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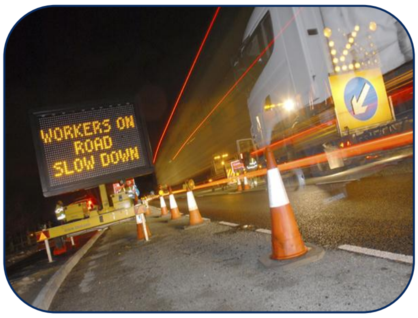

DRAFT REPORT RPN3122

Evaluation of HGV Safety Technology: Technical Report

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Executive Summary

Background

Heavy Goods Vehicles (HGVs) are overrepresented in collisions resulting in cyclist and other Vulnerable Road User (VRU) fatalities. Between 2008 and 2012, 53 per cent of cycling fatalities in London involved HGVs despite making up just 4 per cent of the road miles driven in London. A disproportionate number of HGVs involved were construction related vehicles.

Previous trials by TfL have investigated the effectiveness of a range of after-market safety systems which were on the market for retrofitting to vehicles. There are now over 20 different manufacturers, suppliers and distributors and a number of emerging technologies which presents both fleet operators and those specifying contractual requirements for vehicle safety technology in supply chains with an ever increasing challenge to decide which solution is best for their needs. There is currently no independent process for gathering evidence and evaluating solutions which these stakeholders can use.

The purpose of this project was to create a process for evaluating all types of safety product which are available now or in the future and provide an independent assessment of their strengths and weaknesses of each one over a range of qualitative and quantitative metrics. The process will involve evaluation and limited testing of any product which is submitted to a test house and result in a short, easy to understand report which can be used by clients to set contractual requirements for vehicle safety technology in supply chains and by fleet operators to guide their purchases.

Methods

A defined process has been developed by TRL to gather, assess and test safety products intended for retro-fitting to HGVs. The process has to be a compromise between the cost and duration of exhaustive quantitative testing and a balanced mix of quantitative and qualitative assessments which could be performed in an appropriate timescale and at a price which suppliers could bear. The approach taken is a combination of validation of functional and performance specifications and the assessment by experts of the quality of the product and its performance over a limited set of tests.

The evaluation methodology developed into a three-stage process. It was felt that the practical testing component should be completed within the space of one week, and the total duration of the evaluation should be compact.. If the cost and timescales were excessive then no supplier of safety products or systems would be prepared to pay for it. This means that the evaluation and testing cannot be exhaustive. Statistically significant performance figures cannot be attained by a relatively small team over a few days of work. The approach is therefore to use the skills of experienced staff and drivers to conduct the following process:

Stage 1 is a pre-test evaluation; A supplier that has registered a product or system for testing will be requested to deliver documentation to the test house in a timely fashion, so that it can be scrutinised ahead of a scheduled practical test period. This will concentrate on the completeness and quality of documentation relating to installation, set-up, initial and periodic testing, driver and fleet operator testing and documentary evidence of product testing. The maturity of the product or system in the commercial environment will also be investigated to see how long it has been in service and approximately how many are in the field.

The supplier will be provided with information relating to the test methodology and what is expected of them during the practical testing stages.

Stage 2 involves installation of one example of the product or system in a configuration which is representative of the way it would be offered for sale to fleet operators. The installation will be witnessed by the test house and a comparison made to the methods described in the supplier's documentation. This is followed by a set of stationary vehicle (off-road) tests in which the performance of the system is assessed. This will be as consistent as possible between products with very different approaches to safety and will include a product quality and ease of fitting assessment and some functional and performance testing. Independent recording of video will be made and this will be analysed as part of the process for checking performance. It will give indications of functional and performance consistency as well as evidence of the products potential benefit to the HGV driver. An experienced driver will be in attendance at most of the stationary vehicle testing to provide their feedback on the effectiveness of the product as an aid to VRU safety.

Subject to satisfactory completion of Stages 1 and 2, Stage 3, the moving vehicle (on-road) component will be conducted. This involves the equipped test vehicle being taken into real-world environments including city centre, inter-urban and urban driven routes. The routes have been predefined so that each product tested is subjected to a similar range of environments. Again, independent audio/video recording of the road situation and the information provided to the driver is captured and analysed. The experienced driver is encouraged to provide any feedback on the functionality and performance of the product under test. Finally, the vehicle is driven to a construction site and subjected to a wheel wash to determine whether any immediate problem show up.

At each stage a number of metrics will be evaluated or test results obtained. The approach is to assign a score against each of these metrics, according to a set of guidance tables which an assessor will use to determine the most appropriate score. This approach is designed to provide any assessor with text statements of what is required to attain a particular score (0 -4) for each metric. Given the diversity of product and systems under test, some metrics will be significant whilst others have no meaning. The approach is to show all the metric scores, in a graphical form, so that a fleet operator can compare functionality and performance in a common format and identify strengths and weaknesses of each.

It is felt that some minimum levels of attainment (or minimum scores in certain metrics) must be reached at each stage for the tests to continue[1].

[1] The scoring has been arranged such that, for each metric, a score of 3 is considered the minimum which the product should attain to be successful. A score of 4 shows that the product has exceeded this requirement in some way and scores lower than 3 show varying levels of underperformance.

The process has been developed in parallel with practical testing of six different technology solutions which are currently on the market. This has allowed the process to be refined as the knowledge through testing of different solutions has increased.

Deliverables

The project has delivered a number of documents which provide the basis for a future process for evaluating and testing safety products for HGVs.

• A methodology report which describes in detail the proposed method for evaluating and testing any safety related product which is submitted by a supplier for test. This will remain confidential to TfL and in some areas may still be considered work in progress.

• A draft device report. This is the output from the test process applied to the six technology solutions offered to TRL. The 6 reports have been combined into a single deliverable. The objective is to provide easy to understand information about the products that allows a level of comparison to be made and an assessment of the best product to meet individual's needs for safety or other value added services. These will remain confidential to TfL and will be used to gather feedback on the completeness of the process

• A technical report (this report) intended for public distribution describing the approach to the development of the evaluation process

• A future look report at what technologies can be expected in the future to improve the effectiveness of safety product fitted or retro-fitted to HGVs of all configurations. This is intended for public distribution.

• A summary report for public distribution providing a summary of the technical report, the methodology and future look at the development of the process.

Findings and recommendations

The project has demonstrated that there are many different solutions to providing increased safety for vulnerable road users, each with its own strengths and weaknesses and potential benefit to fleet operators, drivers and VRUs. A number of challenges have been identified which will need further development before the methodology is sufficiently robust for practical use.

- It has proved very challenging to create a single process which gives each solution a consistent and fair assessment in a relatively short evaluation period.
- Fitting equipment to a target vehicle for evaluation is also challenging. The suppliers were instructed that they could not drill holes or modify the vehicle and that it would be returned to its original state at the end of each one-week evaluation. Clearly this will make some assessments difficult and the supplier's ability to get the optimum performance out of their products. Alternative approaches will be suggested in the final methodology which allow "permanent" fixture of all equipment under test to a vehicle such that it can represent a true

and accurate example of the supplier's solution. Options for consideration include the procurement of a "sacrificial" vehicle which is part funded by suppliers using the evaluation process, permitting a suitable vehicle to be provided by the supplier or some other commercially sensible approach.

- In many cases, the suppliers would offer a mix of technologies in a single system solution. The evaluation performed here specifically requested single technology solutions so that their strengths and weaknesses in isolation could be assessed.
- The weather conditions at the time of testing may have an effect on performance. In some respects it is better to have poor weather so that the system is put under worse case conditions. However, this cannot be guaranteed and so the tests have to be performed regardless of the conditions
- The definitions of a *Vulnerable Road User* (VRU) and the *Area of Greatest Risk to a VRU* have been developed. However, it is felt that these are still lacking some validation from statistical information of road accidents and could be improved.
- It has proved difficult to create a standard format for the product report which will be informative to purchasers for a wide range of products whilst keeping to a few sides of A4 paper. There will be a diverse range of comments which the evaluator can choose to use to describe observations and results and the length of the report will inevitably be variable. Reports for more complex multi-technology solutions will be longer. It is suggested that a list is compiled of parts of the evaluation and test process where comments may be inserted and what types and length of comment should be permitted. This may allow a level of control on the size of the report.
- Anti-collision products are coming onto the market and these will prove difficult to evaluate from a performance point of view. Safe stationary vehicle tests may not be possible or relevant and there may be little or no driver alerting during moving vehicle tests to get a feel for their effectiveness.

A process has been developed, exercised with six different technologies and documented. However, the work has been done in relative isolation so that it cannot be influenced by any bias from suppliers or current users of safety equipment. It is recommended that the next step will be to share the process with these stakeholders and identify how it can be improved whilst remaining independent, fair and informative.

The content of the product reports is the most important to get right. If this is not easy to understand and to allow stakeholders to compare one product with another in a straightforward way, then it will not get supported by suppliers or used by fleet operators.

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1 Introduction

The objectives of the project were to develop a methodology for assessing and testing safety products intended for after-market installation on HGVs and targeting vulnerable road users. This would be based on TRL's prior experience with some safety products of this type, combined with a practical real-life assessment, using the proposed methodology, of six different technology solutions provided by volunteer suppliers or distributors. The objectives set were:

- Robustly and consistently perform an independent evaluation of the effectiveness of vehicle safety technology for HGVs against objective performance criteria
- Create a standard procedure for evaluating systems with very different characteristics so that functions, performance, strengths and weaknesses can be determined and recorded
- Provide potential purchasers of such systems with an easy method for comparing different safety solutions and to aid their decision making process by a combination of these objective criteria and qualitative information, given their individual priorities.

Each of the six solutions, based on a single technology, were tested separately and sequentially by asking each supplier/distributor to provide specifications and test data for scrutiny prior to testing and then to install and commission the equipment on a standard rigid tipper HGV so that TRL could exercise a series of pre-defined assessments and tests as developed in the draft methodology.

2 Development of the evaluation methodology

2.1 Previous Work for TfL

Work conducted by TRL on behalf of TRL in 2013 involved the development of a stationary vehicle testing methodology for testing RFID (Radio Frequency Identification) safety solutions. Two such solutions were tested and involved a small battery powered tag fitted to the bicycle or cyclist helmet and a set of detection sensors and driver alerting device on the HGV. In order to obtain significant statistical results for detection rates of vulnerable road users (in this case restricted to cyclists) and false alarm rates from other objects, each test was repeated many times and took a number of days to complete. These tests were conducted using a rigid HGV tipper truck as the target vehicle. The tests were followed by moving vehicle testing of a combined imaging and radar solution which dispensed with any device on the cyclist and operated purely from the vehicle. In this case, a London bus was used to conduct the tests and it was driven through the city centre for two days in order to collect a significant amount of data on cyclists that attempted to undertake the bus on the nearside.

The methodology for this project has taken advantage of both the stationary vehicle and moving vehicle experience gained from the earlier project.

2.2 The Classes of VRU Safety Products

The main challenge is to develop a single methodology which can assess and test a wide variety of products which are intended to improve the safety or lower the accident rate for VRUs. The classes of product which are currently on the market fall into three broad categories:-

- Visualisation systems which use externally fitted cameras and an in-cab monitor to provide more visual information than conventional mirrors can. These can cover blind spots and in some cases, full 360° view around the vehicle which aids slow speed manoeuvring in enclosed spaces.
- Detection systems with an audible and/or visual alert to the driver of the presence of one or more objects in the area where the latter would be a most risk. Simpler systems cannot discriminate between VRUs and street furniture but newer designs have this capacity. Haptic forms of driver alert are not included in the current scope
- Collision avoidance systems with an audible and/or visual alert to the driver of an imminent collision between a VRU and the vehicle.

Systems which alert drivers to VRUs in blind spots and other danger areas have a number of characteristics which can be tested (footprint coverage of the danger area, detection rates, miss rates, and false alert rates). These can be measured during stationary vehicle and moving vehicle tests independently of the reaction of the driver. Evaluation of driver's feedback on such systems' in terms of effectiveness, usability, and annoyance level can be best assessed during moving vehicle testing when the driver can provide "real-time" feedback to the researcher.

Systems which provide visualisation of blind spots and other areas and do not give alerts will not provide such metrics. Adequate coverage of blind spots and other areas can be checked during testing. Evaluation of driver's feedback on such systems' in terms of effectiveness, usability, image quality and field of view can be best assessed during moving vehicle testing when the driver can provide "real-time" feedback to the researcher.

Systems which aid VRU safety, but do not interact with the driver (such as signage on the vehicle, warning lights projected onto the road way, or external warning sounds or voice recordings, etc.) are not included in this methodology.

2.3 The Areas of Greatest Risk to VRUs

The area of greatest risk to VRUs has been defined for HGVs, based on some accident data, expert opinion and practicality and takes into account what the driver is able to see and react to. It is however quite a complex problem to decide when a VRU is actually in danger. The area of interest will change for different configurations of vehicle. It will also change with the relative speeds and direction that both the vehicle and the VRU take or suddenly and unexpectedly decide to travel in. Being in the area of greatest risk does not therefore mean that the VRU is actually in danger. Determining potential collision paths is one possible solution, but the intent of both the driver and the VRU cannot be known.

HGVs tend to have large driver cabs and the more modern models are equipped with six mirrors to the 2007/38/EC directive, a range of nearside (Class II, IV and V) and front (Class VI) mirrors to complement the driver's direct vision. Clearly, fatalities still occur in certain areas around the nearside and front of an HGV.

Some evidence has been analysed to understand better the areas of greatest risk based on fatalities of cyclists and pedestrians in London. A document authored by The Transport Safety Research Centre, Loughborough University and the Centre for Transport Studies, University College London for TfL [2] analysed pedal cyclist fatalities in London between 2007 and 2011. Some general accident characteristics can be concluded from the detailed analysis of a sample of 53 fatalities and seriously injured. Nearly three quarters occurred between November and April, 93% of the fatalities were during weekdays, 74% during daylight, 91% in fine weather and 77% in dry conditions. HGV's were involved in nearly 50% of these accidents and the tipper wagon is involved in over one third of these. The majority of the crashes involving trucks occurred when the cyclist is intending to travel straight ahead and the truck turns left either into a side road or to change lanes. Figure 1 has been extracted from Ref [2] to show the distribution of first point of contact based on the data analysed.

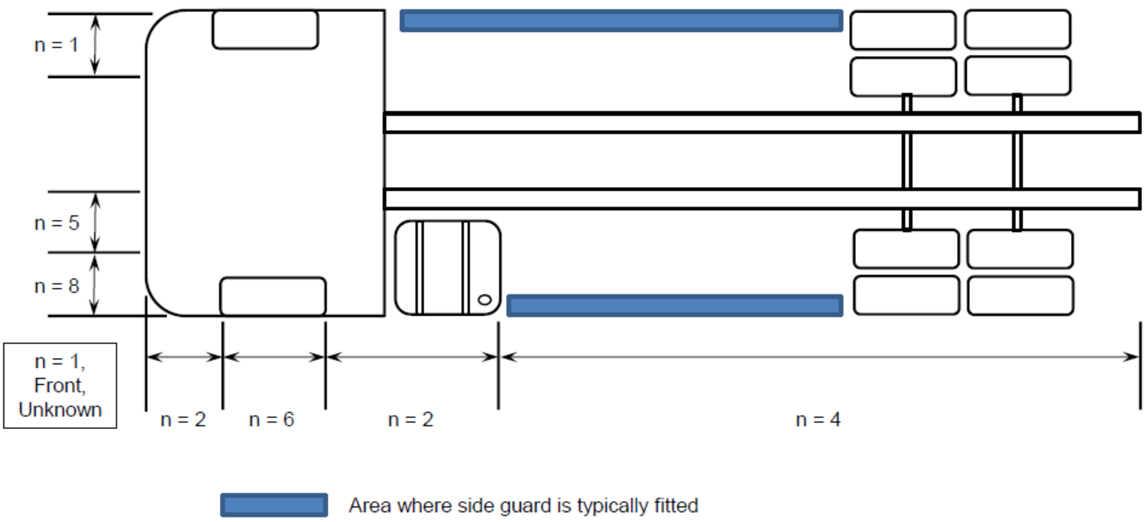

Figure 1: First contact point between HGV/3.5-7.5 tonne vehicle and pedal cyclist

A second piece of work commissioned by TfL was produced by TRL [2] and concentrated on pedestrian fatalities in London between 2006 and 2010. The analysis showed that a large proportion of the fatalities were over 70 years old and one-fifth was 80 or over. About 14% involved at HGV. The figures for the point of first impact of pedestrians with an HGV are shown in Figure 2.

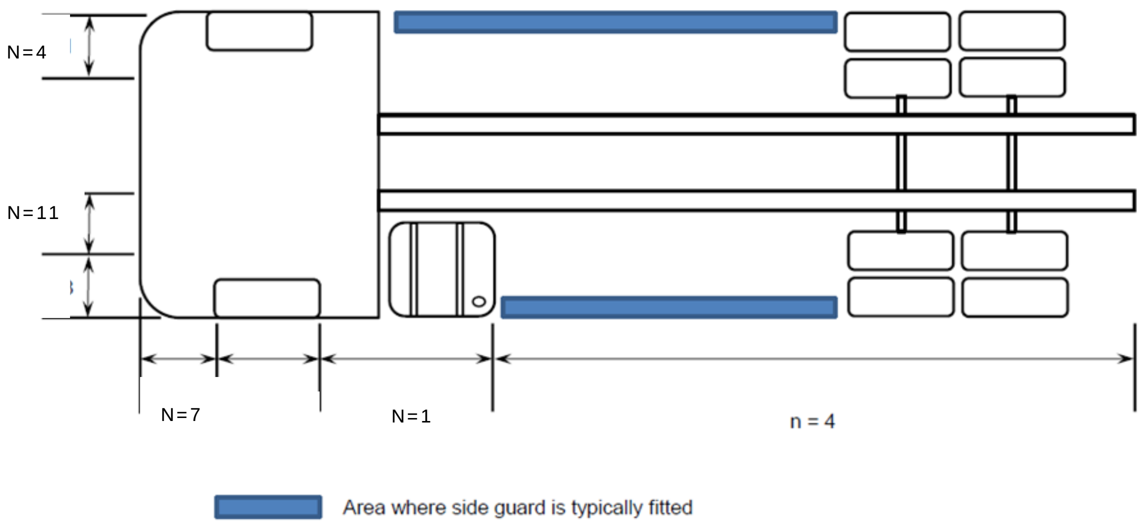

Figure 2: Point of first contact of HGV and pedestrians

Greater detail in the underlying reasons that an accident has occurred would provide a better understanding of what accidents can be avoided or reduced in severity by the use of automatic detection or collision avoidance technology and which cannot be avoided due to insufficient response time or braking distance, or no avoidance options. This may well demonstrate that many pedestrian accidents cannot be avoided especially when they step out into the road without looking or occupy the blind spots to the nearside of, the vehicle when stationary or slow moving.

Given the variation in vehicle design, road layouts and road user and driving behaviour, the methodology is designed to focus on evaluating products which are configured to view or detect VRUs in front of and to the nearside of HGVs.

2.4 The Approach

The approach adopted for this evaluation and test methodology was to conduct a pre-defined set of activities which each supplier would know and understand in advance and would supply both documentary evidence ahead of any testing and then hardware and appropriate installation/decommissioning resources at the beginning and end of the test period. The supplier would need to be very confident that they met all pre-test requirements and that their product was sufficiently robust so that it would perform reliably and optimally for the duration of the practical evaluation and test period. Once the product is installed and commissioned on a test vehicle (details of which would be provided to the supplier with adequate notice) they would be asked to hand it over to the test house and leave the premises. They would be asked not to use any method for remote wireless access to the product for the purposes of uploading performance data or for making parameter changes.

The test house would also follow a well-defined methodology for evaluating and testing the product over the period of (depending on product complexity) about one elapsed week, this being an appropriate amount of time to obtain a good overall indication of the product functionality and performance without loading excessive costs on the supplier.

The underlying method for assessing each product is for the test house to assign scores against a range of predefined metrics. Each metric can be awarded a score between zero (worst) to 4 (best) based on descriptive scoring sheets developed during this project. The scoresheets can be found a further deliverable from the project – Ref [1]. The output of the overall assessment and test is a short report which combines scoring data with supporting commentary and written to a common agreed format.

The approach comprises three stages:-

This methodology consists of three stages:

- Stage 1:
    - Pre-test evaluation: a desk based evaluation of documentation provided by the supplier prior to formal practical evaluation and test of the product itself will be carried out. This will concentrate on the completeness, and quality of documentation relating to specific areas of product description and specification, installation and set-up methodology, initial and periodic maintenance and testing, driver and fleet operator training and documentary evidence of product testing. Metrics have been developed for each of the areas of documentation which are important for this assessment so that scores can be given against each one.
- Stage 2: Installation and stationary vehicle testing

  Subject to satisfactory completion of Stage 1, the supplier will be invited to provide a suitable system and expertise to install and commission a system at the Test House onto a representative HGV. The Test House will then:
    - Witness the installation and compare it to methods described in the suppliers documentation
    - Carry out stationary vehicle testing: an evaluation and stationary vehicle test will be carried out, in which the performance of the system is assessed in a stationary vehicle situation. This will be as consistent as possible between products with very different approaches to safety and will include an assessment of product quality and ease of fitting, functional and performance testing and human factors evaluation. Some testing under low light and darkness will also be carried out.
- Stage 3: Subject to satisfactory completion of stages 1 and 2, a moving vehicle moving-vehicle test will be conducted, in which an equipped test vehicle takes the product into real-world environments including city centre and urban driven routes and exposure to cleaning practices at a construction site. A predefined route will be driven through London during both daytime and normal street lighting after dark to assess the systems on-road performance and further human factors.

Given the diversity of possible products, it was found impossible to define a common set of stationary vehicle and moving vehicle tests which are applicable to all. It was therefore decided that a part of the Stage 1 evaluation would be to understand the capabilities of the product under test and decide which subset of tests from the complete suite of tests available would be appropriate. This would be agreed with the supplier prior to commencing Stage 2 to ensure that the scope of the testing was adequate to cover the functionality and performance of the product under test. A written statement in the form of a matrix will indicate which assessments and tests will be carried out. The Test House has final say as to which tests are appropriate for a given system solution. This works well with single technology solutions. In the future, however, if the same approach is applied to multiple technology solutions it may be found that most or all tests in the suite are relevant and a test period of one week may be insufficient to conduct them all. The Test House will be responsible for assessing the level of work needed to complete the evaluation and will provide a quotation based on a set of fixed price options.

At each stage, metrics or attributes have been identified which will be of interest to potential purchasers or specifiers of VRU safety equipment. The approach is to provide a score against each of these metrics which are appropriate to the product under test. Those metrics which are not relevant will not be scored. The assignment of scores against each metric will be based on a guidance document for test house staff who are making the independent assessments of the product. The guidance provides a text description for each metric and for each score which can be assigned to that metric (zero-lowest to four-highest). This is designed to “normalise” scores across different assessors at different test houses, so that comparisons between products tested at different test houses are valid. However, the effectiveness of this approach in achieving a high level of normalisation of scores has not been tested.

It is clearly to the purchaser’s advantage if a set of minimum functionality, or performance thresholds is set by the evaluation and test methodology. An initial attempt has been made to set minimum requirements by using the scoring mechanism. A score of 3 has been defined for each metric to represent the minimum quality, functionality or performance expected of a system which is considered effective at improving the safety of VRUs. Any system which scores 4 for a particular metric has, in the opinion of the assessor, exceeded the minimum requirement and similarly, a score of 2 or less means the system has failed to meet the minimum requirement. There is little point in continuing to spend both money and resources on any product which fails to meet one or more of these thresholds. However, should the supplier still wish to continue the independent test, at their expense, to get a full picture of the product’s performance against the process, then it would seem reasonable to allow this to occur.

The test house will have to demonstrate that it has all the relevant skills and resources to be able to carry out the full assessment and produce product test reports for any type of VRU safety product for fitment to an HGV which is already, or may appear on, the market.

2.5 Selecting the Metrics

At the appropriate stage in the method, the test house assessors will be expected to score the following metrics:-

Stage 1: Pre-test evaluation

- Quality of product description and specification as tested
- Quality of installation methodology
- Complexity of product. Likely ease of understanding by the user
- Quality of product testing
- Product maturity or potential
- Ease and need for cleaning
- Maintenance regime (preventative) and quality of instructions
- Calibration requirements

- Faulty system detection
- Quality of training documentation/instructions
- Driver/supervisor training (practical)
- Fleet operator training

Stage 2a: Installation

- Ease of retro-fitting
- Installation and Commissioning time (per unit)
- Adaptability to different HGV classes
- Integration and interference with existing vehicle systems

Stage 2b: Stationary vehicle testing

- Nearside visualisation footprint
- Nearside visualisation performance - daytime
- Nearside visualisation performance – night unlit test area

- Nearside detection footprint (area of greatest risk at ground level)
- Nearside detection performance (true positives) with VRUs in the footprint
- Nearside false alert rate (per 100 detected VRUs)
- Nearside detection - response times.
- Nearside detection performance (night - unlit test area)

- Frontal and frontal crossing visualisation footprint
- Frontal visualisation performance – daytime
- Frontal visualisation performance – night unlit test area

- Frontal and frontal crossing detection footprint (area of greatest risk at ground level)
- Frontal and frontal crossing detection performance (true positives) with VRUs in the footprint
- Frontal and frontal crossing false alert rate (per 100 detected VRUs)
- Frontal and frontal crossing - response times.
- Frontal and frontal crossing detection night performance (unlit test area)

Stage 3: Moving vehicle testing

- Nearside visualisation footprint – daytime
- Nearside Visualisation footprint- night – lit urban roads

- Nearside detection footprint
- Nearside detection performance - daytime
- Nearside false alert rate
- Nearside average time between false alerts
- Nearside detection - response times.
- Nearside detection performance (night – lit urban environment)

- Frontal and frontal crossing visualisation footprint – daytime
- Frontal and frontal crossing Visualisation footprint – night – lit urban roads

- Frontal and frontal crossing detection footprint
- Frontal and frontal crossing detection performance - daytime
- Frontal and frontal crossing false alert rate
- Frontal and frontal crossing average time between false alerts
- Frontal and frontal crossing detection - response times.
- Frontal and frontal crossing detection performance (night – lit urban environment)

Human Factors assessment (Off and On Road)

- Driver distraction
- Usability (on-road daytime)
- Operator interference
- Usability (urban after dark lit roads)

Jet-wash Cleaning

- Durability of system to Ipx6 jet-wash

The score for each of the metrics will be assessed by the test house assessor based on the score sheets developed during this project and contained within the methodology document [Ref 1]. It is not felt that product cost is a metric which can be scored due to the diversity of capabilities and technologies available. A more expensive solution may give the added performance or functionality which a purchaser is looking for and offer value for money. A section of the test report will allow the assessor to describe the value added services and functions which a product under test can offer.

2.6 Development of the methodology

The detailed methodology was developed during the course of the project. The methodology is contained in a document written as part of this project [Ref1]. A brief summary will be provided here.

The Methodology provides a test house with all the details necessary to set up the process for evaluating and testing VRU safety systems for HGVs and how to deliver a final assessment report on the findings. The major contents of the document are:-

- The objectives
- The skillset and resources needed to act as a test house for the evaluation process
- The scope of products which can be evaluated
- Test House responsibilities
- Product or system supplier responsibilities
- The methodology, including details on the three stages of evaluation and test
- Video data analysis
- Generation of the product report

The methodology has been validated in parts by the evaluations and tests performed on the six technology solutions supplied to TRL by the volunteer suppliers. Since the methodology was developing in parallel with the tests being conducted, there will be some tests which were not performed (or could have been performed in a more efficient way) during the testing of the first products. This is to be expected. Any lessons learnt during testing have resulted in improvements to the methodology when used in a formal way in the future.

3 Selection of candidate technologies and suppliers

3.1 Survey of candidate companies and selection

TRL contacted a number of manufacturers, suppliers and integrators and described the practical work that was planned on behalf of TfL and requested their support. This resulted in a number of positive responses and TRL then had the task of selecting suitable candidates that would permit as diverse a set of technology solutions as possible to be evaluated during the development of the methodology. The solutions chosen included:-

1. Standard side and front vision using cameras
2. 360° vision around the vehicle from a “bird’s eye view” using camera technology
3. Side and front Ultrasonic detection
4. Side and front RFID cycle tag and vehicle based detection
5. Side and front collision avoidance using cameras and image processing
6. Frontal radar detection

The six technologies were supplied by five different organisations. Arrangements were made to invite each supplier to TRL, to arrive on a Monday morning to install the equipment on the test vehicle and to complete testing by the following Friday afternoon. The equipment would then be removed by TRL staff and stored safely until it could be returned or collected by the supplier.

3.2 The timetable

The original plan was to spend one elapsed week with each product and perform the full set of tests on six products on six consecutive weeks. Despite some changes to the plan, the timescale was achieved.

3.3 Test facilities

3.3.1 The test vehicle and driver

A 26 Ton rigid 4 axle vehicle (a tipper wagon) was loaned by Laing O’Rourke for the duration of the testing. It represents a class of vehicle which, statistics show, is particularly dangerous to VRUs.

The heavy vehicle was compliant with safety requirements to allow it onto Crossrail sites and for driving in central London. Part of the test includes driving onto a construction site and subjecting the safety equipment under test to a wheel wash process. The vehicle, including existing safety equipment, had to be compliant with all requirements to enter such an environment[2].

The drivers used during the testing had full training to the level required for driving in central London, including the necessary CPC training, and training in vulnerable road user safety as specifically required by Crossrail and/or TfL. The drivers also had good experience of driving 26T rigid HGVs and had their licence for no fewer than two years.

3.3.2 Preparing the evaluation site and the vehicle for system testing

Stage 2 evaluations were carried out with a stationary vehicle, in a secure, controlled environment within the TRL grounds. For the project, the rigid vehicle and testing site were prepared for testing as follows:

a) Appropriate camera(s) and a Digital Video Recorder (DVR) were set up on the site to record the stationary vehicle testing. One camera was mounted on a pole, some 6m high and viewed the side of the vehicle from approximately 15m away. A second camera was mounted in the vehicle to record any detection system user interface or a visualisation monitor. The two signals were recorded synchronously on a single DVR so that timings of alerts and the position of the VRU could be analysed. The captured video will record the VRU performing the required manoeuvres around the vehicle, showing the points at which they become visible to the driver or the point at which the detection system provides a driver alert. Figure 4 shows the field of view of the pole mounted camera providing full coverage of the path of a cyclist or pedestrian down the side of the vehicle.

b) Appropriate cameras were also be fitted to the HGV in preparation for moving vehicle tests. One camera will capture the area down the nearside of the vehicle. One camera will be mounted inside the vehicle. This can reuse the camera used for Frontal detection performance – stationary vehicle testing. Depending on the product under test, it may capture video of the monitoring or alerting system or it may point directly out the front of the vehicle. Given that the methodology relies on the feedback from one driver and his or her personal feedback relating to the systems under test, it was not thought appropriate to record the driver's face to check what he or she was observing during the testing. A test house observer will be in the cab to monitor driver behaviour.

c) An audio channel was available for recording with the video capture during both stationary and moving vehicle testing to capture any comments made by the driver and/or the assessor to support the evaluation.

d) A series of track lines running parallel to the long axis of the vehicle and at several lateral distances from the nearside of the vehicle were marked out on the track. These extended from a point 5m from the back of the vehicle to 5m in front of the vehicle. Lines were marked at 0.5m, and 1.5m from the vehicle. A further line at 2.5m was also marked. This would tend to be the distance at which

[2] Where the vehicle is accessing, for example, a Crossrail site for evaluation of operation in construction site conditions and use of the wheel wash, it is assumed that the requirements placed on Crossrail for vehicle used on that project will be applicable except with regards to the safety equipment being evaluated. This may cause a conflict between existing safety systems and the safety system under test.

alerting systems should not alert but it will also be useful to determine the footprint of monitoring systems. This is shown in **Figure 3**.

e) Around an area on the road surface where the VRU enters the greatest risk region, a further series of markings, 0.5 metre apart, at right angles to the VRU tracks were marked.

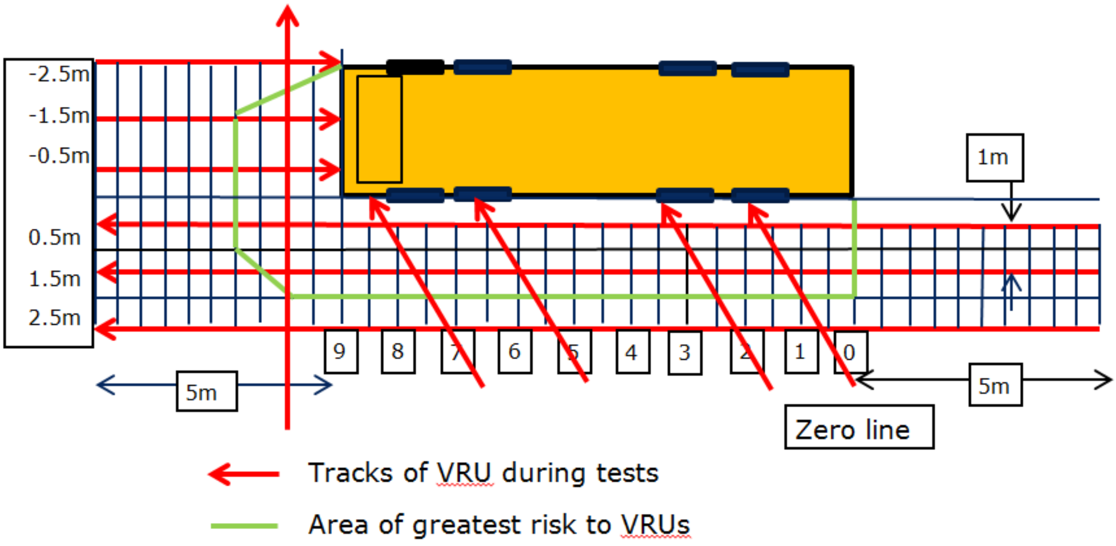

Figure 3 Road markings

Figure 4: View from the main camera

f) For the moving vehicle tests, the vehicle was equipped with a 4-channel DVR which is designed for use within a mobile environment. A timestamp is also recorded in the video to assist with the review process.

3.3.3 Moving vehicle test routes

The test vehicle was driven on the open road on two different test routes which had been pre-agreed with TfL. These are designed to ensure the vehicle is driven both in dense urban environment (at times when there is a high density of cyclists and pedestrians) and on inter-urban roads where there would be a rich density of roadside infrastructure and vehicles. The objective was to determine whether the product behave appropriately on the open road, providing he driver with good information, but without over-distracting or delivering a high level of false alerts to the driver. It would also show if the system suffers for any form of instability due to vibration or electromagnetic interference. The routes which were developed for testing the products are shown in Appendix A.

4 Commentary on the methodology

This section will concentrate on the practical challenges of evaluating and testing VRU safety products using the methodology as it developed through the course of the project.

4.1 The suppliers

Generally speaking the volunteer suppliers were very positive in their approach to the tasks they were set. The biggest challenge was to agree what equipment they should supply. Most products can be supplied with a large number of different physical configurations, mixes of technologies and ways in which it can be configured for the driver's use. TRL's stance was that we wished to evaluate a single technology solution which was fitted in a way which would demonstrate its potential for improving the safety of VRUs. Many suppliers will tend to offer more complex solutions and then configure them to the purchaser's requirement. If this methodology is to be successful in the future, it will have to accommodate any solution which suppliers manufacture, many of which will combine detection and visualisation systems. The nominal duration of the evaluation is one day prior to testing and 5 elapsed days for the testing itself. More complex system will require a day or two longer but a ceiling on time (and hence cost to the supplier) will be set with appropriate costed options.

The key to this challenge is to ensure that the documentation and support provided by the test house prior to a supplier submitting a system for test is clear and concise and explains exactly what is required.

4.2 Stage 1 Pre-test evaluation

Relevant documentation was supplied by most of the suppliers. Mature products will have been thoroughly tested and be compliant with environmental standards to an adequate level. There will be a network of distributors or integrators which are trained in the installation and commissioning of the system onto a range of vehicle configurations. Suppliers of less mature products will have less to offer at this stage.

The overall conclusion is that the industry is aware that professional documentation is necessary for marketing, technical specification, installation, test, training and maintenance, but is not available to a consistent standard or quality. This methodology will specify the suite of documents necessary to be presented prior to testing to meet minimum requirements and what each should contain. In practice, there has been little time on the project to consider what this consistent standard should be. The assessors have reviewed the documentation provided, sufficient to assign a score to its coverage and content, but not to create a more formal template to define minimum standards and content.

4.3 Stage 2 Installation and stationary vehicle testing

The installation process was found to work smoothly with the suppliers. The biggest challenge for the supplier was to make a temporary fit to the vehicle which would be roadworthy and operate correctly on a vehicle which is already equipped with some safety equipment so that it could operate in London. It is assumed that this issue will not prevail once the assessment process is operated normally by a test house and a "permanent" fit will be permitted. The vehicle was already fitted with a visualisation system (side and rear cameras), some ultrasonic detection equipment down the nearside and an audible warning for cyclists which was activated whenever the driver wished to make a left turn. This was either disabled or reused (for example the video monitor) whilst these test were being conducted. It raises the question for the future as to whether such a vehicle will be compliant with any future regulations which apply either to the vehicles use in London or on construction sites whilst conducting moving vehicle tests on the safety equipment under test. The reason for driving in London in the peak traffic hours is to witness a high level of VRUs and assess how the product under test is aiding the driver to negotiate these dangers. It would be very difficult and expensive to simulate this situation in any other way.

The evaluation and test processes developed for the methodology have been based on prior experience and therefore were relatively well developed early in the project. However, prior testing has been performed to provide statistically significant performance data and therefore involved significant numbers of repetitions of each test and then analysis of the results from data captured over many days of testing. For the process required here, there is limited time to perform a range of visualisation or detection tests. However, a good indication of the reliability and consistency of performance can be obtained, both for visualisation and detection systems. It does rely on staff having a good understanding of the strengths and weaknesses of the technologies involved and noting down any systematic failures or advantages observed. The experience of the driver is also essential to understand the added safety value of the products being tested.

Evaluating the visible footprint offered by visualisation systems is not particularly challenging. There are many robust external miniature cameras which can be fitted to a vehicle and provide side, front, rear or 360° vision for the driver. The field of view of any such camera can be adjusted to suit the customers' needs and this is the way many systems are sold today. The important factor is how and when any visualisation is presented to the driver. Setting minimum requirements for the visible footprint, safety (driver distraction) and image quality are built into the scoring system, the former being based on a quantitative assessment whilst the others rely on driver feedback.

The sequence of nearside and frontal tests performed on detection systems presented little problem. The two factors which will cause variability in the test process are the prevailing weather conditions and the ability to repeat testing after dark. Given the limited time to test, there is little that can be done to control the weather conditions. It is not proposed that the stationary vehicle testing should be done inside a large building so that light levels can be controlled, but such an approach could reduce the variability considerably. There could be some flexibility in the order in which tests were performed. By observing the weather forecast for the week of testing, it may be possible to swap stationary vehicle and moving vehicle testing around. However, it is likely to be the stationary vehicle testing which has to be subjected to the worst conditions. The best conditions would be used for moving vehicle testing so that the maximum number of cyclists and pedestrians would be in the city centre.

4.4 Stage 3 – Moving vehicle testing

The moving vehicle tests span two days of the test programme. The vehicle was driven from TRL to London during the afternoon of the first day and taken to a suitable location where the vehicle could be parked up for a short time so that the alignment of the video capture cameras could be checked. TRL were able to use the Abellio bus depot in Battersea for this purpose, the location which had been used for previous work with VRU safety equipment testing in 2013. The vehicle was accompanied at all times by a TRL expert assessor who witnessed the journey, checked the correct functioning of the equipment under test and the monitoring equipment and made notes relating to observations on the road and driver input.

The vehicle was then driven on the first test route to catch the evening traffic peak between 4pm and 6:30pm. This is shown in Appendix A as the afternoon route. The vehicle is then driven back to the bus depot and parked up for the night. The driver and assessor make their own arrangements to get home or stay in London. The second day starts early with an equipment check and then the vehicle is driven for 2.5 hours around the morning route to take advantage of the morning rush hour, returning to the depot for a rest break at around 10:30am. Between 11:30 and 14:00 a final 2.5 hour session is then performed using the same morning route as before and will coincide with the off-peak morning period. The driver then had a further 1 hour rest break at the bus depot.

The final leg involves refuelling the vehicle and then driving to a construction site in Barking so that the equipment could be subjected to a wheel wash. It was thought that such an exercise would check that the equipment was robust to one of the more stringent environmental pressures which all construction vehicles are subjected to on a regular basis. However, the majority of the visualisation and newer detection products tested during this project were fitted higher up the vehicle and the wheel wash does not affect them. If this test is to be included in the methodology then it would be more appropriate to use a hand-held jet wash with defined water pressure, water delivery rates and distances, angles and durations which are employed to direct water at the various external components of the system under test. This has not so far been done. Unless the system is installed to a sufficient level of robustness against such water jet pressures it might be damaged in a way which would not have occurred had it been a permanent fit to the vehicle.

Following the wheel wash, the product under test was checked to ensure it was continuing to operate satisfactorily. The vehicle was then driven back to TRL to complete the test.

The moving vehicle component of the project was conducted during the summer months and so there was no opportunity to observe the systems at night on lit London roads. The general opinion is that it is important to test such systems when there is a high density of VRUs and urban lit road conditions. Since it is very inefficient to split the methodology into two distinct phases, one for daytime testing and the other during the winter months when the rush hours coincide with hours of darkness, TfL should consider whether this test can only be conducted during the winter months. The cost to the supplier and the test house in equipping a vehicle twice would be excessive. In addition, there is no guarantee that the same driver or the sane test house personnel would be available.

4.5 Data extraction and analysis

During both stationary vehicle and moving vehicle testing, the captured video was taken from the DVRs on removable hard drives and backup copies of the data made in the laboratory. This could be replayed on standard PCs directly from the backup hard drives and using commercially available video player software which allowed playback at single frame, slow, normal and fast speeds. The practical testing provide the team with a better understanding about which useful metrics could be obtained or derived that would add value to the overall assessment of the products, given the limited amount of test time available.

5 Findings and Recommendations

The project has provided a much better understanding of the compromises and achievements which can be made in a relatively short evaluation and test process such as the one developed here. It has delivered a complete methodology which has been tested in parts by applying it to six different technologies and attempting to create a set of reports which document the findings in a way that will be useful to fleet operators and specifiers of safety equipment on HGVs. The following recommendations are proposed.

5.1 The test vehicle

It is recommended that a dedicated vehicle is acquired for testing which can be modified by suppliers (for example by drilling) so that any equipment can be fitted in the correct manner and the supplier is able to get maximum performance out of the product. The vehicle itself would need to be fully roadworthy and compliant with all relevant regulations for use in London, but would not need to be new. It should have all mirrors to the latest directive (six mirrors to the 2007/38/EC directive). However, it would not be used as a working vehicle again. The cost of such a vehicle and its maintenance would be amortised over a number of tests and hence paid for in part by each supplier which uses the evaluation and test service. It would not be expected that all cabling would be installed to a high standard for one week of testing but it should be secure and robust to the environment.

5.2 Feedback from stakeholders

The methodology has been constructed in relative isolation from most of the stakeholder who would normally be involved. Some feedback has been obtained from the client relating to the scoring regime and a representative from the Metropolitan Police did assist with off and moving vehicle testing of one of the products. Now that the methodology is in a well-developed state it is important that other stakeholders, including TfL, those suppliers which have assisted so far, other suppliers/distributors/integrators, selected fleet operators, and organisation or authorities which specify minimum safety standards for HGVs to operate in urban environments are consulted. If there are to be minimum levels of safety to be met (through the scoring system proposed in the methodology) then these will need to be agreed and specified.

5.3 Definition of area of greatest risk

The area of greatest risk to VRUs has been defined for HGVs, based on some accident data, expert opinion and common sense and takes into account what the driver is able to see and react to. It is however quite a complex problem to decide when a VRU is actually in danger. The area of interest will change for different configurations of vehicle. It will also change with the relative speeds of the vehicle and the speed and direction that the

VRU is or suddenly decides to travel in. Being in the area of greatest risk does not therefore mean that the VRU is actually in danger. Determining potential collision paths is one possible solution but the intent of both the driver and the VRU cannot be known. Greater detail in the actual reasons that an accident has occurred would provide a better understanding of what accidents can be avoided or reduced in severity and which cannot be avoided due to insufficient response time or braking distance, or no avoidance options. This may well demonstrate that many pedestrian accidents cannot be avoided especially when they step out into the road without looking.

5.4 Slow moving stationary vehicle detection

The stationary vehicle evaluation and test (Stage 2) component of this methodology assumes that the test vehicle will not move. TRL understand that at least one system is designed to operate only when the vehicle is moving above a certain minimum speed. This would make stationary vehicle testing as envisaged have no value. It is recommended that alternative tests for inclusion in the methodology for tackling this issue are investigated.

5.5 How to combine technologies

A number of the suppliers/integrators have stated that systems often exploit a combination of safety technologies (for example a visualisation system and a detection system) since together they provide a significant improvement in cycle/pedestrian safety. The exercise so far has tested single technologies in isolation and may not show up products strengths when combined with a complementary technology. The methodology will need to be validated against system solutions offered by suppliers and distributors rather than single technologies.

The concept of one methodology to fit all safety products is challenging. There will be some tests which are clearly of no relevance to a particular technology. TRL has developed a process which contains a range of different tests and the assessment of documentation during Stage 1 will ascertain which tests are relevant for a solution submitted for test by the supplier. The resulting test report will show the reader which tests have been conducted from the suite of options available. If a system for testing combines a number of technologies then the process will still work, but nearly all the tests available will be relevant. This will inevitably increase the time taken to complete all tests. It may be necessary to provide a range of costs depending on the complexity of the product submitted for test.

5.6 Weather conditions during testing

The tests must be completed within a relatively short time to keep costs reasonable and should include both stationary vehicle and moving vehicle testing. Delays for bad weather will make this difficult to attain. On the other hand, bad weather can show up limitations in a product. It will be almost impossible to ensure consistent weather conditions within such a testing process.

5.7 Disabling existing safety products on the test vehicle

There may be an issue if there are existing minimum requirements for safety products on the test HGV for use in the moving vehicle testing. The normal approach would be to disable all existing products so that the assessment is purely done on the product under test. If by disabling existing products and relying on an unproven one does not comply with local requirements then the vehicle as a whole is non-compliant for driving on road in the test area. This may prevent the driving of the best test routes where the conditions for interacting with VRUs and evaluating the safety product under heavy cognitive loads is ideal. Driving in alternative locations may require longer travel distances and times and not provide such an ideal situation.

5.8 Environmental testing

Performing a wheel wash exercise on a construction site provides a relatively easy way to check that the product is sufficiently robust to withstand it. However, some products are mounted high on the vehicle and would not be affected by a wheel wash. It would be more appropriate to specify a hand-held jet wash so that any external component anywhere on the vehicle can be subjected to a water jet. The methodology has been upgraded to include two separate sessions with a jet wash, applying the water jet requirements specified to IPx6 levels. Unless the system is installed to a sufficient level of robustness against such water jet pressures it might be damaged in a way which would not have occurred had it been a permanent fit to the vehicle.

References

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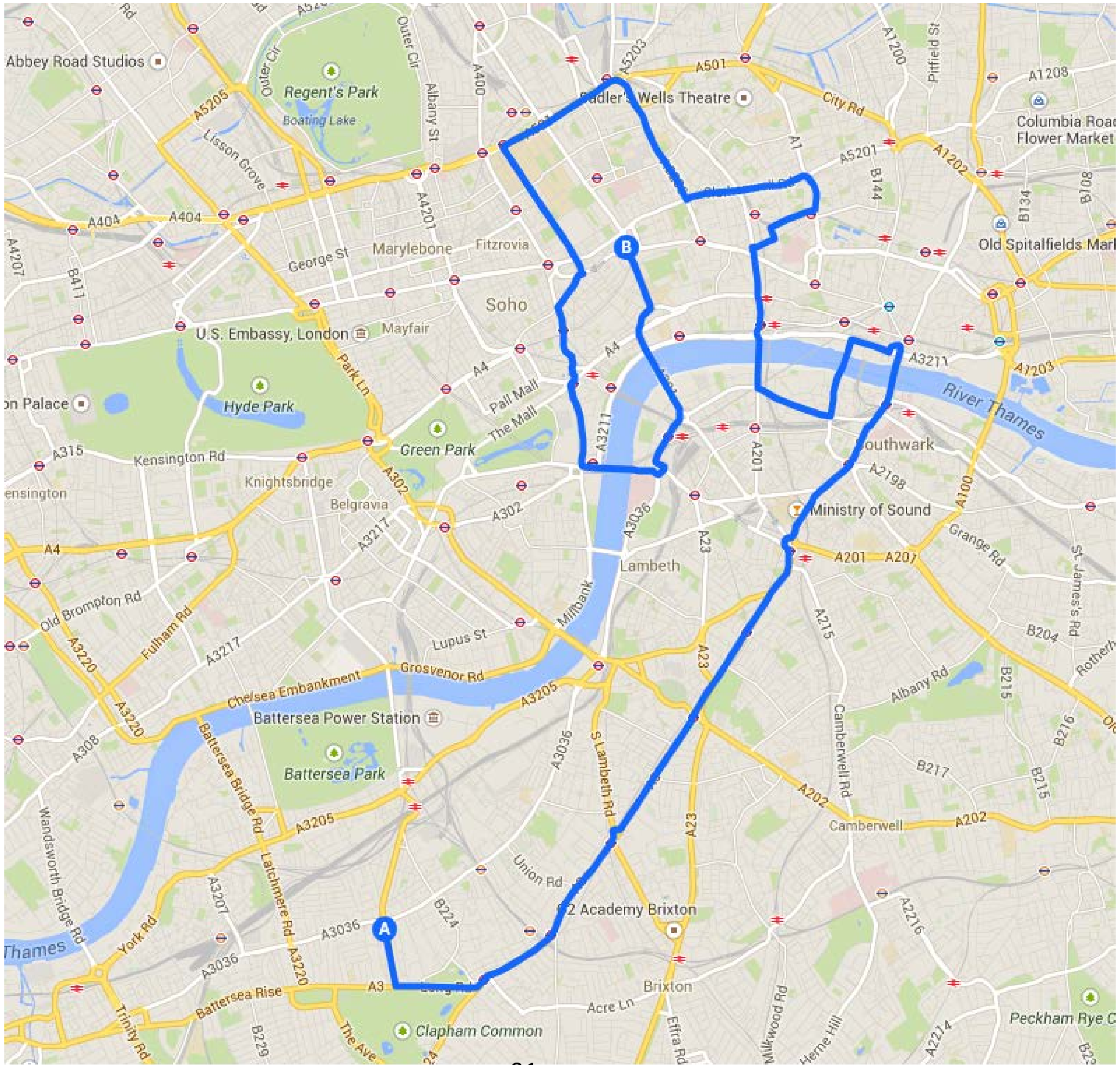
Appendix A Moving vehicle Routes

The morning route



The afternoon route