Congestion Charging Technology Trials

Stage 3 Final Report

Version 1.0

31st July 2008

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ANPR	Automatic Number Plate Recognition (or Reader or Reading)
CC	Congestion Charge / Congestion Charging
DSRC	Dedicated Short-Range Communications
DTO	Directorate of Traffic Operations
FOV	Field of View
GPS	Global Positioning System
OBU	On Board Unit
OCR	Optical Character Recognition
SLA	Service Level Agreement
TfL	Transport for London
UCP	Urban Charge Point
VAS	Value Added Services
VRM	Vehicle Registration Mark

Executive Summary

Introduction

The Congestion Charging (CC) technology trials programme commenced in August 2003. The overall objectives of the trials were to investigate the different technologies available which may:

- give more flexibility for paying the charge

- allow for new charging approaches (policies) or

- reduce the scheme's costs

The main focus of the trials was to identify technologies which could be deployed between 2005 and 2015.

Stage 1 of these trials was completed in late 2004 and Stage 2 was completed in July 2006. These previous stages focused on initial discovery of multiple technology options through the progression of a specific technology, a 'Tag and Beacon' based technology known as Dedicated Short-Range Communications (DSRC), to a carefully monitored trial in southern section of the current Congestion Charging Zone (known herewith as the 'mini-zone').

This report presents the results and conclusions from Stage 3 on the DSRC tag and beacon trial conducted in a "mini-zone" in South London.

Stage 3 has focused primarily on usability, aesthetics, operational issues and interoperability aspects of the tested solutions

This report focuses on the following areas:

- Results from the DSRC mini-zone trial

- The development of the capability to ignore travel in the "wrong" direction and to detect U-turns

- Integration of 'stand-alone' DSRC systems with the Congestion Charging Western region ANPR cameras

- Interoperability of a tag and beacon system in London with tag and beacon systems elsewhere in the country (and abroad)

- Integrating DSRC / ANPR infrastructure with the streetscape to minimise visual impact

The distance-charging element of the Stage 3 trials has not reached a point where substantive conclusions can be drawn and will be the subject of a separate report. This report therefore only comments briefly on this aspect.

DSRC mini-zone trial

Through previous stages, the mini-zone trials demonstrated that a fully functional congestion charging zone can be operated using Urban Charge Points (UCPs) integrating tag and beacon (DSRC) and ANPR sub-systems. Throughout Stage 3, the mini-zone was tested using dedicated trials vehicles and drivers and volunteer drivers driving a variety of vehicles, including cars, buses and HGVs in the course of their everyday business.

The mini-zone trial demonstrated detection rates for dedicated trials vehicles of 99.93% overall, 99.7% for DSRC alone and 96.6% for ANPR alone. The ANPR result was significantly higher than the manually "ground-truthed" correct read rate for the overall vehicle population; this is in part due to the trials vehicles being well maintained and cleaned, making reading of the number plates easier. The overall detection rate varied by 0.3% between suppliers and the DSRC and ANPR detection rates varied by 1.7% and 10.4% respectively between suppliers.

Roadside matching of ANPR readings to tag transactions was also successful, with matching rates of 97%, 99% and 99.7% respectively for declared VRM matching, spatial matching and combined matching.

Driving many tag-equipped vehicles together past charge-points produced no significant change in performance. It was possible to evade detection by driving at the edge of the DSRC communication zone or behind other vehicles at 2 or 3 sites. Although the reduction in performance at these sites was significant, the overall impact on the performance of the system as a whole was not. It is clear that for particularly difficult sites, care needs to be exercised in the design of DSRC coverage and in site location to prevent drivers evading detection. Nevertheless, considering the system as a whole, the overall reduction in DSRC detection is small even if drivers deliberately try to escape detection.

The technology trials achieved a worldwide first in developing the ability of independent back-to-back charge-points (which monitor opposite directions of travel) to correctly detect the direction of travel, to ignore transactions from vehicles travelling in the non-monitored direction and to detect U-turns. One of the mini-zone sites was configured to extensively test the solution. Overall detection rates were in line with the standard tests as was the spatial matching performance. Only 0.05% of vehicle passages resulted in transactions with the charge-point monitoring the opposite direction of travel and these were all detected as such. 99.7% of U-turns were successfully detected and only 0.1% of U-turns resulted in a set of transactions which were ambiguous.

For volunteer vehicles, detection performance was slightly lower than for the dedicated trials vehicles but was nevertheless comparable (99%, 93% and 99.5% for DSRC, ANPR and combined detection respectively). Although spatial matching performance was significantly lower for the volunteers at 83%, declared and combined matching performances at 94% and 98% respectively were comparable to those for dedicated trials vehicles. Some aspects of this lower performance are due to errors in the trials setup which would not be present in an operational system.

The volunteer trials provided a number of valuable operational lessons. The greatest impact on the system performance came from tag mounting issues. The volunteers were not incentivised to mount tags correctly or to keep them mounted. It is clear that in an operational system tag mounting will be a key factor and that incentives and terms and conditions will have a part to play in addressing this issue.

During the trials programme it was found to be difficult to capture and maintain the tag-VRM mapping for the volunteers. As this was a trial system the processes and procedures followed were less tightly defined and less rigorously followed than would be the case in an operational system. Nevertheless, it is clear that keeping track of the mapping will be key to system performance and again incentives and terms and conditions will play a part. However, the trials demonstrated that the system itself will play a part in identifying mismatches. Spatial matching allowed these anomalies to be detected and action taken to correct them.

Performance measurement in an operational system

The trials were designed to assess the technical performance of a DSRC system in conditions simulating operational conditions as much as possible. Nevertheless, since trial conditions may differ from such operational conditions in a number of ways and may be more optimal than live operational conditions, the trials were not designed to measure or prove an operational DSRC system.

Trial conditions may differ from operational conditions in a number of different ways. In particular, the wealth of data available to the trials for measuring performance would not be available in an operational system, which would require a much simpler, more efficient method of measuring performance. Such an approach has been put forward by TfL in the performance indicators defined in the subsequent procurement of DSRC equipment. An additional analysis of the trials results was undertaken to obtain an indication of how performance measures obtained in an operational system might differ from the trials results, based on this approach.

From this analysis, it appears that, for a variety of reasons, operational measures of the performance of the technology may be lower from those obtained in the trials. The performance levels set for procurement and for Service Level Agreements should be lower than the performance levels suggested by the trials results. However, consideration should be given as to whether these operational performance measures can be used as they stand, or whether further work needs to be carried out, given that the measures were calculated for a period significantly before the end of the trials and may thus not take into account all improvements and lessons learnt.

Direction detection and insulation and U-turn detection

The mini-zone tests demonstrated that direction insulation and U-turn detection can be effectively implemented. The results of the volunteer tests, particularly in relation to Police drivers, have demonstrated that detection of U-turns is a more significant issue than previously thought. Although the Police form only a small proportion of drivers, there are other groups which are likely to perform U-turns in large numbers, including taxi drivers and delivery drivers. Without a direction insulation/U-turn detection capability it is likely that there would be significant issues in determining precisely what was happening at a charge-point. It is believed that there are no IPR issues with the general method used by the supplier who implemented this facility (although of course the detailed programming would be subject to IPR); however, different manufacturers use different technologies and it is not known whether or not those technologies would permit the implementation of effective direction insulation/U-turn detection capabilities.

Integration of DSRC with ANPR

Integration between an ANPR camera and DSRC systems from two different vendors is feasible and comparable performance to a single supplier solution can be realised. This can be achieved with an ANPR camera with a lens of different focal length and an aim point closer than that used in typical ANPR cameras, giving a partial overlap of detection zones for ANPR cameras and DSRC beacons. No hardware modifications, other than relensing, are required. However, difficulties were faced in developing a repeatable and accurate installation and alignment method. It is expected that these difficulties could be overcome with the correct level of installation crew training.

Inter-scheme interoperability

The mini-zone trials have demonstrated that tags and beacons from different suppliers can successfully interoperate. As part of the Stage 3 Trials, TfL is examining the interoperability of tags with other schemes. Several demonstrations have already proved technical interoperability (i.e. tags from other schemes and the trials beacons mutually recognise each other and are able to communicate). The main implication of interoperability with partner schemes (charging schemes or tag issuers with whom TfL has an interoperability agreement) will be information on security keys and tag-VRM associations will need to be received from partner operators in order that tag equipped vehicles from partner schemes can be processed in a similar way to vehicles equipped with TfL tags. In addition, processes will need to be implemented so that charges can be passed to the partner operator and payments received. All these processes would need to be mirrored so that TfL tags could operate in partner operators' schemes.

Streetscape study

The streetscape integration study has shown that developing infrastructure (poles, outriggers and cabinets) to support equipment for a tag and beacon system, which satisfies the aesthetic and clutter-reduction requirements of streetscape guidance, is possible. Some integration with existing street furniture (lamp-posts, traffic signals) is possible, but in the main DSRC/ANPR equipment is likely to be mounted on stand-alone poles. The streetscape integration study has; through reviews of guidance and design options, the testing of aesthetic improvements to trial sites and conducting 54 case studies of potential DSRC/ANPR sites, identified a series of

design choices, options and guidelines for the implementation of DSRC infrastructure, giving a "toolkit" of potential solutions. However, design is likely to be site-specific, albeit working with this "toolkit" and there will be a need to consult with relevant stakeholders during the design process.

Improvements already made through the knowledge from the trials

The technology trials have already had a significant impact on the development of the operation of the Congestion Charging Scheme:

- Integrated cameras with roadside ANPR and broadband communications from the roadside to the central system have been introduced for the Western Extension and will be used for the Low Emission Zone (LEZ). These changes result in lower setup and operating costs and a communications network which is more resilient and flexible

- The infrastructure being procured under the re-procurement of the main service provider (to cutover in 2009) has been designed to support any future implementation of tag and beacon technology

Achievement of trials' objectives

The trials have met the three objectives set out above.

- **Payment flexibility**. The high levels of detection of DSRC allow for the introduction of user accounts, particularly if more differentiated charging policies are introduced. The trials have demonstrated that there are also possible methods for notifying a driver that he has driven into the zone and prompting him to pay, although there are outstanding issues of accuracy and liability in this area.

- **Allowing for new charging policies**. The high detection rates of DSRC mean that charging policies which rely on single detections become possible, unlike the current area scheme which relies on multiple detections in case one is missed. In addition, the GPS / distance-based charging trials have demonstrated that the introduction of charging by distance driven is possible, provided that certain logistical and operational issues are overcome.

- **Reducing scheme costs**. The trials have already achieved reductions in scheme costs by demonstrating that the use of lower cost roadside ANPR and broadband communications is feasible, allowing these to be procured for the Congestion Charging Western region implementation. DSRC, because of its high accuracy, can in theory reduce the operational costs of processing detection events, although this cost reduction does of course have to be offset against the capital costs of the DSRC infrastructure.

1.   Introduction

1.1.   *Purpose of this Document*

The Congestion Charging (CC) technology trials programme commenced in August 2003 to investigate how new technologies may provide more flexibility for paying the charge, allow for new charging approaches or which may reduce the operating costs of the congestion charging scheme.

Stage 1 of these trials was completed in late 2004 and Stage 2 was completed in July 2006. Previous reports on the trials programme are as follows:

- Stage 1 Report, published in Feb 2005[1].
- Stage 2 Report, published in October 2006[2]. This report was in two parts covering Stage 2 in general and tests of on-board units for distance-based charging

This report presents the final results and conclusions from Stage 3 of the trials, with the exception of the ongoing Stage 3 distance-based charging and back office trials, which are expected to complete in January 2008. This report also summarises at a very high level the key findings of Stages 1 and 2; a later addendum will present the results of the ongoing DBC Stage 3 trial.

1.2.   *Background*

The overall objectives of the trials were to investigate the different technologies available which may:

- give more flexibility for paying the charge
- allow for new charging approaches (policies) or
- reduce the scheme's costs

The main focus of the trials was to identify technologies which could be deployed between 2005 and 2015.

The Stage 1 trials performed "proof of concept" tests of a long list of technologies, trialled, and identified technologies and key design issues to be investigated further.

Technologies selected from the Stage 1 trials were taken forward to Stage 2, which undertook testing on a wider scale. Stage 3 has focused primarily on usability, aesthetics, operational issues and interoperability aspects of the tested solutions.

---

[1] Congestion Charging Technology Trials Stage 1 Report, Transport for London, February 2005. http://www.tfl.gov.uk/tfl/cclondon/cc_publications-library.shtml#trials

[2] Congestion Charging Technology Trials Stage 2 Report, Transport for London, October 2006. http://www.tfl.gov.uk/tfl/cclondon/cc_publications-library.shtml#trials

1.3.　　　*Stage 3 Scope and this Report*

Stage 3 was primarily focused on operational issues relating to the use of tag and beacon (DSRC) technology for charging. These included:

- the design of street furniture to reduce the impact on the streetscape
- integrating new stand-alone tag and beacon with existing ANPR cameras already deployed
- interoperability of a tag and beacon system in London with tag and beacon systems elsewhere in the country (and abroad)
- interoperability between equipment from different suppliers
- on-street trials in the Southwark mini-zone, using test vehicles and volunteer vehicles, to obtain comprehensive results regarding the performance of the system and to identify and address specific technical issues
- tests on test tracks and in the mini-zone to address specific design issues identified during the trials

Chapter 2 summarises the work carried out in Stages 1 and 2, including the findings and conclusions. This chapter is organised around the technologies tested. A section is devoted to each of the groups of related technologies. The work carried out on tag and beacon in Stages 1 and 2 is included in this chapter.

The bulk of the report is devoted to the new work carried out in Stage 3 on tag and beacon (DSRC) and Chapters 3 to 7 discuss different aspects of this work, including the mini-zone trials of Urban Charge Points (UCPs) which integrate DSRC and camera/ANPR technology.

Chapter 9 discusses the implications of the findings of the technology trials for road user charging policy while Chapter 9 sets out the key conclusions.

2. Summary / Review of Stage 1 & 2

2.1. ANPR Cameras and Image Processing

The objective of the work on ANPR (Automatic Number Plate Reading) cameras and image processing in Stages 1 and 2 of the trials was to test how advances in technology since the start of congestion charging could improve the effectiveness and reduce the cost of deploying or operating the system.

The technical infrastructure initially put in place to support congestion charging used analogue cameras at the roadside to capture video images of vehicles, transmitting these images via dedicated fibre-optic cables to a central processing site, where the output from each camera was fed into a separate ANPR device.

The Stage 1 and Stage 2 trials found that:

- it was possible to use one ANPR device to serve two cameras instead of just one, thus potentially cutting costs

- there were new methods of optimising existing cameras to improve the correct read rate of cameras

- new ANPR technology, in particular digital cameras, could improve the correct read rate of cameras

- digital cameras from some manufacturers had a sufficiently wide field of view that a single camera could cover the full width of the carriageway, instead of using one camera per lane

- digital cameras may be suitable for use in a London Congestion Charging scheme. However, there are insufficient standards and therefore significant variations in performance levels between suppliers' products, which would require careful selection at the procurement stage

- locating the ANPR unit at the roadside instead of centrally gave results as good as centralised ANPR

- ANPR units located at the roadside were able to withstand the elevated temperatures experienced due to direct exposure to the sun

- units integrating ANPR and camera gave results almost as good as separate cameras and ANPR units

- passing an image which resulted in an ANPR read with a mid-confidence level through a secondary ANPR unit, using a different algorithm, resulted in ANPR reads with an increased confidence level in a significant number of cases, meaning that the read could be automatically accepted without the need for manual intervention. Images which originally had high or low confidence levels of read could automatically be accepted or rejected – secondary processing did not change the result. The trials identified the thresholds where reads could be automatically accepted, rejected or passed for secondary processing. The use of secondary ANPR processing reduced the number of images which might require manual verification by the order of 50%

- small self-contained units combining cameras and ANPR processors can be easily and cheaply installed on existing street furniture such as traffic signal heads, transmitting results using the data capabilities of mobile phone systems. The performance of such units is comparable to the best of breed of conventional systems. This allows such units to be rapidly deployed as required for specific applications where only VRMs are required, such as journey time monitoring.

2.2. Broadband Communications

The benefits of roadside ANPR processing are the potential for reduced communications costs as live analogue video would no longer need to be brought back to a hub site for every camera. Instead, the roadside ANPR processor would create an evidential record for every passing vehicle, and pass some or all of these to the central evidential store depending on quality and other business rules.

The Stage 1 trials tested whether Digital Subscriber Line (DSL) technology could be used for such communications and demonstrated that they could.

One potential drawback of having roadside ANPR and DSL communications is that there is no direct continuous video feed back to the control office. However many applications do not require real-time viewing of video images; in particular, congestion charging does not need such real-time surveillance for enforcement purposes. The trial demonstrated that when necessary single images could be retrieved for maintenance and diagnostic purposes.

2.3. DSRC Tag and Beacon

2.3.1. Technology Overview

"Tag and beacon" technology uses a small piece of equipment (the "tag") on board the vehicle and small roadside transceivers ("beacons") to detect passing vehicles equipped with tags. Beacons can be positioned at strategic points in and around the congestion zone or at the entrance or exit to toll road sections.

A tag carries a unique identifier which can be linked to the Vehicle Registration Mark (VRM) and/or the customer through a database lookup. Tags can also carry other information about the vehicle, including, for example, the VRM, vehicle class, whether the vehicle is exempt from a charge and the account number to which fees for road use should be charged. As the vehicle with the tag passes the beacon, the beacon communicates with it, using low power radio, microwave or infra-red (IR) transmissions. The tag sends to the beacon the required information (e.g. tag identifier, VRM, exemption, account id etc.) in a secure manner to complete a transaction.

Tag and beacon technology is in wide use – for example, it is used to implement tolls on many motorways, bridges and other river crossings (e.g. the Dartford crossing). However, it has rarely been used in an urban freeflow environment, which has significant differences from these "traditional" environments. For example:

- in urban environments traffic is not constrained to specific lanes and may be on the wrong side of the road and therefore apparently heading in the opposite direction to that expected

- traditional environments use gantries across the road for mounting the DSRC beacons, allowing simple unobscured coverage of lanes, but such gantries may be unacceptable in an urban environment close to historic buildings or where the "Streetscape" has been coordinated or designed. Consequently, the beacon equipment would have to be mounted in a way that minimised streetscape impact.

The standard protocol for tag and beacon is microwave-based Dedicated Short Range Communications (DSRC); the trials focused on this type of solution from multiple manufacturers. Limited tests were carried out on an Infra-Red (IR)-based DSRC system. However, at present the IR variety is not recognised by UK or European Commission legislation and it was not taken further than Stage 2.

As it cannot be assumed that all vehicles will be equipped with tags or that the tags will be working properly, it will still be necessary, for enforcement purposes, to capture the image of the vehicle as it passes the beacon and the image will need to be matched to the tag transaction.

2.3.2.   Stage 1 Overview

The aim of Stage 1 of the DSRC (Dedicated Short-Range Communications) trials was to test whether an Urban Charge Point (UCP) comprising a DSRC microwave beacon and ANPR camera equipment mounted on a pole and outrigger was a feasible concept. Stage 1 of the trials demonstrated that it was and that such a UCP can operate on typical London streets with an achievable DSRC tag detection rate of > 99.5%. It proved almost impossible to deliberately avoid detection. The trials showed that it is possible to cover an 8m wide two-lane single-direction carriageway from a pole with a 1.5m outrigger overhang over the carriageway and a 10m wide bi-directional carriageway from a pole with a 4m outrigger overhang over the carriageway.

Whilst placement of the DSRC equipment at the roadside (rather than on an overhead gantry) would be preferable (from an aesthetic and outrigger loading view), this increases the possibility of obscuration by high-sided vehicles. On-street and test track trials tested this in a practical situation. To complement these trials, obscuration modelling was carried out to establish theoretical obscuration effects. For a 7m wide road, there is no DSRC obscuration with a 3.5m outrigger and DSRC obscuration only starts to occur with a 2.5m outrigger when the height of the outrigger drops below 6m; however, a 1.5m outrigger requires a minimum height of 7.5m.

The DSRC and camera/ANPR sub-systems of a UCP produce separate datastreams of vehicle detections. In order that a single vehicle passage is not processed twice (once for each datastream), which might introduce errors and increase costs, it is necessary to "match" the received information of the tag transaction with a relevant image of a Vehicle Registration Mark (VRM). Such matching also provides an additional evidential record to back up the record of a tag transaction. Certain methods of matching, such as tags declaring their VRM or predefined roadside mapping of tags to VRMs are seen as potentially impractical when scaled up and have problems with interoperability and privacy. Spatial matching is a third method which uses accurate timing, tag localisation and VRM localisation data to spatially co-ordinate DRSC transactions and ANPR passages. This method requires no predefined mapping of tags and VRMs.

Although existing DSRC systems already carry out spatial matching using the DSRC system to control the VRM capture on gantries, this is the first time it has been done with a self-triggered VRM system in skewed geometries from the roadside. A prototype spatial matching process was developed and tested. A 95.5% level of correct matches was achieved.

2.3.3.   Stage 2 Overview

In Stage 2, the concept of an integrated Urban Charge Point (UCP) was developed further. This included mounting the DSRC and ANPR (Automatic Number Plate Recognition) sub-systems on a single pole and integrating them at the roadside and ensuring that a series of UCPs would work together to provide an overall system solution

The core of the Stage 2 and Stage 3 on-street trials was the establishment of a "mini-zone" consisting of UCPs at 20 sites, shown in Figure 2-1 below.

Two suppliers were initially selected to demonstrate their off-the-shelf UCP designs, each at a trial site within the mini-zone. One supplier was then selected to provide UCPs for the rest of the mini-zone. UCPs at nineteen of the twenty sites forming the mini-zone were thus provided by one supplier, with the other supplier providing the UCPs at a single site.
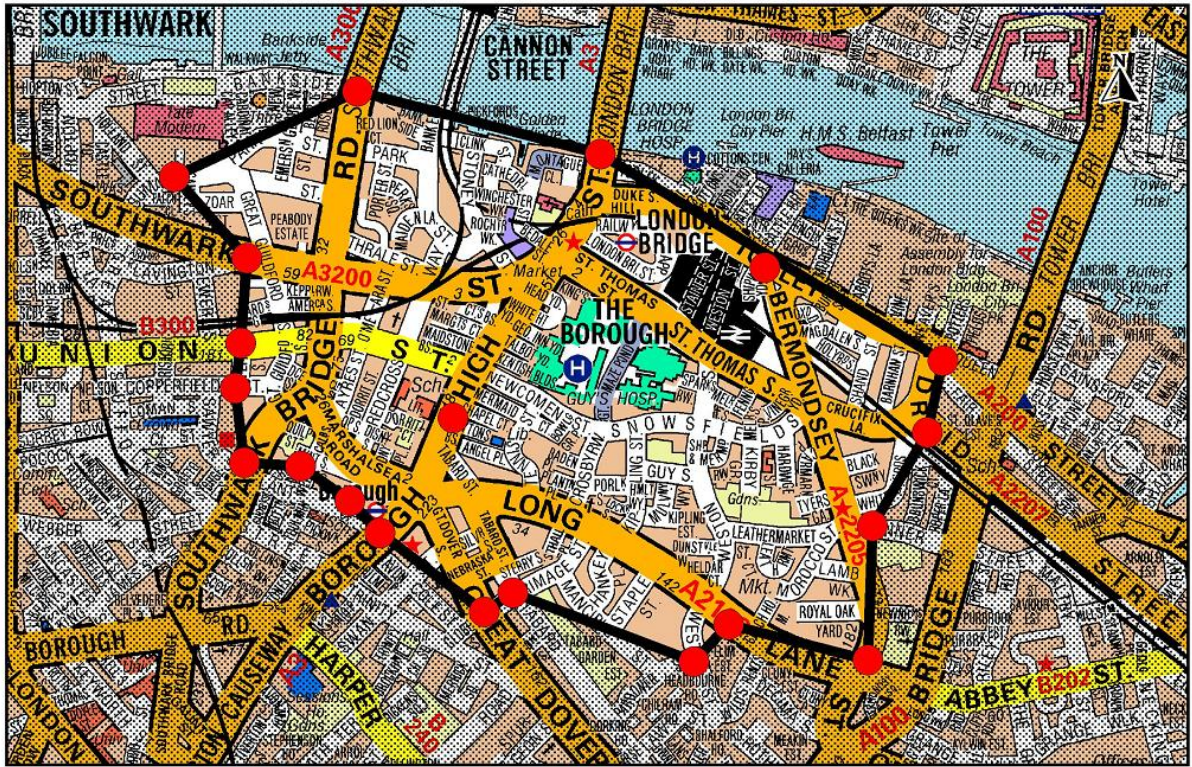
This map is reproduced from Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. (GLA)(100032379) (2002)

Figure 2-1: Map of the "mini-zone" trials area

The sites used for the UCPs were chosen to give a representative distribution of site types, covering different carriageway widths, traffic patterns and complexities such as crossings, parking, bus lanes etc. Details of the trials methodology and infrastructure were set out in the Stage 2 Report and are not repeated here.

2.3.4. Stage 1 & 2 Design Issues

The trials examined a number of design issues which would need to be addressed to allow a DSRC system to be deployed in London. The design issues covered in Stages 1 and 2 and already reported in previous reports are summarised here. Design issues addressed in Stage 3 are covered in Chapter 7 below.

2.3.4.1. Single Pole Design

The key overall design issue for DSRC is ensuring that the communications footprint of the microwave transceiver is coincident with the capture zone of the accompanying enforcement cameras, whilst adhering to the constraints of the London environment:

- no overhead gantries
- minimising the number of poles, for both cost and aesthetic reasons
- keeping the power output of the transceiver within appropriate limits.

Without coincident zones, spatial matching between the passage of a car recorded by the camera / ANPR system and the transaction between the tag and the roadside system is not generally possible.

In order for an enforcement camera to obtain a sufficiently good image for the ANPR system to process, the camera must be set at a sufficiently shallow angle. In the configuration used in the original Central London Congestion Charging Scheme, this means that the zone observed by the camera is some 20m away from the pole on which it is mounted, whilst the range of

DSRC transceivers is typically 8m when mounted on a 6m pole. Therefore, in order for the two zones to be coincident, the DSRC transceiver and ANPR cameras need to be mounted on separate poles. In the London environment two poles may not be acceptable. The trials explored how the DSRC and camera configurations could be adjusted to allow them to be mounted on a single pole.

A single pole solution was successfully demonstrated in Stage 1.

2.3.4.2. Battery Drain

Assuming that DSRC charge-points would be sited at the locations of existing Congestion Charging cameras, for a large proportion of these locations there may be vehicle parking bays coincident with the DSRC communications zone of the charge-point. There is little or no scope for siting charge-points away from the parking bays, due to the physical site layout, furthermore the bays themselves cannot be removed. Most of the parking bays are also long term residential; thus vehicles may be left in the same spaces for quite considerable lengths of time. In such a situation, it is possible that a tag left in such a vehicle could continuously interact with the DSRC beacon, draining the battery and reducing battery life from 5-7 years to as little as 30 days. This would pose obvious practical, logistical and credibility issues for a DSRC scheme deployment.

Stage 2 of the trials examined the scope and impact of the problem, examining battery performance in different scenarios of parking behaviour and using tags from different manufacturers.

The analysis indicated that less than 1% of residential vehicles will be affected by the battery drain scenarios which would reduce the battery life below 7 years. Even in those cases, the battery life would remain above 5 years. This is based on tags which have a function which, when the tag is activated, places the tag into sleep mode for 3 seconds if it determines that the tag is still in the communication zone of the beacon that it last communicated with. The tag is active for some 11 milliseconds between sleep periods, i.e. for only 0.4% of the time that it is in the communication zone.

There is one particular set of circumstances where, despite the sleep option described above, the tag's battery life would be very quickly drained. This is where the tag is at the edge of the communication zone, but this applies only for a distance of approximately 0.5 metres at the edge of the communications zone. The number of vehicles thus affected can therefore be expected to be very small.

Assuming an appropriate procurement strategy is adopted by TfL, i.e. tags with an appropriate high ratio of sleep to active periods, none of the battery drain scenarios will result in a battery life of less than five years, given the expected number of DSRC events in London. Most DSRC suppliers' current products have advanced battery management solutions to tackle the issues of battery drain in an urban environment.

It remains possible that tags from other schemes which do not incorporate this design feature could be affected by long term parking within the DSRC communications zone of a chargepoint. However, it is considered unlikely that tags from non-London schemes would be installed in residents' vehicles, which are the ones most likely to be affected.

In addition, as DSRC schemes spread around the UK and Europe, all tags (whether from a TfL scheme or not) would undertake transactions more frequently, which would also tend to decrease battery life. Both these cases are ones over which TfL has no control; as the trials only had access to the tags supplied for the trials themselves, no empirical data are available as to how the mini-zone may have affected other schemes' tags in these respects.

Where parking bays are coincident with DSRC equipped sites there are a number of options that can be considered at the initial site survey and design phase to reduce the potential impact of battery drain which can be considered on a site by site basis:-

- Modifying DSRC communication zone coverage strategy at an individual site

- Switching off DSRC equipment out of charging hours

- Switching off DSRC equipment when no moving traffic is detected

- Changing the pole location

- Removing parking bays and creating build outs to facilitate pedestrian crossing

2.3.4.3. On-board charging

On-board charging is based around the concept of an intelligent OBU which holds an account balance and which is able to charge that account as the vehicle passes a charge-point. Stage 2 of the trials carried out a desk study of this. An OBU used for on-board charging can be either a monolithic OBU or a two-part system with a card (ICC) inserted into an OBU. There are potentially 3 ICCs that could be considered for on-board charging solutions for congestion charging: Oystercard, EMV cards as used for "chip and pin" and ITSO cards (the national standard for smartcard based ticketing for public transport).

Charge points would have to hold tariff tables and calculate charges at the roadside. Schemes which require central processing, such as those with a daily flat rate charge, would have difficulty charging at the roadside and avoiding charging where it has already been levied. Since, in London, the charge is related to the vehicle, the use of cards for on-board charging opens up fraud possibilities which would need to be addressed.

Depending on the OBU selected, it may be the case that in order to achieve the required transaction time, a pole on each side of the road would be required to give a bigger communication zone, rather than a single pole covering both sides. This remains to be validated.

On-board-charging has been implemented in a very limited number of operational schemes and in a small number of technical trials. Most of these trials have been performed with schemes which are not optimised for applications which require short transaction times such as would be required for London's Congestion Charging scheme. There are no agreed standards for on-board charging either at a national or at a European level.

2.3.4.4. Face-to-face Charge-Points

DSRC beacons interact with tags in the front windscreen of a vehicle and need to be facing the windscreen in order to carry out the transaction. Therefore, for a single carriageway road with two-way traffic, it would be necessary to have two UCPs, one to face each direction of traffic. Normally, these would be mounted "back-to-back" on the same outrigger.

This configuration requires 30m of unrestricted carriageway. However, site surveys have shown that there are a significant number of cases where this amount of free carriageway is not available. This may be due to tree-lined avenues, mews roads only a short distance from boundary points or various obstructions. In such cases, the only possible physical configuration is to split the UCPs and place them on separate poles and outriggers in a face-to-face configuration, accepting the consequent increase in street furniture. A number of different configurations are possible, but in all cases DSRC beacons would be facing each other.

However, results from the Stage 1 trials indicated that the minimum distance between charge points to eliminate interference between the DSRC elements was 50m – significantly more than the 30m (or less) which would separate the face-to-face UCPs. One of the design issues investigated as part of the trials was how interference between face-to-face chargepoints less than 50m apart could be addressed, as well as how the data streams from the two charge points could be synchronised.

In Stage 2, desk studies and tests at the supplier's test site showed that the theoretical minimum distance of 50m is in practice 24m and that this can be reduced further to 15m by having the facing beacons use different non-adjacent channels and by techniques known as beacon and bit synchronisation.

Table 2-2 below shows the results of the tests, showing that there is no performance degradation for a face to face configuration.

Expected number of Events	1,190
DSRC Transactions completed	1,190 – 100%
Images captured	1,189 – 99.9%
Correct ANPR Result	1,182 – 99.3%
Correct Spatial Match Result	1,187 – 99.7%

Table 2-2: Face-to-face Demonstration results

The tests at the supplier's test site only tested one configuration of the face to face chargepoints, but this was chosen to be the configuration which represented the worst case configuration; the results can therefore be applied with confidence to other configurations. The design study concluded that face to face charge-points can be implemented when the length of free carriageway does not permit back to back ones.

2.3.4.5. Front to rear matching

Ideally, spatial matching of DSRC transactions and ANPR reads of VRMs is done from UCP equipment mounted on a single roadside pole and outrigger, where the transaction zone of the DSRC beacon and the capture zone of the ANPR camera overlap. For a bi-directional carriageway, the two UCPs monitoring each direction of travel are ideally mounted "back-to-back" on a single pole, but, as discussed in Section 2.3.4.4 above, face-to-face UCPs mounted on two separate poles may be required. However, these two configurations may not necessarily address siting issues in all cases. In some cases the geography of the site may dictate that rather than having the ANPR camera and the DSRC transceiver on the same pole it is necessary to have the ANPR camera on one pole and the DSRC transceiver on another. In this case it is necessary to match the tag transaction with the ANPR read of a rear number plate; the normal requirement for spatial matching is to match the tag transaction with the ANPR read of a front number plate, since the tag is mounted in the front windscreen of a vehicle.

The Stage 2 trials demonstrated that it is possible to perform such front-to-rear matching. However, different classes of vehicle require different separations of the two poles for optimum performance of the UCP. A small vehicle such as a standard car requires a separation of some 15m, whilst a large vehicle such as a bus or HGV requires a separation of some 25m. A UCP using front to rear matching which is optimised for one class of vehicle is likely to perform less well for other classes. Thus the choice of geometry (i.e. the distance between poles) must be optimised not only for the site, but also for the expected vehicle fleet.

A secondary consideration for front-to-rear spatial matching is the possibility that it may be more difficult to detect and read rear number plates than front number plates, either because of inherent properties of a rear number plate or because a rear number plate is more prone to obscuration. Trials have demonstrated that, in fact, with front to rear geometries, the level of obscuration will be similar to the normal charge point geometry.

2.3.4.6. Infra-Red DSRC

Although microwave based DSRC is widely used around the world, it is not the only version of DSRC tag and beacon technology available. A version is also widely deployed which uses Infra-red (IR) instead of microwaves to communicate between the roadside beacon and the tag. The trials also examined this variant of the technology.

Due to commercial difficulties, it was not possible to commence a trial of this technology until late in the trials process and the trials were therefore only conducted at a test track and not at a roadside location. The tests focused on those key elements of IR DSRC which could offer benefits over and above microwave DSRC.

The results showed that IR DSRC technology is adaptable, may solve some of the issues relating to microwave DSRC and is suitable for further trials on road and with some form of integration with an ANPR camera system.

However, there are a number of areas which were not investigated and which would need to be addressed before IR DSRC could be considered as a candidate for implementation:

- integration of IR DSRC with ANPR systems
- tag localisation and spatial matching
- direction insulation
- competition issues

In particular, IR DSRC is not recognised by UK or European Commission legislation and it was not taken further than Stage 2.

2.3.5. Deployment Approach

Within the mini-zone trial, each UCP has been a unique design. In a more extensive deployment, involving hundreds of sites, it may not be practical to design each UCP individually. TfL is therefore aiming to develop a modular, systematic approach addressing all the practical and logistical issues of a large scale roll-out. This part of the trials aimed to develop a complete view of the step-by-step roll-out of charge-points for a London zone, with a defined "toolbox" of UCPs to cover London's diverse charge-point configurations and also a practical plan for roadside roll-out with the objective of de-risking the roll-out.

In an actual major deployment, the delivery team should be able to pick up this blueprint and use it to plan and execute the roll-out. It should:

- determine all the equipment needed at each site
- provide a checklist for developing the plan of logistics for getting all the equipment to sites
- provide a checklist for planning site installation
- include any UCP tuning required for particularly difficult site configurations
- provide a checklist for the commissioning of sites onto the network.

General rules have been developed to configure a site, covering:

- numbers of DSRC beacons and ANPR and overview cameras
- outrigger length
- pole height
- equipment mounting locations on the outrigger
- site configuration based on road width

From these rules, seven detailed configurations have been developed for single directional sites, based on road widths and eight configurations for bidirectional sites without a central divided between the directions. A divided bidirectional site would be treated as two single directional sites of appropriate road width.

Key recommendations and findings include:

- the system is designed for a pole height of 7m +/- 25cm. It is possible to use poles of a lower height but with some reduction in performance

- two poles should be used for all roads above ten metres width. This recommendation is based on both performance and on the fact that 2 poles are more aesthetically acceptable than a pole with an outrigger of greater than 4 metres

The site configurations are specific to one supplier and will differ for each supplier. However, it is expected that the differences will be in the detail, rather than being of a fundamental nature.

2.4.   Mobile Positioning Systems

2.4.1.   Overview

The use of camera / ANPR and tag and beacon technologies as means of charging and enforcing a congestion charging system requires the implementation of an extensive (and expensive) fixed infrastructure. This infrastructure also means that charging and enforcement can only take place at those points where infrastructure is present. By contrast, satellite positioning systems, generally known as GPS, and mobile telephone (GSM) systems require no additional infrastructure to be put in place and are able, in principle, to establish the position of a vehicle anywhere. In addition, GSM handsets have become ubiquitous and GPS systems are becoming more and more widespread, both built into vehicles at manufacture and as handheld units.   The mobile positioning systems part of the technology trials sought to establish whether the flexibility and ubiquity of these systems could be harnessed to support congestion charging.

The Stage 1 and Stage 2 trials focused on the collection and analysis of comparable location and detection data from a variety of Global Positioning System (GPS) and GSM Mobile devices to ascertain the performance of various technologies within London.

The trial collected three main categories of positioning data:

- GPS location fixes from a variety of GPS devices including GPS enabled mobile phones

- GSM-based location fixes via the Location Based Services (LBS) of the four major mobile network operators

- cell identities (Cell Ids) and coverage of mobile networks in Central London

The positions thus reported were compared to the known positions obtained through ground-truthing using a number of techniques.

The Stage 3 trials built on these results to conduct a trial of distance based charging, where vehicles are charged according to the distance that they travel, the time that they travel and the class of roads that they travel on.

2.4.2.   GPS

2.4.2.1.   Technology Overview

The Global Positioning System (GPS) became operational in 1994. It is a system of 24 satellites orbiting the earth in 6 different orbital planes, each transmitting a unique identification signal, orbit information and a precise time signal defined by an onboard atomic clock. At any one time, at any point on earth, there are 5-8 satellites above the horizon, from which a GPS receiver on earth would in principle be able to receive a signal. Not all these 5-8 satellites would in fact be visible, due to blockage by buildings, hills etc.

By calculating the difference between the times of arrival of signals from the visible satellites, a GPS receiver is able to calculate its position. The more satellites that it can see, the more accurately it can calculate its position.

Due to factors such as orbital variations, atmospheric conditions or a signal from a satellite being received multiple times due to being bounced off buildings, the position calculated is not in fact a single position. Rather it is an ellipse within which the position may lie. The GPS receiver reports both the position at the centre of that ellipse and the parameters defining the shape and size of the ellipse. The more satellites that are visible, the smaller the size of the ellipse.

GPS is a specific instance of a generic technology called Global Navigation Satellite Systems (GNSS). In practice, the term GPS is used generically as well as specifically and the term GNSS is rarely used.

2.4.2.2.   GPS Stage 1 Results

On average, the positions reported by the GPS devices tested were approximately 15m in error. However, this average concealed a wide distribution and errors of up to a kilometre were detected (although they were rare). If London's congestion charging scheme were to rely on single positions reported by OBUs, a buffer zone of 57m on average would be required for the system to be 99% confident that a position which was reported as being inside the zone was actually in the zone. This was for the "average" device – in order to be able to cope with the worst performing devices, this buffer zone might need to be extended to 93m on average. In some areas, where "urban canyons" of tall buildings result in satellite signals being reflected, this buffer zone would need to be extended to about 250m for the average device and more for the worst performing device. The conclusion drawn was that individual positions reported by GPS devices did not provide **on their own** the accuracy required to be used for a congestion charging scheme.

2.4.2.3.   GPS Stage 2 Results

Although the Stage 1 trials indicated that the performance of GPS in the Central London area was too poor to form the basis of a robust enforcement system, it was however accepted that advances in GPS technology and various enhancements to the current GPS systems could significantly improve the performance of GPS and might allow its use in the future. The Stage 2 trials therefore tested:

- GPS units which used enhanced technology and GPS units incorporated into 3G mobile handsets, which can combine GPS data with location data from the 3G network

- two different techniques for stand-alone GPS units to detect and self-correct errors arising from poor reception or poor satellite observation

- commercially available OBUs and fleet management systems which claim to be able to identify whether a vehicle has entered the Congestion Charging zone

- the efficacy of various map matching techniques

Enhanced GPS devices

The enhanced devices tested in Stage 2 did not provide any significant improvements over Stage 1.

Error-correcting techniques

There are two basic approaches to this:

- single fix correction

- Kalman filtering.

The single fix technique examines "residual errors" in positions that are calculated from satellites. On the basis of this analysis, readings giving low quality data are discarded in an iterative process. However, each position is considered in isolation.

The trials demonstrated that whilst the technique is able to remove erroneous positions, in order to eliminate the majority of these erroneous positions, the degree of filtering had to be made so stringent that the proportion of positions reported which were considered acceptable dropped to 30% and in some cases as low as 10%. In particular the technique was unable to cope adequately with consistent, correlated errors, such as where along the length of a road a set of satellites is hidden and subject to multi-path reflections.

A Kalman filter interprets a given position estimate reported by the GPS unit in the light of previous estimates. A Kalman filter gives large performance improvements because it can operate for short periods with only two or three satellites, and because it greatly smoothes random positioning noise. However this also means that if an error creeps into the filter due to a non-random set of errors, (for example several satellites blocked and operating on reflections from one side only), while slow to go wrong, it is also slow to recover. No specific tests were carried out on Kalman filters but some of the units tested in Stages 1 and 2 incorporated Kalman filters and these did not perform significantly better than other units.

Commercially available systems

The trials team commissioned a separate demonstration of a commercial GPS OBU programmed to detect whether the vehicle had entered the congestion charging zone or not. The demonstration was not carried out by the trials team and cannot be considered as a rigorous trial.

The system demonstrated, whilst it detected every transition into and out of the zone, proved to have a typical latency of some 75m before reporting that it had made the transition. No tests were carried out as to whether it erroneously detected any entries or whether it was able to successfully detect any short incursions. The system does not appear to provide any significant improvement over generic GPS devices tested in Stage 1.

Two commercially available fleet management systems were also tested using GPS devices sending data over GPRS links. Both systems relied on so-called "geo-fences". A geo-fence is a set of geographical coordinates which define a virtual boundary. The systems report when the vehicle enters the area bounded by the geo-fence and then when it leaves the bounded area.

Only limited results are available. One system had a 100% success rate in detecting geo-fences, whilst the other had a 50% success rate. In both cases, reporting of entry was prompt in 99% of cases. The overall accuracy of the systems proved to be worse than the results of the Stage 1 trials. At the 99% confidence level, the error margin for System A was 64m, whilst for System B it was 113m, compared to a Stage 1 99% confidence level of 57m.

Map-matching

The Stage 1 trials demonstrated that reported GPS positions were insufficiently accurate to serve, on their own, as the basis of an urban congestion charging scheme. One common use of GPS is in-car navigation systems, which use an electronic map combined with reported GPS positions to deduce which road segment the vehicle is on and thus adjust the reported position. Such adjustments can be carried out using a number of different algorithms. The Stage 2 trials tested six such algorithms.

The trials results suggested that the map matching algorithms tested were insufficiently accurate for use in an urban congestion charging scheme, as they incorrectly detected vehicles as being within the zone for 5% of each journey and, more generally, showed the vehicle as being on an incorrect road segment between 20% and 75% of the time, which for different road charging schemes could result in the vehicle being incorrectly charged. It should be noted that these were generic algorithms designed for the trials, rather than proprietary ones actually used in satellite navigation systems, which could be expected to have superior performance. Such proprietary systems were tested in the Distance Based Charging Trials.

2.4.2.4. GPS Conclusion

The trials have demonstrated that GPS is not sufficiently accurate **on its own** to allow a road user charging system to rely on the accuracy of any individual reported point. The accuracy of virtual gantries appears to be adequate. Although such virtual gantries have the virtue of no roadside infrastructure and therefore could be set up anywhere and at any time they would still require OBUs to be installed in the national vehicle fleet and a back-office infrastructure to be established to process the reported positions. If that effort is being undertaken, it is likely that a fully fledged distance-based charging system would be implemented.

2.4.3. Future Increases in Satellite Navigation System Accuracy

Stage 1 of the trials demonstrated that the accuracy of the individual positions reported by satellite navigation systems was inadequate (on its own, without map-matching) to support congestion charging. Stage 2 of the trials examined how future developments in satellite technology might improve the accuracy of the individual positions, which would improve the overall accuracy of map-matching systems, but could also open the way for individual reported positions to be used as the basis of charging or VAS. These developments include:

- the further development of the European Space Agency's (ESA's) EGNOS (European Geostationary Navigation Overlay System) system. This consists of a series of ground-stations whose true position is known with a high degree of accuracy. Each station continually calculates its position from GPS signals and the difference between this calculated position and the known true position allows an error correction to be calculated. The error correction from all the ground-stations is integrated and broadcast, either via geo-stationary satellites or via SISNET (GPRS). This allows GPS receivers with the ability to receive this corrective signal to correct some inaccuracies in GPS

- the implementation of ESA's Galileo satellite navigation system. This is a similar system to GPS. It is due to be launched in 2010 and completed in 2012 and will have 27 satellites (plus 3 spares), compared with 24 (plus 3 spares) for GPS. Galileo satellites will be positioned in different orbits to GPS satellites and will have 12 satellites in view at any one time, compared to GPS' 8. A similar system to EGNOS will calculate a corrective signal for Galileo, which will be broadcast via the Galileo satellites themselves, unlike the corrective signal for GPS, which is broadcast via separate geostationary satellites or GPRS. Thus all Galileo receivers will receive this corrective signal which allows a probability of accuracy to be calculated (i.e. that it is x% likely that the true position is within y distance of the calculated position) allowing positions to be corrected or those with low accuracy probability to be ignored

The key determinant of satellite navigation accuracy is the number of satellites directly visible to the on-board unit – at least 4 are required for a good fix and the more that are visible, the better the fix is likely to be. The trials used a software tool to model the number of satellites visible from any point in the original Congestion Charging region at any moment in time, for the current GPS system, for GPS + EGNOS and for the combination of GPS, EGNOS and Galileo. Although the EGNOS satellite does not broadcast a GPS signal, the increase in accuracy due to the corrective information that it broadcasts is equivalent to being able to see an additional GPS satellite, *provided that a minimum of 4 GPS satellites can be seen*; thus for the purposes of this modelling it was treated as an additional GPS satellite where at least 4 could be seen and ignored otherwise.

Preliminary analysis shows that the introduction of EGNOS on its own will not significantly increase satellite visibility in London. However, as expected, Galileo will significantly increase satellite visibility, although this increase in visibility is not uniform. Currently 33% of the road length in Central London does not allow the critical "4 visible satellites" threshold to be crossed. The introduction of Galileo will reduce this to 7% but there will remain road sections with inadequate satellite visibility.

2.4.4. Distance Based Charging

2.4.4.1. Overview

One possible method of implementing road user charging, is distance based charging; where vehicles are charged according to how far they drive along different classes of road, with tariffs potentially varying by class of road, day of the week and time of day. If introduced, it is likely that this would be based around satellite positioning technologies, such as GPS, with each vehicle carrying an on-board unit (OBU) which uses this technology to detect its position.

The objective of the trial was to take forward the Stage 1 and Stage 2 trials of GPS units and the Stage 2 map-matching trial to better understand how accurately a complete GPS-based system would be able to charge for a journey in London and hence to evaluate the technical feasibility of a complete distance based charging scheme. Systems from fourteen vendors were tested in this part of the trials.

The raw location data from the on-board units were processed through different combinations of:

- TfL mapping data / vendors' mapping data
- TfL map-matching algorithm / vendors' map-matching algorithm
- TfL billing / vendors' billing system

At the level of average single point location performance, there was little difference between the different OBUs tested, with the exception of one OBU which performed significantly worse than the others, although there were wide variations at any given location. The different chipsets used in the OBUs did not have a significant impact on the results, nor did the sensitivity of the OBUs (the ability to detect weaker signals).

However, the average error had significantly decreased since the Stage 1 trials were completed two years ago. At that time the average error was 9.7m; this had now reduced to 6.8m, a reduction of 30%. Similarly, the error margin for the 99% average confidence level had fallen from 57m to 39m; this is the distance from the actual location that 99% of readings will fall within. This increase in accuracy can be expected to continue with continuing improvements in receiver technology. However, there is an (as yet unknown) limit on this increase; as discussed above, problems relating to "urban canyons", namely multi-path reflection and a limited number of satellites in view, will always remain, degrading accuracy.

At the map-matching level, the key factor affecting accuracy was the sampling rate (how often an OBU reported its position). Systems which used a high sampling rate (1 position per second) gave the best performance. It should be noted that the sampling rate claimed by vendors was not always the same as the sampling rate actually detected. The impact of map-matching algorithm used (the vendor's own or TfL's) and the quality of the mapping data used (TfL's high quality truthing data or other mapping data, typically Navteq or Teleatlas) was difficult to assess. The only consistent factors were that:

- for a given device, the results from the vendor's map-matching algorithm (some of which used TfL mapping data and some of which used other mapping data) were better than from TfL's map-matching algorithm, using TfL mapping data

- generally, combinations using TfL mapping data performed better than those using other mapping data

It is notable that OBUs which gave the best results at the location level did not necessarily give the best results at the map-matching level; similarly OBUs giving the worst location level results did not necessarily give the worst map-matching results. Map matching performance of the best performing system was significantly better than the results obtained in Stage 2. This was as expected; the algorithms used in Stage 2 were generic ones designed for the trials, whilst the algorithms used in distance-based charging systems were proprietary ones refined over a period of years.

Overall billing level performance was closely correlated with map-matching level performance. However, an over-estimation of journey length did not necessarily result in an over-estimation of cost; the over-estimation of journey length would typically arise through replacing correct segments with incorrect ones – if the incorrect ones had a lower tariff, a lower journey cost would arise.

Map-matching and billing performance varied substantially between vendors. The best vendor had a billing performance between 0.5% and 1% different from the true charge.
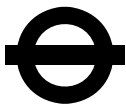
2.4.4.2.   *Current DBC Conclusion*

DBC can be regarded as the "Gold Standard" of road user charging or congestion charging, being able to charge users by time of day, road type, specific roads, distance travelled and direction. DBC systems are based on GPS mobile positioning, combined with map-matching.

The trials have demonstrated that the best available systems (based on a purely hypothetical charging scheme) are sufficiently accurate to serve as the basis of a distance based charging scheme, although some systems tested were wildly inaccurate. The best systems had charging errors of about 1%, which compares favourably with the performance quoted for taxis and tachometers of approximately +/- 4%. The key factors in performance were not the accuracy of the OBU, but its frequency of reporting and the quality of the map-matching algorithm.

Although the best systems performed very well overall, even they produced significant errors in certain parts of London, characterised by "urban canyons". Such urban canyons mean not only that there is a restricted view of the sky and hence that a GPS OBU cannot see the minimum of four satellites needed to get an accurate positional fix, but also that reflections of the satellite signals from buildings distort those signals as received by the OBU and hence produce positioning errors. These errors are particularly difficult to detect and cure as they tend to be correlated, producing a consistent error (e.g. moving all positions 30m to the North) rather than random errors. Whilst the introduction of Galileo (scheduled for 2010-2012) will alleviate these problems to some extent, there will still be some parts of London which, even with Galileo, will not have sufficient visibility of four satellites to permit a firm location fix and which will be subject to multi-path analysis.

It is likely therefore that if a DBC charging system were to be introduced in London, some form of fill-in data would need to be provided to OBUs in these difficult areas. For example, additional transmitters transmitting a GPS signal could be installed at key locations in London, providing an extra signal. Precisely how such a system would work, its accuracy and its cost are unknown at present. Alternatively, a dense system of DSRC beacons, interacting with an OBU which combines DSRC and GPS, could be installed in these difficult areas to provide supplementary positioning data.

In conclusion, from a technical point of view, it is possible to start introducing satellite based DBC systems now, providing that it is accepted that there are some areas of London where there will be some inaccuracies and that only some service providers would be able to provide adequate accuracy. The advent of Galileo in around 2010/2012 will reduce (but not eliminate) the inaccuracies and the OBU technology is likely to be technically mature by then, if not significantly earlier. There is a question as to whether Galileo will be implemented at all and, if so, whether it will happen on time. The project has suffered from significant funding difficulties and delays and, in addition, some (but not all) of its technical advantages have already disappeared with improvements in GPS technology. Nevertheless, as it is in many ways a political project, it is likely to be implemented, albeit that one can expect the implementation date to slip significantly.

There are a number of other, logistical and operational, issues which need to be resolved prior to the introduction of this technology. These include:

- what will be the enforcement approach for a widespread satellite based system?

- how can privacy be ensured, when by the nature of the system, position data is continually being gathered?

- the interoperability of different DBC schemes in the UK and abroad

- the accuracy of mapping information

- equipping the vehicle fleet with OBUs - will a dashboard mounted, cigarette lighter powered OBU be sufficiently robust or will a permanently installed OBU be required? If the latter, will it be factory installed or retro-fitted? It is our understanding that no legal powers currently exist in the UK to mandate the fitting of such a device.

As with tag and beacon, a self-reporting DBC scheme which relies on an OBU reporting its position means that there is a temptation for users to simply switch the OBU off so that no positions are reported and hence no charge is incurred. Some enforcement mechanism is therefore required.

The German Toll-Collect system covers 12,000 km of motorway and carries out enforcement by means of 300 fixed and 300 mobile units interrogating the OBUs of lorries as they pass the enforcement unit. The enforcement unit reads the VRM of the lorry using ANPR technology and interrogates the OBU using DSRC technology. If the OBU responds correctly, then the image and VRM are deleted; otherwise they are retained for enforcement.

For a motorway system, with a relatively low density of junctions, and targeted at lorries which will generally drive significantly longer distances than the 40km between static enforcement units, this provides a high degree of deterrence. However, extrapolating to London or to the whole of the UK beyond the motorway system requires balancing a sufficient density of enforcement units with acceptable costs. For the original Congestion Charging region, with an existing boundary of fixed sites and a number of internal sites, enforcement would be likely to be a small incremental cost. However, beyond this, an adequate enforcement infrastructure may prove unacceptably costly. Depending on the evidential requirements that may be set by the courts, infrastructure based on integrated camera/ANPR equipment could be integrated with GPRS and DSRC to provide a low-cost infrastructure solution. Back-office software could also be used to determine whether a newly reported position or set of positions was compatible with the last known position; this could be used to deter users from switching off the OBU for those parts of the journey where they believe that they are unlikely to be detected by enforcement infrastructure.

An effective DBC scheme relies on accurate mapping data. Accuracy in this case relates not only to geographical accuracy and differentiation (are the coordinates of a particular road junction correct and provided to the right level of granularity? are coordinates given for both side of a carriageway or only for the centre of the road?) but also to accuracy in time (what is the delay between a change occurring to the road network and an update to the mapping information? how frequently are those updates provided to the system?). The geographical accuracy required depends on the policy desired. For example, a scheme simply charging on the basis of distance travelled requires less accuracy than one differentiating on the basis of direction or class of road. However, all schemes will require that mapping information is kept up to date. This is a major logistical exercise – it is estimated that for the GLA area, there are some 50,000 changes to the road network every year.

In summary, while DBC is more or less technically mature at present, there are still significant logistical, political and operational issues to be addressed before DBC can be introduced. It is likely therefore that DBC would be introduced initially on a voluntary basis, in parallel with other road charging schemes.

2.4.5.   Mobile Telephony

2.4.5.1.   Technology Overview

Digital mobile telephony has been implemented in the UK using GSM (Global System for Mobile) technology for many years. Recently, third-generation mobile technology has been introduced. The Stage 1 trials mainly tested GSM technology. Limited trials were carried out using third-generation (3G) technology.

A mobile telephone network is divided into a number of cells, each of which is served by a base station. A cell is the area of radio coverage of the base station. The size and shape of a cell depends on topography, buildings and transmitter design and the cells overlap. In general, handsets talk to the base station with the strongest signal – this will normally be the closest one but topography or buildings may mean that the signal from another base station is stronger, in which case the handset will attempt to talk with that base station, rather than the closest one. In addition, a given cell may have a limited capacity – so if the nearest base station's capacity is exhausted, the handset will talk to a more distant one.

Since individual base stations have limited capacity, in areas where there are more users and hence more capacity is required, network operators make the base stations operate at lower power, effectively shrinking the size of the cell and enabling more to be fitted into a given area.

From the perspective of the technology trials, there are two ways in which the location of the handset can be identified. Others exist, but these were not been tested in these trials as they are too complex or expensive to be of practical use in a congestion charging system.

The first approach is to identify the cell with which the handset is communicating. This information can be simply obtained from the signal received from the base station as this contains the cell id. If the location of the cell is known, this is taken as the location of the handset; clearly, the smaller the size of the cell, the more accurate the estimated location.

The second approach is to query the network for location based information. The network maintains a record of the last base station with which the handset communicated. Based on knowledge of the network design, the LBS (Location Based Services) system on the network is able to calculate a circle within which the handset is most likely to be and give the location of the centre of the circle and its radius. Note that the centre of the circle is usually not the same as the location of the base station. Rather, it is approximately the centre of the cell.

Although there are a number of major technical differences between GSM and 3G technology, from the perspective of the trials the main difference is that a 3G handset is in communication with multiple base stations simultaneously, rather than just the one base station for a GSM handset. (Note that in GSM, although the handset is able to detect multiple base stations it does so passively and is in active communication with only one). Consequently, the use of cell id or LBS in a 3G network for location identification is likely to be less accurate than in a GSM network; although the base stations communicating with the 3G handset can be distinguished, this does not provide enough information to say which is closest. Instead 3G handsets have GPS capability built into them and it is this which is used to identify the location of the handset. In effect, a 3G handset can be considered as a GPS unit with continuous position reporting via a 3G network.

2.4.5.2.   Mobile Telephony Stage 1 Results

The major conclusion from the Stage 1 trials was that LBS accuracy was very poor (average error 2.3 Kms), even after outlying results were eliminated. LBS would not be suitable as a congestion charging methodology, although the accuracy may well be accurate enough to support Value Added Services (see section 2.4.6 below). In addition, the correlation between the observed accuracy and the accuracy quoted by the operator was poor. In 61% of cases, the true position of the vehicle was outside the error radius quoted by the operator. Consequently the quoted error radius cannot be relied on. Moreover, there were problems with the timeliness of the results; in many cases they were delivered hours after they were

requested. This is clearly a problem for a real-time system, although it might not necessarily be so for a system which carries out batch processing at the end of the day.

Similarly, using Cell Ids to identify the location of a vehicle was insufficiently accurate. Partly this was because cells are large and a mobile phone does not necessarily use the one closest to it. In addition, identifying the physical location of a cell whose Cell Id was identified was problematic – this is not information that is in general publicly available. Whilst it is conceivable that commercial arrangements could be reached with mobile operators to secure this information, keeping it up to date would cause further difficulties as operators are constantly re-engineering their networks, introducing new cells, changing power outputs and hence cell coverage and sometimes removing old cells.

2.4.5.3.   Stage 2 - Mobile Telephony Pico-cells

The Stage 1 trials demonstrated that mobile telephone technology, as currently deployed by the mobile operators, is not sufficiently accurate to allow its use for accurate location of vehicles for congestion charging purposes. The chief reasons are that cells are large and that a mobile phone can at any one time potentially lock on to any one of a number of cells – not necessarily the closest one to the phone.

Mobile network operators use a variety of cell sizes for different purposes. One of these is a so-called "pico-cell", whose range is a matter of 10s of metres, rather than 100s of metres or even kilometres. If such a cell was deployed at a zone boundary, (or indeed at any other charging location) then the position of a phone detected by that cell would be known with a high degree of accuracy. If, in addition, it can be guaranteed that every phone within the range of that cell is detected, then two key requirements for the use of mobile phone technology for congestion charging purposes would be met:

- Accuracy - a phone detected by a particular cell can only be in a very precise location and

- High detection rate - a phone in a given location will be detected by a given cell.

Detection by other cells would be ignored. Thus the mobile phone would effectively act as a "tag" and the cell as a "beacon" in a tag and beacon system.

The trials investigated whether this concept was feasible and showed that given the correct radio frequency (RF) engineering at the cell site, then a reliable detection rate of about 93% can be achieved. However, such RF engineering is complex and site specific. Moreover, at RF frequencies the footprint of the detection area fluctuates to a certain degree; depending on the site layout and the RF engineering, it is possible that a fluctuation in the footprint could capture a tag which is outside the zone. For technical reasons, the high detection rate can only be guaranteed if the phone is in idle mode, not in talk mode. As a user's existing handset will not be in idle mode permanently, it would not be possible to use a user's existing handset as a tag; a dedicated unit, with minimal functionality, would be required. Thus it would not be possible to benefit from the ubiquity of mobile phones. Whilst technically feasible then, there are few advantages from using this approach to tag and beacon over the established DSRC approach.

2.4.5.4.   Mobile Telephony Conclusion

The trials have demonstrated that mobile positioning based around mobile telephony is not accurate enough to be used as the basis for road user charging and the nature of the technology means that it is never likely to be so. There is one exception and that is that it is possible to use so-called pico-cells (cells with a very small radius) as a form of tag and beacon system; but this would only be feasible in small areas. However, because of the way that mobile telephony technology works, there are a number of practical difficulties with this, including the need to operate a separate network, rather than piggy-backing on established operators' networks and requiring separate mobile units rather than users' own phones. The result of these practical difficulties is that there would be no advantage in using this as the

basis of a tag and beacon system, rather than DSRC which has been developed specifically for the purpose.

2.4.6. Customer Information Services

2.4.6.1. Overview

One of the objectives of these trials was to improve the "user-friendliness" of the congestion charging system. As well as improving the ease of payment, one area being considered is the provision of additional services. Mobile positioning technologies require the vehicle to have on board appropriate equipment to receive external signals from which the vehicle's location can be identified. Once the location of the vehicle has been identified, this equipment can be used to inform the congestion charging system of the vehicle's location and / or as the platform for the provision of additional services to the user. The Stage 1 trials therefore tested a number of representative services of this sort.

These were:

- alerting the driver of an event (e.g. – about to enter the congestion charging zone)
- allowing the user to request information from the congestion charging system
- allowing the user to register exemptions to the congestion charge
- allowing the user to make payment.

Additional software is loaded onto the on board equipment to allow it to communicate with the central system and to display information received. However, the provision of the service is controlled by the central system.

2.4.6.2. Conclusion

The trials have demonstrated that it is possible to provide customer information and other services related to road user charging to users' mobile telephones. Such services could include:

- information about diversions related to or temporary suspensions of the scheme
- alerts about major congestion in the Congestion Charging Zone
- information about locations of paypoints
- tourist information related to location
- indications that the user has entered or left the zone and that a charge is payable
- payment of the charge

If such services are to be provided, it is necessary to ensure that they are sent to a phone which is not only switched on and in the congestion charging zone, but also in a vehicle, rather than being carried around by a user who is on foot. The trials demonstrated that with the use of Bluetooth it is possible to ascertain that the mobile phone is in the vehicle and thus it is possible to prevent spurious messages being sent to the mobile phone when it is not in the vehicle. Although some vehicles now come equipped with Bluetooth enabled devices, issues related to retro-fitting Bluetooth in older vehicles would need to be addressed in the same way as for GPS devices, as discussed in Section 2.4.4.2 above, which discussed the issue of who would pay for this for GPS devices. For Bluetooth, this would not be a problem; as the fitting of Bluetooth to obtain information services would be voluntary and for the benefit of the user, the onus would be on the user to pay. Since Bluetooth would not be used for charging purposes, security of fitting and preventing equipment being moved from vehicle to vehicle would not be a concern in the same way that it would be for GPS devices.

The trials demonstrated that although information services can be provided to users' mobile phones related to their movements into and out of the zone, the use of the mobile phones to determine the location was neither terribly accurate, nor timely. Until a more accurate and timely service can be provided by the mobile phone operators, it would be inadvisable to use this method to advise users of their liability to pay. Even if the terms and conditions of such a service stated that this was merely advisory, it is conceivable that there could be legal

challenges to a PCN if an advisory notification that someone had entered the zone was never received.

The trials demonstrated that the provision of information services is technically feasible. The content of such services is a separate issue as is how that content should be paid for. It is likely therefore that TfL would wish to restrict itself to providing information directly related to London road user charging and to traffic flows, possibly working with third parties who would provide a broader range of chargeable information in a separate relationship with the user. Addressing the operational principles and details of such a service would require significant work.

Although no specific work has been done in this area, it is likely that the trials' results of the provision of information services could be adapted to other aspects of TfL's work. For example, public information screens on buses could be provided with information about interchanges, routing, delays etc. specific to the route and location of the bus. These information messages could be triggered not just by the location of a mobile phone, as in the trials, but also by the use of GPS units on buses or by the detection by roadside beacons of a tag on the bus.

2.4.7. Supporting Technologies for Mobile Positioning Systems

2.4.7.1. Overview

The main part of the mobile positioning technology trials focused on technologies relating to the detection of a vehicle's position. In order to make a GPS or GSM based congestion charging or road user charging system work or to provide customer information services, other, supporting, technologies would be required. The trials therefore examined two such technologies – Wi-Fi and Bluetooth.

2.4.7.2. Wi-Fi

A system which uses OBUs to detect the position of the vehicle will generate a need for large data files to be transferred between OBUs and external infrastructure for the following purposes:

• Passing journey data to a back-office for processing and charge calculation
• Transferring map and tariff data to the OBU (if processing takes place in the OBU rather than in the back office)
• Downloading software updates.

The greater the communications capacity to and from the OBU, the more feasible it is to use lower cost OBUs with limited processing capability or to allow more intelligent OBUs to be updated with location-specific map-matching files, local road information and road tariff information. There is also a balance to be struck between communications costs and OBU cost.

The most obvious method is to use the mobile telephony networks for this communication. However, this is potentially costly. The trials therefore investigated whether Wi-Fi technology could be used for this purpose.

The trials demonstrated that Wi-Fi technology shows potential as a practical method for communicating large amounts of data between in-vehicle OBUs and static base stations. The maximum practical range in a built-up area such as London appears to be of the order of 100-150m. Although Wi-Fi at 5.7 GHz has a higher bandwidth and therefore has a higher throughput capability, Wi-Fi at 2.4 GHz is more stable and less subject to interference. The practicality of using Wi-Fi depends on the power of the base station transmitter. At a low power of 5dBm, it is not possible to establish a reliable connection. A transmission power of 11 dBm or 17 dBm (the maximum legally permissible) is required.

These conclusions hold for a single vehicle, where it is not imperative that a vehicle should be able to communicate with each Access Point (AP) that it passes. More vehicles attempting to communicate with the AP simultaneously will result in competition for the available bandwidth and therefore a degradation of the possible throughput. Further tests are required to establish what the impact of more vehicles with OBUs will be. However, it may be that if the requirement is only to transmit infrequent map updates or software updates to in-vehicle OBUs, rather than frequent amounts of positioning data from the OBU, then even if multiple vehicles are simultaneously in range of an AP, they may not be trying to communicate simultaneously and that therefore a degradation of quality with multiple vehicles may not prove to be a problem in practice.

2.4.7.3. Bluetooth

A necessary part of the delivery of information services to a mobile phone is matching the phone's location to the vehicle that it is in. This is required for two reasons. Firstly to ensure that the phone is on and in the correct vehicle before alerts, billing information or traffic news are sent to the device thereby avoiding wasted and potentially annoying messages being routed to a phone which, for example, was left at home. A second reason for this check is to authenticate the user, account and vehicle.

More advanced phones can interact with tags/emitters in the car. For example, a Bluetooth enabled phone (about 40% of the new phone market) can use the handshake that takes place between it and another Bluetooth device embedded in the vehicle, perhaps a hands free kit, to obtain the unique equipment identifier of that Bluetooth device. Since Bluetooth has a range of only about 10 metres and the identifier could only be captured on the phone by a pairing of handset and Bluetooth terminal, the transaction is proof of the proximity of the phone in the car. Additionally if the phone is triggered, by WAP Push or SMS, as it passes a DSRC urban charge point, to send this identifier to the information services server, this not only authenticates the presence of the user phone in the car but also establishes that it is switched on.

The trials demonstrated that Bluetooth used in this manner functioned reliably.

2.4.8. Deliberate Attack and Fraud

GPS and its supporting technologies, such as Bluetooth and Wi-Fi are potentially subject to deliberate fraud and jamming. Such issues would need to be carefully explored before such systems could be used for congestion charging. However, they apply to any applications using these technologies and investigating them was outside the scope of the trials.

3. DSRC Tag and Beacon – Mini-zone Trial (Stage 3)

3.1. Trials Overview

3.1.1. Introduction

The Stage 1 trials aimed to prove the concept of using tag and beacon in an urban environment and to test the accuracy of detection of tags and various matching techniques. Trials were carried out at two on-street locations with differing traffic characteristics. The DSRC beacon was supplemented by camera and ANPR systems so that the collection of images alongside DSRC transactions could be tested. This work was backed up by trials at the equipment supplier's test track. Stage 2 of the trials tested operational issues in a larger "mini-zone".

In Stage 3, the concept of an integrated Urban Charge Point (UCP) was developed still further. Both suppliers continued to develop and improve their trial site UCP designs throughout the period of the trial, in response to the results measured and progress in resolving design issues. The 'mini-zone' continued to be used for further tests and various sites were modified in order to validate certain design issue solutions.

3.1.2. Vehicles

The mini-zone trials were carried out using both dedicated vehicles and drivers, driving specified routes and in specified ways, and volunteer drivers, driving into the test area as part of their normal routines. The purpose of the dedicated vehicles was to ensure that the system was exercised in ways which were reasonably repeatable, would deliver guaranteed data volumes and would provide enough detail around the test execution to allow specific and unexpected behaviour to be investigated and explained. A set of 10 vehicles and drivers was maintained throughout the trials period.

The purpose of the volunteer vehicles was to provide a greater volume of data. Although these data could not be analysed as clearly as the trials vehicle data, they nevertheless gave very useful insights. The volunteer vehicles also served to identify qualitative issues relating to tag distribution and management. Over 500 volunteer vehicles from a variety of groups were equipped with tags. However, many of these did not appear in the mini-zone. The 373 volunteer vehicles whose data were finally analysed, were made up as follows:

- 171 buses
- 116 vans
- 40 trucks, including 6 refuse vehicles
- 8 taxis
- 38 cars, of which 20 were police vehicles

3.1.3. Tests undertaken by dedicated trials vehicles

The testing undertaken by the dedicated trials drivers aimed to exercise the system in terms of volume and diversity of scenarios. A number of core tests were devised to test the system generally as well as a number of tests to investigate specific issues.

Core Tests

For these tests, drivers followed pre-determined routes around the mini-zone. A typical route, passing all the mini-zone charge-points, is shown in Figure 3-1 below:
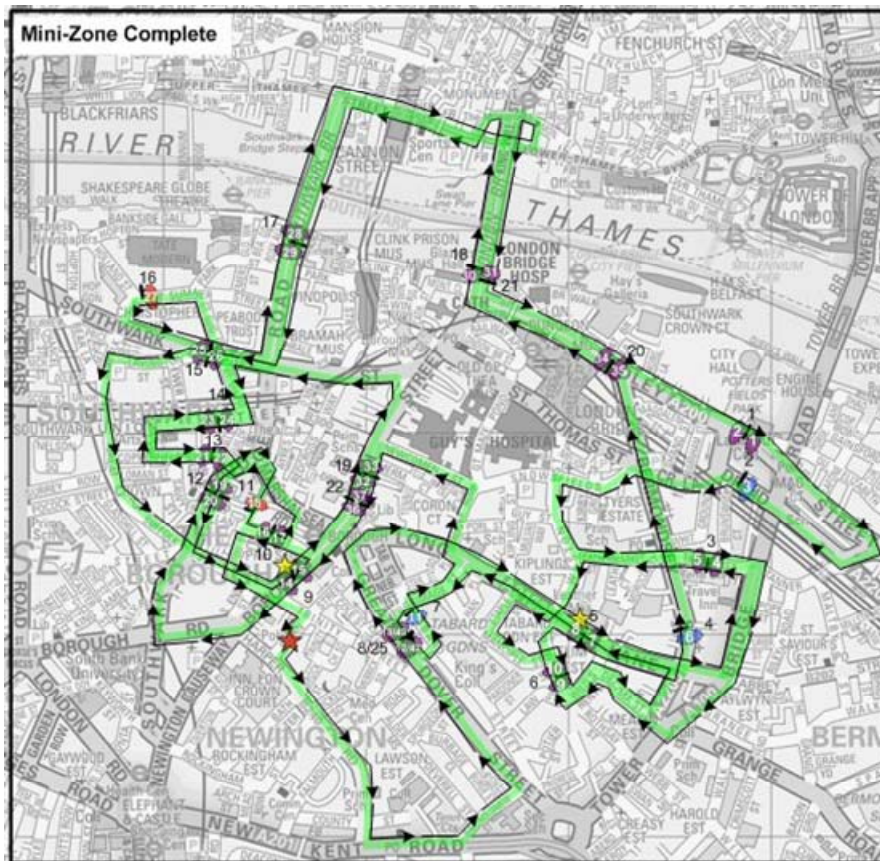
Figure 3-1: Typical mini-Zone test route

Standard Test

The drivers followed the specified test route using a completely normal driving style, in normal traffic conditions and not performing any special manoeuvres. This built up a baseline set of data covering, over time, a wide variety of naturally occurring scenarios.

Ideal Test

In this test, drivers were asked to pass charge-points in a controlled manner, not too close to other vehicles, with a steady speed and aligned with the lanes (rather than positioned at an angle when changing lanes). The object of these tests was to give the charge-point the best possible chance of detecting the vehicle and to check whether there was a significant difference between these ideal passages and the standard test.

Formation Tests

For these tests drivers were asked to drive past the charge-points in various formations (e.g. line abreast, close behind one another in line astern etc.), to the degree that traffic conditions allowed. The aim was to test the capabilities of the charge-point with multiple simultaneous closely spaced vehicle detections and harder matching scenarios.

Specific Tests

Edges and Obscuration

In the urban environment DSRC equipment will often be mounted at the roadside rather than on overhead gantries. This gives rise to the possibility that communications coverage of the road may not be as optimal as if equipment were gantry-mounted and hence that there might be areas at the edge of the communications zone where tags might not be detected. It also gives rise to the possibility that tags might be obscured from the beacon by other vehicles and hence that the tags would not be detected. For these tests drivers were asked to pass the charge-points at the extremities of the carriageway in order to test coverage. They were also

asked to pass charge-points specifically trying to avoid detection by driving behind other vehicles so that the tag was obscured from the roadside equipment.

Direction Detection and U-Turns

Unique to the use of DSRC in an urban environment with roadside equipment is the need for direction insulation (i.e. identifying the direction of travel and ignoring those transactions from vehicles travelling in the direction opposite to that being monitored by the beacon) and the capability to detect and handle U-turns. As far as we are aware, the technology trials are the first development worldwide to address this issue. The method by which this was addressed is discussed in Chapter 4 below. The majority of the sites in the mini-zone had two quasi-independent charge-points monitoring the two directions, where both charge-points shared the same beacon id but could be distinguished by the id of the transceiver which made the transaction. To fully test the implementation of the solution to this issue, one of the sites in the mini-zone was turned into two fully independent charge-points with different beacon ids. The performance of the site in respect of direction detection was based on the standard test and drivers were also asked to perform specific U-turn manoeuvres in and around the communications zones of the charge-points.

3.2. Results of Stage 3 Mini-Zone Trials – Trials Vehicles

3.2.1. Introduction

The Stage 2 report presented initial results from the dedicated trials vehicles only and only for standard tests. This report presents results from both dedicated trials vehicles and volunteer vehicles, covering a wide range of tests and a far larger volume of data. The analysis methodology was described in detail in the Stage 2 Report and is not repeated here.

This section provides a summary of the results of the various tests. The metrics used are common between tests; their meanings are set out in section 3.2.2 below and are not repeated in subsequent sections.

For this report to be accessible to as wide an audience as possible, the results presented in it are at a high level. A substantially more detailed report is currently being prepared.

The results are presented as the average performance for a given test across the system as a whole. The performance of different sites varied and these more detailed site results will be available in the more detailed report. Results are given in terms of an observed performance. No error ranges are given as it is not possible to calculate these meaningfully; there is, in effect, only one sample for each test. Variations in the results, between sites and between suppliers (of tags and of roadside equipment) are discussed in qualitative, explanatory terms.

Although standard statistical techniques cannot be applied to accurately calculate error ranges, their application as a qualitative "sense check" gives confidence that the high volume of observations means that the observed results are statistically valid and that the error ranges would be small (less than 0.1% for the standard test).

In interpreting the results, it must be remembered that they result from technology trials where:

• the technology was being developed throughout the trials

• an objective was to learn lessons about site design; consequently the design of a specific site might be different in an operational system from that used in the trials

• the physical layout of sites varied significantly and the mix of the sites, though representative of an operational system in terms of the range of sites, might not be representative in terms of the proportions in such a system

For these reasons, the results should not be regarded as figures which should be used directly in any procurement as performance measures against which to measure potential vendors.

3.2.2.   Standard test

Table 3-22 below summarises the results of the mini-zone trials, for dedicated test vehicles undertaking the standard test. Figures are shown as percentages.

Metric	Overall Performance (%)
Detection	
UCP Detection	99.93
DSRC Detection	99.7
ANPR Detection	96.6
ANPR Near Detection	97.2
ANPR no DSRC	0.2
DSRC no ANPR	3.3
Weighted Ground-truthed ANPR correct read rate	90%
Matching (ANPR to DSRC)	
Spatial match (correct ANPR)	99.1
Spatial match (near ANPR)	96.7
Spatial candidates	0.6
Spatial incorrect	0.6
Declared correct VRM match	97.4
Declared near VRM match	93.0
Declared VRM candidates	0.03
Declared VRM incorrect	0.2
Combined match (correct ANPR)	99.7
Combined match (near ANPR)	97.7
Sample size	141,000

Table 3-2: Summary results of mini-zone trials – standard test

Notes:

UCP detection is the combined detection rate for a UCP, where a tag-equipped vehicle has been correctly detected by at least one of the DSRC and camera/ANPR sub-systems.

ANPR detection and **DSRC detection** are the separate correct detection rates for the relevant sub-systems.

ANPR near detection is where the ANPR sub-system has read the number plate correctly or to within two characters (e.g. ABC123 has been read as ABC145)

ANPR no DSRC and **DSRC no ANPR** are the percentages of all passages which were detected by the ANPR sub-system but not by the DSRC sub-system or vice versa. In this case, detection by the ANPR sub-system includes near detection, as defined above. An ANPR read with no DSRC transaction may need a lookup against account details or could lead to erroneous enforcement, depending on the back office business rules. By contrast, a DSRC transaction with no ANPR read could be an issue should images be required for enforcing charges.

Spatial match (correct ANPR) is vehicle passages which have a tag transaction and which are spatially matched to a correct number plate read expressed as a percentage of vehicle passages which have both a tag transaction and a correct number plate read

Spatial match (near ANPR) is number plate reads which are correct or within 1 or 2 characters of the correct read, which are associated with a vehicle passage which has a tag transaction and which are spatially matched to that tag transaction, expressed as a percentage of number plate reads which have a correct number plate read or one within 1 or 2 characters which are associated with a vehicle passage which has a tag transaction. Note that a single passage may give rise to more than one number plate read. The complement of this metric is number plate reads associated with passages with a tag transaction where a match has not been made and which would require matching to tag transactions or accounts through back office processes.

Spatial candidates is vehicle passages which have a tag transaction and which are spatially matched to a number plate which is more than two characters different from the correct plate, expressed as a percentage of all passages which have a tag transaction. Note that this includes both the case where the tag is matched to the incorrect number plate and the case where the tag is matched to the correct number plate which has been badly misread by the ANPR sub-system. Note also that the figure is expressed as a percentage of all tag transactions, rather than of those which should be capable of providing a match (i.e. with a tag transaction and a near number plate read). In terms of back office workflow, it is likely that this would be regarded as an incorrect match, unless the same match was seen multiple times.

Spatial incorrect is tag transactions which are matched to a number plate which is known to be incorrect (because the matched number plate is associated with a different ground-truthed vehicle passage), expressed as a percentage of all passages with a correct number plate read (whether or not that passage had a tag transaction).

Declared correct VRM match is vehicle passages which have a tag transaction and which are matched (using a VRM declared by the tag) to a correct number plate read, expressed as a percentage of vehicle passages which should be capable of providing an exact match, namely those which have a tag transaction and which have a correct number plate read.

Declared near VRM match is vehicle passages which have a tag transaction and which are matched (using a VRM declared by the tag) to a correct number plate read or to a near number plate read (within 1 or 2 characters), expressed as a percentage of vehicle passages which should be capable of providing a match, namely those which have a tag transaction and which have a correct number plate read or a near number plate read (within 1 or 2 characters).

Declared VRM candidates is vehicle passages which have a tag transaction and which are matched (using a declared VRM) to a number plate which is more than two characters different from the correct plate, expressed as a percentage of all passages which have a tag transaction. Note that the figure is expressed as a percentage of all tag transactions, rather than of those which should be capable of providing a match.

Declared VRM incorrect is tag transactions which are matched (using a declared VRM) to a number plate which is known to be incorrect (because the matched number plate is associated with a different ground-truthed vehicle passage), expressed as a percentage of all passages with a correct number plate read (whether or not that passage had a tag transaction).

Combined match (correct ANPR) is vehicle passages which have a tag transaction and which are matched (using either spatial matching or declared matching or both) to a correct number plate read, expressed as a percentage of vehicle passages which have both a tag transaction and a correct number plate read.

Combined match (near ANPR) is vehicle passages which have a tag transaction and which are matched (using either spatial matching or declared matching or both) to a correct number plate read or to a near number plate read (within 1 or 2 characters), expressed as a percentage of vehicle passages which should be capable of providing a match, namely those which have a tag transaction and which have a correct number plate read or a near number plate read (within 1 or 2 characters).

Care should be taken in comparing the various metrics as different denominators are used. Due to the nature of the trials system where (as discussed below) full manual ground-truthing was not possible, a common denominator was not possible.

Full manual ground-truthing has not been carried on all these results, whereby all the images / video captured at a UCP over a period of time are examined manually and all the VRMs seen are enumerated. This is then compared to the VRMs detected by the ANPR sub-system to give a true correct read rate.

Consequently, when it is known that a vehicle has passed a UCP but its VRM has not been observed, it is not possible to determine whether this is because the VRM was missed (and hence the correct match result would be "no match") or because the VRM was so badly misread that it could not be recognised for what it was. In order to allow the analysis of matching performance to be carried out, only vehicle passages where the VRM had been read correctly (or nearly correctly) were considered as it was known that in this case a match was possible. The results given above may therefore differ from those that would be obtained for a fully manually verified set of data; however, given the high ANPR detection rates, it is unlikely that the variation would be significant.

A limited amount of full manual ground-truthing has been carried out for a small number of days, encompassing all the vehicles passing the UCPs on those days (not just the trials vehicles). As noted in

Table 3-22, the weighted ground-truthed correct read rate was 90%, somewhat higher than for the cameras used in the Western Extension. The correct detection rate for the trials vehicles was significantly higher than the ground-truthed correct read rate, which encompassed **all** vehicles passing the UCPs. This is in part due to the fact that the trials vehicles were well maintained and cleaned, making the number plates easier to read than those of the population as a whole. As a comparison, some of the volunteer vehicles had number plates which were completely unreadable. It should be noted that the ANPR correct read rate has no effect on the DSRC detection rate and has only a very small effect on the overall UCP detection rate. If the ANPR correct read rate were the lower ground-truthed rate (90%) rather than the observed rate (96.6%), the overall UCP detection rate for tagged vehicles *might* be lower by 0.02%.

Commentary

Detection

Overall 99.9% of all vehicle passages were detected by one or both of the ANPR and DSRC sub-systems, with one supplier having a marginally inferior result than the other (although still well over 99%); the main reason was its ANPR performance was significantly lower.

Overall DSRC performance was 99.7%; both suppliers performed slightly better with their own tags, but the difference was not significant at about 0.03%. Nor was there any significant difference between the performance of the tags from the two suppliers. There was no significant difference in detection rates between site types, narrow and wide roads. However, there was a slightly higher incidence of partial and attempted transactions for skewed beacons, although such transactions were in any case very rare; in an operational system this would have no impact.

One site (covering one side of a dual carriageway) was not of an ideal design and resulted in multiple transactions about 1% of the time, due to interference from the site covering the other side of the dual carriageway. This was due to the signals from that site reflecting off the back of vehicles in stop-start traffic and waking up a tag. Although the tag was not able to complete a transaction with the interfering site, the fact that it had been woken up by a different site meant that it could transact with the correct site again, hence giving multiple transactions. Improved site design (e.g. a greater longitudinal distance between the sites covering the two sides of the carriageway) or appropriate back office software and processes would deal with this issue.

ANPR performance varied far more across the charge-points than did DSRC performance, varying from 82% to 99.8%, although most sites were above 95%. The variance in performance can be attributed to the normal ANPR issues, such as the impact of low sun in the morning and evening due to site orientation, obscuration, camera skew and site tuning.

Matching

The overall spatial matching performance was 99.1%, where a correct number plate read was available. This was measured against those vehicle passages where it is known that a match should be capable of being obtained, i.e. where both a tag transaction **and** a correct ANPR read were available.

In principle, spatial matching performance should be measured against the cases where a tag transaction is available **and** an ANPR read is available, even where that ANPR read is a partial or incorrect. The practical limitations of the trials methodology (140,000 vehicle passages resulting in usable observations) meant that it was not possible to manually verify all the ANPR reads. Where a passage did not result in a correct ANPR read, this could be because the vehicle was missed altogether or was misread – and this is not known to the analysis team.

To allow for this to some degree, a second metric was used, considering ANPR reads which were correct or up to 2 characters different. For the standard test, where trials vehicles were driving on their own, the probability of there being another vehicle passing at the same time

with a similar number plate is negligible and a close read such as this can therefore be assumed to be an ANPR detection of the correct vehicle. Using this metric, the performance dropped to 96.7%. The reason for this drop is that although there are more matches in the numerator (i.e. matches against reads 1 or 2 characters different in addition to matches to correct reads) there are also more candidate ANPR reads in the denominator. Since some of the same things which cause a misread make matching more difficult, a smaller proportion of these additional, misread, passages will be matched than passages which are correctly read; this overall performance will drop. For example, an awkward trajectory through the camera field of view may cause a misread; such an awkward trajectory also complicates matching. This also applies to declared matching (see below).

The second metric allows for the case where there is a close misread; however, it is still not able to compensate for cases where the ANPR read was a complete misread (or a partial read).

It must be noted that the two metrics are not directly comparable. The first considers **passages** of tag equipped vehicles, the second considers **number plate reads of tag equipped vehicles** – a higher number since a single passage may give rise to more than one number plate read if there are misreads as well as a correct read (correct reads are deduplicated) or multiple different misreads.

The true matching performance as a proportion of vehicle passages where there is a correct is somewhere between these two metrics. A lower bound for this can be calculated as 98.5%.

One supplier's spatial matching performed significantly better than the other's. This may be due to site specific conditions, testing method or it may be that the poorer performing ANPR system also delivers poorer trajectory information as an input to the matching algorithm. It may also be an indication that the better performing supplier's matching algorithms are superior.

The calculation of the spatial matching performance using near ANPR reads is also affected by the fact that there were two vehicles with adjacent number plates RV05ULX and RV05ULY which frequently drove close to each other. If these are eliminated from the analysis, the near match figure approaches 99%. In an operational system, although such adjacent number plates driving together would occur occasionally, they would be a far smaller proportion of the population than these two vehicles were of the trials vehicles.

Again, there was little variation across sites and between tags from the two suppliers.

Matching tag transactions and ANPR reads using the VRM associated with the tag id was carried out using the VRM programmed into the tag and declared by it to the DSRC beacon during a transaction. Although an operational system in London is likely to associate VRM and tag id using a back office database rather than tag programming, in terms of the matching algorithms there is no difference between the two methods of association; thus the figures for declared matching can be used with confidence in assessing the likely performance of an operational system using a database association.

The overall performance for declared matching was 97.4% for correct reads and 93% for near reads. There was little difference between the two suppliers' systems. This was an unusual result as a near 100% performance would be expected. The difference is attributable to a software parameter which, in the early stages of the trials, was set to discard all ANPR reads with a confidence level of 90%. Results from the latter part of the trials, where this parameter was corrected, approach 100%. Errors in updating the tag id/VRM association in the tags as tags were moved between trials vehicles contributed to the remaining shortfall. This highlights the importance of system configuration and the management of tag id/VRM mapping. However, even with perfect management of the tag id/VRM association, the system would not achieve 100% matching, for example if the times of the tag transaction and VRM read were further apart than the system allowed for. In addition, matching using the VRM associated with the tag would not be able to cope with complete misreads of the number plate.

Even with the various imperfections in data and calculation, the combined matching across the whole system was 99.7% for correct reads and 97.7% for near reads.

Workflow

Some metrics are of importance to the design and operation of the back-office and business rules. The impact of these workflow metrics depends greatly in the actual policies employed but a number of observations can be made.

About 0.07% of tagged vehicle passages would escape detection, which could potentially result in lost revenue opportunities. Of those detected, about 0.2% would rely on a plate read rather than a tag read and 3% would rely on a tag read with no image to back it up. The former might require a back-office look up against account details or could result in erroneous enforcement, depending on the business rules applied, whilst the latter might mean that a charge could not be enforced, again depending on business rules.

About 3% of vehicle passages would present separate tag transactions and ANPR reads for the back office to match. The scope for deliberate evasion / tag abuse would be low, as only 0.6% of combined matches would be incorrect, which would be too low to be relied on by those seeking to beat the system. Appropriately designed back office processes, including history, consideration of detection / matching from multiple charge-points and manual inspection prior to enforcement would identify those matches which were potentially unreliable and which should be handled according to agreed business rules.

3.2.3.   Ideal test

The "ideal" tests were designed to see if there would be any increase in system performance due to drivers deliberately "making things easy" for the system. Table 3-33 below summarises the results of the mini-zone trials, for dedicated test vehicles undertaking the ideal test. Overall figures for the standard test are given for comparison.

Metric	Performance (%)	
	Standard Test	Ideal Test
Detection		
UCP Detection	99.93	99.93
DSRC Detection	99.7	99.6
ANPR Detection	96.6	96.7
ANPR Near Detection	97.2	97.2
ANPR no DSRC	0.2	0.4
DSRC no ANPR	3.3	3.2
Matching (ANPR to DSRC)		
Spatial match (correct ANPR)	99.1	99.2
Spatial match (near ANPR)	96.7	96.2
Spatial candidates	0.6	0.4
Spatial incorrect	0.6	0.4
Declared correct VRM match	97.4	98.1
Declared near VRM match	93.0	93.3
Declared VRM candidates	0.03	0.004
Declared VRM incorrect	0.2	0.06
Combined match (correct ANPR)	99.7	99.9
Combined match (near ANPR)	97.7	97.5
Sample size	141,000	27,000

Table 3-3: Summary results of mini-zone trials – ideal test

Overall, there was no statistically significant difference between the two tests.

There is some question about how successful the test drivers were in managing to deliver ideal passes in the difficult traffic of the mini-zone. For example, the spatial match results for RV05ULX and RV05ULY were higher than in the standard test, but not as high as if these two vehicles had managed to keep away from each other at all times.

3.2.4. Formation test

The formation tests were designed to see if there would be any decrease in system performance due to large numbers of vehicles passing through the site together. Table 3-44 below summarises the results of the mini-zone trials, for dedicated test vehicles undertaking the formation test. Overall figures for the standard test are given for comparison.

Metric	Performance (%)	
	Standard Test	Formation Test
	Overall	Overall
Detection		
UCP Detection	99.93	99.95
DSRC Detection	99.7	99.7
ANPR Detection	96.6	96.7
ANPR Near Detection	97.2	97.3
ANPR no DSRC	0.2	0.2
DSRC no ANPR	3.3	3.0
Matching (ANPR to DSRC)		
Spatial match (correct ANPR)	99.1	99.0
Spatial match (near ANPR)	96.7	87.4
Spatial candidates	0.6	0.7
Spatial incorrect	0.6	0.6
Declared correct VRM match	97.4	96.8
Declared near VRM match	93.0	83.3
Declared VRM candidates	0.03	0.3
Declared VRM incorrect	0.2	0.5
Combined match (correct ANPR)	99.7	99.7
Combined match (near ANPR)	97.7	91.6
Sample size	141,000	26,300

Table 3-4: Summary results of mini-zone trials – formation test

The test drivers were more successful in carrying out these tests than the "ideal" tests. Although strictly defined repeatable formations could not be established, the vehicles did succeed in moving through the charge-points en masse, manoeuvring around each other as they did so.

There was no statistically significant difference between detection between this and the standard test. However, there were some differences in matching performance.

The spatial match performance using correct reads did not change significantly, but that using near ANPR reads dropped by 10%, due to the pairs of vehicles RV05ULX/RV05ULY and EF53PZD/EF53PZE going through together. The absolute spatial matching performance for these pairs of vehicles remained high.

As discussed in section 3.2.2 above, the limitations of the trials methodology meant that the **calculation** of the near read spatial matching performance considered all the pairs of tag transactions with ANPR reads within 2 characters of the expected read as being matches which should be made. Thus if RV05ULX and RV05ULY passed a UCP together and were both correctly read and matched to the corresponding tag transaction, there would be two matches and the true match rate was 100%. The metric using the near reads which attempts to measure that match rate would however consider the denominator of the calculation to have four possible matches – tag(ULX) with ANPR(ULX), tag (ULY) with ANPR(ULY), tag(ULX) with ANPR(ULY) [a near read to ULX] and tag(ULY) with ANPR(ULX) [a near read to ULY]. Thus, since there are only two matches delivered by the system in the numerator, the **calculated** match performance is 50% compared to the true match performance of 100%.

Thus the fact that the near read match performance drops for these vehicles demonstrates that the tests were carried out correctly.

3.2.5. Edge tests

The edge tests were designed to see if there would be any decrease in system performance due to drivers trying to evade detection by deliberately trying to miss the communications zone by driving at the extremities of the carriageway. Overall, there was an impact on both tag and ANPR detection – a 1.9% reduction in DSRC detection and a 2.8% reduction in ANPR correct reads over 8,000 vehicle passages. There was also a slight difference between the tags from the two suppliers, with the tags from one supplier showing a smaller reduction in tag detection by 0.3%. Matching was not affected overall, but both partial transaction and aborted transaction attempt rates increase fivefold compared to the standard tests, albeit from very low levels (from 0.04% to 0.2% and from 0.1% to 0.5% respectively).

Given the variation in site geometry and design, there was significant variation across the charge-points. Table 3-55 below summarises the reduction in DSRC detection by chargepoint where the reduction is 0.5% or greater. The average number of passages per chargepoint was 250.

Chargepoint	DSRC Detection Performance (%)		Difference (%)
	Standard test	Edge test	Overall
Southwark Bridge Road (Out)	98.5	76.0	-22.5
Southwark Bridge Road (In)	99.8	91.5	-8.4
Borough High Street (Out)	99.8	91.5	-8.4
Weston Street (Out)	99.8	94.3	-5.4
Lant Street (In)	99.7	97.8	-1.8
Southwark Bridge (In)	99.8	98.3	-1.5
Copperfield Street (In)	99.7	98.3	-1.4
Long Lane (Out)	99.6	98.3	-1.3
Southwark Street (In)	99.9	98.7	-1.2
Druid Street (In)	99.8	98.7	-1.1
Union Street (In)	99.9	99.1	-0.8
Tanner Street (Out)	99.9	99.1	-0.8
London Bridge East (In)	99.9	99.1	-0.7
Borough High Street (In)	99.8	99.1	-0.7
Bermondsey Street (In)	99.8	99.1	-0.6
Union Street (In)	99.7	99.0	-0.6
Southwark Street (In)	99.8	99.1	-0.6

Table 3-5: Summary results of mini-zone trials – edge test

The largest differences can be readily explained. The Southwark Bridge Road site was constructed with coverage across only half the carriageway and therefore shows an obvious capability to avoid detection completely by passing on the wrong side of the road. For some tests drivers were indeed driving in this manner. This was detected and for subsequent tests drivers aimed to drive in the edge of the zone rather than evading it completely.

Borough High Street is a wide road and the outbound direction is on the far side of the road from the charge-point and is also a bus lane. The drop in performance is entirely due to the tags from one supplier and indicates that at the edge of the communication zone, differences between tags from different suppliers can be significant.

Weston Street outbound was only covered by a single transceiver whereas inbound was covered by two.

The remaining sites had smaller differences which may not be statistically significant considering the small sample size of c. 250 vehicle passages for each individual chargepoint. Some caution also needs to be exercised in considering these results as it is not entirely clear how well the drivers managed to achieve driving at the carriageway edges in normal traffic. Equally however, this means that it would also be difficult for drivers to drive in such a way as to exploit the idiosyncrasies of individual charge-points.

In conclusion, it is clear that for particularly difficult sites, care needs to be exercised in the design of DSRC coverage to prevent drivers evading detection. If the three or four sites where edge effects were most noticeable were removed from consideration to simulate improved site design, then the drop in DSRC detection reduces to 0.7% or 0.6%. Nevertheless, considering the system as a whole, the overall reduction in DSRC detection is small even if drivers are deliberately trying to escape detection.

3.2.6. Obscuration Tests

Stage 1 of the trials demonstrated that obscuration of the tag from the beacon, resulting in the tag not being detected, was difficult to achieve. The required positioning behind obscuring vehicles was extreme and difficult to achieve in normal traffic. The obscuration tests were designed to see if in a wider mini-zone and with more extensive testing it would be possible to achieve such obscuration. The tests were limited to a small number of sites as only these gave the opportunity for obscuration. Overall, there was an impact on both tag and ANPR detection – a 2.4% reduction in DSRC detection and a 16.9% reduction in ANPR correct reads over 11,000 vehicle passages. There was also a slight difference between the tags from the two suppliers, with the tags from one supplier showing a smaller reduction in tag detection by 0.4%. There was also a small reduction in spatial matching performance of 1.7%. Partial transaction rates were not affected but aborted transaction attempt rates increased sevenfold compared to the standard tests from 0.1% to 0.7%.

Table 3-66 below summarises the reduction in DSRC detection by charge-point.

Chargepoint	DSRC Detection Performance (%)		Difference (%)
	Standard test	Obscuration test	Overall
London Bridge East (In)	99.9	85.0	-14.8
Southwark Bridge Road (Out)	98.5	90.4	-8.1
Borough High Street Supplier 1 (N)	99.8	97.7	-2.1
Borough High Street (Out)	99.8	98.5	-1.3
Southwark Street (In)	99.9	98.8	-1.1
Sumner Street (Out)	99.9	99.3	-0.7
Southwark Bridge (Out)	99.8	99.2	-0.7
Southwark Bridge Road (In)	99.8	99.6	-0.3
Borough High Street (In)	99.8	99.6	-0.3
London Bridge West (Out)	99.9	99.8	-0.1
Southwark Bridge (In)	99.8	99.8	0
Borough High Street Supplier 1 (S)	99.6	100	0.4
Borough High Street Supplier 2 (N)	98.3	99.5	1.2
Borough High Street Supplier 2 (S)	98.2	99.7	1.6

Table 3-6: Summary results of mini-zone trials – obscuration test

As with the edge tests, there was significant variation across the charge-points. The number of passages per charge-point of around 800 is a very large sample in terms of statistical significance and therefore it can be concluded that the changes in the detection performance are not due to random chance. However, the fact that while drivers were deliberately trying to evade detection the performance for some sites actually increased, indicates that even under as controlled conditions as possible, this was not the only factor involved. Conclusions drawn on a site by site basis regarding obscuration must therefore be treated cautiously, except for perhaps the two sites with the largest differences, with more weight being given to the overall result.

The greatest obscuration opportunities occurred on London Bridge East, where the trials drivers succeeded in evading detection nearly 15% of the time. The site is 3 lanes wide, running up to a set of traffic lights near the charge-point. There is persistent stop-start traffic and frequent double-decker buses in Lane 2, providing excellent opportunities for hiding behind them when passing the charge-point.

The drop in detection at Southwark Bridge Road is primarily due to the fact that only half the carriageway is covered; as for the edge tests, drivers therefore tended to avoid the communications zone altogether rather than hiding behind another vehicle. The results are therefore not fully indicative of obscuration effects. As for the edge tests, this avoidance behaviour was eliminated for later tests.

For Borough High Street, the Northbound direction is on the far side of the road to the charge-point, affording more opportunities for obscuration.

If the two worst sites where obscuration effects were most noticeable were removed from consideration to simulate improved site design or location, then the drop in DSRC detection reduces to 0.8%.

In conclusion, while obscuration possibilities will exist at some specific sites, obscuration is not likely to be a factor overall, even when drivers are deliberately trying to evade detection. For particularly difficult sites care needs to be exercised in site design or location to reduce obscuration possibilities.

3.2.7.   Direction Detection And U-Turn Tests

Although these tests were carried out as part of the mini-zone trial, the results are reported separately, in Section 4.4 below so that the discussion of the problem, solution and all relevant results are located together.

3.2.8.   Combined Results

The results for the standard, ideal, formation and direction detection tests were combined to give a sample size as large as possible for analysis purposes. This gave a sample size of 210,000 results, some 50% larger than the standard tests alone. There was no significant difference between these results and the results of the standard tests alone.

3.3.   Results of Mini-Zone Trials – Volunteer Vehicles

3.3.1.   Overview

The volunteer vehicles, once equipped with tags, simply went about their normal day to day business around the mini-zone. No incentives were given to the volunteers throughout the trials. Whilst this meant that their behaviour was unaffected, it also meant that there was no incentive for tags to be kept in place. As a result, for some groups of vehicles, particularly buses, tags were knocked off or removed. In some cases they were not replaced, in others they were replaced in the wrong vehicles.

All the volunteers were commercial or public organisations. No members of the public were involved in the trials; thus the behaviour patterns are not fully representative of what would be encountered in an operational system. The data volumes were also weighted towards the frequent bus routes in the mini-zone.

The trials vehicles had independent means of identifying whether a vehicle had passed a charge-point or not – RFID tags, driver records and knowledge of the route being driven. These means were not, in general, available for volunteer vehicles, although some groups did carry RFID tags. Thus, if a vehicle passed a charge-point and was not detected by either ANPR or DSRC there was no way of knowing this. This could be allowed for on a system-wide basis since the mini-zone was a watertight zone; if a vehicle was detected going in twice, then it was clear that an outbound detection had been missed and this could be added to the overall statistics. However, this missed passage could not be attributed to a specific chargepoint.

Volunteer vehicles used tags from one supplier only. However the results obtained from the trials vehicles demonstrated that the difference in the performance of tags from the two suppliers was small and significantly smaller than the difference in performance of the different volunteer groups.

3.3.2. Summary Results

Table 3-7 below summarises the results of the volunteer trials. Results are shown for the volunteer group as a whole compared to the results of the standard test carried out by the dedicated trials vehicles. The results for the worst and best performing groups of vehicles for each metric are also shown.

Metric	Performance (%)			
	Standard Test	Volunteer Results		
	Overall	Overall	Best result for a group	Worst result for a group
Detection				
UCP Detection	99.93	99.5	100.0	91.8
DSRC Detection	99.7	99.0	99.7	90.6
ANPR Detection	96.6	93.0	97.0	32.2
ANPR Near Detection	97.2	94.2	97.4	74.8
ANPR no DSRC	0.2	0.6	0	4.9
DSRC no ANPR	3.3	6.8	2.9	67.2
Matching (ANPR to DSRC)				
Spatial match (correct ANPR)	99.1	82.8	99.3	39.1
Spatial match (near ANPR)	96.7	81.9	99.4	40.9
Spatial candidates	0.6	1.3	0	4.6
Spatial incorrect	0.6	0.2	0	2.5
Declared correct VRM match	97.4	94.1	99.0	49.4
Declared near VRM match	93.0	91.7	98.1	47.4
Declared VRM candidates	0.03	1.0	0	2.5
Declared VRM incorrect	0.2	1.1	0	2.6
Combined match (correct ANPR)	99.7	98.2	100	90.8
Combined match (near ANPR)	97.7	97.6	100	90.8
Sample size	141,000	528,000		

Table 3-7: Summary results of mini-zone trials – volunteer vehicles

As can be seen, there is considerable variation in performance across the volunteer groups, as there was for individual vehicles within the groups. While some groups tended to perform better or worse, there was no solid correlation; no single group consistently performed best or worst across all metrics. In addition, the extreme range of sample sizes between volunteer groups (both in terms of numbers of vehicles and numbers of vehicle passages) makes it very difficult to draw firm conclusions based on these performance figures. Vehicles, such as buses, which drove the same route frequently, might therefore pass an under- or over-performing charge-point more frequently than other charge-points, thereby skewing the results.

Overall, detection performance was slightly lower than in the standard tests but was nevertheless comparable. Although spatial matching performance was significantly lower, declared and combined matching performances were comparable to the standard test results. The lower spatial matching performance was entirely due to the mounting of tags in the "blind boxes" of some buses (see Section 3.3.6 below) instead of in the windscreen as normal; if these were eliminated from the results, the spatial matching performance was the same as for the dedicated trials vehicles. However, detailed conclusions can only be drawn if the data are analysed at a very low level.

3.3.3. Declared Matching Performance

The declared matching performance is unexpectedly low. This is due to the software parameter used early in the trials and discussed in the section on standard tests (section 3.2.2 above) whereby matches where the ANPR confidence was less than 90% were discarded. Changing this parameter increased the performance to nearly 100%, as would be expected.

3.3.4. Bad Plates

There were a number of number plates which were completely unreadable. The tag was read but there was no ANPR read and the only spatial matches were those in the "incorrect"

category. Clearly in an operational system there will be some vehicles with bad number plates, for example delaminated or broken plates or very dirty plates. The exact proportion is unknown but it is likely to be small. However, in a sample size of some 400 volunteers, just one or two such plates, particularly if on vehicles which make frequent passages past charge-points, can distort the results significantly.

3.3.5.   Tag-VRM Mapping

During the trials programme it was found to be difficult to capture and maintain the tag-VRM mapping for the volunteers. A number of errors were found in the initial listings and in the tag programming. Subsequently there was a large degree of movement of tags between vehicles.

As this was a trial system the processes and procedures followed were less tightly defined and less rigorously followed than would be the case in an operational system. Nevertheless, it is clear that keeping track of the mapping will be key to system performance and again incentives and terms and conditions will play a part.

However, the trials demonstrated, as expected, that the system itself will play a part in identifying mismatches. Spatial matching allowed these anomalies to be detected and action taken to correct them.

3.3.6.   Tag Mounting

The greatest impact on the quality of the results, the ability to analyse them and the system performance itself came from tag mounting issues.

It must be emphasised that the volunteers were not incentivised to mount tags correctly or to keep them mounted. Many, such as bus drivers, would not have known what the tag was.

The quality of mounting varied wildly between groups and even between individual vehicles within groups. With some buses, it appears that deliberate actions were taken to remove tags; in others, tags were particularly prone to being knocked off, the loose tag in the vehicle then performing extremely badly. By contrast, other volunteers had no issues and the tags performed as well as those in the dedicated trials vehicles.

It is clear that in an operational system tag mounting is a key factor in system performance and that incentives and terms and conditions will have a part to play in addressing this issue.

Tags mounted on the main windscreen in buses were frequently dislodged or deliberately removed. Two groups of double-decker buses therefore had the tags mounted in the "blind box" (the box on the front of the bus where number and destination are displayed) where this would not occur. Whilst this gave very good DSRC performance, the higher location of the tag changed the geometry of the tag / number plate offset, which had a dramatic effect on the spatial matching capability, reducing it to less than half that where the tag and number plate were offset as expected. However, the declared matching performance was not affected.

3.3.7.   U-Turns

Other than for the specific U-turn tests at one site later in the trials, none of the mini-zone sites were set up to cope with U-turns. Investigation of some of the poor tag performances (by checking ANPR detections within 256 seconds by the UCP monitoring the opposite direction) revealed that a considerable number of tag transactions were lost to U-turns, where the vehicle returned to the same site within the 255 second period during which the tag could not transact again with the same charge-point. These have not been filtered out of the results presented above, but analysis shows that there were some 1,350 U-turns performed by the expected groups:

Volunteer Group	U-turns identified
Police	997
Taxis	93
Dial-a-Ride	78
Southwark Council	77
Buses	74
Other	30
Total	**1,349**

Table 3-8: U-turns by volunteer group

This quantity of U-turns would not have a significant impact on the overall results, compared to the 500,000 vehicle passages, but would have a significant impact on the performance of the individual groups, particularly the police.

3.3.8.   Conclusions

The volunteer trials provided a number of valuable operational lessons. Overall, the system performance was lower than, but in most cases comparable to, the standard tests carried out by the dedicated trials vehicles. Some aspects of this lower performance would not be present in an operational system; for example, U-turn detection capability would be present at all charge-points and the discarding of matches where the ANPR confidence level was < 90% would not be present. Further work remains to be done on analysing the volunteer performance. It is likely that the results for the volunteer vehicles err on the pessimistic side of what could be expected in reality. The volunteer drivers had no incentives to ensure that tags were correctly mounted, that they were kept in the vehicle and that any malfunctioning was detected and reported; by contrast, in an operational system drivers would have an incentive to ensure that the tags and system were working correctly and the system itself would provide feedback to detect and correct anomalous performance.

3.4.   Operational Issues

3.4.1.   Reliability

The equipment used in the trials proved highly reliable. There was one transceiver failure (out of 53 transceivers used in the trials). One of the batches of tags supplied was faulty; this was detected prior to fitting and the batch was replaced. Once fitted, there were no tag failures.

3.4.2.   Tag Mounting

Provided that mounting rules were followed (i.e. that the tag was mounted in the specified gap in the metallization), metallised windscreens had no significant impact on performance.

The limits of the windscreen are programmed into the space envelope for spatial matching and provided that the tag is mounted in this envelope, matching performance is not sensitive to the actual position of the tag in the windscreen. However, if the tag is moved outside of this envelope (i.e. not mounted on the windscreen), then the programmed spatial relationship between windscreen and number plate is distorted and there is a significant effect on matching performance, as demonstrated by the mounting of tags in buses' "blind boxes".

No significant difference was found in performance for different body types – i.e. vans did not perform any differently from cars.

3.5. Possible Performance in Live Operational Systems

3.5.1. Overview

As indicated in section 3.2.1 above, the results of the trials should not be regarded as figures which should be used directly in any procurement as performance measures against which to measure potential vendors or as performance measures in a Service Level Agreement. The technology trials assessed the technical performance of a DSRC system in trial conditions and were not intended to measure or prove a DSRC system under live operational conditions.

Such operational conditions may differ from the trial conditions in several key areas:

- the types and relative proportions of vehicles covered

- the motivations of the drivers involved

- the sites to be used, in terms of the physical layout, traffic volumes and the mix of sites

- the reliability of the supporting infrastructure

- the equipment suppliers

- the mechanism for measuring performance

An additional analysis of the trials results was undertaken to obtain an indication of how performance measures obtained in an operational system might differ from the trials results.

3.5.2. Performance Measurement Mechanism

The method of calculating performance during the trials involved analysing each vehicle movement in turn and determining what detection events were generated for that movement. This was a rigorous and non-trivial method of analysing performance and was required in order to gain the deep understanding of failure modes in the trials equipment.

An operational system would require a much simpler, more efficient method of measuring performance. Such an approach has been put forward by TfL in the performance indicators defined in the subsequent procurement of DSRC equipment. The figures used below for operational performance use these methods of measurement.

In order to measure performance, a baseline is required against which performance can be measured. In the trials, the fact of the passage of a trials vehicle past a UCP from a combination of sources (ANPR, DSRC, drivers' notes, RFID etc.) and this serves as the baseline against which performance is measured. In an operational system, this wealth of data would not be available and some other way of establishing a baseline must be found. In the system of the original Congestion Charging region what is seen by the ANPR cameras is recorded and samples are manually inspected to identify the VRMs which have actually passed the camera. This serves as the baseline against which the ANPR performance can be measured. However, in a DSRC system, it is not possible to ascertain visually whether a vehicle is carrying a tag and this method cannot therefore be used.

The following method was therefore adopted. "Valid vehicles" were first identified. A valid vehicle was defined as one which was recorded as carrying a tag on that day and which was detected at least once on that day, where the detection was by both the ANPR and DSRC sub-systems of the UCP and where that UCP successfully performed a spatial match. This ensured that all vehicles included in the analysis were carrying the correct tag and that the tag was functioning correctly.

Based on valid vehicles, the following performance measures were defined:

- **DSRC detection rate**. The proportion of the instances where an ANPR sub-system generated a VRM of a valid vehicle, where the DSRC sub-system also detected the relevant tag

- **ANPR detection rate**. The proportion of the instances where a DSRC sub-system detected the tag of a valid vehicle, where the ANPR sub-system also detected the relevant VRM. Two different variants of this metric were used:
  - Only cases where the VRM generated by the ANPR sub-system **exactly** matched the VRM of the tag-carrying vehicle

  - Cases where the VRM generated by the ANPR sub-system was an exact match, a near match or a partial match of the VRM of the tag-carrying vehicle. A near match was defined as having one character different to the expected VRM and a partial read was defined as being a substring of at least 5 characters.

- **Spatial match rate**. The proportion of the instances where a DSRC and correct ANPR detection event were both generated for a valid vehicle movement, where both were successfully spatially matched

The above analysis used measures which would be available to an operational system. It assumed that the performance of DSRC detection and of ANPR detection were independent of each other – thus choosing different baselines would make no difference to the detection rate measured.

3.5.3.   Results and Analysis

Table 3-9 below shows the results of the operational analysis.

	Supplier 1 Sites			Supplier 2 Sites			Trials Results		
	DSRC Detection Rate	ANPR Detection Rate (figures in brackets include near matches)	Correct Spatial Match Rate	DSRC Detection Rate	ANPR Detection Rate (figures in brackets include near matches)	Correct Spatial Match Rate	DSRC Detection Rate	ANPR Detection Rate	Correct Spatial Match Rate
All vehicles	96.9%	92.6% (93.4%)	83.4%	96.4%	81.4% (86.2%)	64.0%			
All Trials vehicles	98.3%	92.0% (92.6%)	97.0%	88.5%	72.9% (80.2%)	94.7%	99.8%	97%	99.5%
All volunteers	95.5%	93.0% (94.2%)	71.4%	98.9%	84.1% (88.2%)	54.9%	99.2%	94.7%	83.2%
All volunteers excluding buses	88.9%	89.5% (90.7%)	97.8%	91.1%	80.1% (89.8%)	94.6%			
All volunteer buses	96.2%	93.4% (94.6%)	68.7%	99.9%	84.6% (86.0%)	49.9%			

Table 3-9: Operational Measures of Trails Performance

It appears from the table above that operational measures of the performance of the technology may be lower from those obtained in the trials, some of which may have been obtained under optimal conditions. There are a number of possible reasons for the differences and these are discussed below.

3.5.3.1. Different Measurement Periods and Datasets

Some caution should be applied in the comparison the results as different time periods and data sets were used.

The trials results quoted in the table above span the entire period of the trials whilst the operational measures were calculated using only results from June 2007. It is possible that the trials result for the trials as a whole may differ from those which would obtain for June 2007 alone since:

- the technology was developed throughout the trials
- errors were eliminated and
- the mix of vehicles, particularly of volunteer vehicles, changed during the trials as new groups were added,

The trials analysis applied a series of filters to the raw data to eliminate data which for one reason or another would seriously distort the results. The operational performance figures did not apply these filters. Whilst some of the filters relate to issues which an operational system would not be aware of, others relate to issues which might be known in an operational system resulting in affected data not being considered for performance measures.

3.5.3.2. Different Types of vehicles

The Trials Vehicles consisted almost entirely of cars. It is known that the customers of the congestion charging zone drive a variety of vehicles that include HGVs, LGVs and cars.
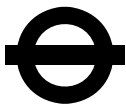
Volunteer vehicles covered a wider range of body types and the work carried out using these vehicles showed that there was considerable variation by body type as shown in Table 3-10:

Body Type	Volunteer DSRC Detection Rate for Supplier 1 Beacons	Volunteer DSRC Detection Rate for Supplier 2 Beacons	Volunteer Spatial Matching Rate for Supplier 1 Beacons	Volunteer Spatial Matching Rate for Supplier 2 Beacons
BUS	96.2%	99.9%	68.7%	49.9%
CAR	61.2%	0.0%	99.2%	
HGV	99.4%		98.2%	
LGV	96.6%	0.0%	100.0%	
VAN	93.7%	99.2%	98.8%	95.5%
TRUCK	76.9%	87.5%	85.7%	86.7%
Overall Value	95.5%	98.9%	71.4%	54.9%

Table 3-10: Operational Performance of Volunteer Vehicles

Note that shaded cells are based on very small sample sizes (<100 vehicles).

It is not clear why the performance for cars is so low. It may be the case that at the period for which the operational measures were calculated (June 2007) there were relatively few cars in the volunteer fleet and that police vehicles and taxis formed a large proportion of these. Such vehicles have a high propensity to perform U-turns, which at this stage of the trials the UCPs were unable to detect. However, detailed analysis for this period is not available.

Several reasons have been suggested as to why the performance may be poorer on larger vehicles; these include:

- tag brackets not being optimised for the angle of windscreens on large vehicles, which may have a negative impact on detection rates

- spatial matching being optimised for the placement of the tag relative to the number plate on cars.

The exact performance that may be expected in full operations would depend very much on the types of vehicles that are involved in the scheme and the relative proportions of each type.

3.5.3.3. *Driver Motivation*

During the trials volunteer drivers were provided with initial advice as to how to have their tag correctly fitted and operational within the vehicle. If the tags failed to operate correctly then they were provided with limited feedback to help them adjust their tag placement. However, they had no specific incentive to comply.

In an operational environment, drivers may be more motivated to ensure that the tag is correctly fitted to ensure compliance with the Tag Account Terms & Conditions, which may result in improved operational performance. Drivers will also receive feedback on Tag performance through the monitoring of detections on charge statements.

Although it is unlikely that users that deliberately seek to evade payment would sign up to a Tag Account, some users may initially seek to hinder detection of the Tag; however vehicles will still be detected by the ANPR systems. Such behaviour may result in slightly lower operational performance.

Operational performance may be improved by using measures such as:

- very clear fitting instructions supported by a help line

- identifying vehicles that are seen without their tags and informing their owners of a potentially poorly fitted or faulty tag

- ensuring that the Terms and Conditions for Tag accounts incentivise Users to ensure tags are fitted correctly.

3.5.3.4. *Sites Used*

The trial was carried out in a part of London that was within the boundary of the existing congestion charging zone. This aimed to ensure that the types of road, traffic and conditions at the trial sites were indicative of the congestion charging sites.

However, the congestion charging zone has significantly more sites than the trial, and the sites involved may contain a more diverse and extreme array of conditions than those of the trial sites, despite the efforts to ensure the trial sites were representative.

The trials did encounter several different site related issues, such as face to face charge points, congested traffic and reflected signals. The trials helped to inform a set of guidelines to help prevent or alleviate such issues when applied to congestion charging.

3.5.3.5. *The Reliability of Supporting Infrastructure*

The trials infrastructure was created in a cost effective manner that was fit for the purpose of trialling technology. It did not include enterprise class features such as resilience, redundancy and continual monitoring.

An operational system would likely be constructed with a requirement for a much greater level of reliability and availability. This would increase the expected performance of an operational system. The trials results filtered out effects such as system outages whilst the calculation of operational measures did not; it is not known to what extent system outages affected the operational measures.

3.5.3.6. Equipment Suppliers

The majority of the trials work involved one supplier of equipment, with the same supplier providing both tags and beacons.

A second supplier was used for a small number of sites; their performance was found to be markedly different to the first, although it is not known whether this is a function of the supplier or due to site specific issues.

A commercial procurement would aim to be competitive; in order to ensure that the competition is not limited to just one supplier the performance required by TfL should be such that TfL is confident that at least two suppliers can reach that target; however that requirement must not be set so low that the effectiveness of the system is compromised. In order to be assured of this, TfL should set a mandatory requirement which is either the lower of the two performances observed in the trials, or the minimum performance which allows for system effectiveness, whichever is the higher. Performance levels should be verified during the mini-competition stage and SLA levels set accordingly.

Other trials were carried out using different brands of tags, for example the tags used by the Dartford Tunnel. Although the tests were not controlled in the same manner as the technology trials and are therefore inconclusive there is an indication that detection rates may be sensitive to the brand of tag used.

Hence, the performance to be expected from an operational scheme depends on the supplier chosen (who may be selected on the basis of service, price or value for money, rather than just DSRC performance) and the types of tag that the scheme will be expected to work with.

3.5.3.7. Conclusion

The technology trials simulated the behaviour of different types of vehicles using a variety of site configurations in order to assess the technical feasibility of a DSRC system. Thus it is not representative of a maintained, live operational scheme. However, the trials implementation provided useful information which may influence future procurement and deployment opportunities. The operational performance measures calculated in this section suggest that the performance levels set for procurement and for Service Level Agreements should be lower than the performance levels suggested by the trials results. However, consideration should be given as to whether these operational performance measures can be used as they stand, or whether further work needs to be carried out, given that the measures were calculated for a period significantly before the end of the trials and may thus not take into account all improvements and lessons learnt.

Transport for London

4. Direction Detection and Insulation

4.1. Introduction

The trials examined a number of design issues which would need to be addressed to allow a DSRC system to be deployed in London (several of which were examined in Stages 1 & 2 and summarised in 2.3.4 above). One design issue remained to be addressed in Stage 3. This related to the detection of direction of travel and of U-turns and is discussed in this chapter.

A UCP monitors and reports events in a single direction of vehicle travel. A bi-directional charge site will consist of 2 independent UCPs, each monitoring a single direction. Where a UCP is located on a bi-directional road without traffic segregation, direction detection is required so that events are only reported for vehicles travelling in the direction being monitored by the UCP. This is termed direction insulation. Tests within the Stage 1 trials indicated that approximately 30% of vehicles travelling in the "wrong" direction were generating DSRC events for skewed antennas covering the far side of the carriageway.

The supplier identified an approach to determine direction of travel based on the localisation information received from the tag during the DSRC transaction, hence permitting the UCP to ignore vehicles travelling in the non-monitored direction. This approach was tested in the mini-zone.

4.2. Overview of Testing

A transaction will commence when a vehicle equipped with a tag enters the DSRC-communication zone and when at least one beacon can communicate with the tag. Each time the tag responds to the beacon the localisation of the tag can be approximately determined by the beacon.

The position will be in either the start of the zone (early zone in Figure 4-2) or in the end of the zone (late zone in Figure 4-2). If the localisation data is in the start of the zone (i.e. furthest from the beacon), the vehicle with the tag will be assumed to be travelling in the charging direction towards the pole. But if the localisation data is in the end of the zone, the vehicle is assumed to be travelling in the reverse or non-charging direction and hence the detection can be ignored.

The demonstration aimed to show that a UCP would correctly ignore all vehicle passages in the "wrong" direction, without degrading its performance in detecting vehicles travelling in the normal direction.

A particular issue to be addressed was that of vehicles performing U-turns. To prevent multiple transactions for a single passage, a tag is configured so that when it transacts with a beacon, it will not transact with a beacon with the same beacon id for 255 seconds. The vendor's original approach to direction insulation had been to have all the beacons in the two UCPs monitoring a two-way carriageway have the same beacon id. Thus when a vehicle successfully transacted with a beacon monitoring one direction of travel it would not then transact with the beacon monitoring the other direction. However, this approach had two consequences:

- As mentioned previously, Stage 1 trials had shown that 30% of vehicles transacted with the UCP monitoring the "wrong" direction of travel. Thus, in a face to face configuration, with the same beacon id and 255 second delay, it would be possible in some circumstances for a vehicle to transact first with a beacon monitoring the "wrong" direction and thereby be prevented from transacting at all with a beacon monitoring the "correct" direction

- A vehicle which passed through the detection zone of a charge-point and then performed a U-turn and passed through the detection zone of the same charge-point in the other direction within 255 seconds would not be detected. For a cordon scheme, this would

mean that a vehicle could cross the cordon, drop someone off and exit the cordon with only one crossing being detected and charged.

With the approach adopted, the beacons monitoring the two directions had separate ids. The demonstration aimed to show that with both beacons switched on, a vehicle which performed a U-turn would be both detected and ignored correctly on both legs of the U-turn, where the two legs occurred within 255 seconds of each other.

Two UCPs, see Figure 4-1, were used for demonstration of the U turn capability and one UCP, see Figure 4-2, was used for evaluation of the direction detection capability.

The reason for using only one UCP in the latter case is that the 2 UCP installation in Figure 4-1 prevents DSRC communication in the "Non charging direction" (second communication zone) as the tag falls asleep for 3-5 seconds after a successful transaction in the right direction (first communication zone). So if the tag were not detected in the "wrong" direction, it would not be possible to tell whether this was because the beacon successfully ignored the tag or because the tag was asleep. Thus the possibilities for evaluating the implemented algorithm are enhanced with only one UCP enabled.
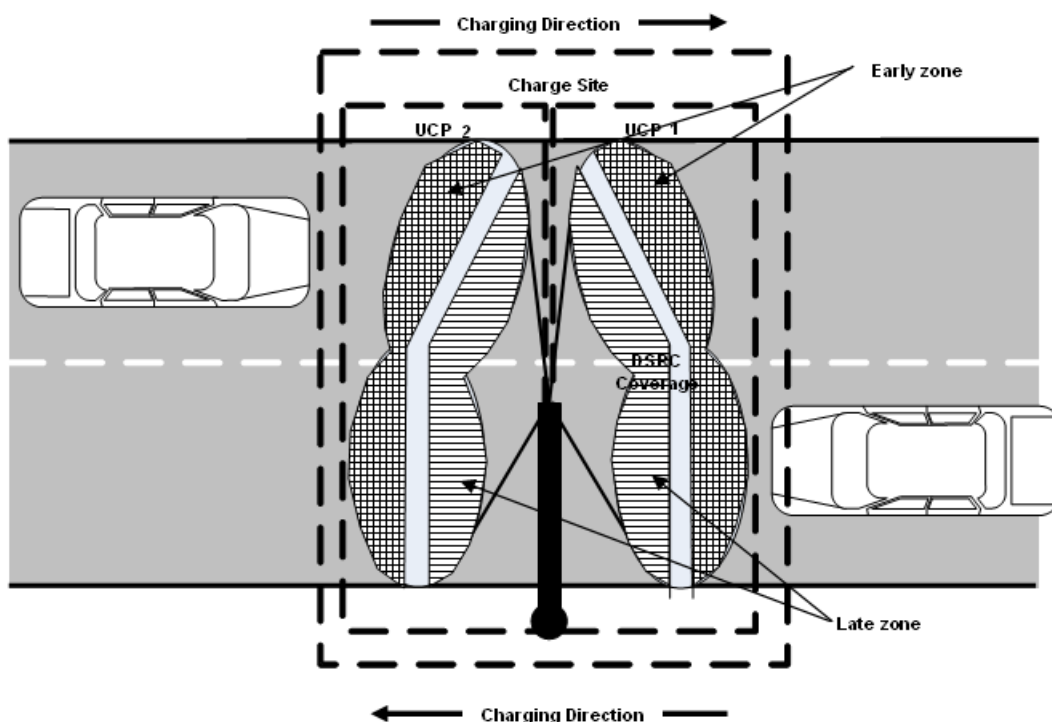

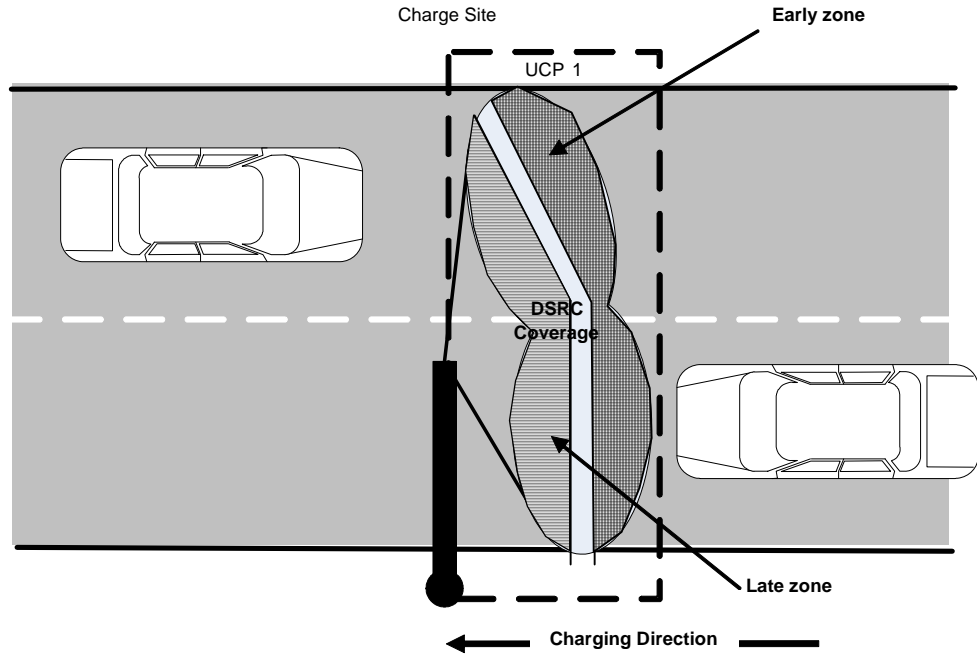**Figure 4-1: Back to back configuration**

Figure 4-2: Illustration of DSRC direction detection method

4.3. Test Results

The demonstration was performed with 3 cars and one bus in different positions, vehicle combinations and directions. In total 1,200 passages were performed, 600 in each direction. 100 of the passages were performed with the bus.

For the 600 passages in the negative direction no DSRC transactions or image based passage records were generated by the charge point. This was the expected result of the test for the correctly functioning direction detection and insulation functionality.

The performance in the positive direction of travel is presented in Table 4-33 below.

Expected number of Events	600
DSRC Transactions completed	600 – 100%
Images captured	598 – 99.7%
Correct ANPR Result	591 – 98.5%
Correct Spatial Match Result	596 – 99.3%

Table 4-3: Direction insulation results

The test results show that there is no performance degradation following the implementation of the direction insulation functionality for DSRC and ANPR events.

In order to demonstrate the capability to allow vehicles to perform u-turns within 255 seconds and successfully complete DSRC transactions in both directions, 20 passages were performed with both UCPs enabled. All passages were, as expected, successfully detected for the "correct" direction of travel for both legs of the U-turn and correctly ignored for the "wrong" direction of travel for both legs.

4.4. Mini-Zone Test Results

4.4.1. Overview

As well as the demonstration described in sections 4.2 and 4.3 above, direction insulation and U-turn detection were tested as part of the wider mini-zone trial. In order to keep the reporting of this issue in one location, the results of the mini-zone trial in respect of this issue are reported here rather than in the main mini-zone results section.

The site at Great Dover Street was configured as two independent back-to-back charge-points, each having a different beacon id. Such independent charge-points make multiple transactions more likely. Once a tag has transacted with a charge-point it ignores "wake-up" messages from the same charge-point for 255 seconds and thus does not transact again in that period. With back-to-back charge-points sharing the same id, the tag would ignore any signals from the charge-point monitoring the opposite direction which had been reflected off other vehicles. With independent back-to-back charge-points, the tag may receive in that period a "wake-up" signal from the "wrong-way" charge-point which has been reflected off other vehicles. As this has a different charge-point id, the tag does not ignore it but tries to complete the transaction. The reflection geometry does not allow the completion of the transaction but the tag is now in a position to respond to a "wake-up" signal from the charge-point monitoring the "correct" direction of travel.

The roadside system was also enhanced to report whether transactions occurred in the near or far area of the communications zone. In most instances this allowed the site to detect events with enough information for the back-office to understand the whole vehicle behaviour. Figure 4-4 below shows in schematic form the configuration of the site and how the coverage area was divided into zones showing which transceiver detected the transaction and whether it was in the far or near area of the zone.
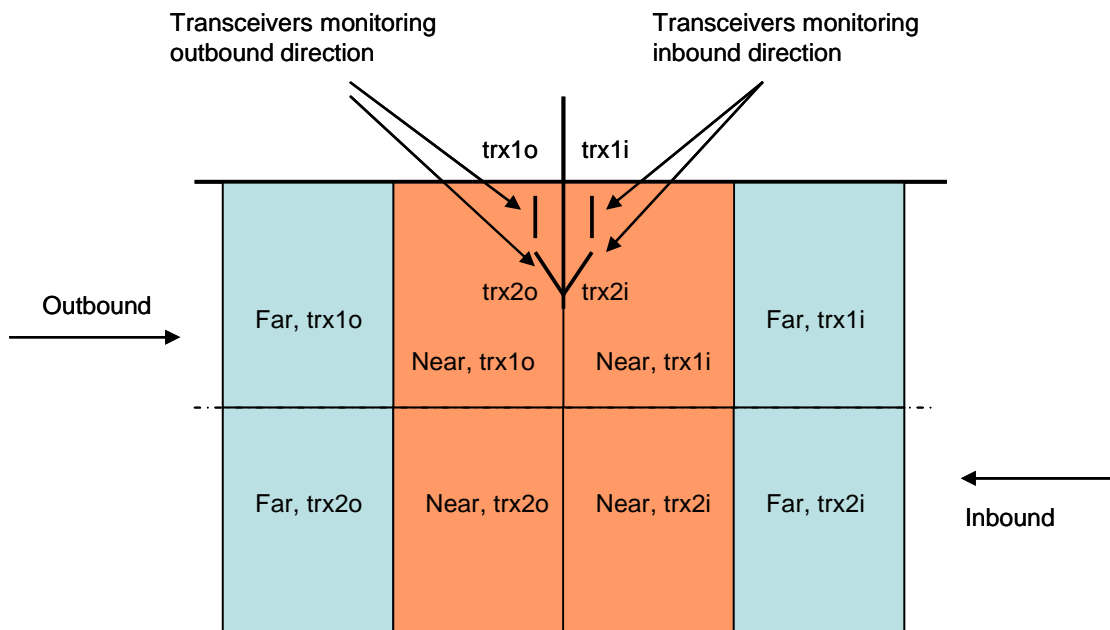

Figure 4-4: Schematic of Dover Street test site configuration and zoning

4.4.2. Direction Detection

Approximately 7,500 vehicle passages were recorded for the direction detection tests, where the trials vehicles simply passed all the way through the back-to-back charge-points. Overall detection rates (DSRC: 99.8%, ANPR: 97%) were in line with the standard tests as was the spatial matching performance (99.3%). Approximately 1% of vehicle passages gave rise to multiple transactions, some of which occurred in the near zone as discussed below.

The aim of the test was to check that minimal wrong-way transactions occurred, where the tag transacted with the chargepoint monitoring the opposite direction of travel and that, where they occurred, the chargepoint had sufficient information to identify them as such. Figure 4-5 below shows the zones in which all tag transactions were recorded.

Figure 4-5: Location of transactions in direction detection test

99.9% of all transactions were recorded in the far (blue) zones. This is as would be expected, as this is the zone which a vehicle travelling towards the chargepoint encounters first.

Of the far-zone transactions, all but 1 (0.01%) were for vehicles travelling in the direction being monitored by the chargepoint.

Only 4 vehicle passages (0.05%) resulted in transactions with a chargepoint monitoring the opposite direction of travel. In all these cases, these were part of a sequence of multiple transactions where the tag had already transacted with the charge-point monitoring the correct direction, which would have allowed the system to identify them as wrong-way transactions and discard them.

All the detections in the near zone were parts of sequences of multiple transactions. There were no cases where the tag had transacted in the near zone but had not, prior to that, transacted in the far zone. 9 were for vehicles travelling in the correct direction, which had already transacted in the far zone. 3 were "wrong-way" transactions which had already transacted with the charge-point monitoring the correct direction, as illustrated in the A-B sequence in Figure 4-6 below. Such a pattern with the timing and zone data could be used to discard transaction B.
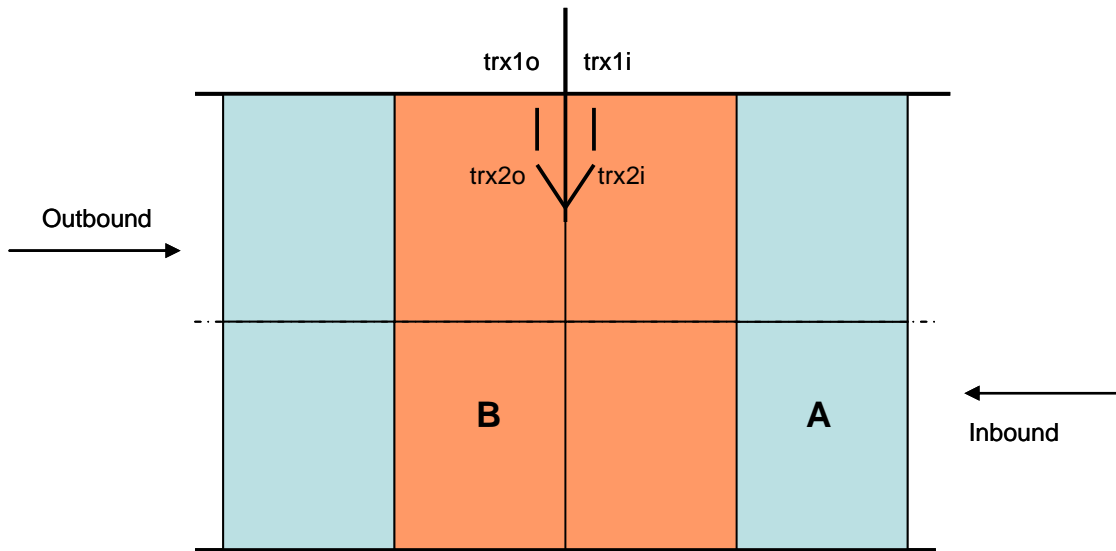
Figure 4-6: Transaction sequence for wrong-way transaction

4.4.3. U-Turns

To test the ability of the paired charge-points to detect U-turns, two types of U-turn manoeuvres were undertaken, as illustrated in Figure 4-7 below. In one test, the drivers drove right through the communications zones of both charge-points before carrying out a U-turn some 10-15 metres further on, so that the communications zones were re-entered within the 255 second shut-out period. A tight U-turn was also attempted where the U-turn was carried out in the communications zone of the second chargepoint. Both tests were carried out in both directions and with both suppliers' tags.
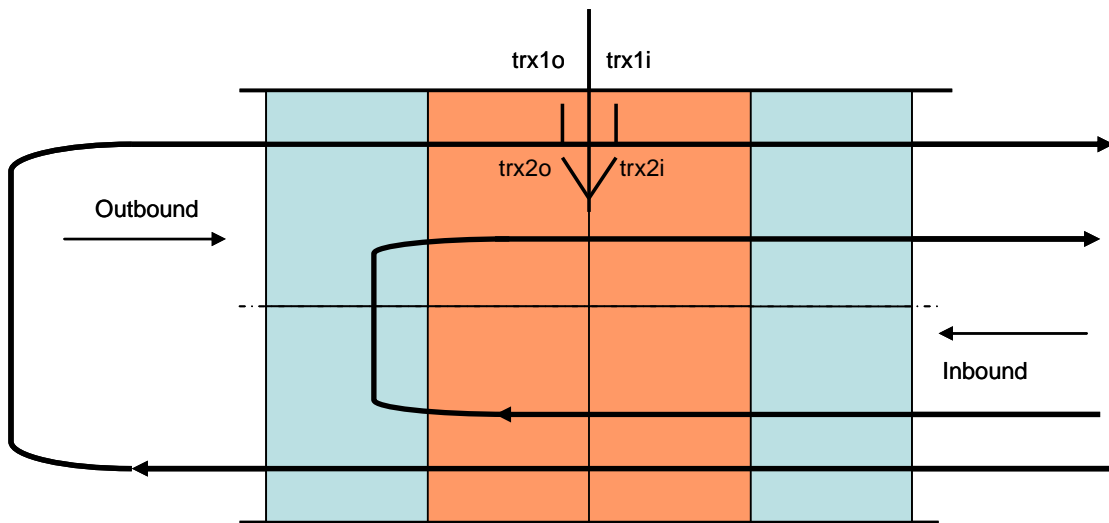
Figure 4-7: Schematic of U-turn manoeuvres undertaken

Approximately 13,000 vehicle passages were recorded for the large U-turn test. Overall detection rates (DSRC: 99.7%, ANPR: 97%) were again in line with the standard tests as was the spatial matching performance (99%). As for the direction detection tests, multiple transactions occurred in the U-turn tests. Figure 4-8 below shows the zones in which tag transactions were recorded.
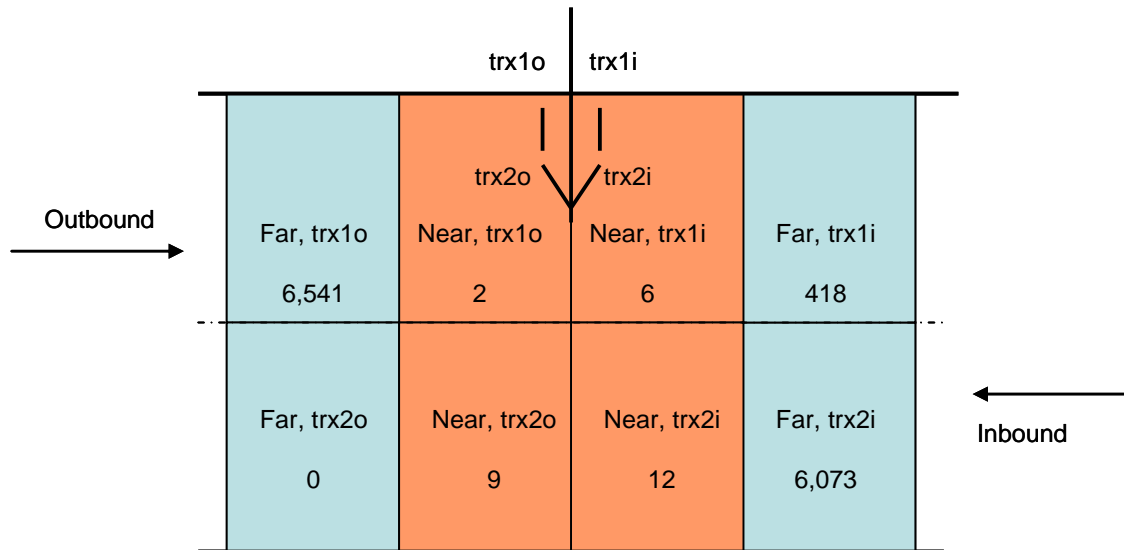
Figure 4-8: Location of transactions in large U-turn test

For this test, it would be expected that a transaction would occur in the far zone of the entry direction, followed by a transaction in the far zone of the exit direction but, as seen in the direction detection test discussed above, transactions can occur in the near zone. The direction detection test showed that "wrong-way" transactions do not occur in the far (blue) zones and a far-zone in / far-zone out sequence therefore indicates successful detection of a U-turn. The 99.7% detection rate shows that this "normal" sequence is indeed successfully identified. The analysis of the tests therefore concentrated on the 30 transactions (0.2%) which occurred in the near (red) zones.

Of these, 20 were identified as being part of a sequence of multiple "right-way" transactions. The system would be able to identify them as such by means of the timing and zoning of the other transactions in the sequence and discard them. The other 10 were potentially either wrong-way transactions or transactions of the return leg of the U-turn. Since this part of the test required the drivers to drive right out of the communications zone before performing the U-turn and since the direction tests had identified that a "right-way" near zone transaction never occurred without a "right-way" far zone one, the trials team were able to identify all 10 transactions as being wrong way and not U-turn detections as no far zone transaction for the return leg of the U-turn was detected. However, in the tight U-turn test (discussed below), where a U-turn is made in the communications zone itself, it is conceivable that a "right-way" near zone transaction could be made on the return leg without a far zone transaction having been made. The system, not having knowledge of the manoeuvre being carried out, would not be able to make the distinction that the trials team made. A limited number (c. 50) of tight U-turn tests were carried out to investigate this possibility. The distribution of transactions is shown in Figure 4-9 below.

trx1o | trx1i

Outbound →

trx2o   trx2i

| Far, trx1o | Near, trx1o | Near, trx1i | Far, trx1i |
| 118 | 1 | 4 | 7 |

| Far, trx2o | Near, trx2o | Near, trx2i | Far, trx2i |
| 0 | 0 | 0 | 106 |

← Inbound

Figure 4-9: Location of transactions in tight U-turn test

As can be seen, even when attempting a tight U-turn test the transactions were generally in the far zone. It appears that there was one tight U-turn manoeuvre which may have caused a transaction in the "right-way" near zone – 2% of a small sample size.

In conclusion, the mini-zone trials demonstrated that 99.7% of U-turn manoeuvres are correctly detected by the independent back-to-back charge-points. 0.1% of U-turns result in tag transaction sequences which are ambiguous and which the system would be unable to identify on the basis of transactions alone as being U-turns or "wrong-way" transactions. Other data, such as ANPR reads, may help to resolve the ambiguity. In the worst case, if all near-zone transactions, which are not part of multiple transaction sequences, were treated as wrong-way and discarded, only 0.1% of U-turns would be erroneously discarded; thus there would be no cases where a user could potentially be charged erroneously.

4.5.   Conclusion

The mini-zone tests demonstrated that direction insulation and U-turn detection can be effectively implemented by one of the suppliers. The results of the volunteer tests, particularly in relation to Police drivers, have demonstrated that detection of U-turns is a more significant issue than previously thought. Although the Police form only a small proportion of drivers, there are other groups which are likely to perform U-turns in large numbers, including taxi drivers and delivery drivers. Without a direction insulation/U-turn detection capability it is likely that there would be significant issues in determining precisely what was happening at a charge-point. It is believed that there are no IPR issues with the general method used (although of course the detailed programming would be subject to IPR); however, different manufacturers use different technologies and it is not known whether or not those technologies would permit the implementation of effective direction insulation/U-turn detection capabilities.

5. Integrating DSRC with Existing ANPR Solutions

5.1. Introduction

The trials examined whether the new cameras could be successfully integrated with DSRC equipment from a different supplier, whilst maintaining a performance sufficient to meet the potential Service Level Agreement (SLA) () requirements. They also:

- developed an interface specification between ANPR cameras and DSRC systems and demonstrated the passing of data across such an interface

- informed a Statement of Requirements on what performance and matching functionality can be achieved at the roadside and what could be delivered in a back-office or in-station

5.2. Integration Trial Methodology and Analysis

5.2.1. Site Selection

Following site surveys, Borough High Street was selected as the target site, with a 6m cantilever outrigger with a 7m clearance height. This site lies between two traffic light controlled junctions and is subject to highly variable traffic flows up to 3,000 vehicles per hour. This site also includes a red route, traffic light-controlled pedestrian crossing and a bus stop.

5.2.2. Systems Interfaces

Typically a DSRC system is closely integrated with ANPR cameras to ensure accurate time synchronisation and to reduce the complexity of the interface to the cameras. However, the need to prevent any disclosure of camera data to any DSRC vendor required software development and led to a revised roadside system architecture as shown in Figure 5-1 that separated the ANPR system (cameras and instation) from the DSRC system.

The system architecture, specifically developed for the trial, includes a 'buffer' between a camera / Instation and DSRC system, comprising a common (but independent) time source and a TfL application to format data records generated by the ANPR Instation to enable them to be used for matching within the DSRC subsystem. A fully integrated solution would not need to employ these buffers, as demonstrated by the DSRC vendor systems already supplied for the minizone trials.

A clear partition between the supply of equipment and related services for Congestion Charging Western region cameras and DSRC systems meant that TfL was required to baseline equipment positions, define a common coordinate system (so that the cameras and DSRC equipment would be aligned to the same reference), provide a common external time source and specify the camera instation to DSRC system interface.

5.2.3. Trial System Architecture
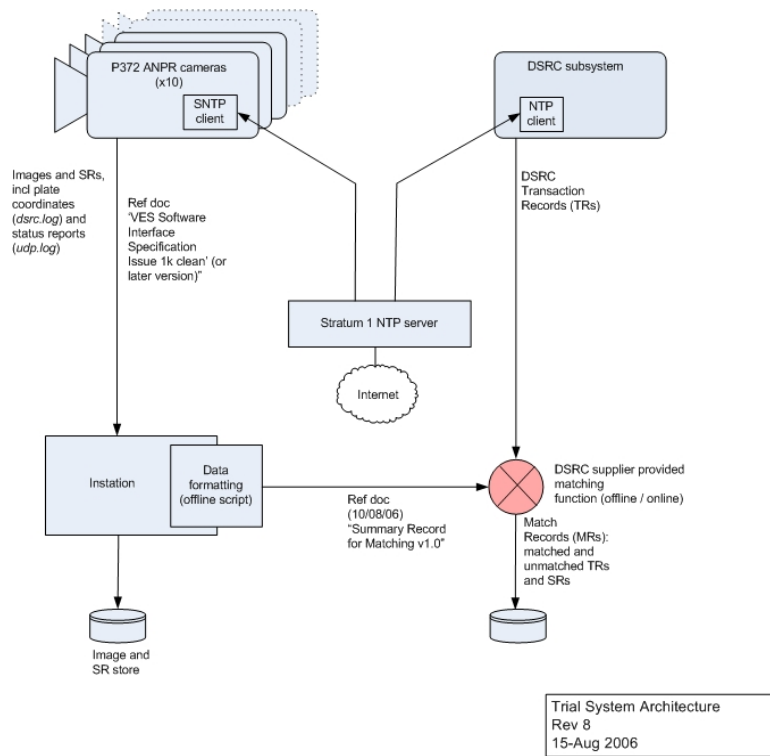
Figure 5-1: DSRC/ANPR integration trial system architecture

5.2.4. Coverage Overview

Four different site geometries were trialled, each providing different overlap between DSRC and ANPR detection zones. The greater the degree of spatial overlap between the ANPR camera capture zone and DSRC communications footprint, the greater the opportunity to spatially match vehicle number plates with corresponding vehicle tags.

The general coverage strategy, as shown in Figure 5-2 below, permits spatial matching from a single mast arm with cameras positioned in high skew and low skew configurations.

Figure 5-2: General coverage strategy

A site is defined by the camera lensing, camera aim points (min and max) and other variables such as the camera pitch and roll. Based on the general coverage strategy above, the four camera geometries applied to each DSRC system vendor were:

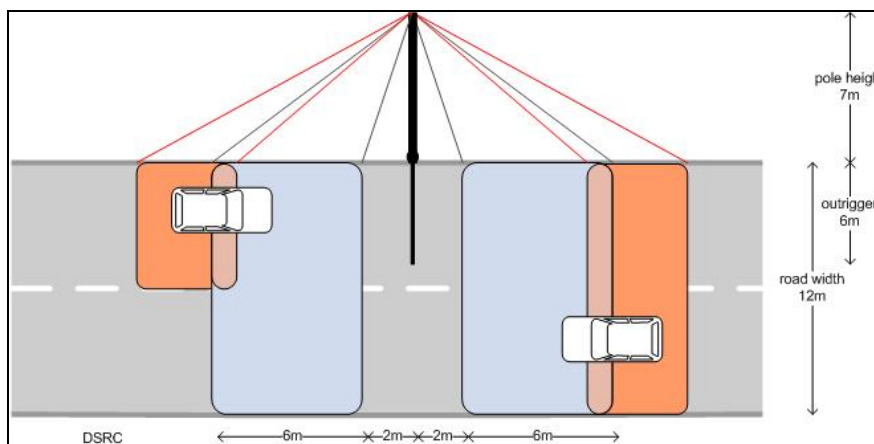- Geometry 1 - non-overlapping camera detection zone and DSRC communications footprints,

- Geometry 2 - tangential/partial overlap (camera with an aim point closer to the pole),

- Geometry 3 - ANPR detection zones lying fully within the DSRC communications footprint, and;

- Geometry 4 – tangential/partial overlap (camera with a shorter focal length lens and a closer aim point than Geometry 2).

Geometry 1 represents a standard Congestion Charging Western region geometry and Geometries 2, 3 and 4 involve a steeper camera viewing angle than used for any Congestion Charging Western region sites. It should be noted that the Congestion Charging Western region sites which use longer aim points are those which cover a wide road and require a long aim point to cope with the resulting skew angle of the camera. If the camera were mounted on an outrigger, which would be required for DSRC transceivers, the skew angle would be reduced and a longer aim point would no longer be required.

5.3.   *Results Overview*

The results gathered to date are presented in figure 5.3 below, which illustrates the relationship between spatial matching performance and compound camera performance. Sections 5.3.1 and 5.3.2 below give the summary results underpinning this chart.

The tests determined that as the camera slope angle increases (i.e. shorter aim point) the compound performance falls off sharply as several factors start to have an aggregated effect, including the reduction of the pixel height of the horizontal strokes and obscuration by the vehicle's bumper. As the slope is increased further the plate satisfies the minimum geometric criteria for reading the VRM for a shorter time thus reducing the performance margin until at no point of the plate's passage through the FOV (Field of Vision) are the criteria met (although the ANPR system is still able to detect the plate itself).

As the angle is further increased this rapidly results in the camera being able to trigger for fewer plates until the plate finder fails completely.

The figure demonstrates that with a longer aim point and consequently little overlap of the camera and DSRC detection zones, the SLA criteria were met but it was not possible to achieve adequate spatial matching performance. Conversely, with a shorter aim point high levels of spatial matching were achieved but it was not possible to meet the SLA criteria for camera performance. It was only with a camera with a particular focal length lens and a specific aim point that both requirements were met simultaneously.
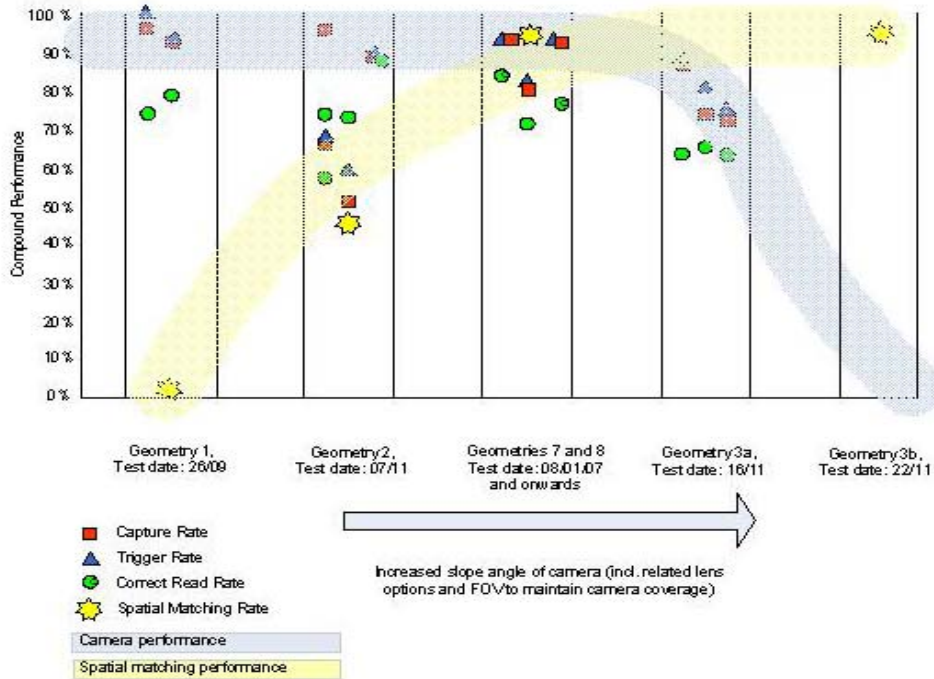
Figure 5-3: Relationship between spatial matching and compound camera performance

5.3.1. Groundtruthing Results

The purpose of this groundtruthing was to determine whether the different geometries would allow the potential SLA requirements to be met. Please see accompanying notes as highlighted in superscript against relevant results.

		Vendor 1	Vendor 2
Geometry 1[1]	Trigger rate	93% - 100%	Tbc[2]
	Capture rate	93% - 96%	
	Correct read rate	74% - 77%	
Geometry 2	Trigger rate	59% - 89%[3] (100%)[4]	Tbc[2]
	Capture rate	51% - 89%[3] (96%)[4]	
	Correct read rate	57% - 89%[3] (74%)[4]	
Geometry 3[5]	Trigger rate	75% - 87%	Test not performed[6]
	Capture rate	72% - 86%	
	Correct read rate	62% - 63%	
Geometry 4[7]	Trigger rate	84% - 94%	87% - 94%
	Capture rate	81% - 93%	84% - 93%
	Correct read rate	71% - 84%	63% - 84%

Table 5-4: Summary results of standard Congestion Charging Western region groundtruthing for different geometries

Table 5-44 above illustrates:

(1) Geometry 1 represented a typical configuration for ANPR cameras and included detection of front and rear plates. The performance of the site satisfied SLAs, which is as would be expected.

(2) The cameras used are the same between the two vendor tests, with only minor differences in the configurations. The main difference is in the DSRC equipment used. Consequently it would not be expected that the results for camera groundtruthing would be significantly different between the vendor tests. At the time of writing results using the second DSRC system vendor are not yet all available, but available results (geometry 4) show camera performance that is not measurably different between the two vendor tests.

(3) The range of results for a given geometry and parameter (e.g. 59%-89% for trigger rate for Geometry 2) is due to the fact that different cameras monitored different mixes of front and rear number plates, with rear plates resulting in a worse performance. This is a normal variance that is already observed in London.

(4) The performance reported above for Geometry 2 was lower than expected as the vendor had entered an incorrect plate width as a parameter for the ANPR software. The software uses this information to determine what in the FOV is actually a number plate. An incorrect setting of this parameter means that some number plates will be incorrectly identified as not being a number plate and hence being rejected. Desk analysis showed that partially compensating for the incorrect parameter setting raised the performance to the figures shown in brackets. This performance could be improved further with filtering. The camera vendor has also confirmed that cameras set up to this geometry should meet the SLA specification

(5) Geometry 3 demonstrated some of the effects of operating at a steep viewing angle, which "squashes" the height of the characters on the number plate in relation to their width - the pixel height of the horizontal strokes approaches the OCR (Optical Character Recognition) engine limit for some of the plates' trajectory through the Field of View (FOV). Some plates were also being clipped by the vehicle bumper. In addition, the reduced FOV could impact camera coverage planning at some sites should this site geometry be used. This geometry would not meet the SLA

(6) Groundtruthing was not carried out for Geometry 3 for Vendor 2 as the results for Vendor 1 showed that the geometry would not meet the SLA

(7) The results for Geometry 4 indicate that this geometry meets the SLA requirements for front plates.

5.3.2.   Spatial Matching Performance

Geometry 4 (for Vendor 2) resulted in a Spatial Matching Performance of 94.5%-98.8%. Given that this was the only Geometry to provide results that suited required SLA performance, this is the only result relevant.

5.4.   Equipment Loading

The load imposed by equipment located on a mast arm can be assessed by considering the total weight of the equipment, the torque imposed by the equipment's position and the force exerted by wind, which is approximately proportional to wind surface area.

For both vendors, using the existing Congestion Charging Western region cameras instead of the cameras used in the vendors' integrated solution reduces total load and total torque. Surface area is increased by 14% compared to one vendor's solution and decreased by 8% compared to the other's solution.

5.5. Conclusion

Integration between an ANPR camera and DSRC systems from two different vendors is feasible and comparable performance to a single supplier solution can be realised. This can be achieved with an ANPR camera with a lens of different focal length and an aim point closer than that used in typical ANPR cameras, giving a partial overlap of detection zones for ANPR cameras and DSRC beacons. No hardware modifications, other than relensing, are required. However, difficulties were faced in developing a repeatable and accurate installation and alignment method. It is expected that these difficulties could be overcome with the correct level of installation crew training.

The use of existing cameras reduces the loading on the mast and outrigger compared to the use of the cameras in the vendors' integrated solutions. Reduced loading means that potentially slimmer outriggers can be used, reducing the visual impact of the system.

6. Inter-scheme Interoperability

6.1. Introduction

The mini-zone trials have demonstrated that tags and beacons from different suppliers can successfully interoperate. As part of the Stage 3 Trials, TfL is examining the interoperability of tags with other schemes. Several demonstrations have already proved technical interoperability (i.e. tags from other schemes and the trials beacons mutually recognise each other and are able to communicate).

There are a number of geographically isolated schemes in the UK, each of which currently acts as a completely independent system with its own tag users.

Depending on the level of interoperability that is achievable and justified with the relevant partner scheme, the following scenarios could be envisaged:

Level	Description	Comments
1	Bilateral technical interoperability	Enables tags to communicate with the beacons of partner schemes. In this scenario, the user registers for an account with each scheme and has separate payment arrangements
2	Bilateral technical and procedural interoperability	As level 1 plus additional agreement on common coding of data in tags (for example vehicle class)
3	Bilateral, technical, procedural and contractual interoperability	Bilateral agreements with one or more partner schemes allow users to register with a single scheme and manage a single account for payment of incurred charges in all partner schemes (for example TfL tag and account valid for payment in M6-Toll)
4	Introduction of a national interoperability service	Agreement and definition of a national interoperability service and contract to be offered to users. Tag issuers may or may not be linked to local schemes.

Table 6-1: Levels of interoperability

The Department for Transport (DfT) is currently encouraging and working towards Level 3.

6.2. Interoperability Demonstration

An interoperability demonstration was carried out in cooperation with the Dartford and M6 schemes. Both operators provided the security codes to allow the mini-zone DSRC charge-points to communicate with tags from these schemes to demonstrate a number of aspects of interoperability including:

- implementation of technical interoperability in the TfL mini-zone;
- exchange of DSRC security keys;
- the generation of 'foreign' (non-TfL) tag events in the TfL mini-zone; and
- the generation of dummy chargeable events in the Stage 3 trials model back-office.

The demonstration showed that all the information necessary to generate a transaction record was read from the tags of these two schemes. Nothing was written back to the tag as it was not wished to interfere with an operational scheme. It is not possible to say what the detection rate of these tags was, as there was no knowledge of the when the vehicles in which the tags were located passed the mini-zone UCPs and as there was also no knowledge of the VRMs of those vehicles it was not possible to identify passages by means of the ANPR stream.

6.3. Detection of Non-Trial Tags

The following table shows the number of tag detections by country for the period 1st June 2006 to 31st August 2007.

The country of origin is determined from the country Code of the tag issuer which is exchanged during the initial phase of a DSRC transaction. It is not possible to determine how many unique tags have generated these events.

For the same period 69,140,000 vehicle passages were recorded by the ANPR cameras, of which 68,310,000 were for non-trials vehicles. From this it can be derived that approximately 1.5% of non-trials vehicles entering the Southwark mini-zone are already equipped with tags from other schemes in the UK, Europe and beyond.

Country	Tag Issuer	Number of Detections
United Kingdom	TfL Trials	823,076
United Kingdom	Dartford	839,106
United Kingdom	M6-Toll	27,839
United Kingdom	DIRECTS	105
United Kingdom	Tamar	303
Austria		57,196
Norway		19,910
France		6,010
Czech Republic		5,978
Spain		616
Ireland		609
Denmark		407
Sweden		176
Greece		119
Australia		11
Faroe Islands		7
Turkey		6
Italy		3
Israel		1
Yemen		1
Mayotte		1
Brazil		1
Venezuela		1
Unknown		1,405
Total		**1,782,887**

Table 6-2: Tag events in the mini-zone by country June 2006 to August 2007

Note: Unknown indicates that country code programmed into the tag was not recognised.

7.   Streetscape Integration Study

7.1.   Introduction

TfL has identified 'tag and beacon' systems, which use dedicated short-range communications (DSRC) technology, as offering a reliable and accurate next generation of Congestion Charging technology. Automatic number plate recognition (ANPR) and colour overview cameras, as are currently used, will still be needed for the following reasons:

- it is expected that fitting an on board unit or tag will be optional, so that payment by user declaration will continue, and

- enforcement by camera / ANPR will always be required.

Thus, 'tag and beacon' systems mean additional, rather than replacement, infrastructure is required. The purpose of the 'Streetscape Integration Study' was aimed at minimising the visual impact of introducing a tag and beacon system. This chapter summarises the findings of the Study.

Whilst the main purpose of the DSRC trials in Southwark was to assess the technology itself, an exploration of aesthetic issues was also started. In Stage 1 of the trials, existing DSRC installations in Singapore, Stockholm and Italy, among others, were reviewed and a report commissioned from an external consultancy on possible structures to support DSRC and ANPR equipment. As a result, TfL opted to trial in Stage 2, as part of the mini-zone trial, a range of simple cantilevered poles that, unlike the other multi-pole / multi-gantry solutions, integrated equipment onto a single horizontal outrigger (sometimes split with one each side of the road).

Whilst the trials infrastructure clearly demonstrates a significant improvement over the gantry structures used in Singapore and Stockholm and results in less clutter than the systems used in Italy, further improvements can be made before such a system is installed across central London. It is this end which the Streetscape Integration Study sets out to achieve, with the technology trials mini-zone in Southwark providing a starting point.

The Streetscape Integration Study in Stage 3 of the trials first undertook:

- a review of the existing streetscape guidance from each of the nine boroughs covered by Congestion Charging, as well as from TfL itself, and

- discussions with some stakeholders on the applicability of this advice to DSRC/ANPR infrastructure and on the impact of the pole/outrigger designs used in the mini-zone in Southwark

Taking into account the results of this work, the study then:

- reviewed the design options available for various elements of the infrastructure

- implemented aesthetic improvements to the design of two sites in the mini-zone

- selected 54 representative sites (from a total of 340) in the original Congestion Charging region and Congestion Charging Western region and for each of these conducted studies into what designs could be implemented. These case studies did not install any physical infrastructure but resulted in photomontages of what the site designs might look like

7.2. Existing DSRC / Tag and Beacon Urban Installations

Typical Congestion Charging Western region Cameras (Smaller than in the original Congestion Charging region)

Figure7-1 shows typical installations of automatic number plate recognition (ANPR) cameras in the original Congestion Charging zone and the newly commissioned Congestion Charging Western region. Note that the sites shown here are not comparable as varying street widths and configurations require different equipment levels.

The significant reduction in size from the original Congestion Charging cameras to the Western extension region cameras is of particular note and demonstrates a trend that TfL hope to see continue with a view to minimising the visual impact of potential systems. The shorter poles and neater camera arrangements found in Congestion Charging Western region also demonstrate considerable aesthetic improvements in this regard, which the Streetscape Integration Study aimed to continue.

Typical original Congestion Charging region cameras

Typical Congestion Charging Western region Cameras (Smaller than in the original Congestion Charging region)

Figure 7-1: Comparison of a typical original Congestion Charging region camera with the Congestion Charging Western region Infrastructure

Figure 7-2 shows the components of the tag and beacon system currently being trialled by TfL in Southwark. Such a system continues the use of ANPR cameras for enforcement purposes, but adds DSRC transceivers, which communicate with the tags.
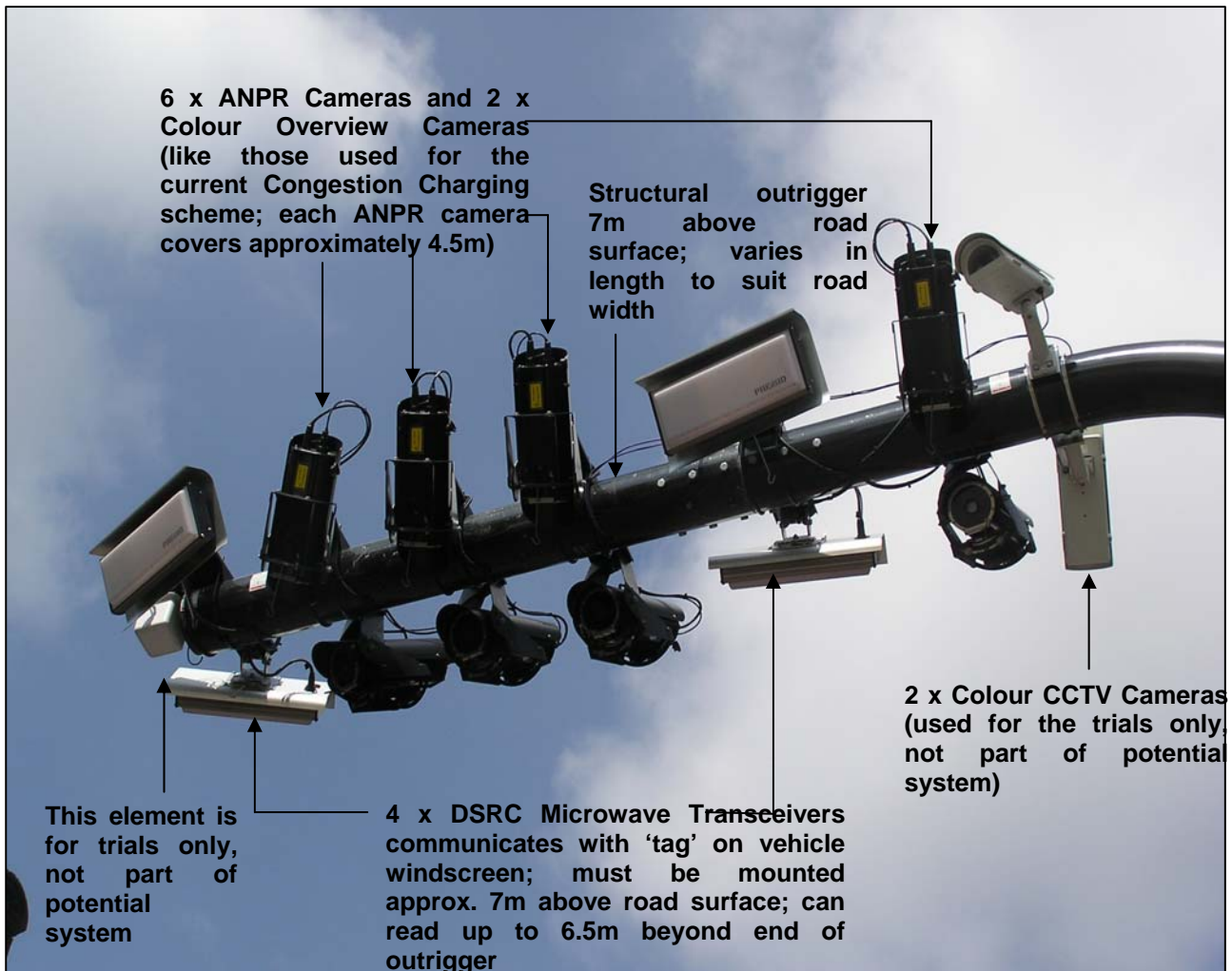
6 x ANPR Cameras and 2 x Colour Overview Cameras (like those used for the current Congestion Charging scheme; each ANPR camera covers approximately 4.5m)

Structural outrigger 7m above road surface; varies in length to suit road width

2 x Colour CCTV Cameras (used for the trials only, not part of potential system)

This element is for trials only, not part of potential system

4 x DSRC Microwave Transceivers communicates with 'tag' on vehicle windscreen; must be mounted approx. 7m above road surface; can read up to 6.5m beyond end of outrigger

Figure 7-2: Components of a tag and beacon (DSRC) system being trialled in Southwark

7.3. *Review of Existing Streetscape Guidance and Stakeholder Consultation*

None of the streetscape guidance specifically anticipates DSRC/ANPR infrastructure, so principles in the guidance regarding character must be applied instead. There is a generally consistent approach across all the guidance, although there are discrepancies in specific areas. A common theme is to reduce street furniture clutter and not to impede movement.

The main comments from stakeholders about the trials sites related to the large size of the poles and outriggers and the cluttered arrangement of equipment on the outriggers.

7.4. *Design Options Review*

This summary of design options incorporates inputs from the guidance review and stakeholder discussions.

7.4.1. Integration and Mounting

As reduction of clutter is such a strong theme throughout all the guidance, it is understandable that the initial response/reaction may be to integrate Congestion Charging infrastructure as much as possible with similar elements, namely by mounting DSRC/ANPR equipment on

strengthened replacement lamp columns. However, current technology constraints, including the requirement to provide a stable platform, result in structural requirements that cannot be satisfied by lamp column dimensions, even by increasing structural wall thickness. In other words, the column needed to support DSRC/ANPR equipment is likely to be noticeably larger than the sizes used to support most street lighting. Therefore, if a lamp column is replaced by a new DSRC/ANPR column that also supports the street light, it will look very different from the original and may interrupt the rhythm along the street that regularly spaced lamp columns so often provide.

Given this and the inappropriateness/impossibility of integration with historic elements, it is most likely that any DSRC/ANPR infrastructure will need to be designed as stand-alone elements in the streetscape. However, where meaningful integration with other streetscape elements is feasible and represents the lesser visual impact, especially with control cabinets, this should be pursued.

Where the mounting of DSRC/ANPR equipment on buildings or structures is achievable and delivers advantage in terms of reducing physical and/or visual clutter, it should be pursued. However, the potential for camera shake caused by vibration from traffic or train movement across bridges needs to be considered when mounting on such structures. Another important technical consideration relates to reflection of beacon transmissions off nearby surfaces. For example, beacons mounted near windows may have their signals reflected off the window surface, whilst beacons pointing back under bridges may cause reflections between the road surface and the underside of the bridge. Mounting beacons in such locations should therefore be avoided.

7.4.2.   Cabinets

Although the siting of cabinets is often dictated by site conditions, best efforts should be made to integrate the cabinet into the streetscape and make it as unobtrusive as possible. As technology develops, it is TfL's aspiration that equipment sizes be reduced as far as possible.

The "standard" cabinet currently approved for street furniture actually consists of two separate cabinets: a large cabinet to hold the bulk of the equipment plus a smaller pillar for power. These add significantly to street clutter. It is hoped that these standard cabinets will not be used for any tag and beacon systems in London. Instead, a combination of three other options should be used to suit various site conditions:

- a single cabinet, integrating power and communications with the bulk of the equipment, mounted on the pavement, as with existing standard cabinets

- an integrated cabinet, which is able to sink level with the pavement. Such a cabinet has been trialled but is impractical for many sites

- an integrated cabinet, which is integrated with a seat or bench. Under normal use, this piece of furniture appears to be a normal street / park bench or seat. For maintenance purposes the seat part of the bench is swung up, allowing the cabinet, concealed beneath the seat, to also be swung up so that equipment can be accessed. This option is also impractical for many sites and would require consultation with the relevant boroughs

7.4.3.   Colour

The streetscape guidance on colour was that equipment should be black or grey dependent on area. On the assumption that congestion charging infrastructure should recede into urban background as much as possible, it makes sense that grey should be used where infrastructure is mostly viewed against a background of light-coloured buildings or sky, whereas black will recede more against dark-coloured buildings or vegetation, albeit that summer and winter may be very different. There is a case for selecting colour on a site by site basis, rather than simply following the streetscape guidance.

7.4.4. Outrigger Mounting and Aesthetic Embellishments

A number of aesthetic embellishments (enclosed designs, hoods (half-enclosed) and heritage-style embellishments) were explored but rejected for a variety of reasons. However, the study concluded that the way equipment was mounted made a significant difference to the appearance of the installation. Equipment should be mounted under rather than over the outrigger and within the depth of the outrigger to maintain as clean a line as possible.

7.5. Aesthetic Improvements in the Trials Mini-zone

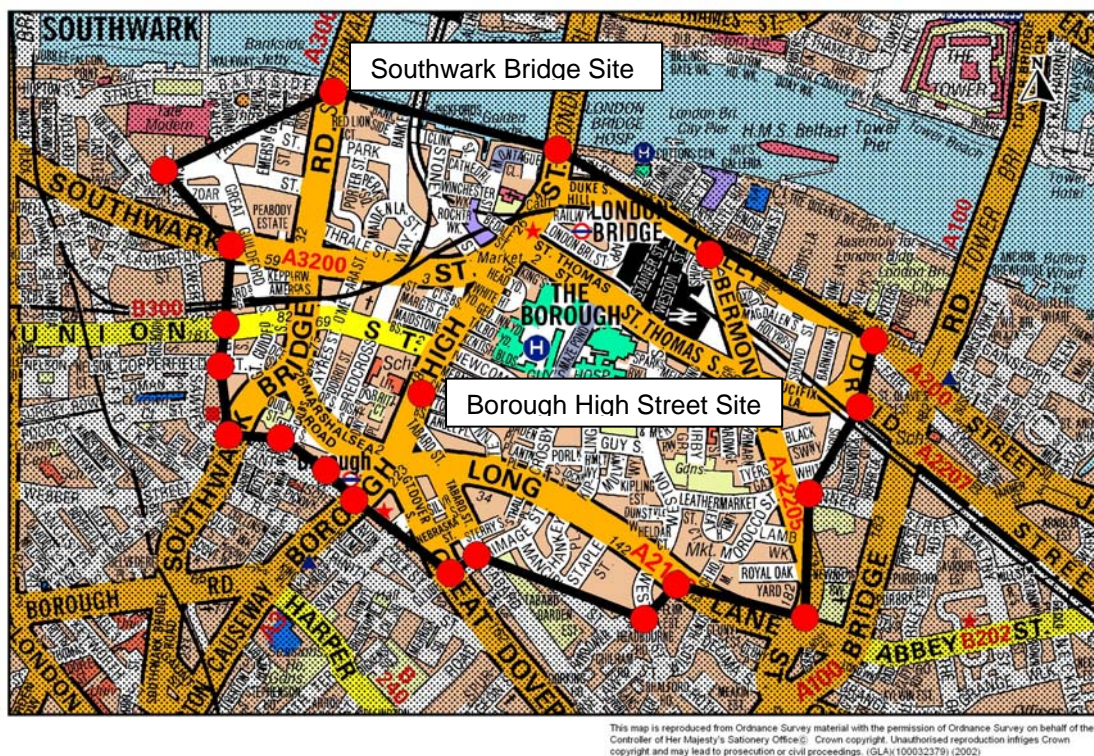The Technology Trials minizone is made up of 20 sites as shown in Figure 7-3.

**Figure 7-3: Mini-zone with 20 trial sites**

Through the Streetscape Integration Study, two sites were identified for aesthetic improvement, in response to feedback from stakeholders:

Southwark Bridge – replace a pole (with a 6m outrigger) at the side of the carriageway with a T-bar (1.5m arms) in the central reservation

Borough High Street – replace a pole (with a 6m outrigger) at the side of the carriageway in Tooley Street with 2 poles (each with a 2.5m outrigger) on each of the street in Borough High Street

7.5.1. Southwark Bridge

The old 6m pole, as seen in the background in Figure 7-4 below, was removed and replaced with a new T-bar pole in the centre of the road. The new pole is a grey colour instead of black. Stakeholders agreed that grey would blend into the streetscape better than black.
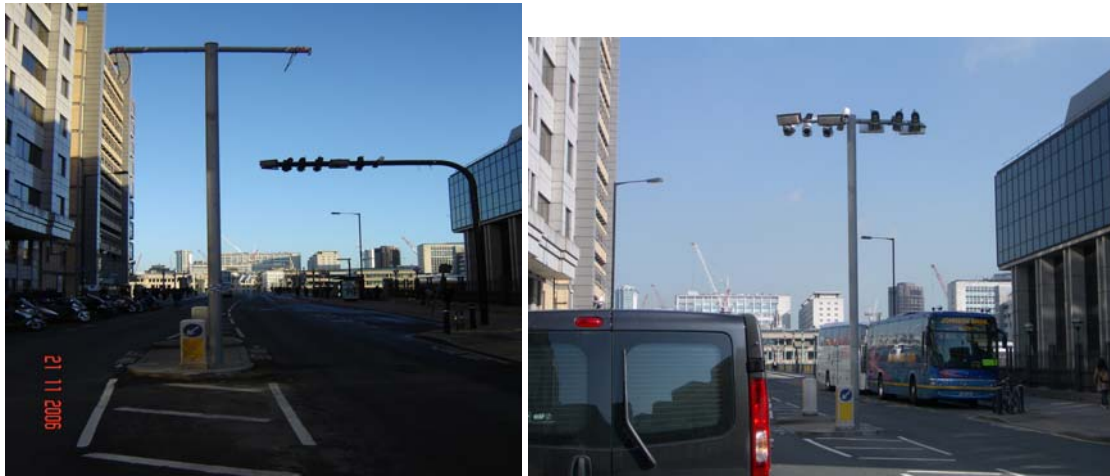
Old black pole and new T-bar pole   **New T-bar pole with equipment**

Figure 7-4: Southwark Bridge - aesthetic change

7.5.2. Borough High Street

The old pole with 6m outrigger as seen in the background in Figure 7-5 below was the first pole erected for the trials. The site has been replaced by 2 new poles (each with a 2.5m outrigger). The new pole is a grey colour instead of the original black. It should be noted that poles with shorter outriggers are easier to maintain since they do not require as much traffic management.

Figure 7-5: Tooley Street / Borough High Street - aesthetic change

7.6.   Case Studies

54 representative sites were selected. For each of these design case studies were conducted. These case studies did not install any physical infrastructure but resulted in photo-montages of what the site designs might look like. They should be considered simply as examples of what the sites could like rather than definitive statements of intent; detailed site design, taking into account technical requirements, may result in different outcomes. The results of two of these case studies are shown below for illustrative purposes. All 54 case studies are shown in the full Streetscape Integration Study report.

Existing site

Key site issues:

- Wide street with building against right kerb
- Existing line and rhythm of regularly spaced contemporary feature lamp columns on left

Photomontage showing potential 'tag and beacon' installation

Key site changes:

- Grey T-bar suggested on extended central island to minimise impact on existing feature lamp columns
- Existing original Congestion Charging region pole removed

Comments received:

Grey colour recedes very well against the background and has less visual impact than existing black pole

Figure 7-6: Case study 1 - Victoria Street

Existing site

Key site issues:

- Very wide street with central island
- Trees on right

Photomontage showing potential 'tag and beacon' installation

Key site changes:

- Three black poles suggested to minimise outrigger lengths, including central T-bar on island

Observations:

Possible issue with road curvature causing difficulty for reading number plates on an angle

Figure 7-7: Case study 2 - Cromwell Road

Overall, the conclusion from the case studies was that DSRC/ANPR equipment can be mounted at all sites with reasonable aesthetic results whilst minimising clutter. However, it is likely that designs will need to be site specific, even when utilising a palette of design options.

In testing the preferred designs using the 54 case studies, a number of key lessons emerged:

- no case study necessitated the use of an outrigger exceeding 2.5m in length, albeit that actual ground conditions may dictate otherwise in rare cases. Where case studies included very wide roads, coverage was achieved using a central T-bar with poles on one or both footways. However, this may not be possible for other very wide streets

- smaller twin poles located directly opposite each other in wider streets provide a "gateway" effect that many stakeholders liked

- many sites have opportunities to remove clutter in the immediate vicinity, including, for example, integrating signage or police check-point ANPR cameras within the City of London

- the use of kerb/footway build-outs to channel traffic and thereby reduce outrigger lengths is worthwhile in certain situations and can be particularly beneficial in providing mid-block pedestrian crossing points and breaking the barrier effect of long rows of parked cars

- careful choice of colour (for pole, outrigger and equipment) made a significant difference to visual impact on many sites as discussed in section 7.4.3 above

- building-mounting will only be feasible with legal agreements in perpetuity with freeholders, but may be worthwhile in specific cases in order to keep narrow footways clear of obstructions

- bridge-mounting of equipment is possibly one of the best ways of reducing additional visual impact, albeit that it is subject to structural approvals and is only possible for very few sites

- T-bars located on central islands provide a good siting option when it is desirable to avoid footway locations, either due to lack of space or to reduce proximity conflicts with heritage or other distinctive streetscape elements located on the footways

The trials' system architects suggested that the outrigger lengths used for the case studies generally appeared too short, certainly when compared to those used for the mini-zone trials in Southwark. However, closer inspection of many of the trials sites in Southwark suggests that equipment could be physically mounted at closer spacing, which would allow shorter outriggers to be used. However, it should also be noted that there are minimum separation requirements between two or more transceivers to avoid interference. TfL wishes to encourage equipment suppliers to continue reducing the size and bulk of their equipment and hence the length of the outrigger required to support it. Given that the length of the outrigger is probably the main factor in determining the level of visual impact, any effort that reduces outrigger lengths will bring the most benefit, albeit that there is a balance to be struck between outrigger length and technical requirements. This balance would need to be evaluated for each supplier's equipment and configurations.

One of the surprise results was that eleven out of the 54 sites have the potential for integration with existing lamp columns and/or traffic signals, the main aim of which is to reduce clutter by minimising the need for additional poles. Although it would appear that in the order of 20% of sites may have potential for beneficial integration with existing lamp columns and/or traffic signals, there are some challenges that may compromise the feasibility of such an approach.

Firstly, it is important that an integrated lamp column maintains the same lamp type, height and profile of the existing lamp column so it fits in with adjacent lamp columns, especially at night when the lamps become more prominent. This would result in many integration sites requiring a custom-made one-off "lamp column extension" to be fabricated to match the existing lamp column, the cost of which may be prohibitive when compared to the potential benefit. As traffic signals are mounted below the height of the congestion charging equipment, integration with these is more straightforward.

Secondly, integrating a lamp column or traffic signal requires the cabling for those items to be incorporated in a separate duct inside the congestion charging pole, which may be particularly difficult in the case of the lamp column at the right-angled joint that connects the outrigger, where space is already tight.

Third and finally, the integration of a lamp column or traffic signal with a congestion charging pole introduces additional weight and wind loading that may make the already large poles even larger again.

7.7.   *Conclusion*

The Streetscape Integration Study has shown that developing infrastructure (poles, outriggers and cabinets) to support equipment for a tag and beacon system which satisfies the aesthetic and clutter-reduction requirements of streetscape guidance is possible. Some integration with existing street furniture (lamp-posts, traffic signals) is possible, but in the main DSRC/ANPR equipment is likely to be mounted on stand-alone poles. The Streetscape Integration Study has, through reviews of guidance and design options, the testing of aesthetic improvements to trial sites and conducting 54 case studies of potential DSRC/ANPR sites, identified a series of design choices, options and guidelines for the implementation of DSRC infrastructure, giving a "toolkit" of potential solutions. However, design is likely to be site-specific, albeit working with this "toolkit" and there will be a need to consult with relevant stakeholders during the design process.

8. Implications for Policy of DSRC

As discussed earlier in the report, the trials have demonstrated that technical and aesthetic issues related to the use of DSRC in an urban environment have been solved, allowing tag and beacon to be introduced as a detection mechanism for congestion charging / road user charging in London.

The introduction of DSRC has some implications for what sorts of policies could be introduced and how the scheme would need to be operated and enforced.

8.1. Detection as a Charging Mechanism

The main implication is that DSRC's higher detection rate of 99.7% (as opposed to the read rate of ANPR cameras of c. 85%) allows for charging to be done on the basis of individual events. In the current scheme, where a user is liable for the charge if (s)he drives in the zone at all, it is reasonable to assume that users know when they have been in the zone and therefore what their liability for the charge is. In this case, detections serve as an **enforcement** mechanism – the risk of detection must simply be very high, not certain, to serve as a deterrent to avoidance. However, when charging is done on the basis of individual events (e.g. how many times has the person been detected) or a small groups of events (in which of 3 time periods has the user been driving) it is not reasonable for the user to calculate their liability himself. Therefore, the system must perform the detections, carry out the calculation of liability and inform the user. In such a case, detections are a **charging** mechanism and a low detection rate not only lowers revenues but also, because it therefore lowers the effective charge, has a behavioural impact lower than that desired.

.

8.2. Compliance

The introduction of tag and beacon does not mean that ANPR cameras can be dispensed with. Allowance will always need to be made for occasional visitors and for users who, for whatever reason, do not wish to use tags. In addition cameras will be required to ensure compliance with the terms and conditions related to the use of tags. Without the use of cameras, a user could sign up for a tag and then never put the tag in the vehicle; they would thus not be detected and would not be charged. There is a significant difference between London's congestion charging scheme which is barrier-free and many motorway and river crossing schemes where the absence of a tag would mean that a barrier would not rise.

A reasonable scheme will allow for users occasionally forgetting to put tags in vehicles etc. and where a tag is not detected but is expected would then charge based on the ANPR reading. However, given the lower detection rates of cameras, this then potentially allows users to sign up for tags and never use them, on the basis that they will then benefit from the lower detection rate at no cost to themselves. Any tag scheme in London therefore needs to allow for this, by barring persistent offenders from the tag scheme or by imposing other penalties. The precise rules are a matter of policy, but business rules need to be in place to allow the system to differentiate reasonably between users "working the system" and those who are simply persistently forgetful. The specification for the re-let of the congestion charging scheme allows for a variety of business rules to be defined and modified as appropriate in this area.

Such business rules will also need to cope with other misuses and abuses of the system. For example, until such time as tags are physically integrated into vehicles, users may try and swap tags between vehicles in an effort to reduce their liability. The effectiveness of this and hence the rules that need to be in place to cope, will depend on the charging policies. At one extreme, if every detection is subject to a charge, with no cap on charges, then swapping of tags between vehicles is of little consequence apart from administrative inconvenience. At the other extreme, if a tag is used as a basis of an area scheme, and only one charge is applied to a tag regardless of the number of detections, then swapping tags between vehicles could

potentially mean a large number of evaded charges. Thus tags need to be linked to specific vehicles and business rules need to be in place to detect potential swaps, whilst allowing for any legitimate ones which policies may allow for (e.g. moving a tag to a courtesy car whilst the main car is being serviced).

8.3.   Interoperability

One of the key benefits of tag and beacon is that it makes it easier for users to have one account and tag for multiple schemes, which is clearly desirable as such schemes spread. From a technical point of view, it is clear that such interoperability is perfectly feasible. The trials have demonstrated that tags from multiple manufacturers can be read by beacons from different suppliers. They have detected tags from operators in many different countries, although they have not been able to complete a transaction with them without the appropriate security keys. Work is being carried out at present with Dartford Crossing and M6 Toll to demonstrate that tags from different operators can be used interchangeably. Security keys have been exchanged between TfL and Dartford/M6 and the mini-zone transceivers are successfully completing transactions with Dartford/M6 tags.

However, for there to be full interoperability, operators need to exchange between themselves detection data (i.e. Operator A informs Operator B that it has detected one of Operator B's tags) and financial settlements (i.e. Operator A tells Operator B that the relevant charge for the detection is X; Operator B pays Operator A that amount and then collects it from his customer). Bilateral agreements between operators for settlement are conceivable in the near future, although still complex and uncertain, but a more generalised clearing system is still some way off. Even with bilateral agreements a number of issues remain to be resolved; for example, some operators simply do not record a VRM against a tag id, but TfL would require that information to be provided.

8.4.   Tag Fitting and Use

The detection rate of tags can depend on how the tag is mounted. For example, a tag mounted in the wrong place on a metallised windscreen can be largely shielded and therefore generate a far lower read rate. Thus the instructions for tag fitting, as well as the fitting process itself, must be simple and straightforward and differentiate between different types of vehicle in which the tag is mounted. The mini-zone trials with volunteer vehicles have demonstrated some problems with tag mounting with some types of buses, where the mounting position has meant that they get easily knocked off.

DSRC tags can (but do not have to) have a user interface in the form of a bleep when the tag is detected, which can be varied according to circumstances (e.g. one bleep normal, two bleeps battery low). Inevitably such tags are (marginally) more expensive. Consideration must be given to the trade-off between tag cost and whether the user will notice and act on the information given. The mini-zone trials have had the bleep function turned off for volunteers, so no direct experience can be quoted here. However, the drivers of dedicated trials vehicles have reported that after a time they started to become accustomed to the bleep and to not notice it and there have been occasions when the bleep malfunctioned, switching itself on or continually bleeping until the next beacon was passed. If this occurred in real life it could have a significant impact on battery life. These factors suggest that this interface should not be used or should be restricted to unusual circumstances, e.g. a low battery warning or a "contact operator" indicator.

9.   Key Conclusions

9.1.   *Improvements Already Made*

The technology trials have already had a significant impact on the development of the operation of the Congestion Charging Scheme:

- Integrated cameras with roadside ANPR and broadband communications from the roadside to the central system have been introduced for the Western Extension and will be used for the Low Emission Zone (LEZ). These changes result in lower setup and operating costs and a communications network which is more resilient and flexible

- The infrastructure being procured under the re-procurement of the main service provider (to cutover in 2009) has been designed to support any future implementation of tag and beacon technology

9.2.   *DSRC*

Stages 1 and 2 of the trials concluded that an Urban Charge Point was an achievable concept with a detection rate of > 99.5% and a spatial matching accuracy of 95.5%. They also demonstrated that a number of key design issues which needed to be addressed to allow DSRC to be used in an urban environment could be successfully solved, namely that:

- The DSRC and camera/ANPR sub-systems of the UCP could be successfully mounted on a single pole, thus reducing the impact on the urban streetscape which would have resulted from using separate poles for the two sub-systems

- It was possible to design tags which would have a reduced battery drain if the vehicle they were in was parked long-term in the DSRC communications zone of the UCP, ensuring that battery life would remain above 5 years in all cases and above 7 years in most

- Face-to-face chargepoints on two separate poles, which would be required instead of back-to-back chargepoints on a single pole if less than 30m of unrestricted carriageway was available, could be implemented without interference with a separation of as little as 15m

- Matching of a rear number plate to a DSRC transaction (front-to-rear) matching, which might be required to address specific siting issues, could be successfully implemented, but such implementation must be tailored not only to the physical site but also to the expected vehicle fleet at that site as different sized vehicles require different front-to-rear configurations

Stages 1 and 2 of the trials also concluded that although IR (rather than microwave) DSRC technology had some promise, it had some areas which needed to be addressed before it could be considered as a candidate technology; in particular, because it is not recognised by UK or European Commission legislation it was not taken further than Stage 2.

The Stage 3 trials demonstrated that the performance of UCPs in a live system (the mini-zone) was consistent with (and in fact, slightly better than) the performance found in Stages 1 and 2, with a DSRC detection rate of 99.7%, a UCP detection rate of 99.9% and a spatial matching accuracy of between 98.5% and 99.1%. Some 0.07% of tagged vehicle passages would escape detection, which could potentially result in lost revenue opportunities. Of those detected, about 0.2% would rely on a plate read rather than a tag read and 3% would rely on a tag read with no image to back it up. The former might require a back-office look-up against account details and would require appropriate business rules to prevent erroneous enforcement, whilst the latter ***might*** mean that a charge could not be enforced, depending on the terms and conditions and business rules which are in place. About 3% of vehicle passages

would present separate tag transactions and ANPR reads to the back office and appropriately designed processes would be required to cope with these.

The performance of the system was not affected by multiple tagged vehicles passing a UCP together, but at some specific sites there were some limited opportunities for drivers to deliberately avoid detection. It is clear that at such particularly difficult sites care needs to be exercised in the design of DSRC coverage to prevent drivers evading detection.

For volunteer drivers, the system performance was lower than, but in most cases comparable to, the results from the dedicated trials vehicles. For volunteer drivers, tag mounting issues had the greatest impact on system performance.

An analysis of trials data, based on analysis of data which would be available to an operational system and the approach put forward by TfL for performance indicators in the procurement of DSRC equipment suggested that operational measures of the performance of the technology may be lower from those obtained in the trials and that therefore the performance levels set for procurement and for Service Level Agreements should be lower than the performance levels suggested by the trials results. However, consideration should be given as to whether further work needs to be carried out on the performance levels to be used.

Stage 3 of the trials demonstrated that UCPs monitoring the two separate directions of a carriageway can be configured to correctly detect only vehicles travelling in the direction being monitored, not missing any but correctly ignoring vehicles travelling in the opposite direction. The trials also demonstrated that such a configuration would allow the chargepoints to detect U-turns which were made within 255 seconds of first detection; 99.7% of such U-turns were correctly detected. This means that cordon-based schemes could be implemented without the risk of vehicles driving in, doing a U-turn and driving out and being charged for only one crossing of the cordon. The volunteer trials also demonstrated that detection of U-turns was a more significant issue than previously thought, with some groups such as police, taxis and delivery vehicles performing large numbers of U-turns. Without a direction insulation / U-turn detection capability it is likely that there would be significant issues in determining precisely what was happening at the charge-point. The development of this capability represents a worldwide first.

The trials demonstrated that it was possible to integrate the recently installed ANPR cameras with DSRC equipment from a different supplier. This was difficult to achieve but a specific focal length of camera lens combined with a specific aim point made the integration possible. This means that if DSRC were to be introduced, the considerable investment in new cameras would not need to be replaced prematurely.

The trials demonstrated that it was possible to transact with tags from different schemes, such as M6 Toll and Dart, meaning that it would be possible, from a technical point of view, for a user to have a single tag and account for London Congestion Charging and other schemes. Such interoperability depends on other procedural and contractual measures being put in place.

Finally, the streetscape integration study developed a toolkit of guidance and design options for integrating UCPs with existing urban streetscape features, to reduce the visual impact of such UCPs. Whilst consultation with relevant stakeholders at site design stage will still be required, this toolkit makes it more likely that the implementation of DSRC will be acceptable.

9.3.   GPS and Distance Based Charging

The trials have demonstrated that GPS is not sufficiently accurate **on its own** to allow a road user charging system to rely on the accuracy of any individual reported point. However, GPS mobile positioning combined with map-matching can be used as the basis of a distance based charging system. The trials demonstrated that the best systems currently available are sufficiently accurate for this purpose, with charging errors of about 1%, which compares favourably with the performance quoted for taxis and tachometers of approximately +/- 4%. Although the best systems performed very well, even they produced significant errors in certain parts of London, characterised by "urban canyons" where insufficient satellites can be viewed

directly. Whilst the advent of Galileo (scheduled for 2010-2012) will alleviate these problems to some extent, there will be some parts of London where these problems will remain.

From a technical point of view, it is possible to start introducing satellite based DBC systems now, providing that it is accepted that there are some areas of London where there will be some inaccuracies and that only some service providers would be able to provide adequate accuracy. The advent of Galileo in around 2010/2012 will reduce (but not eliminate) the inaccuracies and the OBU technology is likely to be technically mature by then, if not significantly earlier. However, there is a question as to whether Galileo will be implemented at all and, if so, whether it will happen on time.

Whilst DBC is more or less technically mature at present, there are still significant logistical, operational, enforcement and political issues to be resolved before DBC could be introduced. It is likely therefore that DBC would be introduced initially on a voluntary basis, in parallel with other road charging schemes.

9.4. Mobile Telephony

The trials have demonstrated that mobile positioning based around mobile telephony is not accurate enough to be used as the basis for road user charging and the nature of the technology means that it is never likely to be so. There is one exception, based around the use of pico-cells (cells with a very small radius) and a GSM phone as a form of tag and beacon system. However there would be no advantage in using this approach instead of DSRC which has been specifically developed for the purpose.

9.5. Customer Information Services

The trials have demonstrated that it is possible to provide customer information and other services related to road user charging to users' mobile telephones.

If such services are to be provided, it is necessary to ensure that they are sent to a phone which is not only switched on and in the congestion charging zone, but also in a vehicle, rather than being carried around by a user who is on foot. The trials demonstrated that with the use of Bluetooth it is possible to ascertain that the mobile phone is in the vehicle and thus it is possible to prevent spurious messages being sent to the mobile phone when it is not in the vehicle.

The trials demonstrated that although information services can be provided to users' mobile phones related to their movements into and out of the zone, the use of the mobile phones to determine the location was neither terribly accurate, nor timely. Until a more accurate and timely service can be provided by the mobile phone operators, it would be inadvisable to use this method to advise users of their liability to pay. Even if the terms and conditions of such a service stated that this was merely advisory, it is conceivable that there could be legal challenges to a PCN if an advisory notification that someone had entered the zone was never received.