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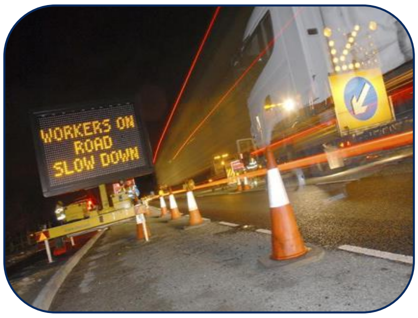


PUBLISHED PROJECT REPORT 746

Detection of vulnerable road users near buses

An evaluation of systems fitted to buses to detect vulnerable road users

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Version	Date	Description	Editor	Technical Referee
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0.8	03/06/15	Draft following client comments	SG	MJ

Contents

Executive Summary

Purpose

One of Transport for London's (TfL's) top priorities is to reduce the number of people killed or seriously injured on London's roads by 40 per cent by 2020. As part of this commitment, TfL is exploring the role that innovative technology can have in further improving road safety, and recently ran a trial of cyclist and pedestrian detection technology on London buses. This report details the evaluation of the technology which TRL was commissioned to undertake. The aim of the evaluation is to better understand the effectiveness of the technology, so that TfL can determine its use in the future.

The trial

TfL issued a tender for discriminatory optical / radar detection systems, and selected two systems from those suppliers that responded. The chosen technology systems purport to detect cyclists and pedestrians in the vicinity of the bus to alert the driver so that the driver can take mitigating action to avoid or reduce the severity of a collision. The two systems were placed on two buses each on pre-selected London bus routes (the 25 and the 73) for several months over the summer of 2014. These routes were chosen to provide the optimum conditions for testing different variables (such as street type, traffic conditions, high/low cycle flows, high/low pedestrian flows). TRL were commissioned to evaluate the systems and report on their potential role in reducing the risk to cyclists and pedestrians from buses in London.

The two different systems (A and B)[1] utilised different technologies and alerted the driver in different ways. System A was configured to detect only cyclists undertaking the rear quarter of the bus, using the assumption that any cyclist in this area is at risk. System B had both a wider detection area, covering both the nearside and front of the bus, and also claimed to alert the driver to other road users, including pedestrians and cyclists. System B worked by attempting to track a route of convergence of a cyclist or pedestrian with the bus, then warning the driver of impending collision so that they can take appropriate avoiding / mitigating action.

Firstly, TRL carried out work to understand how such systems might work in an idealised scenario, to better understand which metrics of the system's performance to measure, and the areas of greatest risk around a bus. This utilised STATS19 data of collisions involving buses with pedestrians and cyclists, and determined the most common point of impact with the bus.

The trial buses were then fitted with video cameras to provide a record of cyclists, pedestrians and other objects in the vicinity of the bus during the trial.. This was a blind test, so the driver was not aware of the system's operation. A hidden light was used (instead of an audible alert) when the system gave a cyclist or pedestrian alert, and this light was recorded simultaneously by the video camera systems. Several weeks of video data were collected and viewed by researchers, noting down the details of each instance of the system warning light being triggered, or a pedestrian or cyclist that should have triggered the system.

[1] As the aim of the trial was to evaluate detection technology rather than a particular product, the systems tested will be referred to as System A and System B.

Findings

Key findings of the trial are that pedestrians are more difficult to detect accurately and usefully than cyclists, and strategies adopted for sensor location and warning set up can have a large impact on the systems' effectiveness.

Pedestrians displayed less predictability than cyclists, as there is a higher degree of randomness in their direction and speed of travel. Pedestrians often walk up the edge of the pavement and suddenly stop, with no intention of stepping off into the road. This would trigger a warning, despite the pedestrian not being at risk. Frequent false alerts such as these will lead to reduced trust and reliance on the system from the driver, reducing its value in avoiding collisions. Additionally, if a pedestrian does step into the road and becomes at risk, there may not be sufficient time for the technology to detect them, and for the driver to then take appropriate mitigating action. This may rule out the usefulness of pedestrian detection systems until a point when pedestrians at risk can be identified more accurately and systems can more reliably respond to such situations. This also highlighted the issues in determining actual high-risk behaviour by cyclists or pedestrians and the need for a detection strategy which took them in to account.

With regard to sensor location, cyclists undertaking a bus on the nearside were often already near to the centre of the bus before detection occurred. Therefore, a cyclist could conceivably have passed the front of the bus within the reaction time of the driver. The relative potential speeds of buses and cyclists have an impact on the area that the technology should monitor and detect. With regard to warning set up, many lessons were learnt, including that systems should also work when the bus is stationary, so that cyclists or pedestrians in an area of risk when the bus starts moving are detected.

The evaluation also attempted to identify a level of performance for each of the systems. System A was found to have a success rate for false positives of 89.3 per cent, i.e. if a detection warning was given to the driver 100 times, in 11 cases no vulnerable road user would actually be present. The success rate for false negatives was 89.6 per cent, i.e. if 100 cyclists passed through the detection area, 10 of them would not have resulted in a detection warning for the driver. A level of performance is not available for System B, as it was discovered following the trial that the system's settings had been incorrect, invalidating the quantitative findings.

Recommendations

Based on the detection issues faced, and the performance of these two systems, it will be challenging for such systems to achieve high vulnerable road user detection performance combined with a low false positive rate, especially with pedestrians. The most likely solution which may achieve some success would be one that only detects the more predictable behaviour of cyclists. Because of the quantitative and qualitative performance evidence found, neither of the systems can be considered as yet suitable for immediate implementation on board buses at this time.

In terms of future engagement with this technology, TfL could consider identifying a minimum level of performance for systems. This would ensure future systems are sufficiently reliable to reduce collisions, as well as allowing for any risk of bus drivers becoming reliant upon the system. This would also facilitate the development of a full system specification in order to provide clear objectives to industry.

As it fell outside the scope of this evaluation, this analysis did not determine whether the driver had seen any of the observed pedestrians or cyclists, whether he/she needed to take notice of them (e.g. the driver does not need to be aware of all pedestrians on the pavement) or whether the warnings would have provided the driver with sufficient time to react to prevent any potential collisions. Identifying answers to these research questions would give a greater understanding of the safety improvements that this technology can offer.

1 Introduction

In Safe Streets for London, the road safety action plan for London, the Mayor set a target to achieve a 40 per cent reduction in Killed and Serious Injury (KSI) casualties by 2020, compared to the 2005-09 baseline. In 2012, 80 per cent of all KSI casualties were cyclists, pedestrians or motorcyclists. Also, the Mayor's Vision for Cycling in London commits TfL to improve safety in order to get more people cycling in London; with a target to increase cycling by 400 per cent by 2026 (from the 2001 baseline), as described in the MTS[2] (2010).

In order to achieve such goals TfL has considered some of the main factors contributing towards cyclist and pedestrian collisions. It was noted that buses and coaches were disproportionately involved in collisions with cyclists and pedestrians (Cycle Safety Action Plan[3] and Pedestrian Safety Action Plan[4]). Actual numbers were relatively small with 72 cycle collisions involving a bus per year, compared with 1140 involving a car. However, allowing for kilometres travelled, buses are two and a half times more likely than cars to be involved in a collision with a cyclist. Examination of STATS19 data has revealed that the front and nearside of buses were most commonly involved in collisions with pedestrians and cyclists. Pedestrians were involved in most of these KSI collisions (80%), which mainly occurred at the front of a bus. In contrast, cyclist KSI collisions were mainly with the nearside of the bus.

The Pedestrian Safety Action Plan and Cycle Safety Action Plan, both of which build upon Safe Streets for London, committed TfL to investigating technological solutions. The Cycle Safety Action Plan includes a commitment to 'trialling innovative vehicle technology to identify the potential benefits to cyclist safety of radar and optical sensors on London buses'.

In 2013, TRL was involved with the initial evaluations of potential detection equipment for cyclists and pedestrians on heavy vehicles. Options included RFID (Radio Frequency IDentification) tags which alert drivers to their presence. However, these require the bicycle to be fitted with a tag in order to be detected, which would be outside of the control of TfL, and was therefore rejected.

In March 2014, TfL submitted a Prior Information Notice (PIN) to the Official Journal of the European Union's TED (Tenders Electronic Daily) website. The PIN called for suppliers to submit systems for test against the following technical specification:

- Must be radar and optical technology or similar
- Must consist of on-vehicle fitment only

[2] Mayor's Transport Strategy 2010, Greater London Authority

[3] http://www.tfl.gov.uk/cdn/static/cms/documents/cycle-safety-action-plan.pdf

[4] https://consultations.tfl.gov.uk/streets/pedestrian-safety-plan

- Technology must be discriminatory and have the ability to accurately detect vulnerable road users (non-occupants)
- Available for trial from May 2014

Two suppliers of systems responded to the PIN and they subsequently delivered and installed systems for testing. This document reports on this testing and analysis of the results.

Each supplier installed and commissioned their system on an individual bus on each of two routes (therefore four buses in total). These routes (25 and 73) were chosen to provide the optimum conditions for testing different variables (such as street type, traffic conditions, high/low cycle flows, high/low pedestrian flows). TRL were commissioned to collect video-based evidence on the effectiveness of these systems, providing accurate information on the presence of cyclists (and if possible) pedestrians in key areas around the bus.

2 Terminologies

The following terminologies have been used throughout this report:

- Detection Area: The area (relative to the bus) in which the system detects VRUs
- Detection Warning: A detection occurs when a system informs the driver of the presence of a VRU within its detection zone
- Collision Warning: A collision warning occurs when the system informs the driver that a detected VRU is assessed to be on a collision course with the bus

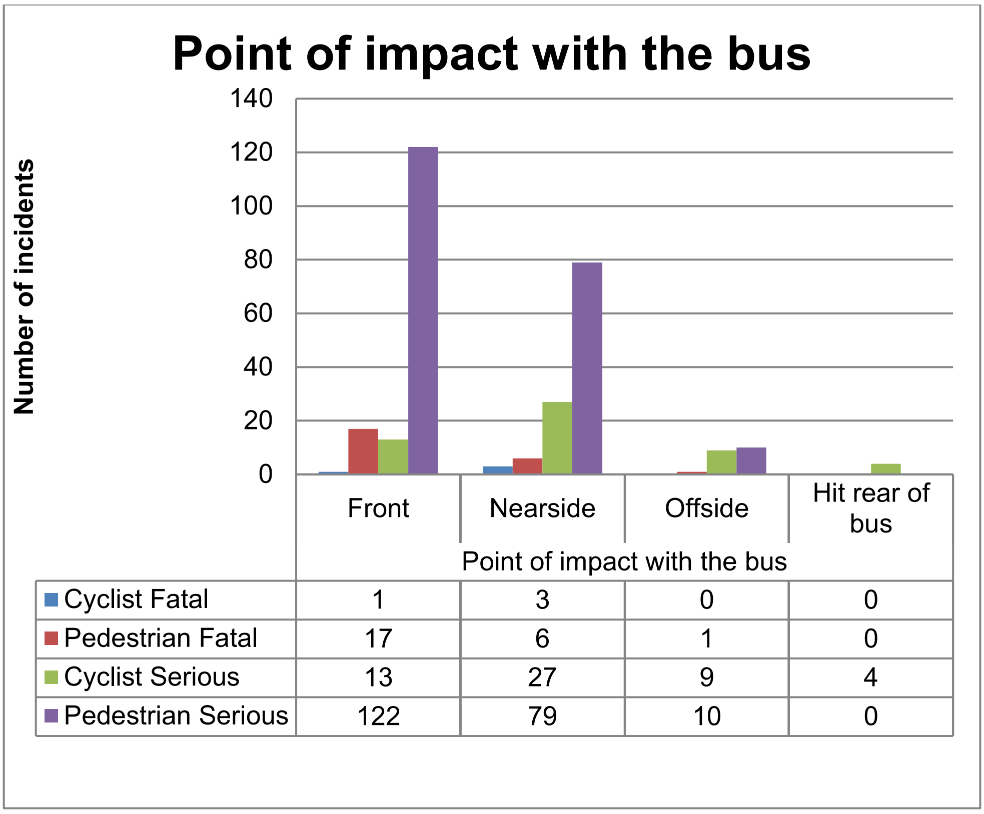
3 Collisions between London Buses and Vulnerable Road Users

TfL, as both the highway authority for a heavily trafficked part of the road network in London, and as procurers of London's public bus services, has a level of responsibility for the actions of those buses including reducing collisions with vulnerable road users. For this reason TfL is interested in investigating any technologies which can reduce these types of collision.

The relative scale of this issue can be seen in Figure 1, which indicates the Killed and Serious injury (KSI) statistics from the Stats19 data for pedestrians and cyclists in collisions with buses during the period 1st March 2011 to 28th February 2014 in London. Note that this excluded motorcycles. The key findings are that:

- The front and nearside of the bus were most commonly involved in collisions with pedestrians and cyclists.
- Pedestrians were involved in most of these KSI collisions (80%). Of these, 59% occurred at the front and 36% at the nearside of the bus).
- For cyclists, 53% of KSI collisions were with the nearside of the bus and 25% were at the front of the bus.

For these reasons, suitable detection technologies for buses might most usefully be focussed on the front for pedestrians, and the nearside for cyclists.



	Front	Nearside	Offside	Hit rear of bus
Cyclist Fatal	1	3	0	0
Pedestrian Fatal	17	6	1	0
Cyclist Serious	13	27	9	4
Pedestrian Serious	122	79	10	0

Figure 1 Pedestrian and Cyclist KSIs and point of impact with the bus (Stats19)

4 A Performance Specification for an Idealised System

Any system that is to be introduced for Vulnerable Road User (VRU) detection, or providing collision warnings, will need to conform to a set of defined performance criteria to be fit for purpose. The TfL specification for this trial was extremely broad and did not differentiate between detection warnings of VRUs and collision warnings with VRUs. It also set no minimum requirements for the area adjacent to the vehicle in which a VRU is considered to be vulnerable. Clearly, the more classes of VRU which a system can *successfully* discriminate (pedestrian, cyclist, small motorcycle and other small wheeled vehicles such as wheelchairs) the more effective the system will potentially be.

The systems under test can be validated against the functional and performance specifications which the suppliers provide. However, the technology in this area is developing and at present systems will not be able to achieve all the requirements of an ideal system. The target for such systems should address all the following performance requirements:

1. The system shall be able to discriminate cyclist, pedestrians and motorcyclists as a class of vulnerable road users so that it can monitor these from each other and to the exclusion of all other classes of object including other road users (e.g. vehicles) and adjacent infrastructure
2. The system shall detect all VRUs which enter a region adjacent to the vehicle which shall be called the area of greatest risk

3. The system shall continually monitor an area of greatest risk down the nearside of the vehicle inside which VRUs might enter and put themselves in a potentially dangerous situation[5]
4. The system shall continually monitor an area of greatest risk around the front of the vehicle inside which VRUs might enter and put themselves in a potentially dangerous situation
5. The system shall take into account the vehicle speed in calculating whether a VRU is potentially in danger
6. The system shall provide the driver with a timely detection, or collision warning, such that he or she can take avoiding action against any VRU inside the area of greatest risk AND potentially on a collision course with the vehicle[6]
7. The system shall not place an undue cognitive load or distraction on the driver; it will be obvious where to look and make optimum use of any direct or indirect (mirror) vision aids
8. The system shall operate down to 0mph but stop functioning above a certain speed above which it would offer little or no safety benefit over direct and indirect vision
9. The system shall not create any false alerts (false positive), that is, such an ideal system would not inform the driver that a VRU was in the detection area when none was present, due to:
    a. other classes of object in the area of greatest risk
    b. any object outside the area of greatest risk
    c. no object inside the area of greatest risk

5 The Performance Specification of a Practical System

The target specification as described above is probably not achievable for a bus under normal operating conditions at this time. Current known systems have been designed to address some or all of the above requirements. Two elements of a practical system are discussed in this section. Firstly, which road users should be detected and where. Secondly, the minimum required accuracy of the system at detecting them. Finally, acceptance criteria have been derived from these for the systems tested within this trial.

[5] It will be assumed that the system is restricted to the nearside and front of the vehicle and not including the offside or rear. The lateral distance between the vehicle and the VRU down the side of the vehicle is usually taken as between 1.5m and 2m.

[6] Given the brake reaction time of a driver to an alert (50th percentile takes 1 second and 90th percentile takes 2 seconds) it is clear that it would be impossible for a system to detect a cyclist travelling at 5m/s up the nearside of a 10m long vehicle to give 2 seconds warning before the cyclist is adjacent to the front wheel.

5.1 Which VRUs should be detected and where

In terms of VRUs detected, the main ones should be pedestrians, cycles and small motorcycles, the latter two exhibiting similar behaviour in the vicinity of a heavy vehicle. The area of greatest risk around the bus comprises a nearside component and a frontal component. For a bus, the front and front nearside corner tend to be areas where pedestrians move around and can put themselves in danger. Cyclists and motorcyclists tend to be most vulnerable down the entire nearside of the vehicle. Simpler systems may only tackle the requirement to detect, for example, cyclists on the nearside of the bus. A more complex system may detect all types of VRU at both the nearside and front of the vehicle.

Also, a system should only provide a detection warning (or collision warning) of a VRU in an area of greatest risk. There could therefore be a range of potentially useful systems, or a minimum standard could be developed.

Decisions on the correct balance between which types of VRUs should be detected, where they should be detected, and whether they should only cause a collision warning are outside the scope of this research. However, some initial consideration has been given to scoping some of the main elements of a practical system.

- **The width of the side detection area**. Previous work has suggested that a width of 2m would be the best compromise distance (see the green oblong area to the side of the bus in Figure 2[7]). If the width is too narrow then there would be insufficient time for a system to alert the driver in a timely fashion. If it is too wide then the level of false alerts caused by VRUs on the pavement could be excessive and distracting.

- **The starting point of the side detection area.** It is proposed that it should start at the rear edge of the bus, i.e. when a cyclist first commits to undertaking and putting themselves at risk.

- **The distance in front of the bus to start the detection area.** It is proposed that a distance of 11m[8] from the front of the bus is reasonable. This assumes that a combined driver reaction time and time for the brakes to start responding is 2 seconds, and that a bus is travelling at an average London speed of 9mph. Clearly, different assumptions on the vehicle speed will yield different distances of interest. For example at 20mph, this distance increases to 34m.

[7] Note: that unless specific dimensions are given, all drawings within this document should be regarded as indicative.

[8] Assume a vehicle deceleration of $2.5 m/s^2$

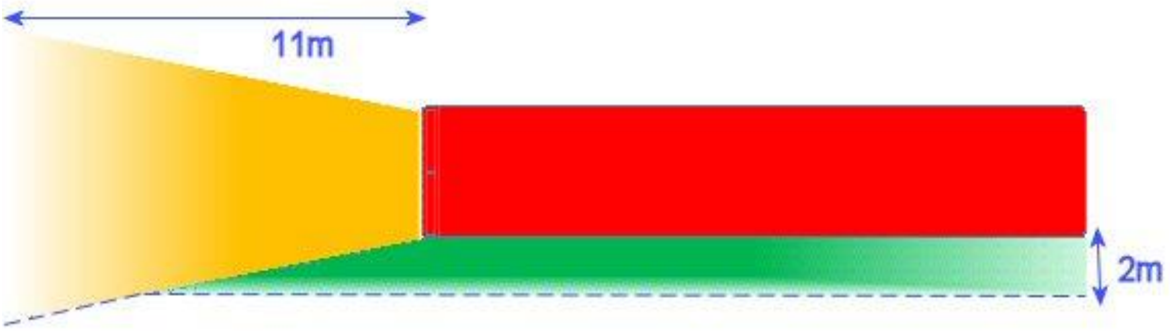


Figure 2 'Practical' detection area

It is these areas that should be considered in the evaluation of the system performance.

Other considerations that have become apparent during this trial are described in Appendix A for elements concerning the system specification and Appendix B for functionality.

5.2 Degree of accuracy of detections

An effective system should inform the driver when specified types of Vulnerable Road Users (VRUs) are either within a defined area of risk, or on course for a potential collision. As mentioned earlier, some systems provide detection warnings, whilst others will detect and track VRUs and only provide the driver with a collision warning if there is a risk of a VRU colliding with the vehicle. In either case, the system must achieve this objective with a high degree of success. Otherwise the user will not gain confidence in the information provided or see any benefit in its deployment.

A system should clearly have a high proportion of correct detections, referred to as **True Positives** and a high probability of not responding when no VRU is present, referred to as **True Negatives**.

However, there are two types of potential errors associated with such systems:

1. **False Positive** – an detection/collision warning when no VRU is present in the detection area(s) or on course for a potential imminent collision
2. **False Negative** or miss - no detection/collision warning when a VRU is present in the detection area(s) or on course for a potential imminent collision.

A system would be considered suitable for purpose only if there is a high detection rate of true positives: that is a detection/collision warning when a VRU is present in the detection zone. There must also be a low percentage of false positives: that is the percentage of detection/collision warning received when no VRU is present in the detection area must be low. Also, the percentage of false negatives must be low: that is the percentage of VRUs in the detection zone that failed to generate a detection/collision warning must be low.

If these criteria are not met on either count, then a bus driver might either ignore or attempt to disable in some way the system because of the false positives, or could potentially miss dangerous situations because of false negatives.

System performance against the metrics describes above will reveal the effectiveness of any VRU safety system and should be measured. However, TRL are not aware of any behavioural research which has been conducted to determine minimum performance levels, below which a system is deemed to either be ineffective, non-trustworthy or too distracting. Therefore, we propose three bands of performance against which any system (whatever functionality it claims as shown in Figure 2) can be compared. Although only a guide, they do, in our opinion represent the minimum performance which is likely to be acceptable, a mid-range performance and a top level which would be the target for all future systems.

Level 1 (minimum); A system with detection warning/collision warning performance for the types of VRU it is designed to detect of:

- >5% and up to 10% of detection warnings/collision warnings being false (False Positives), and
- >5% and up to 10% of VRUs being missed (False Negatives).

Level 2 (mid); A system with detection/anti-collision performance for the types of VRU it is designed to detect of:

- >1% and up to 5% of detection warnings/collision warnings being false (False Positives), and
- >1% and up to 5% of VRUs being missed (False Negatives).

Level 3 (best); A system with detection/anti-collision performance for the types of VRU it is designed to detect of:

- 1% or fewer detection warnings/collision warnings being false (False Positives), and
- 1% or fewer of VRUs being missed (False Negatives).

It should be noted that even Level 3 (best) has a small failure rate and therefore does not meet the criteria for an ideal system. However, it is suspected that no system is ever likely to meet this ideal standard under ALL practical operational conditions.

5.3 Evaluation criteria for this trial

Both the ideal specification and the practical specification have been partially developed and further work would be required to create either a single, or a range of, specifications that could be used to guide developers and manufacturers towards acceptable minimum requirements.

The systems tested within this trial were developed independently of any common specifications, and therefore could not be expected to meet all the functional requirements in the previous sections. However, we would expect any system to at least meet the Level 1 performance target to be considered worthy of consideration.

It should be noted that the trial was conducted on existing products which have been designed with their own areas of detection and types of VRU detected. Therefore, the systems had to be tested against their own claimed specifications and not against the ideal requirements presented in sections 4 and 5. Please see section 6 and Appendix B for further details of our understanding of the systems.

6 The Systems Tested

The two systems under test will be described as "System A", and "System B". A high level description of both systems as tested is provided in Table 1 below, and further details are provided in Appendix B.

Table 1 Description of systems under test

Description	System A	System B
Technology	Video and radar	Video only (this system is understood to use a camera and signal processing algorithms to calculate distance, rather than use radar)
Location and direction of sensors	One sensor mounted externally on the front nearside of the bus looking backwards.	One sensor mounted centrally inside the windscreen looking forward with a horizontal field of view of 40°. Another sensor mounted externally on the rear nearside of the bus looking forward with a 40° horizontal field of view.
Type of alert(s)	Detection	Collision warning (Detection warnings were also accessible)
Description of operation	Detects cyclists entering (from the rear or side) a small zone approximately 3m x 2m towards the back of the bus on the nearside.	Identifies objects and informs driver of potential collisions based upon the relative speed vectors
Vulnerable Road Users identified	Cyclists and small motorcycles.	Cyclists, pedestrians, and motorcyclists

Referring to Table 2, (a copy of **Error! Reference source not found.**) the functional capability of Systems A and B, as claimed by the manufacturers, can be seen.

Table 2 Classification of Systems A and B

Detection Areas/ VRUs Detected	Cyclists/ motorcyclists	Pedestrians
Nearside	System A and System B	System B
Front	System B	System B

7 The Trial Methodology

The trial involved installation (by the suppliers) of a unit of either System A or B onto four in-service London buses (operating on bus routes 25 and 73). One of each type of system was driven around each route. The trial was conducted between September and October 2014 with regular drivers.

Data were collected to:

- Measure the extent to which the systems performed as described by the manufacturer and
- Measure the extent to which the systems performed compared to the above practical specification

Video cameras were also installed to monitor the footprint(s) of the sensor system under test and a somewhat greater area so that any activity immediately outside could be observed during analysis:

- Camera 1 monitored the front of the bus looking forward.
- Camera 2 monitored the side of the bus. Those buses fitted with System A were fitted with a nearside camera facing forward from the rear of the vehicle. Those buses fitted with system B had a nearside camera facing backwards from the front of the vehicle.

Both systems provide audible alerts in their normal deployment, but since the driver was not permitted to see or hear any alert during the trial[9] ("silent running") the cab units were hidden from the driver and a method devised for converting audible alerts into visual (LED based) ones. However, the study considered the extent to which the driver reacted to the surrounding activity during driving.

- Camera 3 monitored these LEDs
- Camera 4 monitored the driver.

The driver reaction to VRUs in the vicinity of the vehicle could then be compared with the responses of the systems to the detection of VRUs.

All four video channels were recorded on a Digital Video Recorder (DVR) to provide 4 streams of synchronised video data. The data were stored on removable hard drives which could be swapped over periodically and the data brought back to TRL for backup and analysis.

Figure 3 indicates the location of TRL's video cameras and monitored footprints (in blue) and System B's sensor and detection system (in yellow). A similar set-up was used to cover System A's sensor view with a camera, and an additional camera to see what was missed by not having a forward mounted sensor to allow for cross comparison with System B. Figure 4 shows a typical video screen-grab and the 4 active video channels. Note, that for privacy reasons, the driver has been obscured in this report).

[9] Note that a separate trial run by a third party later observed driver reactions to the alarm when it was switched from silent to audible.

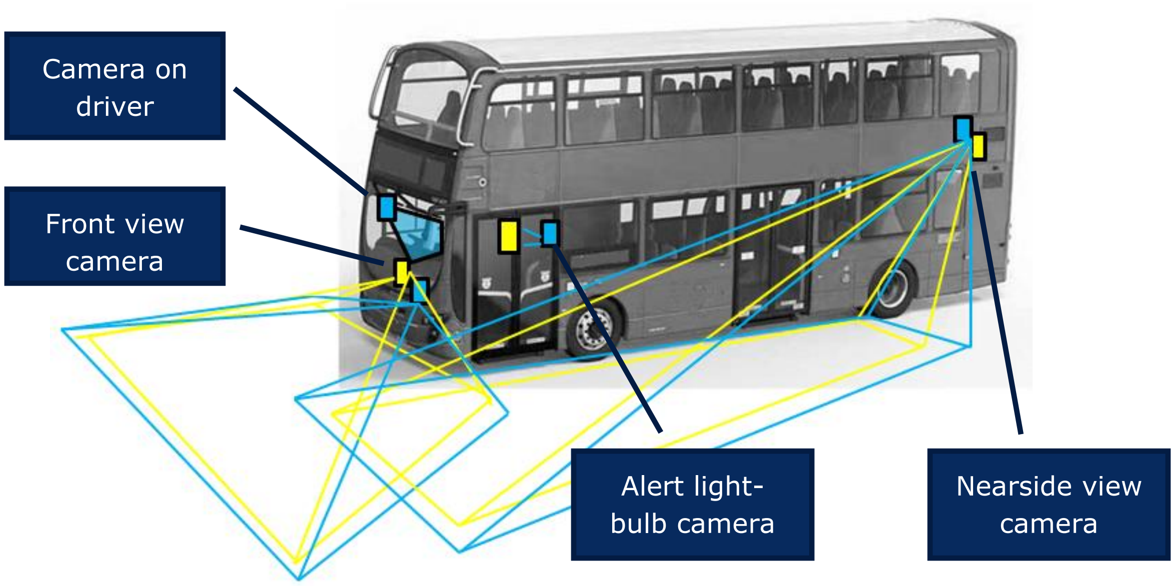


Figure 3: Verification camera locations for System B

Figure 4: Video view for System B

The video data recorded were then brought back to TRL for analysis. An agreed sample of 1500 observations was recorded over different weather and lighting conditions and observations logged in a spreadsheet designed specifically for this project. Observations included any alert and any VRU observed within the area of risk.

Table 3 indicates the amount of video which was analysed for the buses and the number of relevant observations obtained.

Table 3 Video capture metrics

System	Dates of video capture used for analysis	Observations recorded
System A	September 11th (Thurs), 12th (Fri), 13th (Sat), 15th (Mon), 17th (Wed), 18th (Thurs), 19th (Fri), 20th (Sat), 22nd (Mon), 24th (Wed), 25th (Thurs)	1516
System B	August 28th (Thurs) 29th (Fri) and 30th (Sat) 2014	1599

It should be noted that the rate of observation on System A was significantly lower due to the difference in area around the bus being measured and VRU type detected. For this reason the amount of time required to collect the data set was higher for System A than System B.

8 Observed system performance

The performance of the two systems has been evaluated against the proposed performance criteria shown in Section 2. Following the trial, the suppliers of System B noted that the LED (fitted especially for the tests to replace the audible warning), was also illuminating for other reasons such as Forward Collison Warning, Lane Departure Warning and Headway Monitoring Warning. It was not possible to isolate these other warnings from the one of interest to the trial and therefore full quantitative results for System B cannot be provided.

8.1 System A

With regards to System A, researchers examined the video data and logged:

- Each time a valid cyclist passed the correct way through the detection area, and if the detection warning alerted or not
- Each time the detection warning alerted, including a note on the potential reason (i.e. either as a true positive, or a false positive)

Following discussions with the System A suppliers, it was discovered that several changes from the expected specification were likely to be occurring:

- That the system would deactivate for 5 seconds following a detection warning (so as not to over burden the driver with alerts from platooning cyclists)
- That the system would deactivate once the bus had been stationary for 1 minute, and would restart when the bus moves off again.
- That the actual area of detection may have been pessimistic in the analysis, so that detection may occur over a larger footprint
- That some motorcycles and scooters may also give positive alerts.

System A supplier employed a method for capturing and storing data relating to significant events which occurred during bus operations. This method, it was claimed, would allow the supplier to observe the vast majority of true positives, false negatives and false positives. TRL's initial findings did not fully match with these records retained by the System A supplier, and therefore further examinations were made to cross reference both sets of data to find out the causes of differences. It should be noted that motorcycle/scooters were not included in TRL's assessment of a valid VRU, therefore any motorcycle/scooter which passed through the detection zone and did not trigger a detection warning was not recorded by TRL.

Further examinations were made in to the System A data using records collected by the System A suppliers. In examining this data, TRL first reduced the TRL list of records to all cyclists travelling in the correct direction (i.e. were undertaking the bus) and in the detection area (i.e. a 2m by 3m rectangle to the rear nearside of the bus). TRL then took the System A records, selected all which were marked as true positives, made adjustments to compensate for timestamp differences between the two data sets, correlated the two data sets, and removed any records from supplier A's data relating to times that TRL did not examine. For example TRL did not examine any night-time records. Where TRL's records matched System A's data no further action was taken. There were found to be anomalies in both data sets, with different reasons for them. TRL also examined those records where the alert was raised by the System A but there was no valid item within the detection area (i.e. a false positive).

Table 5 indicates the residual comparative records for each day, and the reasons for these anomalies are explained below.

Table 4 indicates the number of records examined. This includes all cases where there was a cyclist within the detection area travelling in the correct direction (whether it alerted or not). Furthermore all cases whereby an alert for an item other than a cyclist were included. TRL records relating to the 19th September 2015 have been removed since no data was supplied by Supplier A. Over 72 hours of video was examined over these 10 trial days.

Table 4 Dates of data cross examination

Bus	**Date**	**Samples**
Arriva	17/09/2014	41
Arriva	18/09/2014	127
Arriva	20/09/2014	42
Arriva	24/09/2014	16
Arriva	25/09/2014	5
Tower Transit	11/09/2014	47
Tower Transit	12/09/2014	107
Tower Transit	13/09/2014	35
Tower Transit	15/09/2014	142
Tower Transit	22/09/2014	122
Total		684

In addition to the samples found in Table 4, there were 92 cases of cyclists within the detection zone but being overtaken by the bus (a situation which supplier A stated would not cause an alert). In all but 3 of these cases there was no alert. This brings the total sample size to 776. Cyclists to the front of the vehicle were also noted to allow for a comparison of ratio with the System B records, and the total sample set was 1516.

Of the 82 detection warning records that the System A supplier provided which were not matched by TRL:

- 33 were a cyclist but were outside of the detection zone as assumed by TRL
- 48 were a motorcycle (22) or scooter (26)
- 1 was a mobility scooter

These all fall within the justification provided by the supplier for a wider detection zone and the inclusion of motorcycles/scooters within the definition of VRU.

Table 5 below gives an overview of the likely reasons for each non-audible, and (true and false) audible alarms following examination of the video. Note that the 19 cyclists included as false audible alarms were outside of the assumed detection area.

Table 5 System A findings

Likely detection warning trigger	FALSE NEGATIVE (No AUDIBLE alarm but cyclist present)	TRUE POSITIVE (AUDIBLE Alarm and cyclist present)	FALSE POSITIVE (AUDIBLE Alarm but NO cyclist)	Total
A cyclist within 5 seconds of another	68			68
Bus			1	1
Bus stationary for more than a minute	2			2
Car			18	18
Cyclist		375	19	394
Cyclist entering from side junction	2			2
Cyclist missed	79			79
LED came on for cyclist but no record from System A suppliers		8		8
Mobility scooter			1	1
Motorcycle/Scooter			49	49
Nothing obvious to set it off			1	1
Pedestrians			57	57
Push Scooter			1	1
Rickshaw			2	2
Van			1	1
Grand Total	**151**	**383**	**150**	**684**

8.1.1 False negatives - no audible alarm

These are cases where it was considered the detection alert should have occurred because a cyclist met the conditions for it, but no such alert was given. It is understood that due to a setting within System A's algorithms, cyclists appearing within 5 seconds of a previous detection warning alarm will not trigger the system, and this was found to have occurred 68 times. The bus being stationary for longer than a minute was also understood to cause the system to 'stand down', and was found in 2 cases. However in 81 cases a cyclist was simply missed (2 of these cases were where a cyclist entered from a side junction) and these might be considered as system failures (false negatives). The false negative rate is therefore 81 cases of a sample of 776 (10.4%).

8.1.1.1 Reasons for potential failures

Whilst TRL does not expect to understand the potential failure mechanisms of system A, we might hypothesise from examination of the video evidence that failures appear to be correlated in some way to:

1. low elevation sunlight hitting the detector
2. the effect of cyclists approaching relatively slowly (i.e. travelling just very slightly faster than the bus)
3. slightly unusual angles (such as appearing from immediately behind the bus)
4. being very close to the bus, or
5. being very close to another travelling or stationary object.

Figure 5 indicates a cyclist (in the bottom left video window) just about to exit the detection zone having travelled from the rear to undertake the bus. Had the alert been triggered, a red dot would have appeared in the video recorded in the top left video window, however it did not which indicates that the cyclist was missed.

Figure 5 False Negative example

8.1.2 Successes (True Positives)

In 402 cases, System A detected a cyclist and caused an alert, 383 being in the correct detection area, 19 being outside of the detection area, and 8 times when an alert was raised but there was no corresponding record within data from supplier A. If we take into account the cases whereby the system was stood down (bus stationary for >1 minute and that these would have been correctly detected), and also include motorcycles/scooters and some other classes of item, then the total number of true positives is 523 out of 684 or 76.5%. If to this the 89 correctly excluded cyclists being overtaken are added, this totals 612 out of 776, or a 78.9% true positive rate.

Figure 6 indicates a cyclist (in the bottom left window) entering the detection zone and being correctly identified (see LED spot in the top left window indicating a positive alert).

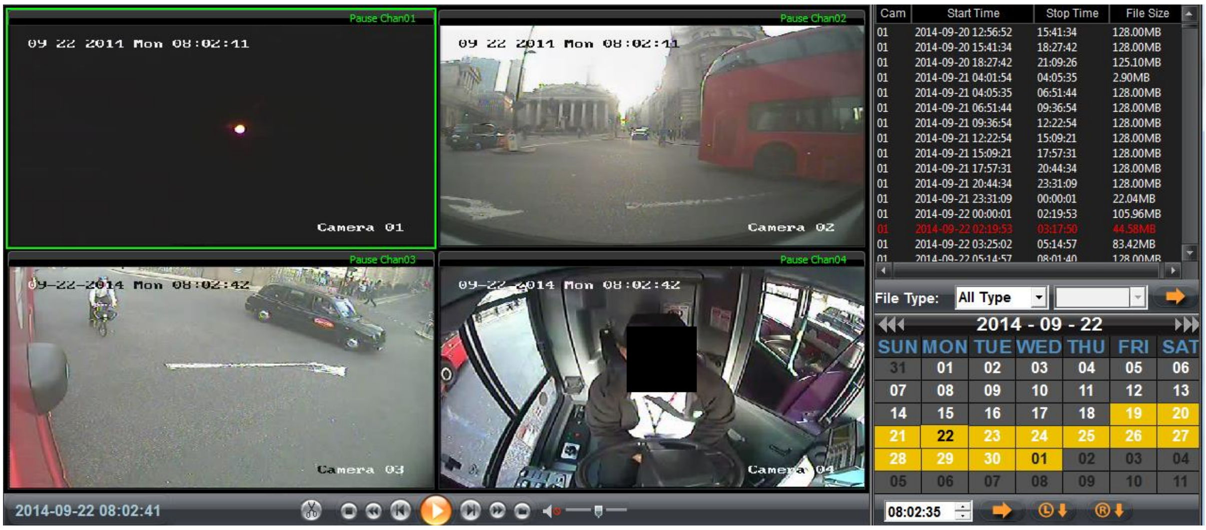


Figure 6 True Positive example

8.1.3 Audible alarm for incorrect detection (False Positives)

There were a large number of cases (150) where the alert was given for an incorrect object. Some of these may be described as True Positives if a more generous approach to correct detection is allowed, including motorcycles/scooters and rickshaws, and a wider area of detection for cyclists. If these were removed, there were 80 cases were the alert was incorrect. These appear to be predominately related to pedestrians (57), and often appeared to trigger an alert on those running for the bus. It also included a number of cars (18), a bus, a van, a child's push scooter, and a mobility scooter. Further to this, the 3 cyclists who were being overtaken and for whom an alert was given can be added. Based upon these 83 cases, the false positive rate is 10.7%.

These false positives did not appear in System A's supplied records which may account for the differences found with TRL's data.

In Figure 7, the LED in the top left window is illuminated to indicate a detection alert, however as can be seen in the bottom left window (which shows the detection area at the nearside rear of the bus), only pedestrians can be seen. There was no equivalent record provided by the System A suppliers.

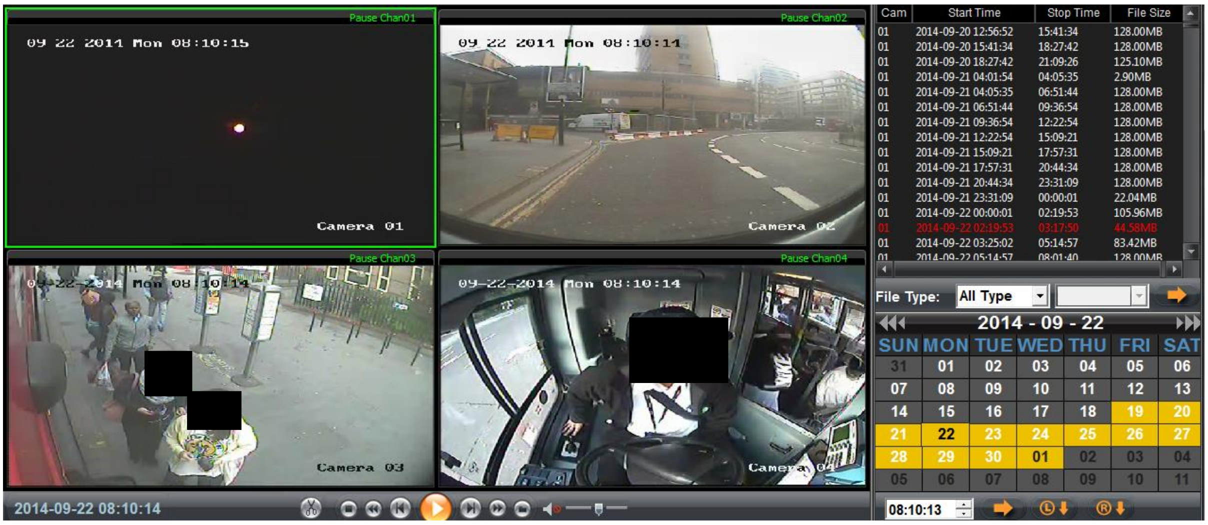


Figure 7 False Positive example

8.1.4 *System A quantitative conclusions*

In conclusion there were very few cases where the system would set off an alert for something that was not a) a moving object in b) broadly the correct area and c) moving in the correct direction. However there still a large number of false negative cases where the detection alert would not sound for a valid cyclist, as well as false positives where the detection warning would sound for things that were not meant to be detected by that system (such as pedestrians).

Table 6 Summary of findings for System A

False Negative	10.4%
True Positive	78.9%
False Positive	10.7%

If all cyclists were counted and it was assumed that the detection alert would have been given correctly for all cyclists within 5 seconds of each another and for the bus being stationary for longer than a minute, the sample size would be 553 and the failures would total 81, which is 14.6%. Furthermore detection of motorcycles/scooters were not included in the analysis so detected and missed ones will affect the results.

There may be a benefit to the supplier of further understanding the reasons for failures and false positives to improve the system in the future. The exercise has shown that there are anomalies to be resolved in both the suppliers data set and that produced by TRL which would need further detailed investigation. This falls outside of the scope of this project report.

System A failure rates did not meet the minimum performance requirements of a Level 1 system.

8.2 System B

System B is primarily a collision warning system for cyclists and pedestrians, with the detection areas at both the nearside and front of the bus. However, there was a problem with interpreting this data. Discussions with the manufacturer during the analysis of the data revealed that any observed detections or warnings could have occurred as a result of other capabilities that the system performed, in addition to the expected collision warnings. The full list of capabilities were:

- Forward Collision Warning
- Headway Monitoring and Warning
- Urban Forward Collision warning
- Motorbike Collision Warning
- Pedestrian and Bicycle Detection and Collision Warning (Front and Side)
- Lane Departure Warning
- Speed Limit Indicator

It was not possible to differentiate which of these functions had triggered a given detection or warning within the available data set, and it would be difficult to isolate the cause of warnings from a re-analysis of the video. Consequently, a warning that would have been classed as a false positive could also have been an alert from one of the other warning functions; and a warning classed as true positive could also have been triggered by one of the other types of event. In the discussion below, the results are discussed in terms of a more general classification of "detections" and "warning", and no attribution of the warning to a function is made.

The number of detections was 940, and the number of warnings was 128 over a period of 345 minutes: i.e. an average of 2.7 detections every minute, and a warning on average every 2.7 minutes.

All video observations have been classified according to the reason for making a data entry. That is, if there was a detection or a warning (which includes collision warnings), and if a VRU was present.

Table 7 Classification of observations

Type of observation		**Number**
Detection	VRU present	899
	No VRU present	44
Warnings	VRU present	100
	No VRU present	28
No Detection	VRU present	496
Unknown		32
TOTAL		**1599**

A further complication with this system was that it was not possible to determine the true likelihood of a collision occurring (or how the system predicts one will occur). TRL did not have access to the underlying calculations that would have been used to predict if a detected VRU was on a collision course with the bus, so it was not possible to assess if it had worked correctly. Also, TRL had no independent frame of reference on which to assess the likelihood of potential collisions. However, it was noted that pedestrians correctly walking up to crossings could be classified as on a collision course by the system.

Detections and collision warnings when a VRU was present are summarised in Table 8.

Table 8 Classification of Correct Observations

Type of observation		Detections	Warnings
Not in defined detection zones	Pedestrian only	61	1
	Cyclists only	1	0
	Both	1	0
	Unknown	3	1
In defined detection zones	Pedestrian only	681	82
	Cyclists only	62	0
	Both	82	16
	Unknown	8	0
TOTAL		**899**	**100**

It is impossible to assess how many of these observations were actually associated with the VRU detection and collision function. However, if the 98 warnings were associated with the observed VRU, it implies that the system was warning of a potential collision every 3.5 minutes.

The difficulties with establishing causal effects mean that no analysis of the validity of the detections and warnings (i.e. false positive and false negative rates) could be conducted.

System B‘s assessment was confounded by it having multi-functions active that were not relevant to VRU detection. This resulted in no formal assessment of its capabilities being possible within this study.

9 Discussion

9.1 The ability of the systems to discriminate and correctly detect cyclists and pedestrians

System A was designed to only produce detection warnings for cyclists, and potentially for motorcyclists. This may, or may not, be seen as of sufficient safety benefit to be considered as an useful interim step towards a complete bus safety system.

System B aimed to produce collision warnings for both cyclists and pedestrians. Its multi-capabilities resulted in no firm conclusions being drawn with regard to its suitability, but qualitative observations did indicate accuracy issues, particularly with pedestrians correctly approaching the kerb.

One of the main difficulties in the analysis of System B was fully understanding when a collision warning should have been provided to the driver according to its own specification. Complex algorithms combining detection, recognition, tracking and vehicle and VRU speeds are involved, but no information was available on how they worked to enable an assessment to be made of their performance.

Lesson learned – system manufacturers should ideally provide access to their diagnostic tools, so that the suitability of systems can be ascertained to a higher degree of accuracy.

9.2 The ability of the systems to detect to the nearside of the bus

Neither system covered an area of detection to the nearside of the bus that matches completely the 'ideal' system that was defined.

System A focussed upon a small area (2m by 3m) to the nearside rear of the bus at all speeds. This appeared to be suitable for identifying cyclists undertaking the bus.

Lesson learned – The nearside area of detection should commence at the rear of the vehicle to provide maximum opportunity to detect cyclists and provide a timely alert to the driver.

System B was designed to worked at speeds above 1kph, and System A stopped detecting after the bus was stationary for one minute. This is potentially problematic because it would not detect cyclists when a bus is waiting at a junction or traffic light, which may allow the cyclist to enter an area of danger without being detected.

Lesson learned – systems should still operate fully when the vehicle is stationary and up to a practical speed where the alert would provide the driver with additional information upon which he or she can respond effectively.

System B was rear mounted and looked forward-left at a viewing angle of 40°. This meant that everything on the footway was potentially detected, which was arguably too great an area for coverage as a pedestrian on a convergent path with the bus, but at some distance from it, has plenty of time to react at such distances.

The position and direction of system B mounting also meant that cyclists approaching from the nearside rear were only detected around half-way along the bus. Timely warnings would therefore be almost impossible, especially for fast moving cyclists.

Lesson learned – the strategies adopted for sensor location can have a large impact upon system effectiveness.

9.3 The ability of systems to detect to the front of the bus

System A was not designed to monitor the front of the bus and so could not meet this requirement.

However, any strategy for detection to the front raises questions regarding how many incidents could be avoided (for example a pedestrian walks in front of a bus within the braking distance, leaving no opportunity to stop or avoid the collision). Can a detection system under these circumstances provide the driver with any additional time to initiate avoiding action?

Lesson learned – future work should better explore the factors involved in avoiding forward bus collisions and the extent to which any detection system could effectively reduce collisions. This work may conceivably lead to other collision mitigation measures such as buses which inflict less harm on pedestrians during a collision.

9.4 The ability of the systems to detect vulnerable road users in sufficient time

Both systems appeared to detect vulnerable road users within their detection areas relatively quickly. However a fast moving cyclist (5m/s) would be at the front of the bus within 2 seconds which is similar to the reaction time of a driver.

Lesson learned – the actual detection areas need further investigation to ensure the systems can perform to an adequate level

10 Conclusions and Recommendations

The project has examined the functional and performance characteristics of two VRU detection systems, pre-selected by TfL, that are currently on the market. They both met the broad requirements set by TfL of 1) exploiting radar and optical technologies and 2) being on-vehicle only and claiming to be able to discriminate vulnerable road users.

Experiences during the project identified a number of practical and technical difficulties with implementing such systems, and the lessons learned were drawn together to assist in developing future practical advice.

TRL has identified the following conclusions and recommendations:

1. No definitive specification for such systems currently exists. TfL deliberately challenged the market with a very broad requirement. This report contains a draft specification for a general "ideal" system which would tackle the complete challenge of detecting all types of VRU which enter any area adjacent to a vehicle in which their safety is at risk. The report also presents a method for classifying the level of detection performance which a system might achieve. These levels were used to allow assessment of the systems tested, and a framework on which further evaluation criteria can be based, but do not imply a formal acceptance criteria. A basic minimum (worst) performance (Level 1) system would only miss between 5% and 10% of VRUs (false negatives), and only alerts the driver incorrectly between 5% and 10% of cases (false positives). An intermediate level (Level 2) would have a false negative rate of between 1% and 5% , and a false positive rate between 1% and 5%. A highest quality (best) system (Level 3) would have a false positive and negative rate of less than 1%.

   To TRL's knowledge, there has been no behavioural research which can quantify a minimum required level of VRU detections or collision warnings, or a maximum rate of false warnings which would be deemed acceptable to the majority of bus drivers. A threshold would be expected at which the positive aspects of driver warning are negated by the mistrust caused by too many false warnings or too high a VRU "miss" rate.

2. The two systems under test were evaluated against the specifications which were provided for them by their respective supplier and also against those developed by TRL for an ideal system. Neither system was expected to meet all functional requirements of an ideal system, but the VRU detection and false warning rates could be compared with those being proposed by TRL and shown in item 1 above.

   a. System A was a cyclist detection warning system operating down the nearside of the vehicle. It would not have achieved the proposed Level 1 (lowest) performance levels. The failure rate for false positives was 10.7%: that is if a detection warning was given to the driver 100 times, in 11 cases no VRU would actually be present. Also, for false negatives the failure rate was 10.4%: that is if 100 cycles passed through the detection area, 10 of them would not have resulted in a detection warning for the driver. Note that following discussion with the System A suppliers, the definition of VRU was widened to include motorcycles/scooters.

   b. System B was a collision warning system operating both on the nearside and front of the vehicle and detecting all types of VRU. Owing to system warnings being triggered by more factors than simply VRU detection, it was not possible to ascertain the performance level of System B.

It should be noted that the analysis did not ascertain whether the driver had seen any of the observed VRUs. Also, it was not assessed whether any warnings would have provided the driver with sufficient time to react to prevent any potential collisions.

3. Our observation of VRUs during the analysis of the video recordings provided a number of potentially interesting points.

    a. Cyclists were mainly present in the detection zone down the nearside of the bus, towards the rear of the front door. Cyclists tend to behave in a more predictable manner, approaching from the rear of the bus (or occasionally from the side), showing a front profile to any detection system fitted at the front of the vehicle and undertaking the bus at a relatively small differential speed.

    b. Pedestrians displayed less predictability, i.e. a higher degree of randomness, in their direction of travel. They also had the ability to stop very quickly. They tend to be at maximum risk around the front and front nearside corner of the vehicle. However, when detected, they tend to be on a footway with no identifiable intention stepping into the carriageway (even though they are physically close to a bus).

From a technical point of view, cyclists therefore present a behaviour that is easier to model and therefore would be expected to result in more accurate driver warnings. In contrast, pedestrians present a much greater challenge for behavioural prediction and producing accurate driver warnings. It is therefore suggested that systems limited to producing cyclists warnings, with a target performance approaching that proposed as Level 3, could be a justifiable initial practical step towards reducing the level of KSIs caused by London buses, as based upon this finding, such systems are likely to be feasible in a shorter timescale.

Appendix A Other Functional Considerations

We have also noted the following functional considerations during the course of the trial, and these have been noted in this appendix for consideration in future specifications.

A.1 Power supply

System B was fitted by the supplier and was believed to operate within the normal voltage and current limits of a typical bus. System A was understood to require a transformer.

Lesson learned – supplied systems should preferably operate within the power ranges available on the bus without a power transformer.

A.2 Electrical regulatory requirements

Equipment on buses will be subject to heat and vibration. Similarly electrical items can be subject to, or be the cause of, electrical interference.

No issues were apparent during the tests conducted and reported here. For production versions, appropriate compliance with electrical regulation will be required and can change depending upon the configuration of the system (for example radar may require tests over and above those required by a video system). Such tests are available through third party accredited laboratories.

Lesson learned – suppliers should provide sufficient evidence that their system is compliant with all relevant electrical regulations..

A.3 Installation time

It was estimated that a reasonable time for retro-fitment was 2 hours. System B took longer than this, however it was noted that this included initial calibration. System A took around 2 hours to fit.

Lesson learned – on the Wright Gemini 2 bus the system can be installed within a reasonable timeframe, however this may be different for different buses and an assessment should be made of the fit on each bus type of any given system.

A.4 Robustness of the external components and connectors to the environment

Buses are harsh environments for electrical devices, with ingress of water and dust, the impacts of vandalism, vibration and heat. Also, System B's frontal sensor was mounted on the inside of the windscreen within the area of the wiper blades, therefore the view should remain relatively clean, but could be obscured by the blades operation.

The side sensor for System B was unlikely to be cleaned by the bus cleaning rollers given the angle that the unit was mounted. Over time, insufficient cleaning may lead to dirt interfering with sensor performance. System A was housed in a blister unit which is more likely to be cleaned by the bus cleaning rollers.

Lesson learned – consideration should be given to ensuring that the design of the sensors allows for their regular (and perhaps self) cleaning if required. Compliance with IP66 should be a minimum for all external components. This would include total protection against dust and protection against strong jets of water as used during cleaning

A.5 Impact robustness of externally mounted equipment

Both systems had externally (nearside) mounted systems, and in both cases it was understood that the primary electronics were contained within that unit. Therefore the systems were susceptible to being knocked off, and the impact of that loss is an expensive component of the system. It should be noted that no systems were damaged during the test.

System B was mounted to a small bracket to the rear nearside of the bus, and as such was extremely vulnerable to being knocked off, especially at in locations where a bus was leaving the bus stop and has to immediately pass another bus, or passes low-hanging branches.

System A was less exposed because it was mounted largely behind the side view mirror (which drivers may more naturally drive to protect).

Both systems were subject to special approval by the DVSA because they extended the width of the bus greater than that normally allowed, and were allowed dispensation as a driver's aid (in the same way in which mirrors are) via a VTP5 form. Neither system extended by more than around 150mm, and both were placed at a height which would not come in to contact with pedestrians.

Lesson learned – systems will need to be compliant with regulations pertaining to vehicle dimensions.

A.6 Tamper-proof measures

System B relies upon a lighting-box inside the cab (which can be covered by the driver) and a fairly rudimentary box for the sensor on the side of the bus attached by a rotating bracket. This part of the design was not tamper-proof from the public, or from accidental interference by the driver (such as accidently covering the lighting-box with a jacket). Its front camera was however far more robust because it was within the driver compartment (therefore out of reach of the public) but also largely out of reach of the driver and adhered to the windscreen.

System A's system was encased within a blister unit out of reach of the public and does not have a unit within the cab, therefore the design was inherently tamper-proof.

Lesson learned – a requirement shall be for facilities within the design for detecting attempted tampering, and methods for alerting the bus operator or the service provider.

A.7 Built-in test facilities

Failure in neither system is apparent unless an event occurs which does not trigger the system (by which time it is too late for that event). Neither system was known to have a built-in failure warning system.

Lesson learned – consideration should be given to built-in test facilities within each system which warns the driver of failures either upon system start-up or during operation, so that a decision can be made regarding the continued use of the bus until the system is repaired.

A.8 System suitable for all bus types

The systems under test were only tested upon largely identical Wright Gemini 2 buses, however future systems would be required to work upon a range of different London buses. The testing revealed this may be an issue in two areas: that suitable places can be found to fit the equipment; and that the systems may interface with the bus' systems where required.

Lesson learned – future potential suppliers should demonstrate how their systems can be readily installed on the range of different bus types. Height may be an issue as the sensors on System A were fitted at a height which may not be possible with single-decker buses.

A.9 Impact of weather and light conditions

Neither system was tested in heavy rain or excessively dark periods (due to the time of year of the tests and the available video). However as both systems are reliant upon visual information there is a potential for the efficiency of the system to be adversely affected by such conditions. It is entirely feasible that these systems will be required to operate in all types of weather and light levels which may not be available in an on-road test.

Lesson learned – tests to an appropriate IP rating should be part of the requirement specification, and evidence obtained from the supplier that this has been done.

Appendix B Overview of each system

B.1 System A

It is understood that the system is designed to detect any cyclist entering a box 3m forward of the rear nearside of the bus, and up to 2m out from the side (as shown in the blue box), and approaching in the direction of the arrows. It is not currently designed to recognise pedestrians. Figure 8 indicates a representation of the area of detection and location of the sensors.

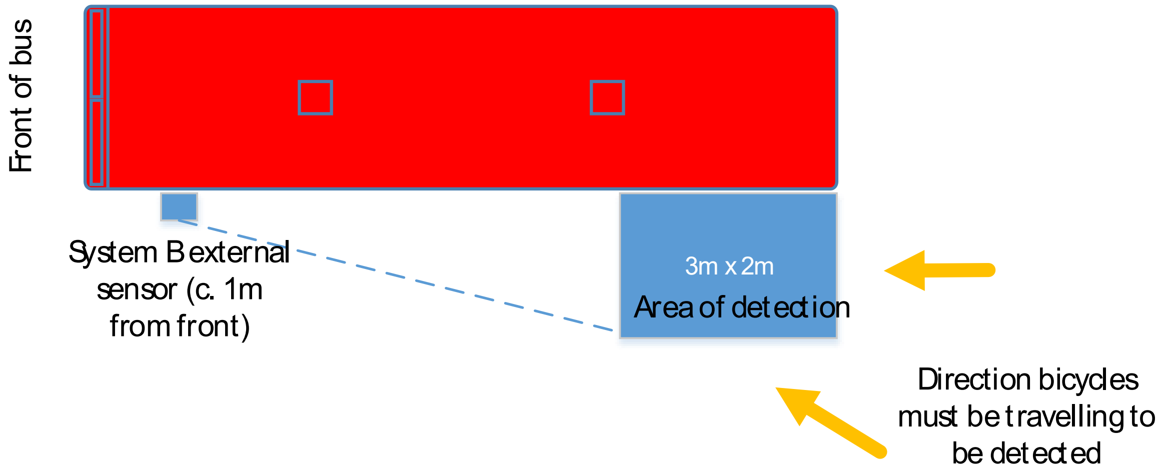


Figure 8: System A area of detection

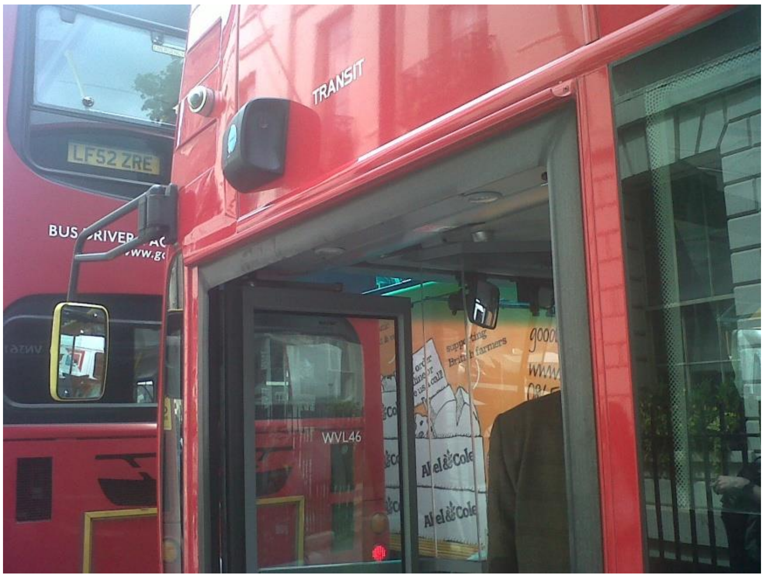


Figure 9: Processing equipment fitted to the nearside front of a London double-decker bus (curved black box fitted above the passenger door)

B.2 System B

The area of view is at 40° from the system's detection cameras, and it is understood that this extends to a distance of 400m. The system is designed to alert the driver if it considers the bus and the object it is tracking are on a collision path, and only operates when the bus is moving at >0.5mph and the brakes are not being applied. Further details of the exact triggers for alert were not possible to obtain. Figure 10 indicates a representation of the areas of VRU detection. However it is understood that other capabilities were also active during the trial.

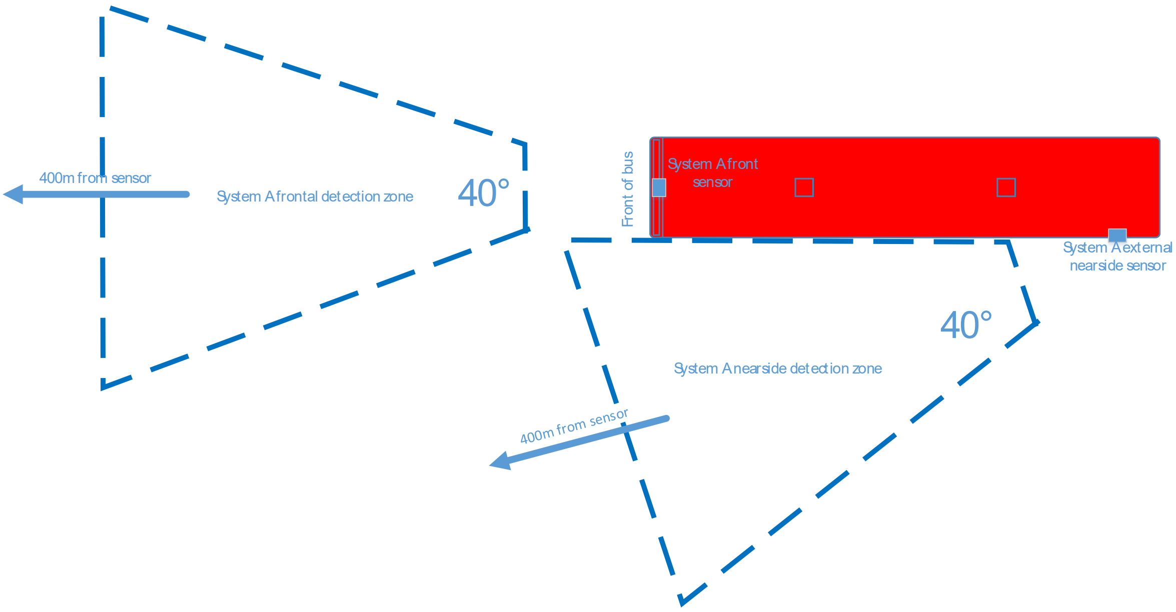


Figure 10: System B areas of detection

Figure 11: Front camera system (rectangular box in the windscreen)

Figure 12: Rear-mounted nearside camera system (rectangular box mounted to outside of bus)