RESULTS FROM THE DEMONSTRATION OF INTEROPERABLE ROAD USER END-TO-END CHARGING AND TELEMATICS SYSTEMS (DIRECTS)

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ABSTRACT

In 2001, the Fareway Alliance, comprising Kellogg Brown & Root (KBR), Atkins and Thales Telecommunication Services, was selected by the UK Department for Transport (DfT) to set up and operate DIRECTS, a fixed price research project to demonstrate the operation of Road User Charging (RUC) systems for open multilane trunk roads and urban roads. The project is aimed at preparing technical specifications and proving equipment interoperability, including Dedicated Short Range Communication (DSRC) and Mobile Positioning System (MPS) charging equipment, exception handling, enforcement and full Back Office functionality. Based on a business model proposed by the DfT following successful on-track testing completed at the TRL in Crowthorne, UK, the project moved to the demonstration area in the city of Leeds, UK, where on-road trials were completed in March 2006. This paper provides an insight into the practical experiences and results gained in integrating, testing and operating an end-to-end RUC system.

Keywords
Road User Charging, Urban Area, Main Road

INTRODUCTION

The first paper [1] on this challenging project summarized the project objectives, the parties involved, the developing technical specifications and the aims of the demonstration in Leeds. In summary the relevant project objectives were to:-

• Develop, over the period of the contract, a suite of specifications known as the Open Preliminary Minimum Interoperability Specification Suite (OPMISS);

• Design, develop, test, install, operate (for a minimum of 12 months and 600,000 DSRC transactions from volunteer vehicles and 115,000 images of non-volunteer vehicles) and decommission a complete end-to-end demonstration system for RUC at a number of urban and motorway locations in the City of Leeds. Volunteers were to help test the system by going about their normal business. No volunteers were to be charged, and the project was not to affect other motorists using these roads;

• Prove, via the demonstration, multi-lane free flow charging and enforcement capability, and the interoperability of systems and equipment provided by multiple suppliers;

• Show, via the demonstration, the viability of the OPMISS and the DfT Business Model.
Fareway selected seven sites (comprising fourteen Charge Points) from the set of fifteen made available by the DfT. Over 500 vehicles from local volunteer organizations took part in the year long demonstration, and the RUC system gathered transaction data in accordance with the DfT’s requirements. Originally the volunteer strategy was based around recruiting participants from the general public with incentives for continued compliant participation in the trial. The DfT later restricted volunteers to commercial organisations only, however, with no incentives. All data captured underwent detailed analysis by Fareway, and the billing and customer care facilities supporting the volunteers provided valuable feedback for the operational procedures.

This paper provides an insight into the design and practical experiences gained in integrating and testing the end-to-end RUC system, and the performance results obtained. This paper presents further details on:-

- Overall architecture and business model;

- Practical front-end system issues when operating with real users under actual traffic conditions, including interoperability, effective charging, capture of adequate and sufficient image data to handle exceptions and effectiveness of Automatic Number Plate Recognition (ANPR);

- End-to-end performance, Back Office billing, charge reconciliation between sub-system entities, and methods for minimizing front-end imperfections.

**ASPECTS OF DESIGN AND OPERATION**

In this section, a short summary of the system architecture and business model is presented and then a number of design and operational issues, relating specifically to RUC, follow. These show the areas where interoperability is important and where technical choices may have to be made when procuring RUC system entities.

**ARCHITECTURE AND BUSINESS MODEL**

An open architecture was adopted, to demonstrate the ability of sub-system suppliers to deliver and integrate both front-end and back office entities, designed and built to comply with trial areas of OPMISS. This meant that any operator (a Local Authority or tolled crossing operator etc) wishing to introduce an electronic RUC scheme in the UK can use OPMISS for a competitive tendering process, knowing that, provided suppliers can comply, they will interoperate with all other sub-system entities that use these specifications as a basis for their systems. The exact nature and form of these specifications is subject to further development and consideration within DfT [2]. The architecture proposed by the DfT is presented in [2] and will not be reiterated here.
The major OPMISS entities are:-

- The user establishes a relationship with a Payment Services Provider (PSP) for the provision of services related to charged road use. This may also include the issue and fitting of the vehicle On-Board Unit (OBU) itself.

- Users, as they drive on charged roads, will have their related Vehicle Passages logged by the On-Road Services Providers (ORSPs). These entities gather charges relating to road usage for each individual charging scheme (local authority, toll road, bridge, tunnel etc). ORSPs may capture data from the roadside via different technologies, for example DSRC or MPS based vehicle equipment. Any exception handling requiring manual checking of images is performed at the ORSP.

- ORSPs will also capture evidential data (e.g. images) from the roadside of suspected non-payers either for the generation of Charge Records based upon images or for supporting the enforcement process through the issue of Penalty Charge Notices (PCNs).

- The Data Clearing Operator (DCO) provides a both a ‘bridge’ and a ‘block’ between ORSPs and PSPs; a ‘bridge’ to route Charge Records from an ORSP to the correct PSP and a ‘block’ to provide users with privacy concerning their movements. (ORSPs do not need to know who is using their roads. Conversely, PSPs do not need to know where their clients have been unless a user requires an itemised bill).

- Each ORSP and PSP will establish a business relationship with the DCO.

- The ORSP will establish Vehicle Registration Numbers (VRNs) from images of suspected non-payers. This information will be used by the DCO as the basis for determining whether the users’ vehicle has an OBU and therefore the relevant PSP, or that there is no known OBU linked to the vehicle as the basis for initiating either an image based Charge Record or a PCN.

![Figure 1 DIRECTS System Architecture](image-url)
Each of the above sub-systems establishes a business model for effective charging for the individual services provided and for the agreement, reconciliation and passing on of charges to the next sub-system in the end-to-end RUC process.

In order to demonstrate every entity within the architecture and business models, as shown in Figure 1 above, an end-to-end system was installed at Leeds. This was designed to meet and trial elements of the open interface specifications defined within the OPMISS, and to demonstrate interoperability of equipments from seven different manufacturers.

PRACTICAL FRONT END SYSTEMS

There are a number of ways in which charges can be levied for road use. These range from a fixed charge, through charges based on vehicle class, time of day, distance travelled or the number of times per day entering a cordon, area or road section, to a full demand control using one or more of the above. In addition, exception handling (a more general term for checking of potential violators of which enforcement is a subset) may be introduced at fixed or mobile positions within or on the perimeter of the scheme.

Both DSRC and MPS based technologies were included in the DIRECTS project. These were employed to demonstrate cordon, area and distance (segment) based charging schemes. Each method has strengths and weaknesses, and the project has been used to investigate how the end-to-end system may be designed to minimise any weaknesses and thereby optimise performance. The following sub-sections present some of the challenges which have been observed and what measures were taken to address them.

DSRC PERFORMANCE

The DSRC technology is well developed and based on well proven International standards as described in [1]. The DIRECTS project exploited six different DSRC based OBU designs, (four off-board [central] account and two on-board account designs, based on the A1 and A1+ air transactions respectively [3,4,5]), and two Road Side Equipment (RSE) designs to test the level of interoperability achievable. Testing on TRL’s test track, under controlled conditions, demonstrated that DSRC transaction success rates exceeding 99.9% are achievable. Even when attempting to stress the transaction process with, for example, unusual vehicle manoeuvres [6] results in excess of 99% are achievable. Similar results were obtained throughout the on-road trial in Leeds using a fleet of test vehicles. Despite a number of attempts at the detailed technical level to maintain this level of accuracy over the entire volunteer fleet, however, DIRECTS only achieved an average performance of approximately 88.5% for raw DSRC transactions. (No DSRC accuracies were specified, they were driven by the end-to-end targets discussed below).

This drop in performance was mainly attributable to two practical issues. The first relates to non-incentivised volunteers, who were neither rewarded for taking part nor penalised for “inadvertent” lapses in maintaining their vehicles’ equipment status during the year long trial in which, overall, some 800,000 DSRC transactions were collected. The second reflects the change in make up of the test track fleet, which was predominantly private light goods vehicle based to that of the commercial volunteer fleet in Leeds. Additionally, there was an overall level of 0.6% incomplete transactions that were detected at the roadside but standing alone, contained insufficient DSRC data to charge the user. This figure divides into incomplete transaction rates of 0.25% and 3.6% for off-board and on-board transactions respectively. The data is summarised in Table 1.
Table 1 Raw DSRC Interoperability Performance by Manufacturer and Vehicle Class

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Supplier A Gantries</th>
<th>Supplier B Ganttries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Passages</td>
<td>Transactions</td>
</tr>
<tr>
<td>PLG</td>
<td>155859</td>
<td>137462</td>
</tr>
<tr>
<td>PSV</td>
<td>151710</td>
<td>131743</td>
</tr>
<tr>
<td>VHGV</td>
<td>25970</td>
<td>22968</td>
</tr>
<tr>
<td>HGV</td>
<td>6099</td>
<td>5252</td>
</tr>
<tr>
<td>Totals</td>
<td>339638</td>
<td>297425</td>
</tr>
</tbody>
</table>

OBU Manufacturer

| Off-Board OBU #1 | 84315    | 71658      | 84.99%       | 81660   | 73378       | 89.86%       |
| Off-Board OBU #2 | 101601   | 90676      | 89.25%       | 97939   | 90191       | 92.18%       |
| Off-Board OBU #3 | 59020    | 51121      | 86.62%       | 56439   | 50206       | 88.96%       |
| Off-Board OBU #4 | 42514    | 38017      | 89.42%       | 41235   | 37769       | 91.59%       |
| On-Board OBU #1  | 11079    | 8196       | 73.98%       | 10753   | 7386        | 68.69%       |
| On-Board OBU #2  | 41109    | 37757      | 91.85%       | 40411   | 35992       | 89.06%       |
| Totals          | 339638   | 297425     | 87.57%       | 328337   | 294922      | 89.82%       |

Although further analysis is ongoing, no interoperability issues between different manufacturer’s OBUs and RSEs have been identified that would substantially alter these results. The Fareway end-to-end design mitigated this drop in performance within the DIRECTS trial system as discussed below.

IMAGE CAPTURE PERFORMANCE

Exception Handling within RUC systems is usually associated with the capture of an evidential image(s) which allow details such as VRN or vehicle class and trailer status to be assessed manually or automatically. This may be used for a number of reasons, including creation of an image based account for unequipped vehicles (i.e. those with no OBU), creating PCNs for unequipped or wrongly classified vehicles or recreating vehicle details when the DSRC transaction has failed.

In some cases, there is no option but to suffer an undercharge e.g. where an image is the only means of charging and the VRM cannot be identified from the image. In other cases, where for example, the trailer status cannot be determined, it may be more prudent to apply an “undercharge” to a user by assuming there is no trailer, rather than “overcharge” in error and risk a challenge that is indefensible. This decision would be driven by an ORSP’s business rules and over and undercharging targets. For RUC schemes where vehicle class and trailer status are used to vary tariffs, the camera system must be able to provide operators with images showing sufficient field of view and clarity at all times of day and night to determine such parameters unambiguously. Lane cameras (ideal for determining VRNs) and overview cameras (for vehicle class and contextual information) are therefore necessary and may have to be used in tandem. From the safety aspect, infra-red illumination and monochrome cameras are the best choice. The use of colour cameras to UK Home Office recommendations [7] is not essential for an RUC scheme, but can assist further in vehicle identification. The DIRECTS trial system provided Fareway with an opportunity to compare the performance of two designs of image capture system under a range of traffic density, weather and lighting conditions, to ensure the OPMISS contains best practice.

The average image capture accuracy was 83.9% and 91.7% [2] for the test-track and Leeds on-road testing respectively. Of the images captured the usability rates were 98.3% and 84.6% respectively. Hence from a given traffic flow the number of usable images that would be captured were 83.2% and 77.6% respectively. The specified targets were 85% and 80% respectively. It should be noted that the average image capture accuracy between charge points for the Leeds on-road trial varied between 84.5% and 99.6%.
In addition one of the suppliers significantly improved image capture performance between the test track and on-road tests and that it was always expected that image usability would decline in real open road traffic as opposed to that of the test track.

CLASSIFICATION SYSTEM PERFORMANCE

Although there were no requirements for external, independent (measured) vehicle classification systems, they were installed as part of the DIRECTS system. The DIRECTS system utilised OBU declared class data and measured vehicle classification system based upon overall vehicle dimensions. Current European specifications are based upon axle, weight and environmental metrics. Given the limited space available here, these results have been omitted.

MANUAL OPERATOR CHECKING

The process of manual checking of image material is costly, subject to human error and any methods for increasing efficiency are therefore beneficial. Sometimes the images are collected because the vehicle is unequipped and therefore the VRM is of prime importance. This would be used to identify the vehicle keeper so that charges due may be levied. For an equipped vehicle, an exception may be due to a class or trailer mismatch requiring validation of these parameters and the VRM is not necessarily required. The specified process for image analysis dictated that both the vehicle classification (including trailer) and VRM be entered. Over the period of the trial, 67000 images of volunteer vehicles were analysed with resulting average vehicle classification and VRM accuracies of 97.8% and 99.7% respectively. Additionally a one hour test was carried out where a target performance was set at analysing 150 images. Resultant speeds ranged from 96 to 190 images per hour, depending on the operator, with a non-corresponding accuracy range 90% to 98%. (A speed increase in manual checking could be achieved by indicating to the operator which parameters require checking and which are not necessary).

AUTOMATIC NUMBER PLATE RECOGNITION PERFORMANCE

ANPR systems potentially allow a percentage of image based exceptions to be processed without manual checking and both increase throughput and reduce processing costs. Although there were no requirements for ANPR, it was installed as part of the DIRECTS system. Its performance was therefore not a primary concern of the trial. All DIRECTS RUC lane cameras were equipped with ANPR capability.

Some performance analysis of these ANPR systems was carried out, but it was found that the relationship between the confidence level and the probability of correct VRM interpretation was not monotonically rising to allow for its inclusion in any automatic process for reducing the operator workload. It was given to the operator as a prompt, however, for correction or confirmation. The maximum accuracy achieved by the ANPR systems barely matched the average accuracy of manual checkers as stated above. This reflects the fact there were no performance requirements for ANPR systems within the DIRECTS trial.

In addition to general levels of ANPR accuracy, there still remains the question of interoperability between ANPR systems from different suppliers. Unless the confidence level profiles and corresponding accuracy of VRM estimates are harmonised, ORSP image processing rules cannot be generic and ANPR supplier independent.
END-TO-END PERFORMANCE

The accuracy requirements of the DIRECTS contract were defined by means of end-to-end performance criteria for over and under charging of equipped, i.e. the volunteer fleet, vehicles. These were set at six overcharges and thirty-six undercharges, at 95% confidence level, in 600,000 transactions. These targets were independently financially incentivised. Given the limitations of the Front End equipment Fareway took a commercial decision, given the fixed price nature of the DIRECTS contract, to concentrate on the overcharging target and to not actively pursue the undercharging target.

A number of processes have been developed to improve the Back Office functionality and implement a practical scheme. Each entity would expect to be paid for the value added by its functionality. The concept of charges passing between entities (ORSPs to the PSP via the DCO) allows each process to add a charge for their services. All charges from all entities result in a combined charge for road use which is levied at the roadside and appears on the user’s monthly itemised or accumulated bill. If additional processing is performed by the ORSP or PSP in determining the owner of an unequipped vehicle or a classification or trailer violation, an additional charge is made. These additional charges, incurred for a violation, are agreed between entities at the time of establishing their business relationship and their combined result is published as a surcharge on the standard road use charge or as a penalty charge.

The design of end-to-end DIRECTS system attempted to mitigate the imperfections of the Front End systems through the ORSPs’ transaction processing rules for charging transactions. These allowed charging where there was sufficient information to unambiguously charge as opposed to invalidating all incomplete transactions. It also recovered situations where the DSRC transaction proved inconclusive, by allowing vehicle passages to be charged based upon the VRN derived from the exception images captured. Consequently the raw DSRC accuracy of 88.5% quoted above was recovered to an end-to-end accuracy of 97.5% using these methods.

Additional Back Office algorithms were developed by Fareway to check for duplicated charges (e.g. a duplicated DSRC charge, a DSRC charge and a VRM based charge, a DSRC charge and an MPS charge) for the same vehicle passage to overcome or minimise overcharging and to provides early warning of any fraudulent use in the system. These algorithms resulted in the DIRECTS system producing an overcharging rate of approximately 0.0011% of equipped vehicle passages.

SUMMARY AND CONCLUSIONS

The DIRECTS project has demonstrated a practical open road RUC scheme using interoperable equipment and volunteer vehicles within a real motorway and urban environment. The knowledge and experience gained from this exercise has been captured in a suite of open and interoperable specifications which will allow any Local Authority or Back Office agent to procure, install and operate any RUC entity within an interoperable national framework, subject to their subsequent development and refinement within the DfT. This could then avoid potential non-interoperable deployment of RUC infrastructure in the UK, and the need for road users to fit multiple OBEs, or manage multiple contracts (in the longer term) before being able to travel country-wide.
Additionally DIRECTS has demonstrated that:

- An end-to-end design approach should be adopted to counter Front End imperfections;
- Transaction accuracies for real users do not necessarily match those obtained using test fleets, even using the same set of “real” charge points;
- Without volunteer incentives, the results from a road user trial cannot replicate the realistic situation where users are penalised for non-compliance with operational rules.

REFERENCES


