The Technical and Operational Feasibility of Automatic Number-Plate Recognition as the Primary Means for Road User Charging

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Following the publication of the Government's White Paper on Integrated Transport in July 1998, and a shift in emphasis by Local Authorities away from road building to demand management techniques, the current trend is to a more balanced approach, whereby the use of road-space may be charged to vehicle drivers, i.e. road users pay to use (at least some) roads, just as public transport passengers pay each time they travel. Key to this is the introduction of some form of road user charging or vehicle access control. In urban areas, this may be achieved using paper licences (as in Singapore, 1975–1998), electronic (microwave) tags and transponders (as in Trondheim and Oslo, Norway and in Singapore since 1998) or by the use of automatic video-based licence-plate recognition (ALPR). The use of video-based registration to check whether a vehicle has purchased (or been granted) some form of licence rights to use a particular road or cordoned area on a particular day seems both logical and attractive. However, this form of urban road use pricing has not been operated in anything other than small-scale pilot schemes, and there are a significant number of technical, organisational and operational issues that need to be researched before such a system could safely be implemented for everyday use. This paper is specifically aimed at addressing such key issues, to determine whether in the short term (next 5 years) ALPR could deliver a practical tool for use by local authorities, whether in isolation or as part of a package of applications, to reduce traffic congestion within urban areas.

KEY WORDS

1. Road. 2. Telematics. 3. Traffic Control.

1. INTRODUCTION.

1.1. *Background.* Road user charging (also known as road tolling, or electronic road pricing, or congestion charging) has been proposed for managing congestion

and raising revenue for many decades. The initial theory was published by Smeed (1964). Since then a number of attempts to introduce urban road user charging have been made, most notably the Hong Kong trials (1983–85 and 1998), the Singapore Area Licensing Scheme (1975–1998) – now replaced by an automatic electronic scheme (Figure 1), and the toll-rings around Bergen, Trondheim and Oslo in Norway

Figure 1. Gantry indicating the boundary of the 'Restricted Zone', Singapore.

(Blythe, 1999). Motorway schemes include Toronto's Highway 407 and the Melbourne CityLink (See: http://www.407etr.com and http://www.lta.gov.sg).

1.2. *Recent UK Policy*. Charging for use of roads has a long history in the UK and elsewhere. Many countries charge for their principal roads or for estuarial crossings and major tunnels. Charges have traditionally been a simple means of *financing roads and road infrastructure*. Recently, problems of congestion and pollution caused by increasing numbers of vehicles (especially private cars) led to charging being viewed as a means of *traffic management*. Renewed interest in the UK came in 1993 when the Government published a consultation paper, *Paying for Better Motorways*: *Issues for Discussion*, on new ways of meeting the cost of maintaining and improving *inter-urban* roads. It noted that legislation was required for any charging on existing roads, and invited views on whether it could be introduced to pay for improvements to the UK road network. The Government's response to the consultation in December 1993 said that electronic tolling was the best way of introducing motorway tolling in the UK instead of either conventional tolling via plazas, or an interim paper-based system. A research programme and trials were initiated to identify the capability of existing technology, and to draw up a specification for electronic motorway charging.

1.3. *The Transport Research Laboratory and DIRECTS Trials*. Two consortia participated in trials of microwave tolling systems at the Transport Research Laboratory (TRL) at Crowthorne in Berkshire during 1996/7 (TRL, 1998). The trials showed that commercially available technology could charge vehicles, but that further work was needed on how a complete system, including financial and back-office sub-systems and the capture of images of vehicles of non-payers, would be put together and perform in a live environment. In 1997, a General Election was held that returned a new administration. The Department of Environment, Transport and the Regions (DETR) published a White Paper *A New Deal for Transport: Better for Everyone* (Cm 3950) in July 1998, which recognised that improving public transport and introducing traffic management measures were not sufficient to alleviate the road traffic problems. As part of a package of measures including improved public transport, it made a number of commitments to improve the situation, including the introduction of legislation to permit local authorities to charge road users so as to reduce congestion. There was a switch in emphasis to urban areas, from the previous focus on motorways. Another key feature was that revenue raised from these new charges would be 'hypothecated' i.e. ring-fenced for improvements to local transport services and infrastructure, at least initially.

Although early charging schemes were envisaged as cash or paper-based, the White Paper recognised the potential of electronic charging, and proposed a further technical trial (known as the DIRECTS project – Demonstration of Interoperable Road user End-to-end Charging and Telematics Systems). It would go beyond the TRL trials in that it would:

(a) take place on real roads (in Leeds),
(b) involve equipment from different suppliers inter-working,
(c) demonstrate a complete end-to-end system including a 'Back Office' billing system as well as a video-based enforcement system for non-equipped users, and
(d) produce a UK National specification for electronic road-user charging systems to ensure that they would be interoperable wherever they might be deployed, so that vehicles require only one set of in-vehicle equipment.

1.4. *London*. A Government Office for London (GOL, 2000) report in 1998/99 reviewed the Road Charging Options for London (the 'ROCOL' report). It studied the feasibility of road user charging and parking-place charging as well as impacts on business, traffic and user/business reactions to the charging proposals. It recommended that London should implement a video-based road user charging system, at least until the results of the DIRECTS project were available. The newly elected Mayor reviewed these recommendations earlier this year and a full-scale programme towards an implementation target of 2002/3 is now underway in London; See Appendix A.

2. TECHNOLOGY DEVELOPMENTS. Currently, there are several electronic technologies that are used or have been considered for charging; some of these are briefly reviewed below. Infrared-based systems, as used in some countries, are broadly similar to microwave, but use infrared 'light' as the short-range communications link.

2.1. *Microwave-based Digital Short Range Communication* (*DSRC*) *Systems*. These systems need roadside equipment, typically gantry-mounted (Figure 1), with an electronic tag in the vehicle that may be *read-only*, *read-write*, or *smart card*-based. Read-only tags contain a fixed identification code which, when interrogated by a roadside reading device at the charging point, conveys this identity to the roadside system. The code relates to the user's or the vehicle's identity or the identity of the user's account. Read-only tags only operate correctly if used for single lane operation – by far the most common situation. However, their inflexibility in charging tariffs and inability to work in a multi-lane road situation severely limits their applicability. Read and write tags are a logical further development of the read-only tag. They can receive data from the roadside and store this data directly on the tag or on a separate value-card (which may be interfaced with the tag whilst in the vehicle).

The most flexible In-Vehicle Units (IVUs) are transponders that support smart cards. They are 'intelligent' (utilising an on-board micro-controller and associated circuitry), have the capability to handle and process many kinds of data and (potentially) to be programmed to manage a number of different applications. See Figure 2.

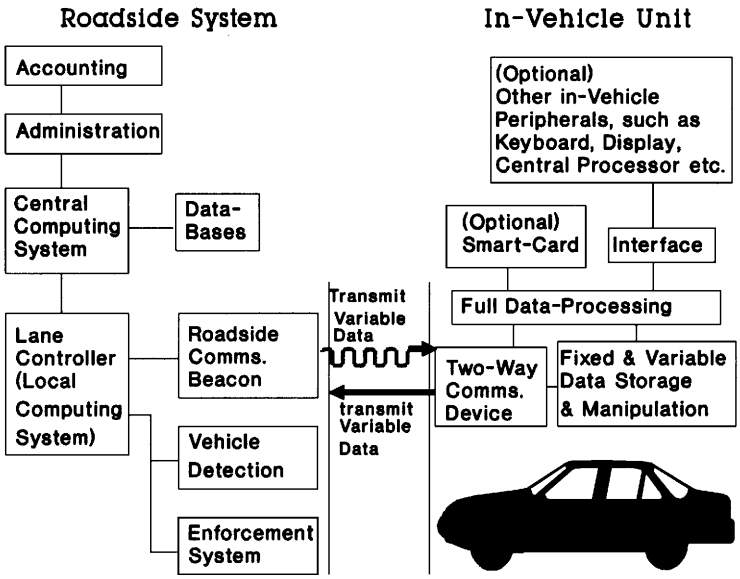

Figure 2. Schematic of a transponder with Smart Card.

Such a system requires a reliable and high-speed two-way data communications link with the roadside, and more complex on-board equipment, replacing some of the processing requirements traditionally handled by the roadside equipment. A modular approach is adopted to the transponder's design, facilitating 'add-on' peripheral equipment (smart card readers, keyboards, displays, and connections to other in-vehicle equipment. Figure 3 shows a transponder and smart card from the ADEPT project (Blythe, 1999) that installed trial systems in the UK, Sweden, Portugal and Greece.

Figure 3. Transponder and Smart Card.

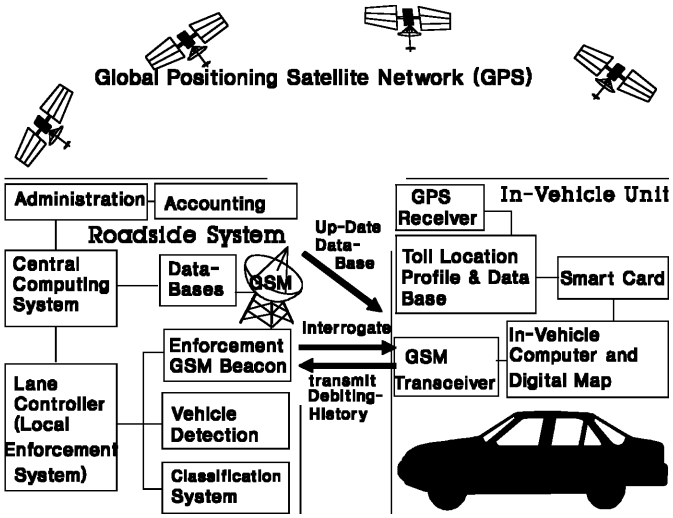

Figure 4. GPS and GSM-based fee collection system.

The modularity of the design of the automatic debiting transponder prototypes will allow several different forms of payment with one device. The transponder offers the possibility to hold the user's credit-balance, either directly in the transponder's memory or alternatively on a separate smart card interfaced to the transponder.

These systems are perceived by many international road administrations as the future of road user charging, where high-volume, multi-lane roads need to be tolled without restricting traffic flow. In Europe, their standardisation nears completion, and many products based upon 5·8 GHz microwave communications technology will emerge, though to date few commercial installations exist. Worldwide the Singapore system and Highway 407 in Canada utilise such an approach. The key limiting factor seems to be the processing speed of the smart card – in Singapore each charging point has 2 gantries – one to start communications with the vehicle and a second (further

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down the road) to complete the transaction and perform enforcement measures if necessary. The infrastructure requirements and costs make the solution unattractive for many authorities considering automated road user charging. The DIRECTS project will finally prove the feasibility of these short-range systems and ultimately develop a UK National specification for interoperable payment of road user charges.

2.2. *Wide-area communications-based systems*. Wide-area systems are an innovation in toll collection. They use two technologies developed for other applications, namely GPS (Global Positioning System), whose satellites enable suitably equipped vehicles to calculate their location accurately, and a two-way communications link (e.g. GSM cellular radio). These systems were tested in the German trials in 1994/95 (Blythe, 1999). They are designed not to disrupt the flow of traffic on motorways and to reduce the amount (and environmental intrusion) of roadside infrastructure required, in comparison to DSRC systems.

The In-Vehicle Unit (IVU) contains a GPS receiver and must have a record of the locations of all charging points (Figure 4). At a pricing cordon, the system will debit the charge from its built-in account e.g. in the smart card. It can also use GSM to inform the central system, once sufficient money has been debited from the on-board account, enabling it to initiate the clearing process, and allowing a range of payment options. GSM can also reload an exhausted card and update the charging tariff and locations of the '*virtual*' pricing sites. In most schemes proposed (Hong Kong and Copenhagen being the two serious ones currently), the proposal is to use GSM-SMS as a mechanism for topping up credits and polling the security routines for enforcement.

2.3. *Third-generation cellular radio technology*. Proposals have been made for tolling systems based on charging for entering a cell. Until recently this option could be discounted; however this may change with the award of the third-generation licences for mobile phones. These systems will offer an accurate location service for business phone users – perhaps down to 10–15 metres resolution – which may be enough for road-user charging purposes. As the phones already have secure access and central payment (as well as European interoperability), the technology only needs to provide a credible security scheme to be considered a serious contender. From the point of view of flexibility, the use of wide-area charging technologies is attractive. There is no need for a great deal of infrastructure at each charging point; however, no such schemes are currently in commercial operation.

2.4. *Video-based systems*. This type of scheme has been referred to above in the context of London. Looking at the technology itself, Automatic Number Plate Recognition (ANPR) is a variation on an automatic account identification system, which relies on the vehicle's number plate as its unique identifier. ANPR systems are being introduced for reading vehicle number plates. They process a video image taken by a camera on a gantry, locate the number plate in the image and convert this into the appropriate alphabetic and numeric characters, without human intervention, using Optical Character Recognition (OCR).

The use of video cameras for road traffic monitoring gives an incentive to improve camera technology, including optical processing to provide a wider contrast range, giving clear images even when the licence plates are in heavy shadow, or surrounded by very bright headlights in direct alignment with the camera. Figure 5 shows the new camera technology used at a toll site in Malgara, Greece.

Developments in automatic licence plate reading methods have been undertaken at

Figure 5. Enforcement at toll site location in Greece.

a number of research laboratories. Techniques based on neural network technology and the use of fast parallel-processing machines promise to produce much more robust and reliable licence plate reading systems than are currently available. Within video-based systems there are a number of technical options. The latest implementations utilize digital capture and storage of images, which can be transmitted to remote locations. ANPR minimises the need for manual intervention in the process and greatly reduces the operating cost of the charging system.

Although such technologies have been used for the enforcement of tag/transponder-based systems, they have not yet proved effective as a fee-collection means in their own right – partially because the tag/transponder-based systems are more than 99% accurate, at least for equipped vehicles, whereas the ANPR systems are less accurate. There is not necessarily a problem with the ANPR technology itself, but rather a combination of factors inherent in the way licence plates are designed, issued and used. These include:

(a) Lack of standards for licence plate uniformity.
(b) Dirty plates, damaged plates and obstructions.
(c) Plates mounted incorrectly, temporary or missing.
(d) Supplemental lighting systems not effective for all plates.
(e) Differences in vehicle design and licence plate position.
(f) Ambiguity and similarity of letters/numbers cannot be explicitly determined (such as the letter O and the number 0).

As a result, ANPR systems need human intervention to read images and confirm the result. To improve the overall accuracy, some vendors provide the capture of multiple images; if ANPR determines the same plate information for all, the confidence level of the data is improved and manual review may not be required. Any discrepancy is placed into a manual review queue or treated as a lost revenue transaction. Nevertheless, if the technology for reading licence plates matures to the point of being sufficiently accurate, and/or if a system can be designed to take account of the

inherently lower accuracy, it would offer a cost-effective way of implementing a central account-based or subscription-based road pricing system.

3. HOW THE PREFERRED CHARGING TECHNOLOGY MAY DEVELOP. The ways in which the preferred charging technology may develop over the next few years is difficult to predict. Clearly it will depend on whether a large scheme of video-based road user charging emerges. This seems likely to happen in either the UK (London) or in Scandinavia. Once an impetus is underway towards such a technology, then the necessary industrial development and product design will follow.

In Norway, video is used as the primary charging means in the cities of Kristiansand and Bergen. Here, in a fairly free-flow situation, all vehicles with pre-purchased passes are checked and validated as they pass the charging cordon using on-line video OCR. Vehicle flows are small by comparison with London, but nevertheless the system attempts to read 100% of vehicles. An improved approach will be implemented in Toensberg, Norway in 2001. The requirement is for a full free-flow (multi-lane) video road user charging system. The proposed solution is that all vehicles must stay in lane at the toll site so that their licence plates can be read by the charging system cameras. If they stray across lanes that are clearly marked by two thick white lines, vehicle detectors trigger enforcement cameras that record their licence plate. The fine for straying (or straddling) is substantially higher than the road-use charge! This is a pragmatic approach to the problem of multi-lane operation, and would overcome some of the occlusion and tracking problems associated with video-based licence plate reading.

The performance of the video-front end system (i.e. the camera, digital processing and character recognition algorithm) will improve as the widespread use of cameras for traffic control and speed measurements push the market. A recent study in the Netherlands predicted that the performance of a standard camera arrangement would increase from low 90% accuracy to around 98% by 2005. Our belief is that video-based road user charging has many attractive features that give it a good chance of being adopted by major schemes, and it will then be developed as a key Transport Telematics product. As an interim solution, video does have the advantage of being readily understood by the individual.

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APPENDIX A

Extract from 'Highlights of the Mayor's Draft Transport Strategy', Jan. 2001
GREATER LONDON AUTHORITY: http://www.london.gov.uk

Congestion Charging

Traffic congestion affects all of London, and many of the above proposals will work together to help reduce traffic congestion London-wide. But the worst traffic congestion occurs in Central London. Businesses, bus passengers, pedestrians, residents, taxis, cyclists and all road users suffer as a result. Radical measures are needed. Alongside improving public transport, new powers in the GLA Act to allow congestion charging – charging drivers who use their vehicles in congested areas –

would complement other measures to tackle congestion, including public transport improvements. It provides a powerful and effective means of dealing with congestion on roads within and leading to the charging area.

It is proposed to introduce a congestion charging scheme in central London by early 2003 which would lead to less congestion, improved safety, fewer delays for business traffic and buses, and a better environment.

The proposed scheme would have the following main features:

(a) Standard charge of £5 per vehicle per day;
(b) Charging hours: 7am–7pm, Monday to Friday;
(c) Charging zone bounded by the Inner Ring Road (which joins Euston Road, Pentonville Road, Tower Bridge, Elephant & Castle, Vauxhall Bridge and Marylebone Road). No charge would be made for driving on the Inner Ring Road – only the area within it;
(d) 90% discounts for residents within the charging area;
(e) No charge for motorcycles and mopeds; and
(f) No charge for emergency vehicles and certain NHS vehicles, vehicles used by disabled people, London buses, scheduled express and commuter coaches, London licensed taxis, certain Borough vehicles, and certain 'environmentally friendly' vehicles.

It has been calculated that this scheme would reduce traffic by 10–15% within the charging area, significantly improving journey times and reliability and offering scope for improving the environment of central London. Complementing the scheme, other measures would be introduced to improve public transport and other alternatives to the car prior to and alongside its introduction. Steps would also be taken to take account of changed traffic patterns.

The money raised by a charging scheme must, by law, be spent on improvements to transport in London for at least 10 years. It is estimated that the proposed scheme could raise some £190m per year, which would contribute significantly to improving London's public transport system thereby further reducing traffic congestion as more people shift from using cars.

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