder feedback on fleet fitment and policy implementation timescales.

Table 7: Fleet fitment and policy implementation timescales for both the retrofit and new build visual conspicuity [VCO] safety measure solutions

Safety Measure Solution	First to Market	Date Policy Implemented	Current Fleet Fitment	Full Fleet Adoption (yrs)	
				Retrofit	New Build
Reflective Tape	2019	2019	0%	1	7
Extra Marker Lights	2021	2021	0%	2	7
Marker Lights & Reflective Tape	2021	2021	0%	2	7

6.4 Casualty benefits

Table 8 below summarises the estimated total change in the number of casualties expected in London during the period 2019-2031 by specifying the performance of both new build buses and retrofit system for the visual conspicuity safety measure solutions. Outcomes are then monetised to estimate the total value of these casualty reductions to society.

Table 8: Estimated total change in number and value (NPV) of incidents over the 12-year analysis period (2019-2031) for the new build and retrofit visual conspicuity [VCO] safety measure solutions

Safety Measure Solution	Fitment Type	Injury Severity			Total Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	
Reflective Tape	New Build	0	0	0	0
	Retrofit	0	0	0	0
Extra Marker Lights	New Build	0	0	0	0
	Retrofit	0	0	0	0
Marker Lights & Reflective Tape	New Build	0	0	0	0
	Retrofit	0	0	0	0

6.5 Cost implications

Estimated changes in cost per bus (NPV) and total cost (NPV) are shown in Table 9 and Table 10 for solutions implemented in the new build and retrofit scenarios respectively. The costs of implementing the visual conspicuity performance requirements as part of the bus safety standard can be divided into five key cost categories based on:

1) Differences in development, manufacturing and certification costs
2) Differences in implementation and installation costs
3) Differences in on-going operational costs
4) Differences in insurance claims costs
5) Differences in environmental and infrastructure costs

No objective data was found to consider the differences in development, manufacturing and approval costs due to the regulation of the visual conspicuity performance of buses. The stakeholder consultation was therefore used to establish changes in technology, operational, and implementation costs. Baseline changes in technology, operational and implementation costs for each solution may therefore be found in the relevant section of the associated stakeholder consultation report.

The change in annual value of insurance claims were estimated to be zero: since the proposed countermeasures were assessed as being ineffective. Cost differentials resulting from environmental and infrastructure costs were not considered by the scope of this safety measure.

Table 9: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the new build visual conspicuity [VCO] safety measure solution

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NPV) (£M)
Reflective Tape	Change in Technology Costs	93-167	0.94-1.67
	Change in Implementation Costs	0	0
	Change in Operational Costs	315-629	3.15-6.29
	Change in Insurance Claims Costs	0	0
	Totals	**408-798**	**1.44-2.68**
Extra Marker Lights	Change in Technology Costs	149-261	1.31-2.30
	Change in Implementation Costs	0	0
	Change in Operational Costs	279-557	2.45-4.90
	Change in Insurance Claims Costs	0	0
	Totals	**428-819**	**3.77-7.21**
Marker Lights & Reflective Tape	Change in Technology Costs	168-430	1.48-3.78
	Change in Implementation Costs	0	0
	Change in Operational Costs	557-115	4.90-9.81
	Change in Insurance Claims Costs	0	0
	Totals	**725-1544**	**6.38-13.59**

Table 10: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the retrofit visual conspicuity [VCO] safety measure solution

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NPV) (£M)
Reflective Tape	Change in Technology Costs	115-210	1.25-2.29
	Change in Implementation Costs	96-230	1.04-2.50
	Change in Operational Costs	560-1119	6.08-12.17
	Change in Insurance Claims Costs	0	0
	Totals	**770-1559**	**8.37-16.95**
Extra Marker Lights	Change in Technology Costs	189-331	2.06-3.60
	Change in Implementation Costs	189-454	2.06-4.94
	Change in Operational Costs	472-944	5.13-10.26
	Change in Insurance Claims Costs	0	0
	Totals	**851-1729**	**9.25-18-80**
Marker Lights & Reflective Tape	Change in Technology Costs	208-540	2.26-5.87
	Change in Implementation Costs	379-682	4.12-7.41
	Change in Operational Costs	944-1887	10.26-20.52
	Change in Insurance Claims Costs	0	0
	Totals	**1531-3109**	**16.64-33.80**

6.6 Benefit-cost analysis outcomes

Table 11 provides estimates for the break-even costs, discounted payback period and benefit-cost ratios associated with specifying the performances of new build and retrofit buses. All benefit-cost ratios (BCRs) were found to be zero, due to the ineffectiveness of the proposed safety measure solutions.

Table 11: Estimated 12-year analysis period (2019-2031) break-even costs per vehicle (NPV), discounted payback periods and benefit-cost ratios (NPV) for the new build and retrofit visual conspicuity [VCO] safety measure solution

Safety Measure Solution	Fitment Type	Break-Even Costs (NPV) (£)	Discounted Payback Period	Benefit-Cost (NPV) Ratio
Reflective Tape	New Build	0	2031+	**0**
	Retrofit	0	2031+	0
Extra Marker Lights	New Build	0	2031+	0
	Retrofit	0	2031+	0
Marker Lights & Reflective Tape	New Build	0	2031+	0
	Retrofit	0	2031+	0

Further information on the general approach adopted by the cost-benefit analysis may be found in Appendix A.

7 Conclusions and next steps

7.1 Summary of conclusions

Neither of the proposed counter-measures was effective with respect either to LBFTS or TTC errors in these experiments, for adults in optimal conditions.

A plausible explanation for this is that buses are large, conspicuous objects that are easy to see, and the proposed countermeasures, in being consistent with UNECE R48 (additional end-outline marker lights) or the Road Vehicle Lighting Regulations 1989 (retrofitted reflective tape), added little to their conspicuity.

It is possible that that the measures might nevertheless be effective for adults whose visual perception is impaired due to alcohol, drugs, fatigue, partial vision, and other factors that impact on visual processing, and for children or older adults. Testing with these groups was outside the scope of the present project, but could potentially be carried out in follow-up work.

The experiments did not include conditions representative of out-of-service buses at night-time, with saloon lights switched off. In such conditions the proposed countermeasures might make a bigger difference to overall visual conspicuity. Testing under these conditions could potentially be carried out in follow-up work.

The visual conspicuity of the front faces of buses might in principle be improved by other measures, such as lights projecting onto the road surface, or (for TTC errors) innovations such as a visual display of the bus' speed – but these types of measures would not be compliant with regulations. It might also be improved in night-time conditions by changing the colour and/or brightness of the saloon lights: however, this could also impact on passenger experience, so testing would need to include measures of passenger acceptance.

The discussion in Section 2 indicated that in a substantial fraction of collisions between buses and pedestrians, 'failed to look properly' (71%), and 'careless/reckless/in a hurry' (62%) were contributory factors. These could include cases where the pedestrian glances very briefly in the direction of the bus without carrying out a visual search, and cases where the pedestrian does not look at all. The literature review also indicated that 'distracted walking' – paying attention to a mobile device rather than the road situation – contributes to a substantial fraction of bus-pedestrian collisions.

Evaluating the effectiveness of the proposed countermeasures for cases where the pedestrian glances very briefly and fails to carry out a visual search would require a different form of test (for attention conspicuity), rather than the LBFTS test carried out in this research.

In cases where the pedestrian fails to look at all, the visual conspicuity of the bus cannot be relevant, through increasing the *acoustic* conspicuity of the bus might potentially be effective at redirecting the pedestrian's attention. Measures to improve acoustic conspicuity of buses are discussed in a further report (Ainge et al, 2018).

In the event that the regulatory position were to change at some time in the future, the tests described here would be suitable for evaluating the effectiveness of visual conspicuity countermeasures that might be permitted under new, different regulations. Accordingly, research protocols have been developed based on each of the tests reported here.

This research was completed in 2018. The detailed specification, assessment procedures and guidance notes have been incorporated into the Transport for London specification for buses, which is a continuously updated document to keep pace with the latest technological and research developments. This report is not the specification for a bus and should not be used as such. Bus operators, manufacturers, and their supply chain should consult with TfL for the specification.

7.2 Next steps

Given that neither of the counter-measures (additional top marker lights, additional reflective tape) was effective in relation to either LBFTS or TTC errors, it is not recommended that the Bus Safety Standard be amended to include either measure.

Research protocols based on the tests described in Section 3 can be used to evaluate retrofit countermeasures or potential future countermeasures should there be changes to UNECE R48.

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Appendix A General cost-benefit analysis approach

The following Appendix summarises the general approach taken to perform the cost-benefit analysis (CBA) for each safety measure and its proposed solutions over the 12-year analysis period (2019-2031). Using the research presented in previous sections, a number of key CBA outcomes can be determined for each safety measure solution. These outcomes include values for the target populations, effectiveness, fleet fitment timeframes, casualty reduction benefits, costs per vehicle, total fleet costs, monetised casualty benefits, break-even costs and benefit-cost ratios associated with each solution. The theory behind calculating these values is covered in the following paragraphs.

The target population represents the total number of casualties and/or incidents that a particular safety measure solution has been designed to prevent or mitigate each year. Target populations may be calculated for each relevant casualty type (pedestrians, cyclists, powered two wheelers, car occupants, HGV/LGV occupants and bus occupants) and collision severity level (fatalities, serious injury, slight injury, major damage-only incident and minor damage-only incident) using a range of sources. These may be either directly calculated using casualty numbers from the STATS19 database or through the combination of top-level STATS19 data with an indication of the proportion of relevant casualties from other sources (Equation 1). Further information on what approach was adopted is provided in the relevant following section.

$$Target\ Population = Total\ No. of\ Casualties \times Proportion\ of\ Relevant\ Casualties$$

(Equation 2)

The effectiveness of a safety measure solution is determined by an estimate of how well the particular solution works for the specific target population. Estimates of effectiveness may be calculated based on the percentage of relevant target population casualties or incidents that could have been prevented, or severity mitigated, should the particular safety measure be implemented. Overall effectiveness values may therefore be calculated through several different approaches, including values taken directly from testing performed as part of the BSS project and from those abstracted from the literature. Overall effectiveness may also be indirectly calculated by combining technology effectiveness values from studies with similar scenarios or target populations with percentage based correction factors, such as driver reaction factors (Equation 2). Further information on the approach adopted is provided in the relevant following section.

$$Overall\ Effectiveness = Technology\ Effectiveness\ \times Driver\ Reaction\ Factor \times \cdots$$

(Equation 3)

Fleet fitment and implementation timescales were determined for each safety measure solution based on a stakeholder consultation with the bus industry. This was used to include the temporal aspects of the penetration of each safety measure solution in to the TfL fleet, which can then be used for better determining the changes in costs and benefits over time. The 'first-to-market' timescales were established based on bus manufacturer feedback and represent the earliest point in time that the leading manufacturer will be able to bring the particular solution to market. The timescales for 'policy implementation' were proposed by TfL based on bus manufacturer feedback on when series production would be possible for at least three different manufacturers. Current levels of fleet fitment for each solution were established based on bus operator feedback, whilst the estimated period of time that it would take to fit the entire TfL fleet with the solution was determined for new build buses (12 years), solutions fitted during refurbishment (7 years) and retrofit solutions (timeframes based on supplier feedback). This gave a year-on-year fleet penetration value, based on the proportion of the fleet fitted with the particular solution, for each solution and each year of the analysis period.

Total casualty reduction benefits were then calculated by multiplying the target population and overall effectiveness values together with fleet penetration for each year of the analysis period (Equation 3). To correct for changes in the modal share in London, target population values were adjusted according to the forecasted growth in the number of trips made by each transport mode within London, whilst the bus fleet size was adjusted by the forecasted growth in the population of London (based on TfL forecasts (Transport for London, 2015)). These values were then aggregated to provide the total casualty reduction values associated with each target population and severity level over the total analysis period.

$$Casualty\ Reduction\ = Target\ Population \times Overall\ Effectiveness \times Fleet\ Penetration$$

(Equation 4)

These values were then monetised to provide an estimate of the societal benefits of the casualty reductions to TfL using 2016 average casualty costs calculated by the Department for Transport (DfT) for each relevant severity level (Department for Transport, 2018). For the purposes of this report, fatal casualties were assigned a value of £1,841,315, seriously injured casualties assigned a value of £206,912, slightly injured casualties assigned a value of £15,951 and major damage-only collisions assigned a value of £4,609 based on these DfT estimates, whilst minor damage-only collisions were assigned a value of £1,000 based on a reasonable estimate for such collisions. Net present values (NPV) for the monetised casualty saving benefits for each solution were then calculated for the analysis period. A discounting factor of 3.5% and interest rates that reflect forecasted annual changes in the retail pricing index (RPI), as defined by the WebTAG databook (v1.11) (Department for Transport, 2018), were applied.

When considering the cost based outcomes, both the costs per vehicle and total fleet costs were calculated for each solution. These were based on estimated increases in costs related to the development, certification, implementation and operation of the proposed solution and included operational cost reductions due to a reduction of claims costs associated with the reduction in casualties. The baseline costs per vehicle were adopted from information abstracted from the literature and manufacturer/supplier websites, before aggregating and confirming the estimated cost ranges through stakeholder consultation. Fleet costs were then calculated by multiplying the baseline costs per vehicle and fleet penetration values together for each year of the analysis period (Equation 4).

Claims costs reductions for each year of the analysis period were calculated by combining average insurance claim costs (calculated from operator provided data), with the expected annual changes in incidents for each outcome severity (Equation

4). For the purposes of this report, claims reductions for fatalities was assigned a range of £35,000-45,000, seriously injured casualties assigned a range of £60,000-70,000, slightly injured casualties assigned a range of £6,000-8,000, major damage-only collisions assigned a range of £4,000-5,000 and minor damage-only collisions assigned a range of £1,000-2,000.

Changes in baseline and claims costs were then aggregated to provide the net present value of the total fleet costs over the total analysis period. The net present values of the costs per vehicle were then calculated by dividing the total costs by the total number of fitted vehicles in the fleet. A discounting factor of 3.5% and interest rates that reflect forecasted annual changes in RPI were again applied.

$$Total\ Cost = (Baseline\ Cost \times Fleet\ Penetration) - (Claim\ Cost \times Casualty\ Reduction)$$

(Equation 5)

The break-even costs, discounted payback periods and benefit-cost ratios were calculated for the analysis period by combining values from the net present values for both the costs and monetised benefits. The 12-year analysis period was selected based on a combination of stakeholder and industry expert opinion to ensure the one-off and ongoing costs for each vehicle were combined with the casualty reduction benefits over the estimated operational lifetime of the vehicle. Break-even costs describe the highest tolerable costs per vehicle for the fitment of a safety measure solution to remain cost-effective for society. These were calculated by normalising the monetised casualty reduction benefits by the total number of fitted vehicles in the fleet (Equation 5). This value may be a useful indicator when no cost estimates are available, or there is low confidence in the cost inputs, with higher break-even costs indicating a greater potential for cost-effectiveness.

$$Break\ Even\ Cost = Monetised\ Casualty\ Reduction / Total\ Number\ of\ Buses\ Fitted$$

(Equation 6)

Benefit-cost ratios (BCR) describe the ratio of expected benefits to society (arising from the prevented casualties) to the expected costs (arising from fitment to vehicles) (Equation 6). This was calculated by taking the ratio of the net present value of the total casualty benefits to the net present value of the total costs. As ranges of estimated benefits and costs have been calculated, the greatest possible benefit-cost ratio range was estimated by comparing maximum costs against minimum benefits, and vice versa. Benefit-cost ratios greater than one indicate that the value of the benefits would exceed the costs and so the measure may be cost-effective, with higher benefit-cost ratios indicating higher cost-effectiveness. Should the total costs of implementing the safety measure solution reduce, then the benefit-cost ratio will be shown as a ‘Return on Investment’ (RoI) to indicate that the safety measure solution is likely to provide operators with a return on their investment within the analysis period.

$$Benefit - Cost\ Ratio = \ Monetised\ Casualty\ Reduction / Total\ Cost$$

(Equation 7)

Finally, the discounted payback period (DPP) was established based on calculations for the benefit-cost ratio ranges for each year of the analysis period. To establish the DPP range, the year where each boundary of the benefit-cost ratio first exceeded the value of 1 was calculated. This gives a range for the expected period in time where the societal benefits of implementing the safety measure solution would outweigh the costs of doing so. Should any boundary of the DPP be greater than 2031 (i.e. a BCR value boundary of <1 over the analysis period), then the DPP boundary was assigned a date of 2031+.

The Transport for London Bus Safety Standard: Visual Conspicuity

The Bus Safety Standard (BSS) is focussed on vehicle design and safety system performance and their contribution to the Mayor of London’s Transport Strategy. This sets a target to achieve zero road collision deaths involving buses in London by 2030.

All TfL buses conform to regulatory requirements. TfL already uses a more demanding specification when contracting services and this requires higher standards in areas including environmental and noise emissions, accessibility, construction, operational requirements, and more. Many safety aspects are covered in the specification such as fire suppression systems, door and fittings safety, handrails, day time running lights, and others. However, the new BSS goes further with a range of additional requirements, developed by TRL and their partners and peer-reviewed by independent safety experts.

Visual conspicuity is about making the bus more noticeable to other road users, particularly VRUs. This might help VRUs to detect the presence of a bus and the collision risk it represents if they were to cross in front of it. There are a variety of solutions available that might help, and Transport for London (TfL) is requesting innovative solutions to be evaluated. Test and assessment procedures will have to be developed for specific solutions that are selected in the future.

The assessment of the visual conspicuity solutions has required the development of a new evaluation procedure. This consists of a laboratory-based test reviewing photos of buses in a variety of conditions. This assesses the participants’ ability to search and recognise the bus in a London visual scene. A second phase of testing is track-based and assesses how well participants judge their ability to successfully cross in front of an approaching bus (by releasing the button, but not stepping out). These procedures were designed to assess the ‘looked but failed to see’ and ‘time to collision’ (or saw but misjudged the risk) errors respectively.

Within the regulatory requirements it is possible to add extra marker lights to buses. Additional reflective tape was also investigated, as well as the combination with both lights and tape. The idea is that by creating a rectangular frame of the shape of the bus front then VRUs might better identify and predict the speed of the bus as the rectangle enlarges whilst moving towards them. These conditions were tested against a baseline bus, but were not proved to be more effective for fully able people. However, TfL is considering whether these solutions could be effective for impaired persons, such as visually impaired or intoxicated people.

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TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

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