RFID FOR ROAD TOLLING, ROAD-USE PRICING AND VEHICLE ACCESS CONTROL

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1. INTRODUCTION

The use of radio frequency identification tags and intelligent transponders for vehicle to road-side communications and vehicle identification is now widespread with such technology and systems being seen as one of the early market successes of developments of ICT (Information and Communication Technologies) in the transport sector, known more generically as transport telematics. In order to understand the current importance and relevance of this application area of RFID it is worthwhile to understand the prevalent political momentum towards integrated transport policies - road-use charging being the 'stick' to the carrots of integrated trip-planning information and improved public transport services.

The trend in transport policy, in many parts of the world and in particularly in Europe, is increasingly towards the recovery of construction, operation and maintenance costs of new roads by the use of tolls or road-use charges. Indeed, in some cases, these charges have been extended to the existing "free" road stock. In addition to this, and more relevant to today's colloquium at the IEE in London, is a re-emergence on the political agenda of many governments and city-authorities of some form of variable road-use-pricing to address the management of traffic and travel demand. In the UK such policies are being actively pursued in response to the Integrated Transport White Paper, published in July 1998. Indeed a well funded and wide ranging series of off-road and on-road research contracts have already been let by the DETR, (Sampson, 1999).

To effectively implement the above policies it is desirable to introduce an efficient charging mechanism which is able to levy the tolls and road-use charges automatically from drivers, i.e. without the need for the drivers to perform any action (other than those associated with normal driving activities). Moreover the system should enable the collection of these charges at normal highway speeds and without the need for the separation of lanes as is the requirement with conventional toll collection facilities.

The requirement for an automatic mechanism for charging is borne out by the fact that it is deemed infeasible and unworkable, in many locations, to implement manual means of fee collection where traffic could be segregated into lanes in order that drivers may stop their vehicles and pay a fee either, manually to an operator, or by inserting coins, cash or a card into a collecting machine. Clearly manual collection would require the building of collection plazas (such as may be seen at the Dartford river crossings) which are costly both to build and operate, and more crucially require a substantial land-area for the site. Such manual collection-plazas may only be built when an actual new road is conceived, land purchased and constructed as a purpose-built toll facility. It is generally not practical to 'retro-fit' a toll plaza to an existing road - in urban areas this would be wholly unacceptable on grounds of land-use, the creation of additional congestion, traffic queues and other dis-benefits, such as noise and air pollution and the inflexibility of the charging regime that can be employed. Moreover, purpose-built toll roads generally have a limited number of entry and exit points whilst "free roads" usually are not so restricted - thus creating an additional difficulty when introducing urban road charging.

The introduction of these charges may have a restraining effect on the traffic demand as well as the obvious attraction of raising relatively large amounts of capital which may then be put back into improving the transport infrastructure, supporting public transport and generally offering alternatives to travel by private car. To implement the policy of charging motorists efficiently the use of conventional stop and pay plazas is unattractive thus some form of non-stop automatic charging of road users must be considered.
When RFID was first employed for the collection of road-user charges is was largely limited to use at toll-plazas (1987 in Ålesund Norway being the 1st commercial use of such a system) and later for multi-lane motorway charging. However in the UK the current trend in charging is now more focused on charging in urban and city areas as a traffic restraint measure. Here the problem is generally not high-speed vehicles but extremely large volumes of vehicles in congested or near-congested situations. This in itself raises additional challenges for the technology.

This paper will provide an insight into the use in-vehicle tags and transponders to facilitate roadside to vehicle data-communications for electronic tolling and road-use pricing systems. In particular the devices which adhere to the new European standard on dedicated road to vehicle communications (DSRC) will be described and discussed.

2. BACKGROUND

2.1 Manual Toll Collection Methods: The Case for Automation

Manual collection methods vary in many ways, depending upon the characteristics of the road. However, the overriding requirement for manual collection is that the vehicle driver must stop the car, open a car window (or door) and either hand over cash or a card or insert either of these into a machine. These plazas are common across Europe for the collection of road tolls - no actual road pricing scheme employs such methods although arguably the Oslo and Bergen toll rings in Norway could be regarded as road-pricing installations.

Manual toll collection usually requires that a large toll plaza is built which divides the free-flowing multi-lane road into a number of single lanes. Each lane is serviced by a toll booth which either houses an operator who collects toll payments manually or the equipment (such as a card reader or coin accepting basket) which the driver may use to pay his toll. Generally, the rule for the design of plazas is that there should be at least three toll booths to service each one lane of traffic leading into the toll-plaza - clearly an non-viable option for road-use pricing in urban areas due to the size of plaza required and the high-volumes of traffic that could be expected in morning and evening 'peaks'. Figure 1 shows a 4 lane toll plaza servicing a 2-lane low-flow road in Normandie, France (a four-lane dual carriageway will require typically 12 toll booths to service the traffic efficiently). Naturally, on roads with low flows, this number may be reduced. However, it is necessary to compare the benefits of reducing the number of toll-lanes (thus the land required and the number of operators employed) with the costs of queuing, noise and air pollution which is the consequence of not being able to service the traffic efficiently and quickly at the toll plaza. Moreover, the physical security of storing and moving a large amount of coins and paper-money can cause some logistical problems. At the Mersey River Crossings in the late 1980's for example, somewhere in the region of 15% of revenue was stolen systematically by operators and about half a ton of coins were required to be moved daily.

![Figure 1: Typical Toll Plaza Layout (Courtesy of CS-Route, 1989)](image)

8/2
The enforcement of manual toll systems, in general, relies on the use of a barrier which is not opened until confirmation (by the operator or the collecting machine) that the correct toll charge has been paid. In many cases, these systems are augmented by vehicle detectors (to count the vehicles passing through the lane) and by some form of vehicle classification (to distinguish different classes of vehicle which pay different tolls). Classification is usually based upon axle-counters and/or vehicle height-measuring equipment. Where a barrier is not used, a video camera may be employed. However, this practice is not very common due to the extra cost with little benefit over the barrier (as the vehicles are expected to stop anyway). Another option is to use a flashing light and alarm on the toll booth which attracts the attention of any police vehicles at the toll plaza that a vehicle has violated the system (such an approach is used extensively on the US Turnpike network) however this is not a particularly workable deterrent for congestion pricing where very high vehicle flows can be expected. There are a number of different methods of collecting tolls and road-use charges manually, these include:

- Manual stop and pay toll booths (manned by operators);
- Manual stop and pay toll booths (with coin and card machines);
- Toll collection based upon pre-paid paper licences (as used in Singapore between 1975 and March of this year - when it was replaced by a multi-lane electronic system); and
- Mixed payment lanes where manual payment and electronic tagging may coexist in a single lane (see figure 2a shows a combined stop and pay coin hopper, card reader and read-only 2.45GHz microwave tag reader on a highway near Lyon, France). Figure 2b shows coin machines for use by ‘occasional’ drivers who do not own a tag at the Trondheim toll ring in Norway.

![Figure 2a: Coin, Card and Tag Payment Booth, Normandie, France (Courtesy CS-Route, 1990)](image1)

![Figure 2b: Coin machines at Trondheim Toll-Ring, Norway (Courtesy NPRA, 1995)](image2)

2.2 Generalised Concept of Electronic Tolling and Road-use Pricing Systems

2.2.1 Approaches to Road User Charging

The different classes of automatic fee-charging systems are based upon the broad functionality of the type of in-vehicle unit which is used in a particular system. This means of classifying the systems is the most useful as, generally, the functional characteristics of a system are, to a large extent, dictated by the in-vehicle equipment. Thus, the performance of the charging system under different traffic conditions; the type of payment and account options which may be implemented, where and what data is to be stored and processed are all largely prescribed by the choice of the in-vehicle equipment.

Many approaches have been adopted for the automatic charging of road-use, broadly they are:

- systems which use short-range (5-30m) communications. These are by far the most common automatic fee collection devices and are further sub-divided into three classes (read-only tags, read and write tags and automatic debiting transponders);
- wide-area systems which use satellites or GSM (Cellular Radio) based systems as part of the charging scheme; and
video based systems.

In this paper only the short range systems (which are generally to RFID technology) are considered. For further information on the other techniques refer to (Blythe, 1995 and 1998).

In short-range based systems where a communications dialogue is established between a road-side communications station and a tag or transponder mounted in a vehicle a number of processes must take place to ensure a correct and accurate transaction or passage of ID data. However it is also necessary to consider the case when this does not occur either due to equipment of communications problems or through deliberate evasion or fraud. Looking at the whole package, (Excluding the central processing and administration functions of the wider-system), each system, typically, has five distinct components:

(i) sensor equipment with the ability to detect the presence of a vehicle (and in many cases classify the type of vehicle);
(ii) vehicle-mounted device, referred to as an In-Vehicle Unit (IVU);
(iii) one or more roadside interrogator stations;
(iv) a roadside (or remote) computer system linking interrogators, for the validation, processing and storage of data; and
(v) a photographic or video registration system necessary for recording licence plates for enforcement purposes.

In addition there will be a back end processing, financial processing, administration and customer interface system. In large implementations the complexity of these elements can be extremely high.

2.2.2 Generalised Concept of a Short-Range System

The transponders and tags utilised by RFID systems in road transportation fall into two different classes, those which are read only and those which have the ability to be read as well as to be written to. The performance of a system and its 'functionality' are dependant on the communications link and the level of built-in intelligence of the in-vehicle and roadside systems. These are summarised in figure 3 below:

<table>
<thead>
<tr>
<th>ROADSIDE</th>
<th>N-VEHICLE UNIT</th>
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<tbody>
<tr>
<td>Simplex Mode</td>
<td></td>
</tr>
<tr>
<td>Roadside Transmits Constant Carrier Wave</td>
<td></td>
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<tr>
<td>Roadside Receives and Decodes Received Signal</td>
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<tr>
<td>(IVU 'Listen' Mode)</td>
<td></td>
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<tr>
<td>(IVU 'Talk' Mode)</td>
<td></td>
</tr>
<tr>
<td>Full-Duplex Mode</td>
<td></td>
</tr>
<tr>
<td>Roadside Transmits Modulated Data Signal</td>
<td></td>
</tr>
<tr>
<td>Roadside Receives and Decodes Received Signal</td>
<td></td>
</tr>
<tr>
<td>(IVU Transmits Modulated Data Signal)</td>
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<tr>
<td>IVU Receives and Decodes Received Signal</td>
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<tr>
<td>IVU Receives and Modulates Constant Carrier Wave</td>
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<tr>
<td>IVU Reflects Modulated Carrier Wave</td>
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<td>IVU Reflects Modulated Carrier Wave</td>
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<tr>
<td>IVU Reflects Modulated Carrier Wave</td>
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</tbody>
</table>

Figure 3: Communications Mode

Simplex read only systems have been used since the early 1970's however the limitation for such systems is that they can only read a fixed identification code from the vehicle and there is no credible data collision strategy that can be deployed.
Most systems now in use in the road-transport environment utilise half duplex communications - here the return signal from the vehicle (uplink) is achieved by modulating and reflecting a CW signal from the roadside. In such cases the roadside station is "master". Infrared systems utilise active communications. This has also been adopted by some RF and microwave systems, however this is an expensive and power consuming solution at radio frequencies. Using half duplex systems offers the possibility of supporting 'intelligence' within the vehicle transponder here additional services that could use the same communication link could reside, moreover peripheral devices, such as in-vehicle displays and a smartcard reader could be integrated with, or interfaced to, the transponder. Obviously such devices have implications in terms of cost, size of unit, power consumption and reliability.

Various frequencies are utilised for these systems around the world, these may be from 450MHz, through the 900MHz band and at microwave frequencies in the ISM bands around 2.45GHz, 5.8GHz and 9.6GHz. In the past five years or so the favoured bands seem to be 2.45GHz in Asia and 5.8GHz in Europe - the latter conforms to a range of standards now developed by ETSI, CEN TC278 and ISO TC204.

2.2.3 European Standards

In Europe there has been a concerted action by the European Commission to standardise the results of the various research programmes in the field of transport telematics. With green papers on fair and efficient pricing identifying road-use charging and tolling as key policy objectives towards the interoperability of the road network and also a mechanism for managing traffic demand - one of the main thrusts in standardisation has been in the field of tolling and pricing. Here standards have been developed for both the communications link (known as DSRC - dedicated short-range communication link) and the applications themselves. In addition some specific standards related to AVEI (Automatic Vehicle and Equipment Identification) were defined. The standard is for a relatively high performance system enabling data transfer rates of up to 500kops and using an optimised HDLC data protocol. Initially these standards were developed by the ETSI and the CEN Technical Committee TC278, more recently the global dimension of this technology mean that many of the standards are now delivered by the worldwide technical committee that largely mirrors CEN TC278, named ISO TC204. A list of some of the more relevant standards is provided below (if not stated the standards are CEN TC278 or ETSI):

- ENV 12253: 1997 Dedicated Short-Range Communication (DSRC) - Physical layer using microwave at 5.8 GHz
- ENV 12315-1: 1996 Traffic and traveller Information (TTI) - TTI Messages via DSRC - Part 1: Data specification - Downlink (roadside to vehicle)
- ENV 12315-2: 1996 Traffic and traveller Information (TTI) - TTI Messages via DSRC - Part 2: Data specification - Uplink (vehicle to roadside)
- ENV 12795: 1997 DSRC - DSRC Data link layer; Medium Access and Logical Link Control
- ENV 12834: 1997 DSRC - Application layer
- ENV 13372: 1999 Road Transport and Traffic Telematics (RTTT) - DSRC - DSRC profiles for RTTT applications
- ENV 14815 Automatic vehicle and equipment identification - System specification
- ENV 14816 Automatic vehicle and equipment identification - Numbering and data structures
- ENV ISO 14904: 1997 Electronic Fee Collection (EFC) - Interface specification for clearing between operators
- ENV ISO 14906: 1998 EFC - Application interface definition for DSRC

In support of this process it must be stated that the European standard have helped to open the market for road-user charging as potential implementors are much more willing to procure equipment once a high-level and well defined standard can be used as the basis for a tender - which can be delivered by many industrial companies.

2.3 Mono-Lane Systems

The concept of collecting user fees from a vehicle's driver without the need for the driver to slow down, stop or perform any actions (other than driving) at the point of collection, is not new. Until a few years ago most automatic non-stop tolling systems had been developed for the conventional road-toll market
whereby one or more lanes of a toll-plaza are equipped with automatic reading equipment to enable drivers to pass through the toll-lane at a reduced speed, without stopping and without the need for the driver to hand over coins, cash or a card. There was a real need for some form of automation of the toll-collection process and generally where such systems have been installed they have been met with a high-level of acceptance from both the driver and the toll-site operator. In consequence, a profusion of these systems now exist across Europe. Early systems used extremely short range communications between the in-vehicle tag and the roadside reading device. Communications technologies such as: inductive, LF radio and even bar-code systems (magnetic or optical). These early systems, however, were limited to a very short communications range and thus the passage speed of vehicles is very low or in some cases even required the vehicle to stop. Many systems of this type are still in use with operators, generally using radio or microwave frequencies for communications and allowing vehicle passage speeds of up to 60km/h. Examples of such tags can be found at the Darford, Mersey, Severn and Tyne crossings in the UK. The limitation of these systems are largely due to the fact the toll collection procedure still requires barriers (as with the other collection lanes) and must adhere to the traffic management scheme prevalent at the collection site.

The other shortcoming of these early toll systems were that they were limited to conveying only a fixed identification code to the roadside system. A generalised schematic of such a system is shown in figure 4. This fixed code relates to an account that the vehicle's owner has set up with the collection agency, such systems are known as read-only or AVI (automatic vehicle identification) systems. However, now many mono-lane systems also use read and write capable transponders so the options for payment and functionality are widened. Systems developed for the mono-lane market are generally not suitable for use in a free-flow, multi-lane road-use charging context.

**Figure 4: AVI System Generalised Architecture for Mono-Lane Operation**

2.4 Systems capable of Multi-Lane operation.

Collecting road-user charges and tolls on roads that were not specifically designed for this creates a number of difficulties, first the physical area required for a conventional stop and pay manual toll plaza or 'drive through' single lane AVI system is not available, secondly the number of entry and exit points on the road are generally much higher than on a purpose built toll road and thirdly the technical and procedural problems of how to electronically detect vehicles at the road-user charging site, levy the correct charge electronically and, where necessary, perform real time enforcement of non-compliant vehicles without restricting the traffic flow must be solved. This is the so called multi-lane problem.

A new generation of road-user charging systems have been developed to meet these needs. They use read-write communications - the so-called, intelligent transponders concept. Here transponders are able to communicate with the roadside systems (using half-duplex communications) and are able utilise a modified slotted-aloha collision/avoid protocol which enables a road-side system to communicate sequentially with a number of in-vehicle transponders at the same time. In many cases the systems
employ quite sophisticated data encryption and security mechanisms to protect the electronic dialogue from fraud, tamper and hacking. Quite often this is achieved partly by using a smart card which is interfaced with the transponder which provides an encryption capability as well as a portable (removable) means of carrying electronic credit of access rights around (separate from the transponder mounted in the vehicle). Such security and anti-fraud measures puts a processing, and hence, time penalty on the system achieve a full transaction. This is a critical point. In short range communications at 5.8 GHz, generally using reflective mode transponders (half-duplex) it is only possible to have a two communications range between the roadside antenna and the vehicle of around 30m. With the particular antennae design used this equates to an actual communications window of only about 100ms at a vehicle speed of 160kmh (Blythe and Hills, 1994). To overcome this problem many of the designers of high speed road-use charging systems use two gantries, one to identify and vehicles' transponder, issue it a session number and begin the transaction. The second gantry some 30-50m down the road begins dialogue once the important and time consuming processing and cryptography has taken place and then completes the transaction - or initiates an enforcement action. A typical layout is illustrated in figure 5.

Figure 5: Typical Arrangement for Multilane Road-User Charging

This solution may seem cumbersome however in many cases necessary. The challenge is to design a reliable system that could use a single gantry. The challenge is also to achieve this in two distinct scenarios: on high-speed roads with high vehicle speeds and on urban roads where there may be congestion and thus many tens of vehicle transponders in range of a single roadside tranceiver.

A description of one solution to the multi-lane problem is provided in the following section. Although the solution is specific the requirements and approach taken are applicable to the general case for multi-lane road-user charging

3. THE MULTI-LANE SOLUTION DEVELOPED BY THE ADEPT PROJECT

This section provides one example of a multi-lane road-user charging and enforcement system based upon a 5.8 GHz microwave road to vehicle transponder-based solution which was developed within the EU funded DRIVE project ADEPT. This solution has been further developed by the ADEPT partner SAAB Combitech, and is now at a commercial stage with several installations in place throughout the world.
3.1 The Problem

In a multi-lane free flow situation vehicles are allowed to pass through the road-user charging site without any additional restrictions on speed or lane discipline than those required for normal driving behaviour. This means that vehicles are not required to keep in lane nor are they restricted from overtaking or changing lane at the charging location, but they are free to move as they would in normal traffic on a two, or more, lane highway.

This then poses two problems for a multi-lane road-user charging and enforcement system.

i. communication between the vehicles transponder and the roadside charging system

ii. enforcement of vehicles who do not pay, cannot pay or try to pay the wrong class of toll.

The communication problem arises because of the need to have dialogue in an orderly manner with several vehicles transponders individually, which may be in the communication zone at any one time. This means that the system must maintain a secure logical communication link with each vehicle for the period of time necessary for the debiting transaction to be completed.

The enforcement problem is the problem of determining which vehicle has not performed a valid payment and recording the details of the vehicle. This means that the position of all the correctly paying transponders must be known, to some reasonable degree of accuracy, by the roadside system, in order to allow it to perform a correlation with the vehicle detection and classification (VDC) system, which detects, continually tracks and classifies vehicles passing through the toll site independently from the microwave debiting system.

3.2 The ADEPT Solution

The solution proposed by ADEPT is based on initial ground breaking research carried out in the DRIVE I project PAMELA (ADEPT, 1996 and Burden and Blythe, 1997). In simple terms, a large communication zone is used which covers all the lanes of a carriageway. The 'large communications zone' is a composite zone comprising of one roadside communications beacon per road lane, separated from adjacent lanes by time and frequency diversity In order to carry out communications with several transponders simultaneously a randomised time division scheme, based upon slotted ALOHA, is used and has proven most reliable.

The second problem of enforcement still requires knowledge of the position of each transponder. This is achieved by measuring the incident angle of the microwave signal received from the transponder by one or more receiving antennas each time the transponder communicates with the roadside system. The angular accuracy must be such that the transponder position measurement can be accurately correlated to belong to one of the vehicles on the road, which have been detected using the VDC system.

In CEN TC 278 working groups 1 and 9 (Standardisation of the Dedicated Short Range Road to Vehicle Communication Link) has defined that the data flow between the roadside system performing the charging function and the moving vehicle needs to be divided into a number of phases (ENV 12834 and prENV ISO 14906). These must describe the following functions:

1. The roadside station must identify itself to the vehicle to enable intelligent decisions based on the nature and/or location of the roadside system.
2. The vehicle must present data necessary for the calculation of the fee, commonly referred to as user rights, or contracts.
3. In order to be able to deduct the fee from the smart card in the vehicle, the roadside station must send a request for charging to the vehicle.
4. The vehicle must be able to respond that the balance has been adjusted.
5. A receipt (in electronic form) must be offered to the vehicle.
This has led to the definition of the following Automatic Fee Collection (AFC) transaction phases:

<table>
<thead>
<tr>
<th>Name</th>
<th>RSS</th>
<th>OBU</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFC Presentation Request</td>
<td>➞</td>
<td></td>
</tr>
<tr>
<td>AFC Presentation Response</td>
<td>➡️</td>
<td></td>
</tr>
<tr>
<td>AFC Transaction Request</td>
<td>➝</td>
<td></td>
</tr>
<tr>
<td>AFC Transaction Response</td>
<td>➡️</td>
<td></td>
</tr>
<tr>
<td>AFC Transaction Receipt</td>
<td>➝</td>
<td></td>
</tr>
</tbody>
</table>

In order to gain wide acceptance and pan-European compatibility, the data sent over the link must be coded according to commonly accepted standards. While no standards are yet available, the work performed in CEN TC224 WG 11 (Standardisation of Surface Transport Applications of Machine Readable Cards) can form a base for the future. The use of the data elements and data structures proposed by WG11 lead to an approximate data volume of 500 bytes to be exchanged over the microwave link for each vehicle (not including encryption and protocol overheads). The exact amount is strongly dependent on site-specific and user-specific functionality.

In a free flow multi-lane situation the vehicles arrive in a random fashion at the toll collection facility and it is a requirement of the roadside controller to process the vehicles, as they arrive as illustrated in figure 6. The spherical shape is the communications window on the ground (made up of TDM and FDM separated transmissions from a number of roadside antenna located on the above road gantry - the vertical bar in the diagram)

![Diagram of toll collection zone with multiple vehicles](image)

**Figure 6** Multiple Vehicles arriving at toll site

It is clear that the vehicles A to D in figure 6 are all possibly in different phases of the automatic debiting transaction. While the transaction has hopefully just concluded for vehicle A, it is probably just about to be started for vehicle D.

This imposes the requirement that the roadside system hardware and software is designed in such a way that the controller can efficiently handle the largest number of vehicles simultaneously present in the communications zone. This is not an unreasonable requirement, since the processing power available at the roadside is many times greater than that available in the on-board unit.

Additionally the speed with which the vehicles pass through the communications zone imposes some restrictions on how long the transaction is allowed to take. In general speeds of at least 160 km/h must be handled. With short range DSRC communications this leads to a maximum communication time of around 100 ms.

As stated earlier in the free flow multi-lane situation the vehicles can move freely inside the communication zone and thus there can be more than one vehicle simultaneously inside the communication zone. It is not known by the roadside communication equipment exactly where in the zone a specific vehicle is.
A novel technique for vehicle detection, location and classification was developed. This VDC system (Vehicle Detection and Classification) uses stereoscopic video cameras mounted vertically above the carriageway to detect and classify the passing vehicles using directly measured parameters of length, width and height. Stereoscopic cameras overcome the problem of shadowing as the axis of the cameras are slightly offset from each other. Figure 7 is an output of the VDC camera which locates a vehicle and its dimensions (L, W and H) and classifies based upon the volume of the vehicle.

In addition to the vehicle detection and classification, the missing piece of the jigsaw is to know the exact location of each transponder with the communications zone. This is achieved by using a phase ranging technique, thus the same beacons that communicate with the transponder to perform the debiting transaction are also used to locate the position of the transponder. The data obtained by the transponder localisation function can then be compared with the vehicle detection data in order to identify vehicles with which the system cannot communicate, i.e. do not possess a working transponder, or indeed a transponder at all, and to decide on enforcement.

![Figure 7: Output from the VDC Camera](image)

The situation can be the following:

1. The vehicle detection detects and continually tracks a number of vehicles in the detection zone, see figure 8a. These are reported to the roadside computer.
2. The transponder localisation function localises a number of transponders in the communication zone, with which data transfer is being performed, see figure 8a. These transponder locations are reported to the roadside computer.
3. The roadside computer matches the vehicle location and classification data with the transponder location and classification data, see figure 8b. One vehicle without a transponder is detected.
4. The vehicle without transponder is reported by the roadside computer to the vehicle registration function and enforcement is done on this vehicle when it arrives at the registration zone, see figure 8c.

![Figure 8a Detected Vehicles and Localised Transponders](image)
Installations of the ADEPT multi-lane system are shown in the following figures. Figure 9a from the German Multi-Lane tolling trials on the A555 and Figure 9b shows the arrangement of beacon and classification camera’s mounted on the underside of a bridge at a multi-lane tolling gantry in Austria. This system completed it’s final acceptance trials in December 1995 and moved to commercial operation - the first multi-lane system to do so.
The ADEPT concepts and technologies are currently being deployed in large scale demonstrations of electronic payment and integrated information services for travel demand management purposes in a number of cities in Europe. Indeed the lead industry in the ADEPT Consortium, Saab Combitech signed a contract in March 1997 to provide a multi-lane system with over 600,000 IVTs to the Melbourne City Link toll-road - the Citylink consortium.

Although the main technical development has been focused upon the demanding problem of multi-lane tolling, it is worth considering that the same technology could be used for urban road use pricing and also to support other value added services, such as in-vehicle driver information and car parking guidance. Both communications transponder and the smart card (if used in the final solution) have the potential to support such added services. The ADEPT project was successful in demonstrating how the same equipment could support many applications at the same time in their trials in five European countries. Congestion pricing (Cambridge, UK) and parking management (Lisbon, Portugal) were good examples of urban applications of the high speed multi-lane tolling equipment. Indeed, the EU's Transport Directorate, DG-VII is now actively looking at many possible forms of road use pricing as a means of managing traffic demand and reducing congestion in urban areas (Blythe, 1997 and 1998).

4. KEY TOLLING AND ROAD-USE PRICING INITIATIVES IN EUROPE

4.1 German Trials

In 1994 the German Ministry of Transport established a test site on the A555 Autobahn between Koln and Bonn. Ten different toll-systems were trialled: 6 using microwave communications, 1 using radio beacons, 1 using infra-red and two wide-area systems using GPS and microwave in one case and GPS and GSM in another. In the case of the systems using GPS - the satellite positioning system was used to determine where pre-programmed 'virtual' toll sites existed and an appropriate fee was deducted from an in-vehicle smart card when these sites were passed.

Figure 10: Screen from the Mannesman's ROBIN system which used GPS to define virtual toll-payment locations

Extensive evaluation of the transaction reliability of each system were made. The conclusions were that no one system currently met the requirements of the German Ministry. One outcome of the trials was a political decision that within the foreseeable future electronic tolling will be restricted to heavy goods vehicles (as part of the Eurc-vignette Initiative).
4.2 The Netherlands

The Dutch have been one of the main proponents of electronic tolling and were instrumental in establishing the standardisation body CEN TC278 on transport telematics. They have initiated many of the operator-led harmonisation efforts in Europe.

In 1995 the Dutch Government resurrected the Rekening Ridjen project for multi-lane tolling on the main arterial routes in the Netherlands. The initial research phase started in 1988, however in 1990 the project was cancelled due to political reasons – although some technical research and support for the standardisation work continued. However, the project was brought back to full consciousness with a large team developing a high-level specification for the toll system. Simulation and laboratory trials were undertaken in 1996-1997 with on road trials in 1998 (initially of 5 systems – this has now been reduced to two candidate systems).

4.3 Norway

In Trondheim, Norway an automatic toll collection ring has been in operation since 1991 (Hoven, 1996). 60,000 vehicles are equipped with AVI (Automatic Vehicle Identification) tags which enable roadside antenna to read the identity of the vehicle from the tag, figures 11a and 11b. Money is then deducted for the passage from a pre-paid account the driver holds with the toll-authority or by post-payment (through direct debit from the drivers bank account). Although not a particularly sophisticated system it is effective in its primary objective of managing traffic demand. In a study carried out by the GAUDI project, the scheme has reduced traffic passing into the cordoned area by 8-9% in the peak travel periods, public transport patronage has accordingly risen by 7%. Similar schemes using manual and mixed manual/AVI payment also exist in Bergen and Oslo respectively, (over 120,000 tags have been issued for the Oslo scheme).

Figure 11a: AVI and Manual Lane Toll Plaza at Randheim, Trondheim

Figure 11b: Roadside Antenna from Trondheim Toll Ring, Norway

Within the next 3 years the Norwegian Publics Road Administration is committed to upgrading the current SAW tags (operating in the 800-900MHz range) to systems compliant with the European DSRC standard using 5.8GHz read-write transponders.

Denmark, Sweden, Norway and Finland are participating in the MANS project. Here the four countries are trying to establish a common electronic payment system for both tolls and smart card applications in the field of transport (so-called, Scandinavian inter-operability).

4.4 France

In 1993 ASCAP, the umbrella organisation representing the 14 independent toll road operators in France, awarded a development contract to two consortia to facilitate the development of a high-performance toll system, initially for use by heavy goods vehicles (to replace the current paper Cariss card). A final contract to build the system was awarded to a CGA-led consortium in 1995. The initial deployment of
200,000 in vehicle units was completed in mid-1998. A second tranche of supply contracts is now underway.

4.5 Austria

Österreichische Autobahnen und Schnellstraßen AG (ÖSAG) the largest highway operator in Austria took delivery of the worlds first commercially operated multi-lane toll system in 1994. For 18 months the system underwent acceptance trials with 2000 users and is now in full commercial operation. The toll plaza's around St Michael comprise of a mix of multi-lane free flow, automatic single lane and manual lane. The system was supplied by Combitech of Sweden and is based to a large extent upon the developments from the ADEPT project. A novel feature of the system is the use of stereoscopic cameras looking down onto the road as a means of automatic detection and classification of vehicles (refer to section 3 of this paper).

4.6 Italy

Along with France, Italy has had the longest experience with electronic toll collection systems in Europe. The main focus of electronic tolling have been made by Autostrada which is the largest of the toll road concessionaire in Italy with over 50% of the network. Since the late 1980's they have been offering the TELEPASS system as an alternative automatic means of toll payment. Currently over 100,000 vehicles are equipped with TELEPASS.

4.7 Greece

In Northern Greece the Malgara Toll Plaza participated in the ADEPT trials of multi-lane toll collection between 1993 and 1995. As a result of the success of the system and the sound economic case for replacing a purely manual toll collection system by an electronic system, the Greek Fund for Highways (TEO), which operates all of the country's toll roads, has decided to opt for a full electronic system. Congested cities in Greece (Thessaloniki and Athena, to name but two) are also investigating the use of such a system for road-use pricing and access control. Figure 12a is a photograph of the an ADEPT multi-lane gantry from Thessaloniki and figure 12b shows a typical in-vehicle system comprising of a transponder and smart card (again from the ADEPT project).

Figure 12a: ADEPT Multi-Lane Toll Gantry, Malgara Toll Station, Greece

Figure 12b: Version of ADEPT In-Vehicle Equipment

The Greek Fund for Highway (which manages all toll roads in Greece) have recently (March 1999) let a tender for the installation of smart card based electronic payment for every toll lane of their network. This system employs the DISTINCT smart card which will open up its functionality to many other transport and city-card functions, (Blythe and Shield, 1998).

4.8 Switzerland

Switzerland has introduced a distance-based road-use charge for all HGV's. This system uses vehicle location and tracking to calculate the road-use of a particular vehicle. DSRC is only used for the
enforcement of the system. Such systems are likely to play an increasing role in road-user charging schemes in the next decade.

4.9 United Kingdom

4.9.1 Electronic Tolling Trials (1994-1997)
In 1994, the UK DoT announced their intention to hold trials of multi-lane tolling equipment. Following a call for participation in which 32 submissions were received, 8 consortium were selected for the trials. Due to various delays and difficulties only 2 (GEC and ANT Bosche) of the original 8 consortium selected have actually made it to the trial phase which was carried out in 1996/97.

4.9.2 Early Road-Use Pricing Trials
During the past couple of years various cities have flirted with the idea of electronic road pricing, indeed Cambridge demonstrated a system as far back as 1993 whilst Newcastle, Leicester and Bristol installed trial and evaluation systems in the past 18 months.

4.9.3 Current Road-User Charging Activities
The UK governments recent white paper on Transport supports the concept of integrated transport whereby pre- and on-trip information (including in-vehicle information) will be used to support trip planning, a switch of mode towards public transport and the introduction of inter-urban tolling and significantly urban congestion pricing systems. It is likely that the legislation to enable local authorities to introduce their own road-use pricing scheme - and significantly to keep the revenue to provide support for public transport and related services will be in the Queens Speech next month (November 1999).

In support of the potential legislative framework, the DETR has been developing a large portfolio of both on-road and off-road research in this area. Of most significance are the on-road trials. Here 3 pre-qualified consortium will tender to supply complete multi-lane road-use charging systems to selected trial sites (Leeds and Edinburgh). Here each will have 1000 trialists using the equipment for at least a year (the system must register no less than 1 million transactions). The tender for this shall be released in December 1999 (delayed from June 1999).

A second phase of this research is a tender which enables cities and regions who wish to implement road-user charging to bid to receive financial and technical assistance from the DETR and their research teams. Interestingly, there are a significant number of cities that have bid for to be real implementation sites.

The above is a non-exhaustive list of those active in tolling and road pricing, however it does give a flavour of the wide-range of activities in Europe and the market potential for such systems. For further references the following countries are also particularly active in field (Portugal, Sweden, Spain, Denmark, Singapore, Korea, China, USA, Argentina, Chile, Canada, Taiwan and Japan)

5. SUMMARY

Over the past decade or so the development of high performance vehicle/roadside communications systems for the facilitation of electronic payment has moved on in leaps and bounds. The establishment of a European standard for many aspects of the short range communications link and the application data has opened up the market, not just here in Europe, but worldwide.

With the advent on the political agenda of traffic demand management through tolling and urban road pricing, not least in the UK, it is expected that the market for such systems will grow rapidly as the technology matures. There could be somewhere in the region of 50 million in-vehicle units in Europe within the next decade - a major market for RFID and other microwave products. However there are few places in the world where multi-lane tolling has been implemented on a large scale (Singapore, Toronto and soon in Melbourne) and until these systems are seen to be successful and accepted by the public we may expect more small-medium scale 'trials' of such systems in the UK and Europe.

Finally, what also needs to be considered in the current climate, is that by establishing a market for a high-performance road to vehicle two way communications link, this offers more than just a mechanism
for tolling but also a generic system to support other, so-called value-added services, such as driver information and trip planning, parking booking and payment, dynamic route guidance and vehicle monitoring, to name but a few. Small trials of these "integrated" functions have taken place - but more is needed.

The recently announce beacon based in-vehicle information service trial between Bristol and Gatwick airport will be a major step in bringing such applications towards a commercial implementation in the UK.

6. REFERENCES


