DIRECTS TRIALS OF UNUSUAL MANOEUVRES:
ATTEMPTS TO EVADE DSRC DETECTION IN ROAD CHARGING

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ABSTRACT
The DIRECTS project (Demonstration of Interoperable Road user End-to-end Charging and Telematics Systems) is a Road User Charging (RUC) trial funded by the UK Department for Transport, and implemented by the Fareway Consortium (Kellog, Brown & Root, Thales and Atkins). One objective was to demonstrate that DSRC roadside equipment cannot be evaded by an equipped vehicle carrying out "unusual but legal" road manoeuvres. Trials were carried out at the UK TRL test track and on an urban road in the city of Leeds. These manoeuvres were not successful in evading detection and charging.

KEYWORDS
Road pricing, road user charging, tolling, enforcement, DSRC, demand management.

INTRODUCTION

The paper describes trials which were carried out at the UK Transport Research Laboratory (TRL) and in Leeds as part of the DIRECTS project (Demonstration of Interoperable Road user End-to-end Charging and Telematics Systems). DIRECTS is a multilane free-flow electronic Road User Charging (RUC) trial project funded by the UK Department for Transport (DfT), and implemented by the Fareway Consortium (KBR, Thales and Atkins). See (1), (2), (3) (4) (5) for other papers on DIRECTS.

One part of the trials was to investigate whether vehicles carrying DSRC tags could evade detection by roadside DSRC equipment by carrying out "unusual but legal" road manoeuvres. Because of the potential impact of these manoeuvres on other road users, most of these trials were carried out on the test track at TRL in late 2003, but some were also carried out on an urban road in the city of Leeds in early 2004, and are included in the results below. Six different vehicle On-Board Units (OBUs) from 4 different manufacturers interoperating with two different roadside equipments were used. To our knowledge, whilst such “unusual manoeuvre” trials have been previously conducted as part of research projects in the interurban environment, they have not been reported publicly. Furthermore, manoeuvres which could be considered illegal in the interurban environment (for which the tolling equipment was designed) may in fact be legal in the urban environment and the system behaviour needed to be evaluated, to ensure that the technology could cope with these manoeuvres – and that they were not a systematic way of evading charges.

THE DSRC SYSTEMS

Because the DIRECTS project was particularly concerned with demonstrating DSRC interoperability, these trials used Road-Side Equipment (RSEs) from two different suppliers, Kapsch and Combitech. Note that Combitech is now owned by Kapsch, but this was not the case when the trials started, and the RSEs and OBUs came from independent development streams. Six different on-board equipments (OBUs) from 4 different suppliers (CSSI, Kapsch, Combitech, and Thales eTransactions) were used. Two of these OBU designs could operate in either on-board account or off-board account mode, so there were 8 possible types or modes of operation – all of which were tested by using an 8-vehicle platoon.

Although all the DSRC equipment conformed to the CEN TC278 standards, the Vehicle Classification and enforcement equipment from the two RSE suppliers differed. The Kapsch classification system employed a downward pointing laser scanner, whilst the Combitech classification system employed stereoscopic cameras which were also able to track the passage of each vehicle. Both systems used digital cameras for capture of enforcement images. The two vehicle classification and image capture systems may therefore give different responses to the same vehicle manoeuvre. For the purposes of DIRECTS, vehicle classification was achieved by measuring height, length and width.

As the objective was to check for complete transactions under unusual manoeuvres rather than the content of the transaction itself all tests were carried out with cars, using OBUs with no trailers or charge exemptions – though an HGV was used in manoeuvre 8 "Obscuration". In all tests the system logic was set so that both DSRC transactions and images were generated, enabling the behaviour of both the DSRC and enforcement systems to be evaluated for identical vehicle passage inputs at the same time. The results for both DSRC transactions and image capture were available to an operator using the Image Management System (IMS) at the On-Road Service Provider (ORSP) – the "back office" entity which the RSEs are connected to and controlled from.

THE "UNUSUAL MANOEUVRES"

The DfT requirements stated that "the Contractor shall budget for … 10 tests, each of up to 90 vehicle passes. The tests will be designed… to cover unusual but legal road manoeuvres and shall be scripted and executed by the Contractor. The systems shall show repeatable behaviour ….". Unusual Manoeuvres 1-8 were carried out at the Combitech Uni-Directional Site, and at the Kapsch site in unidirectional mode, as shown in figures 1 to 8. Additional Manoeuvres were possible at the Kapsch site in bi-directional mode; see figures 9-10.

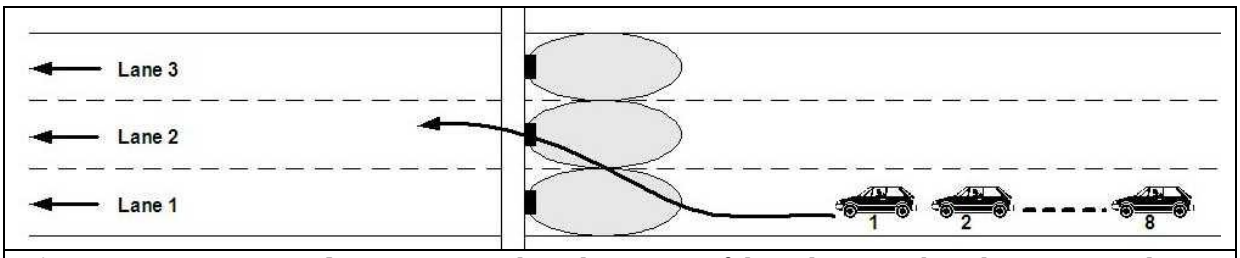

Figure 1. **UM1: Lane Change.** Expected result: a successful single DSRC based transaction plus image-based transaction for each vehicle.

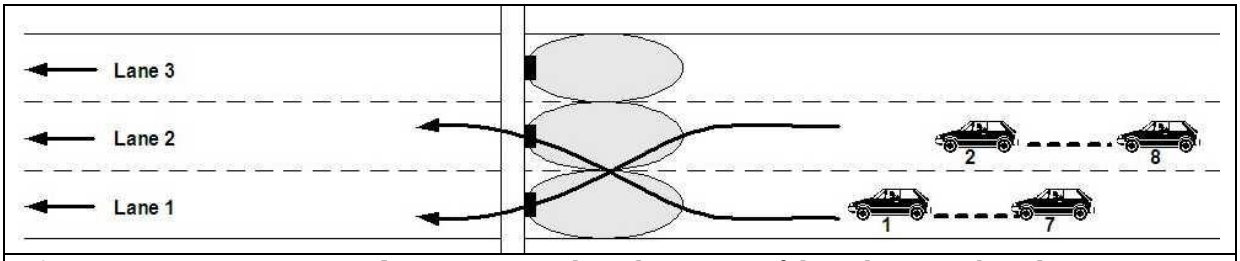

Figure 2. **UM2: Two Lane Change.** Expected result: a successful single DSRC based transaction plus image-based transaction for each vehicle.

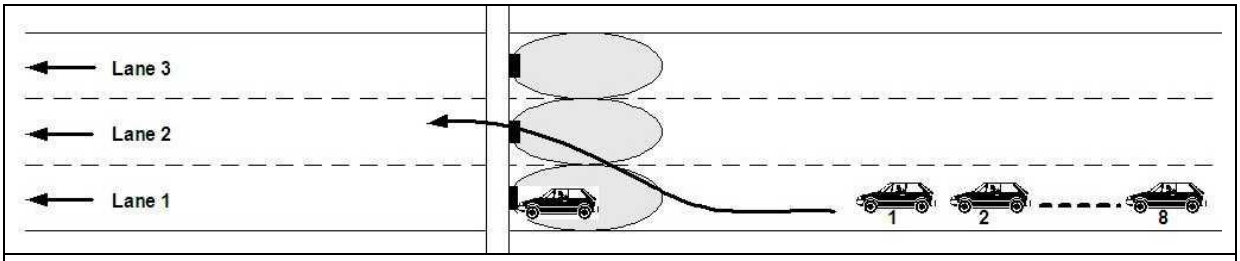

Figure 3. **UM3: Obstacle in Lane.** Expected result: a successful single DSRC based transaction plus image-based transaction for each vehicle. If the stationary vehicle is equipped there should be a single DSRC based transaction every 255 seconds.

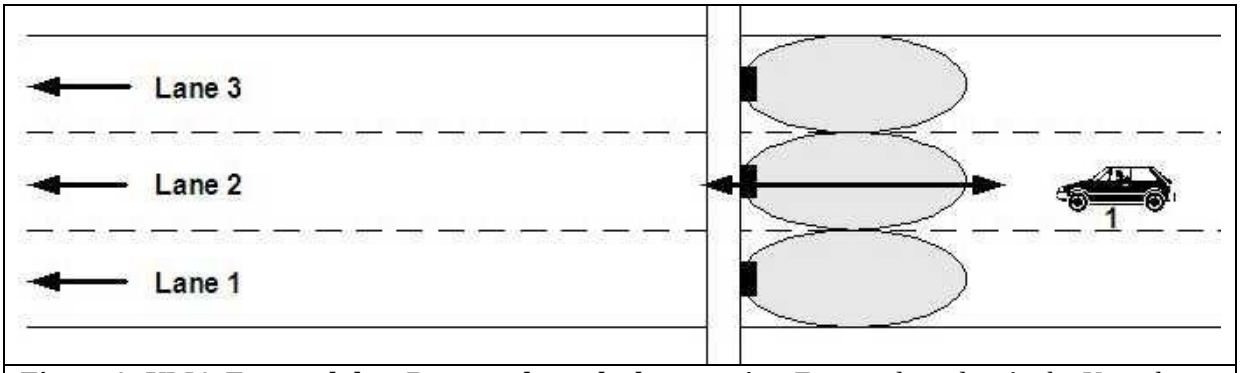

Figure 4. **UM4: Forward then Reverse through charge point.** Expected results: At the Kapsch RSE the passage is not finished until the vehicle has passed the classification sensor. If this is not done, the RoadSide Computing System (RSCS) cannot associate the image to the vehicle. The result will be a VPT (Vehicle Passage Transaction) record without an image and without classification data. It was important to specify precisely whether or not the vehicle passed through the classification sensor, therefore the classification zone was marked on the track. For the Combitech RSE the expected result was both a DSRC and an image-based transaction per passage.

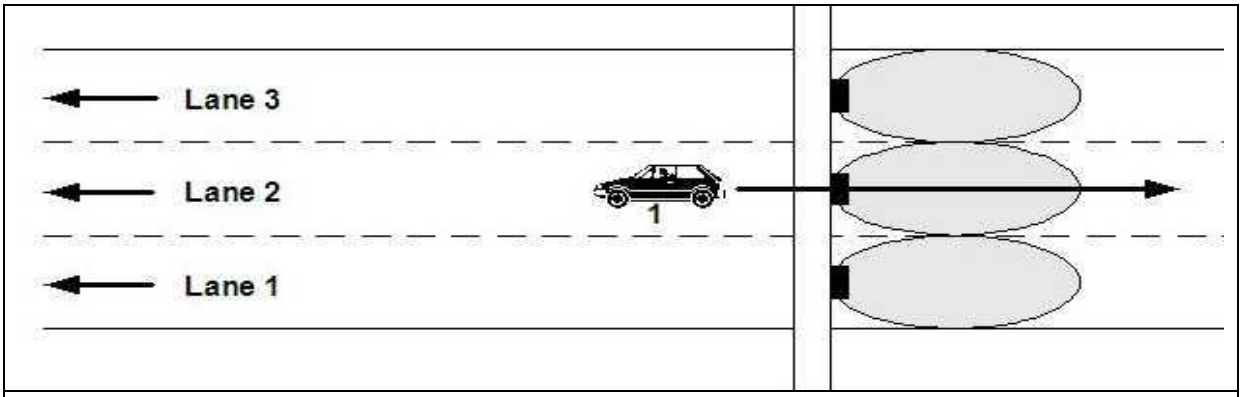

Figure 5. **UM5: Reverse through charge point.** Expected results: a DSRC based transaction for each vehicle pass. For Combitech, a not-valid image-based transaction for each vehicle was likely.

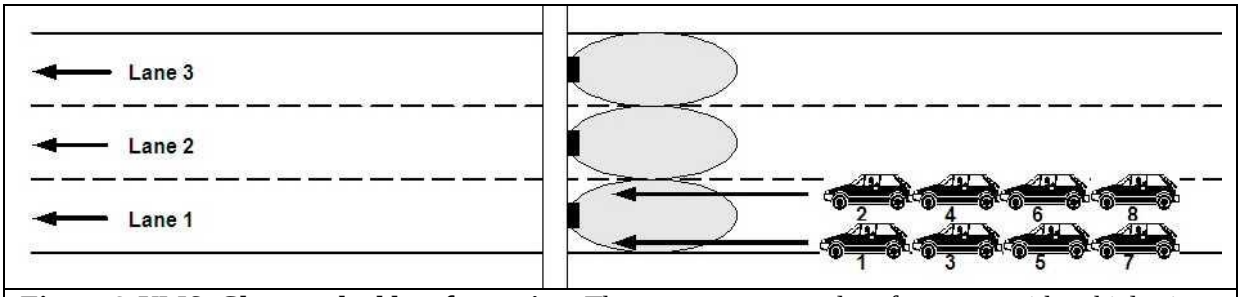

Figure 6. **UM6: Close packed box formation.** The manoeuvre tested performance with vehicles in close proximity at low speed. There was less than a 300mm gap between vehicles. Expected result: a successful single DSRC based transaction, plus image based transaction for each vehicle.

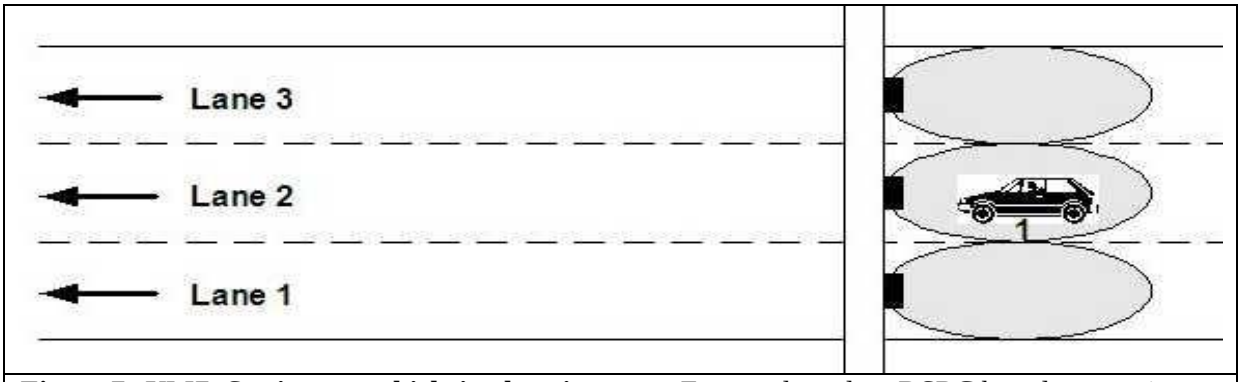

Figure 7. **UM7: Stationary vehicle in charging zone.** Expected result: a DSRC based transaction on entering charge point with another transaction prevented at the same RSE/beacon for 255 sec. (In fact, the stationary vehicle should only give 1 transaction even after 255 seconds, because the 255 second timer is continually reset to 0 until the OBU leaves the communication zone, though one OBU did not perform correctly on this point). At the Kapsch charge point the VPT record is completed when the vehicle leaves the zone in the correct direction of travel. Therefore it was expected that only 1 DSRC transaction and 1 image would be collected per vehicle, even if the car remained in the charging zone for more than 255 seconds.

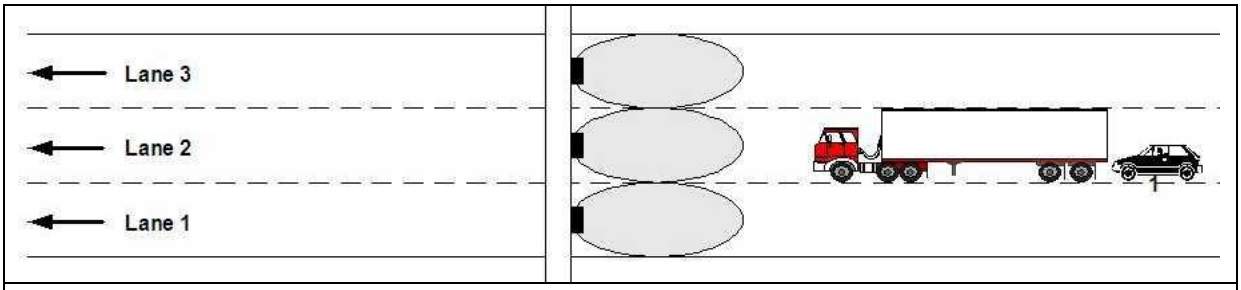

Figure 8. **UM8: Obscuration.** Expected result: a successful DSRC based transaction for the lorry and the car on each pass, but image-based transactions may be affected due to obscuration of the tailgating vehicle.

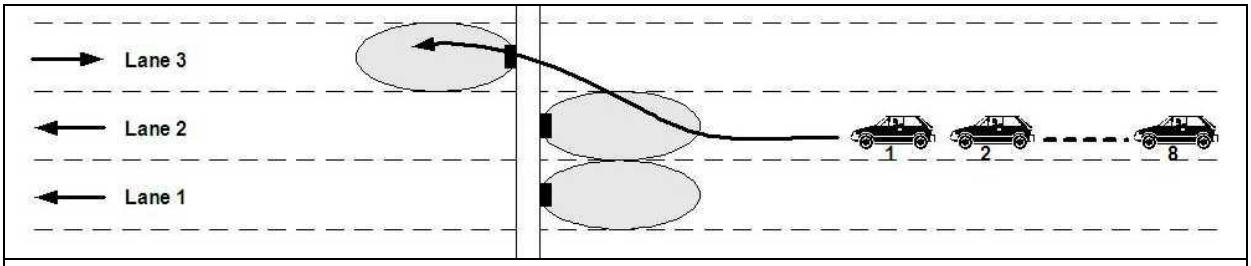

Figure 9. **UM9: Traverse Bi-directional charge point.** Expected results: in Lane 2 only the DSRC transaction will be collected; no image and no classification data would be completed because the

Vehicle Classification Detection Zone is not passed. In Lane 3 the DSRC results cannot be predicted. There is incorrect alignment of the OBU towards the beacon and the communication path is blocked by the vehicle roof. A DSRC communication is possible but unlikely. No image and no classification data were expected because the Vehicle Classification Detection Zone is passed in the wrong direction.

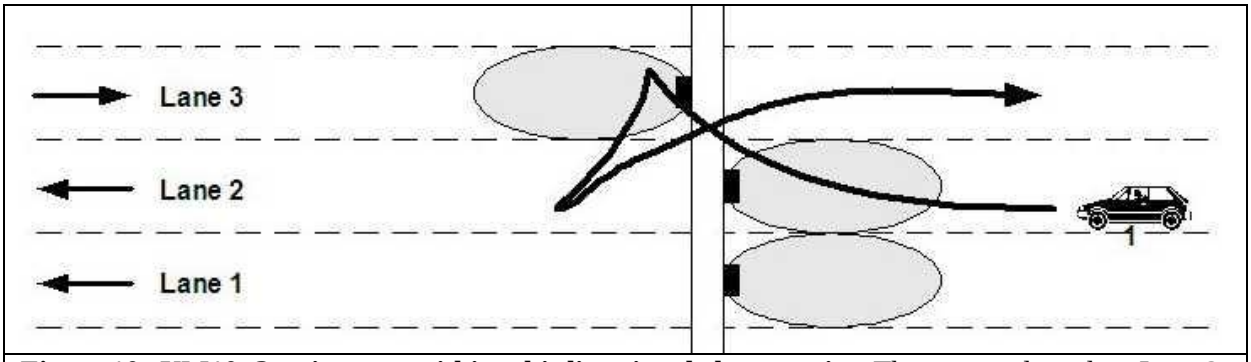

Figure 10. **UM10: 3-point turn within a bi-directional charge point**. The expected result at Lane 2 was a successful DSRC transaction and image provided the vehicle passed through the VAS and classification detection sensor zones. (The VAS is the Kapsch Vehicle Approach Sensor. This triggers the camera capture whenever a vehicle is detected by this forward-pointing laser device).
For Lane 3 a VPT record without an image and without classification data was expected, because the image zone and VAS zone are not entered and the classification detection zone is passed in the wrong direction. DSRC results cannot be predicted. The OBU is not correctly aligned towards the beacon, and is obscured by the vehicle roof. After the turn the vehicle might drive through the classification zone and create a passage with classification data only.

In addition the Unusual Manoeuvres also tested some of the other DfT requirements for the trials, including vehicles traversing the charge point in the ”wrong” direction, or reversing through the charge point, or traversing at a skew angle, or in proximity to other vehicles.

RESULTS

Of the 1018 transactions expected there were 7 missed transactions. Three of these items were missed at the Combitech RSE during test UM7 (stationary vehicle in the charge zone). The remaining four instances of missed transactions are distributed amongst OBU types and tests showing no specific systematic issues. The stationary vehicle test (UM7) also produced an anomaly at the Kapsch RSE where on each of 5 occasions one OBU transacted a second time immediately after the 255-second time-out period; this was a known (and erroneous) feature of that OBU’s behaviour at the Kapsch RSE.

It should be noted that originally during these tests, the Kapsch charge points on opposing carriageways were set with different beacon IDs. This was done originally to minimise time between test runs but led to spurious transactions at lane 3 from vehicle movements at lanes 1&2 during the bi-directional manoeuvres UM9 and UM10. Subsequent regression testing showed that this ‘multi-path’ problem was not observed when the beacons were set to the same ID (as is the case in the equipment installed in Leeds). (Note that this implementation will prevent a DSRC transaction being generated for vehicles performing a u-turn and returning through the charge point in the opposite direction within 255 seconds).

For close lateral or longitudinal proximity, the 'close packed box' test (UM6) shows one missed DSRC transaction and the 'obscuration' test (UM8) shows no missed DSRC transactions out of the 188 vehicle passages in these tests.

The overall error rate for overcharging was 0.5% (5 additional transactions from 1018 expected), and for undercharging was 0.7% (7 missed transactions). It should be noted that the over and under charging targets for DIRECTS were 0.001% and 0.006% respectively.

For all passages through a charge point in the normal direction no more than one transaction was generated. As indicated above, one OBU type transacted multiple times with the same charge point but only when it was left stationary under the gantry for more than 255 seconds (the time-out period set in the RSE).

These tests also showed good performance against another DfT requirement – one transaction per OBU pass independent of antenna arrangement – the Kapsch RSE is lane based and the Combitech RSE gives carriageway coverage from multiple antennae.

A more detailed analysis of the individual Unusual Manoeuvres (UM1-UM10) follows. Unless otherwise stated, 6 laps were completed in each test, 48 DSRC transactions and 48 images were expected, and results were the same for both the Kapsch and Combitech RSEs.

UM1 (lane 1 to 2 change)
At both RSEs 48 complete DSRC transactions and 48 images were collected. The RSEs performed correctly and repeatably.

UM2 (lane change scissor)
At both RSEs 48 complete DSRC transactions and 48 images were collected. The RSEs performed correctly and repeatably for each pair of vehicles in the 2 platoons performing a lane change whilst travelling in the right direction through the charge point.

UM3 (Obstacle in Lane 1)
48 complete DSRC transactions and 48 images were collected. The Kapsch RSE performs correctly and repeatably for both the stationary vehicle and vehicles travelling in the right direction through the charge point. For the Combitech RSE the stationary vehicle was equipped but for some reason the OBU did not transact.

UM4 (forward to, then reverse from charge point)
As identified from the passage records and confirmed by the video taken at the time, the conduct of this test, which was rather complex, was initially executed incorrectly in December 2003 at TRL. But when repeated in May 2004 in Leeds and performed correctly, with vehicles entering, reversing and then continuing forward through the charge point, the expected performance was observed with each vehicle passage being completed when the vehicle passed the classification sensor.

UM5 (reverse through charge point)
In this case for the Kapsch RSE only 47 DSRC transactions were collected, all complete transactions. There was no obvious reason why 1 transaction was missed. For the Combitech RSE 48 DSRC transactions were correctly read, but all were flagged as incomplete transactions. For both RSEs, as expected, the RSE classification sub-systems did not produce “passage records” and no images were collected.

UM6 (close packed box formation 10mph)
For the Kapsch site 48 complete DSRC transactions were collected. There were 29 cases where the passage record from the RSE's classification sub-system was not associated with the DSRC transaction, or not generated at all, given the very small clearance between vehicles (i.e. the classification sub-system failed to distinguish the gap between the vehicles). All unassociated passage records were automatically invalidated by the operator at the ORSP IMS. The other 19 vehicle passages yielded a DSRC transaction correctly associated with a passage record, except for one case where the vehicle 1 passage record/image was associated with the DSRC transaction for vehicle 2. The image collection rate was very low with only 7 images collected from the 48 passages.

For the Combitech site, only 47 transactions were collected, all complete. One transaction was missed with no apparent reason for failure. This driving pattern also triggered some additional unexpected images due to very close proximity of vehicles which is perceived to be at the limit of performance of the vehicle detection sensor. These additional images were correctly invalidated at the IMS Browser.

UM7 (stationary vehicle at charge point)
Only 5 laps completed, comprising a total of 40 vehicle passages. In general, at the Kapsch site the approaching vehicle generated a DSRC transaction but only generated a passage record after moving again after the 6-minute stoppage (ie significantly longer than the OBU's 255 second timer), which generally could not be associated with the DSRC transaction. (Because of the length of time elapsed between the initial DSRC transaction and the generation of the vehicle pass age when the vehicles moved off again). Given that there was no passage record to associate the image with, no image was retained during this test. There were 45 DSRC transactions collected; one OBU on all 5 passages generated a further DSRC transaction when resuming passage after 6 minutes stationary; this was a known issue with that OBU, as mentioned earlier.

At the Combitech site, of the 40 passages, only 37 DSRC transactions were collected; there was no obvious explanation for the missed transactions.

UM8 (vehicle obscuration)
Since there were 2 vehicles, 96 DSRC transactions were expected, and 96 were collected, all complete, at both sites. For the HGV, of its 48 passages, the classification / passage record was correctly associated with the DSRC transaction, though in 2 cases at the bi-directional site the measured class was PLG, in error, and so images were presented to the IMS operator for checking. But at both sites only 2 images out of an expected 48 were collected for the obscured PLG, not surprisingly given the geometry constraints.

UM9 (traverse bi-directional charge point)
The objective of this test was to characterize the behaviour of a bi-directional charge-point when vehicles crossed over into the opposite carriageway. As indicated above, initially the two charge-points on opposite carriageways were given different identities, giving rise to spurious transactons. Re-testing in May 2004 with the same Beacon ID at both charge-points correctly demonstrated zero DSRC response at the "wrong" beacons, except for one "rogue" OBU which incorrectly transacted at the "wrong" charge-point 8 times out of the 10 passes; this was attributed to clock synchronisation differences between the 2 charge-points, effectively producing a negative time shift which this OBU design could not accommodate.

UM10 (3 point turn, bi-directional charge point)
The objective was to characterize the behaviour of a bi-directional charge-point when vehicles performed a 3-point turn. As for UM9, problems were experienced initially but later tests correctly demonstrated zero DSRC response at the "wrong" charge-point for all OBUs, again except one OBU which incorrectly transacted 4 times out of the 5 passes.

CONCLUSIONS

The results indicate that, at least for the specific "unusual but legal" manoeuvres conducted during these trials, it is not possible for equipped vehicles to systematically evade detection and charging – at least, not for the 2 DSRC systems studied at the TRL test track. (Note however that systematic evasion may be possible for unequipped vehicles).

ACKNOWLEDGEMENTS

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REFERENCES

[1] Lumb, N, Tindall, D "Results from the Demonstration of Interoperable Road user End-to-end Charging and Telematics Systems (DIRECTS)" ITS World Congress, ITS Congress Association, Brussels, 2006, paper number 1896.

[2] Matheson, DG, "The DIRECTS road charging project – what has the UK Department for Transport learned?" ITS World Congress, ITS Congress Association, Brussels, 2006, paper number 2030.

[3] Matheson, DG, Lumb, N, Tindall, DW & Souter, E, "Open Minimum Interoperability Specification Suite (OPMISS) For UK RUC" IEE Seminar on Road Use Charging, 6 December 2005, London.

[4] McGhee K & Jones K," DIRECTS Road User Charging Demonstration Project: Results", IEE Seminar on Road Use Charging, 6 December 2005, London.

[5] Tindall D "Demonstration of Interoperable Road-User End-to-End Charging and Telematics Systems (DIRECTS) for the UK Government" ITS World Congress, Chicago, 2002, paper 109

GLOSSARY

DfT	UK Department for Transport
IMS	Image Management System at the ORSP.
ORSP	On-Road Service Provider – the "back office" entity which the RSEs are connected to and controlled from.
OBU	On-Board Unit (also known as "On-Board Equipment, "microwave tag" etc
RSCS	The Kapsch RoadSide Computer System – a real time sub-system within the RSE)
RSE	RoadSide Equipment
TRL	UK Transport Research Laboratory
VAS	The Kapsch Vehicle Approach Sensor sub-system of the RSE.
VPT	Vehicle Passage Transaction