A REVIEW OF CASHLESS ELECTRONIC TOLL COLLECTION TECHNOLOGY

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Cashless Electronic Toll Collection (ETC) is well established in the UK, with installations at the Mersey Tunnels (FAST-Tag), Dartford River Crossing (DART-Tag) and Severn River Crossing (Severn Tag) already in operation. The Department of Transport is currently instigating a research and development programme for introducing electronic tolling on motorways.

This review of current ETC technologies will describe the typical components required for such systems, various methods of implementation and the financial options to be considered. Operational problems affecting the end-users (both operator and customer) are discussed, including those of enforcement and reliability.

SYSTEM COMPONENTS

All implementations of cashless ETC rely on two major system components: a transponder and a communicator. The transponder is assigned to a customer and/or the customer's vehicle and replaces cash as the form of toll payment. The communicator is used to identify the transponder automatically and therefore validate the customer's payment. A typical example of this would be a magnetic card system, where the transponder is the card itself and the communicator is the magnetic card reader and associated electronics.

In the case of non-stop cashless ETC, we require a system that remotely identifies a transponder attached to a moving vehicle, *i.e.* a stationary communicator identifying a moving transponder. Here the communicator consists of an antenna (or antennae) connected to a Central Processing Unit (CPU). The positioning of the transponder depends on where the antennae are located. Figure 1 shows some typical arrangements employed by the major manufacturers.

The transponder comes in one of two forms: either a simple matchbox/credit card sized tag or an In-Vehicle Unit (IVU). Tags require no special installation procedure, whilst IVUs may require connection to the vehicle's electrical and electronic systems. Tags are also far cheaper to manufacture and offer greater flexibility to the customer, as they may be easily transferred between different vehicles.

Tags

There are three types of tag available: read-only, read/write and partitioned. Read-only tags contain fixed information, which is usually encoded during the manufacturing process. Although they are cheap, read-only tags offer the least flexibility to the operator as far as implementation is concerned. Read/write tags can be encoded by the operator and thus offer a greater level of flexibility in their use. This advantage has to be measured against the greatly increased unit cost and decreased operating range, especially during the write cycle. Finally, partitioned tags offer the greatest flexibility in that they enable multiple applications to be supported by the one tag, utilising a separate password protected memory partition for each

application. Each partition may be designated read/write or read-only, making this form of tag the most expensive of the three (an important consideration in the mass market environment).

In-Vehicle Units

In its simplest form, an IVU may just be a tag with a built-in credit indication. Other IVUs incorporate smartcards in order to store credit. The smartcard may be removed by the driver on leaving the vehicle, so as to prevent theft and allow it to be used for other transport payment functions, *e.g.* car parking and public transport. This is becoming more important as integrated transport policies and strategies are being considered by road administrations throughout the world. More complex graphical displays and keyboards (for user input) can also be incorporated, if desired.

IMPLEMENTATION

Depending upon which transponder is chosen, the technology can be implemented in a number of ways. Table I indicates the various transponder types and which implementation of ETC they are suited to.

Automatic Vehicle Identification

Automatic Vehicle Identification (AVI) has been the choice of operators at Dartford, Mersey and the Severn Crossing, all of whom utilise read/write tags encoded with a unique identification number before distribution to the customer. Individual users can be blacklisted to prevent passage in the event of a tag being stolen, lost, misused or unpaid for (1). However, it is not possible to guarantee user anonymity with this system, which can prove unacceptable in certain environments - a notable example being Hong Kong.

Automatic Debiting Systems

With Automatic Debiting Systems (ADS) the transponder, be it a read/write tag or IVU, is used to store the balance of funds remaining. As the transponder is interrogated by the communicator, the current balance is read, the toll due deducted and a new balance is written to the transponder. User anonymity can therefore be maintained, the system effectively being similar in operation to a phonecard. Depending on the memory capacity of the transponder, it may also be possible to store the last 100 or so transactions in addition to the user's balance. A transaction is defined as a self-contained record detailing the location, time and date of the journey undertaken. The operator could then interrogate the transponder on the customer's behalf in order to obtain a list of those journeys undertaken using the ADS transponder.

Hybrid Systems

Hybrid systems utilise partitioned memory tags or IVUs to offer both AVI and ADS facilities to the customer. This raises the possibility of compatibility between different operators, despite employing different implementations of ETC. The same transponder can be used as payment at various tolled locations. Agreement would have to be sought between the companies involved before offering such a scheme. It would also require the use of one manufacturer's ETC equipment across all the sites, as there are no established national, inter-

national or industry standards for the communications link between transponder and communicator as yet.

Road Transport Informatics

Road Transport Informatics (RTI) applications may utilise an IVU to provide in-vehicle real-time information services. These systems can incorporate ETC alongside the other facilities, but again require a common communication link between the transponder and communicator to achieve this goal. Nevertheless, this area must be seen as the future for implementing ETC.

Table I - Transponder types and their implementation of ETC

	AVI	ADS	Hybrid	RTI
Read-only	Yes	No	No	No
Read/write	Yes	Yes	No	No
Partitioned	Yes	Yes	Yes	No
IVU	Yes	Yes	Yes	Yes

OPTIONS

Charging

The options for charging with ETC are either *open* or *closed*. With open charging the transponder is registered as the vehicle carrying it passes the communicator installed at a single point on each stretch of road. Closed charging is where the transponder is registered as the vehicle carrying it passes the communicator installed at its point of entry to and exit from the network - the charge generally being calculated on the basis of the distance between the two. The Dartford, Mersey and Severn Crossing systems are effectively open, as the customer pays for passage through a single stretch of road (the bridge or tunnel).

Payment

There are two options for payment available to the operator, namely pre-payment and post-payment. With pre-payment the customer is expected to pay a cash advance for the purchase of electronically tolled journeys. All UK operators employ such a scheme. Severn River Crossing additionally request a refundable £30 deposit per tag, which covers replacement costs should it be lost, stolen or destroyed. If a DART-Tag or FAST-Tag user requires a replacement tag then the cost is deducted direct from the customer's account. Post-payment is obviously more attractive to the customer, but offers no real advantages to the operator.

Vehicle Classification

There are four basic methods of classifying vehicles for the purposes of ascertaining toll charges. The simplest method is to charge per vehicle, *i.e.* no classifications, but then the toll

bears no relation to the wear and tear that the vehicle has on the road. A motorcyclist would obviously not expect to pay the same toll as a multi-axle Heavy Goods Vehicle (HGV)!

Most operators classify by vehicle type. For example, Dartford River Crossing employ eight vehicle classifications ranging from a motorcycle to HGV plus trailer. Axle counting is another method used. This simply charges according to the number of axles possessed by a vehicle, which could be considered unfair when comparing a mini with a large van. One of the fairest methods charges according to the length of a vehicle, as the toll is then related to the amount of road space taken up.

Accounts

The two options for the location of the customer's account are on-vehicle and off-vehicle. Almost all AVI systems rely on off-vehicle accounts. With all existing UK systems this account is run by the operator and has associated running costs involved in addition to the substantial initial investment for the computer hardware. Encoding a transponder with credit card or bank account details would release the operator from the burden of this accounting, also encouraging customers via the benefits of post-payment facilities. All ADS implementations of ETC and those utilising smartcards employ on-vehicle accounts.

Tolls

Besides the issue of vehicle classifications, there are other options for deciding the toll rates to be charged. The simplest method is to issue a permit for unlimited journeys during a period of time - essentially a season ticket approach. A read/write tag could be encoded with a classification and expiry date for use in such a system. On expiry the customer would pay for the tag to have its life extended, *i.e.* re-encoded with the new expiry date. Examples of such systems are currently in use on some French motorways.

Most operators choose to charge tolls per journey. This can then be linked to the distance travelled. At peak times toll rates can be increased to discourage travel, while during weekends the rate can be decreased to encourage travel. More sophisticated demand management techniques are also possible.

ENFORCEMENT

Effective and credible means of enforcement are essential to the success of any ETC system. Barriers to deny access for customers without a valid form of payment are only suitable for installation on a toll plaza, like those at Dartford and Mersey. Transactions at high speeds (greater than 25mph) are impossible where a barrier requires raising to allow passage. An alternative approach is to keep a barrier in the raised position until a vehicle attempts to violate the system (gain passage without payment). However, this could lead to embarrassing and potentially dangerous accidents in the event of a system fault or a vehicle being equipped with a non-functioning transponder.

An expensive but increasingly effective method of enforcement is to employ a Vehicle Enforcement System (VES). This captures an image of any violating vehicle's number plate by means of camera or video technology. A summons for non-payment can then be directed to the registered driver's address.

Enforcement by means of manual policing is another option to be considered. This is generally relied upon as a backup to another means of enforcement. At the Dartford River Crossing some drivers attempt to gain passage through dedicated "cars only" lanes in vans, but using a DART-Tag encoded with a car classification. This practice is regarded as toll evasion - the offender being treated in the same way as someone who made no attempt to pay.

One approach presently being trialled by the German Federal Ministry of Transport is to employ control vehicles for randomly checking "chip tickets" between the charge collection stations. The times and locations where these checks take place vary and are not foreseeable by the driver. Checking frequency can thus be oriented to the number of drivers refusing to pay. The presence of control vehicles ensures that a minimum payment level is achieved (2).

Another aid in enforcement is Automatic Vehicle Classification (AVC). These systems can work with all the classification methods previously described. Axle counting systems are the most well established of this genre, utilising axle sensors mounted on the road surface. Inductive loops buried underneath the road are often used for length based AVC, although increasing use is being made of image processing based systems. The latter can even work via an interface with existing CCTV equipment. The most complicated AVC equipment is that required to determine vehicle type, but this is generally based on imaging technology.

OPERATIONAL PROBLEMS

Tailgating

The most common form of evasion is that of tailgating. Here a vehicle which is not equipped with a transponder drives nose-to-tail behind a vehicle equipped for valid ETC payment. This form of toll evasion is usually carried out with the two drivers working together, as it requires a fair amount of skill to avoid being distinguished as two separate vehicles without colliding. Tailgating is only practical where passage is at low speeds, *e.g.* when barriers are employed. The use of an affective AVC system coupled with a visible deterrent in the form of VES should prevent such activity.

Frontgating

Frontgating is a phenomenon that has been experienced with DART-Tag. A cash paying customer unknowingly gains passage via a tag fitted in the windscreen of a vehicle behind. The lane equipment ensures that the account holder is only debited once and is able to proceed as normal. Due to the variety of vehicle shapes, this type of problem cannot be entirely eradicated on a toll plaza where queuing inevitably occurs.

Crosstalk

Another operational event that must be guarded against is that of crosstalk between adjacent lanes. The Dartford and Mersey systems are based on a microwave communication link between transponder and communicator. Microwaves are reflected off high-sided vehicles, resulting in two AVI transactions being registered for the same user and at the same time - but on different lanes. Filtering by the central computer system ensures that the customer's account is only debited once.

Systems employing on-vehicle accounts cannot always rely on rogue transactions being filtered, but these tend to feature a more reliable bi-directional data link due to the greater security requirement. The use of a more secure data link virtually eradicates problems of crosstalk.

STANDARDS

As yet there are no formally approved standards relating to ETC. The International Standards Organisation (ISO) has released voluntary standards relating to the automatic identification of freight containers and much of this technology is employed in the field of toll collection. The UK Department of Transport (DOT) began trialling ETC equipment on 14th November 1994, with a view to producing a functional specification for the system by the end of January 1996.

DRIVE is the European Union's research and development programme into Advanced Transport Telematics (ATT), also known as RTI. DRIVE I (1989-91) adopted a standard for transponder frequency, which was formally approved by the European Radio-communications Committee (ERC) in February 1991 as 5.8GHz.

In the DRIVE framework, a working group reporting to CEN (Comité Européen de Normalisation) has been set up on the subject of standardisation problems related to smartcard applications in the transport field. The use of smartcards is envisaged amongst non-stop toll and road pricing systems as well as for payment in public transport and for freight handling.

The Vehicle Information and Transaction Aid (VITA) project has produced a functional specification for the communication infrastructure employed in smartcard based RTI systems incorporating ETC. The work carried out by this consortium of the motorway companies of France, Italy and Spain was used to update another project: Traffic And Roads - DRIVE Integrated Systems or TARDIS (3).

Another consortium has been formed within DRIVE II to work on the Automatic Debiting and Electronic Payments for Transport (ADEPT) project. Its aim is to use the results of the DRIVE I programme to develop the concept of using an intelligent transponder and smartcard for a multitude of automatic debiting, electronic payment and other complimentary RTI applications. This project will only serve to provide background information for the standardisation process, rather than establishing a standard itself (4).

ADEPT is ongoing, but some conclusions have already been reached. The feasibility of using a bi-directional 5.8GHz microwave link with a high data rate has been proved for high-speed vehicle to roadside communications applications. ADEPT has proved that multi-lane tolling and road-pricing is technically feasible. Current ISO standard smartcards appear to be too slow for use in high-speed cashless ETC. A transport-specific smartcard will need developing which offers a higher read-write speed than the current standard. Mono-lane video enforcement has been proven and a full multi-lane enforcement system is planned for the Göteborg test-site in Sweden. This will be the first working demonstration in the world of multi-lane debiting and enforcement using a 5.8GHz automatic debiting system. However, the issue of cross-border management has yet to be addressed.

CONCLUSION

Cashless non-stop electronic toll collection is a viable alternative to previous methods requiring the manual collection and/or processing of cash. Automatic vehicle identification using microwave based tags is a proven technology, with installations at Dartford, Mersey and the Severn Crossing in this country alone. The various implementations of ETC are currently being trialled by the Department of Transport with a view to introducing an inter-urban road pricing system in the UK. The European Union's ADEPT project points the way to the future in developing a single multi-purpose smartcard based system which provides for all transport payment needs.

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BIOGRAPHY

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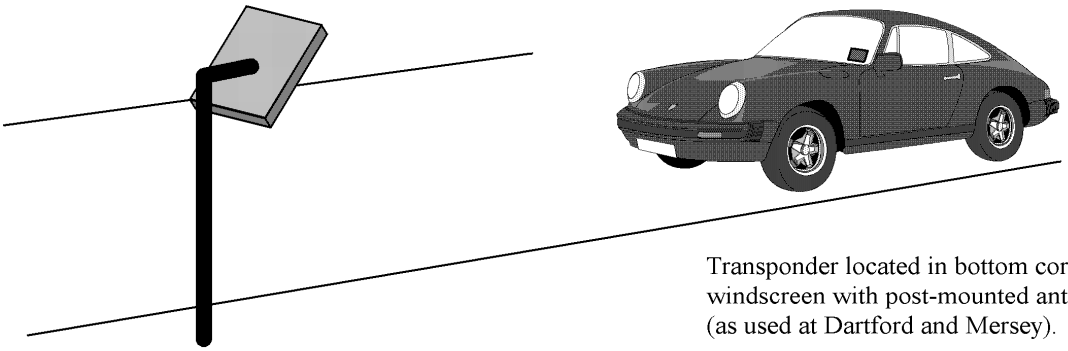
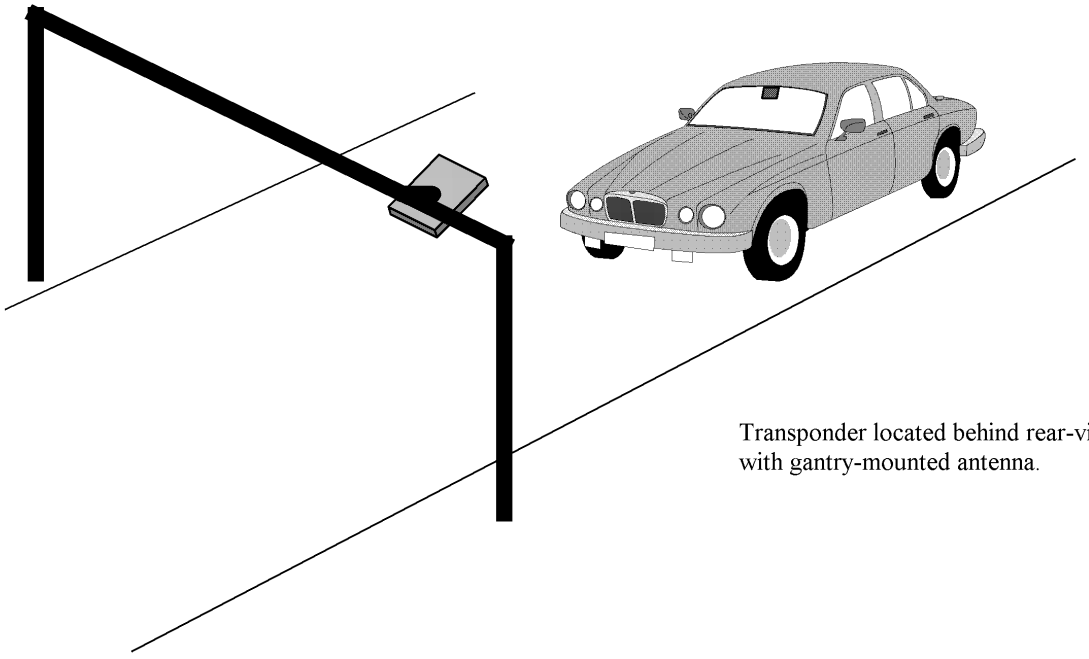
He received his MEng degree in Electronic and Electrical Engineering from the University of Leeds. Since joining Mott MacDonald, he has been involved in the National Motorway Communication System (NMCS2) and all aspects of toll collection technology - both in this country (at the Dartford River Crossing) and internationally (Lantau Fixed Crossing, Hong Kong). He is the author of "Automatic Vehicle Identification and its Application to Inter-urban Road Pricing", which was presented at the Institution of Electrical Engineers (IEE) last year. Alastair Wiggins is an associate member of the IEE.

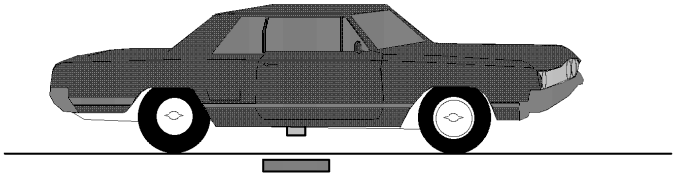
Figure 1 - Typical transponder and antenna arrangements



Transponder located in bottom corner of windscreen with post-mounted antenna (as used at Dartford and Mersey).



Transponder located behind rear-view mirror with gantry-mounted antenna.



Transponder located underneath vehicle with antenna buried in road surface.