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POLICY DEPARTMENT B
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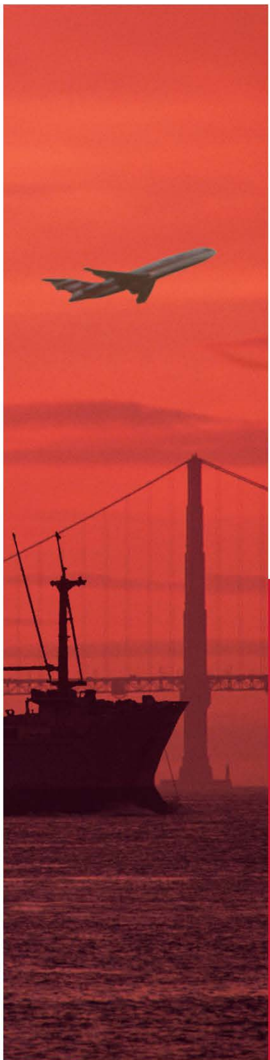

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TECHNOLOGY OPTIONS FOR THE EUROPEAN ELECTRONIC TOLL SERVICE

STUDY

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TRANSPORT AND TOURISM

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STUDY

This document was requested by the European Parliament's Committee on Transport and Tourism.

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Abstract

This study has been prepared to review current and future technological options for the European Electronic Toll Service. It discusses the strengths and weaknesses of each of the six technologies currently in existence. It also assesses on-going technological developments and the way forward for the European Union.

IP/B/TRAN/FWC/2010-006/LOT1/C1/SC7 2014

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CONTENTS

LIST OF ABBREVIATIONS

1G	First generation mobile phone technology, see Table 9
2G	Second generation mobile phone technology, see Table 9
3G	Third generation mobile phone technology, see Table 9
4G	Fourth generation mobile phone technology, see Table 9
5G	Fifth generation mobile phone technology, see Table 9
ANPR	Automatic Number Plate Recognition
ASECAP	Association Européenne des Concessionnaires d'Autoroutes
C2C-CC	Car 2 Car Communication Consortium
CALM	Communications Access Land Mobile
CAPEX	Capital Expenditure
CCD	Charge Coupled Device
CDMA	Code Division Multiple Access
CEN	Comité Européen de Normalisation
CN	Cellular Network
CVIS	Co-operative Vehicle Information System
DSRC	Dedicated Short Range Communication
EC	European Commission
EDR	Event Data Recorder
EETS	European Electronic Toll Service
EFC	Electronic Fee Collection
ETC	Electronic Toll Collection
ETSI	European Telecommunications Standards Institute
EU	European Union

GBPS	Gigabytes per second
GIS	Geographical Information System
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile
HOT	High Occupancy Tolling
ISO	International Standards Organisation
ITS	Intelligent Transport Systems
KBPS	Kilobytes per second
LTE	Long Term Evolution
MBPS	Megabytes per second
MLFF	Multi-Lane Freeflow
MNO	Mobile Network Operator
NFC	Near field communication
OBD	On-Board Diagnostics
OBE	On-Board Equipment (alternative to OBU)
OBU	On-Board Unit
OCR	Optical Character Recognition
OPEX	Operational Expenditure
ORT	Open Road Tolling
PAYG	Pay As You Go
R&D	Research & Development
RF	Radio Frequency
RFID	Radio Frequency Identification

RSE	Roadside equipment
SWOT	Strengths Weaknesses Opportunities Threats
TDP	Time Distance Place
TEN	Trans European Network
TOID	Topographic Identifier
UBI	Usage Based Insurance
UHF	Ultra-High Frequency
UNI	Italian Standards Organisation, Ente Nazionale Italiano di Unificazione
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VES	Violation Enforcement System
WAVE	Wireless Access in Vehicular Environments

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EXECUTIVE SUMMARY

THE EUROPEAN ELECRONIC TOLL SERVICE

In 2012, road user charges were levied on private vehicles in twelve Member States and on heavy goods vehicles in twenty-two. In total, the tolled road network was approximately 72,000 kilometres long of which 60% was equipped with electronic toll systems. These systems are, at best, interoperable at a national level but not at EU level. This creates barriers to the operation of the internal market.

Directive 2004/52/EC was adopted to remedy this fragmentation by creating a European Electronic Toll Service (EETS) to enable road users to pay tolls and charges throughout the EU through a contract with a single EETS Service Provider and with a single on-board unit. Commission Decision 2009/750/EC set the general requirements necessary to achieve interoperability between the EETS providers and the toll chargers' equipment and procedures. Pursuant to the above Directive, EETS should have been available to heavier vehicles from October 2012 at the latest, and should be offered all other types of vehicles by October 2014. It appears however that EETS deployment remains an issue.

CURRENT TECHNOLOGY

Six main electronic fee collection systems are currently in use:

(1) Automatic Number Plate Recognition (ANPR) - a mature technology that use video cameras for vehicle identification.

(2) Dedicated short-range communications (DSRC) technology - based on bidirectional radio communication between fixed roadside equipment (RSE) and a mobile device (OBU) installed in a vehicle.

(3) Radio Frequency Identification (RFID) - the most used Toll Collection system in the United States (US), relying on radio waves to identify devices.

(4) Global Navigation Satellite Systems (GNSS) technology for toll collection purposes - an emerging technology that uses the vehicle's position data to measure the use of the road in order to determine the charge.

(5) Tachograph-based tolling - the system used in Switzerland - records the mileage driven by the user through an OBU connected electronically to the vehicle´s odometer.

(6) Mobile communications (GSM and smartphones) tolling systems - still in an embryonic stage but having significant potentials going forward.

These technologies differ in performance, enforcement, accuracy, cost evaluation and interoperability. Options other than the tachograph and GSM/smartphone tolling can guarantee a level of accuracy of over 99%. Another issue is data protection: ANPR and GNSS may allow the recognition or continuous tracking of drivers, while DSRC, RFID and tachograph-based technology does not seem to affect user privacy.

The costs of options vary significantly. DSRC, which is the most widely adopted Electronic Toll Collection (ETC) technology in Europe, requires the installation of costly roadside equipment. ANPR necessitates "less costly" roadside equipment and no OBUs. RFID has not been widely implemented in the EU and its installation costs would therefore be higher than other solutions. GNSS and GSM option are less costly from the infrastructure point of view although GNSS would require a higher level of investment during the start-up phase and, in particular, in relation to establishing an expensive back office system.

DSRC has a low level of adaptability even though it is the most widely adopted ETC technology and is the only solution with CEN standards available. ANPR is a flexible system that has already been combined with other ETC options for enforcement purposes, but the lack of licence plate standardisation and the challenges for Member State cooperation in setting up an international licence plate database mean that video tolling is not an appropriate technology for achieving international interoperability. GNSS and GSM are flexible and adaptable options but their low penetration rate and privacy concerns also limit their potential.

DSRC, GNSS and GSM/GPRS are the only technologies put forward for the EETS by Directive 2004/52/EC. ANPR, RFID and tachograph cannot currently be considered compliant with EETS.

EMERGING TECHNOLOGIES

In order to best assess which technologies could play a role in future EETS, a series of questions need to be asked to understand if existing technologies are obsolete, if there are opportunities for cost reduction, improved interoperability, and improved performances and accuracy, and what is the state of art of the other technologies in the same sphere.

DSRC, GNSS and ANPR do not present any signs of possible early obsolescence. Improvements in camera technology may render some of the specific components of ANPR obsolete, but units can be upgraded on life expiry. GSM may become obsolete in the near future: by 2017, 40% of mobile subscribers in Western Europe are expected to be on 4G Long Term Evolution with the vast majority of other users on 3G.

Costs relating to OBU and traditional roadside equipment are not expected to fall significantly in the near future, whereas the migration to 3G and 4G provides lower unit costs per data packet transmitted, increasing the potential for using WiFi-based technologies at least in urban areas. The cost of enforcement could also be reduced by pan-European sharing of vehicle and driver registration data and common standards for the data required as evidence.

No currently envisaged technologies would increase interoperability in the EU. Opportunities may come from related technologies, such as Cooperative Vehicle Information Systems (CVIS) and Communications Access for Land Mobiles (CALM) areas, and applications such as telematics for vehicle and driver management, eCall, and usage-based insurance (UBI) using Event Data Recorders (EDRs).

Substantial advances are expected in payment methods, with digital payment channels using mobile internet being adopted as they become the primary medium for customer payments and communications in Europe. Contactless payments through a mobile phone using Near Field Communication (NFC) enable better cashless transactions, as a person's identity does not need to be disclosed during the transaction. By removing cash handling and reducing transaction costs of micro-payments, this technology could enable users to pay per use at a physical location without the need for a tolling account. Many experts claim that, by using NFC technology, smartphones will facilitate the switch to all-electronic toll collection.

THE WAY FORWARD

The following wider policy objectives should be considered in the coming years:

- Generalised and harmonised implementation of road charging across the EU.
- Make the ETC the most common means of payment for tolls and road charges within Europe.
- Set up one single contract and one single OBU valid throughout the EU.
- Minimise the life-cycle cost of toll collection systems.

Policymakers should consider:

- A suitable implementation of EETS requires an egalitarian and harmonised introduction of tolling devices to users.
- Making the installation of an in-vehicle device, either during the manufacturing or registration process of the vehicle, both an attractive option for the end-user and potentially compulsory to facilitate EETS take-up.
- The coordination of all on-board devices, and interfaces for retro-fitting, within a car would make EETS implementation easier.
- The coordinated use of the OBU with other navigation and communication systems would facilitate users´ acceptance of ETC.
- To ensure a harmonised approach to data privacy, agreements are needed on what information should be made available and what should remain confidential.
- The potential constraints of existing ETC standards on future measures should be considered on a case-by-case basis; not all solutions may continue to be compatible, though it is desirable that new measures should be interoperable with existing ETC systems.

The following practical aspects should be reviewed:

- The current technologies (including ANPR) can meet most of the requirements for charging roads in Europe at a technical level, but are not all equally cost-effective.
- Operators and users should have the right to choose the simplest and most economical technology to pay tolls electronically throughout the EU.
- Efficient back office, inter-operator settlement and enforcement systems to guarantee toll payments need to be implemented without generating significant additional collection costs for toll operators or EETS service providers.

WEAKNESSES AND RECOMMENDATIONS TO OVERCOME THEM

From the analysis conducted in this report, we have identified the following weaknesses:

- Most vehicles in Europe do not have devices installed for paying tolls electronically.
  - Recommendation: promote a generalised introduction of ETC devices across the EU.
- Even though current ETC technologies are compatible with EETS requirements, additional factors need to be addressed to reach interoperability throughout the EU.
  - Recommendation: promote a liberalised market for the manufacture and distribution of ETC technologies. This should be accompanied by promoting a more coherent standard for suppliers to follow.
- ETC technologies still require the implementation of reliable enforcement mechanisms to identify toll evaders and guarantee the payment of electronic tolls within the EU.
  - Recommendation: promote sharing of data on registration and evasion through a secure pan-European registration database with evader/nonpayer details, secured through measures set out in the EFC Security Framework.

1. THE EUROPEAN ELECRONIC TOLL SERVICE

KEY FINDINGS

- Different electronic toll collection systems coexist within the European Union. This multiplicity of systems creates barriers to the operation of the internal market.
- Directive 2004/52/EC and Decision 2009/750 defined a European Electronic Toll Service (EETS), with the aim of ensuring interoperability of electronic road toll systems in Europe.
- EETS is intended to enable road users to pay tolls and charges throughout the EU through a contract with a single EETS Service Provider and a single on-board unit. It will simplify the movement of goods and people across the Union.
- Progress to date on EETS deployment is disappointing. The reasons for failure to implement EETS are not primarily technical.

1.1. Road charging in Europe

According to the European Commission, in 2012 twenty-two Member States were levying road use charges on heavy goods vehicles and twelve Member States were also levying charges on private light vehicles. In total, charging applies to around 72,000 kilometres of road.

Circa 60% of the European charged road infrastructure is equipped with electronic toll collection (ETC) systems which have been introduced nationally or locally from the early 1990s and to which more than 20 million road users have subscribed. Dedicated short-range communications (DSRC) have been the most frequently adopted solution for electronic toll collection. New technologies, including satellite-based ones, have also been adopted over the last 10 years alongside the implementation of nationwide truck tolling schemes, for example in Germany (2005) and Slovakia (2010). As a result, different and, in most cases, non-interoperable technologies coexist within the European Union.

1.2. The European Electronic Toll Service (EETS)

The proliferation of technologies for electronic toll collection systems and the related business models are limiting interoperability at many national borders, hampering the internal market. Directive 2004/52/EC was adopted to remedy this fragmentation and simplify the movements of goods and people across the EU according to the principle "one vehicle, one contract, one on-board unit".

Directive 2004/52/EC defined a 'European Electronic Toll Service' (EETS) to ensure interoperability of electronic toll collection systems throughout the continent. Its aim was to enable road users to pay tolls throughout the EU through a single contract, with one single service provider and one single on-board unit (OBU), also known as on-board equipment (OBE).

The EETS is intended to complement national or local electronic toll services, not to replace them. It is based on open and public standards, available in an interoperable, non-discriminatory basis to all system suppliers covering all forms of ETC: private concession roads, nationwide road charging and urban road pricing.

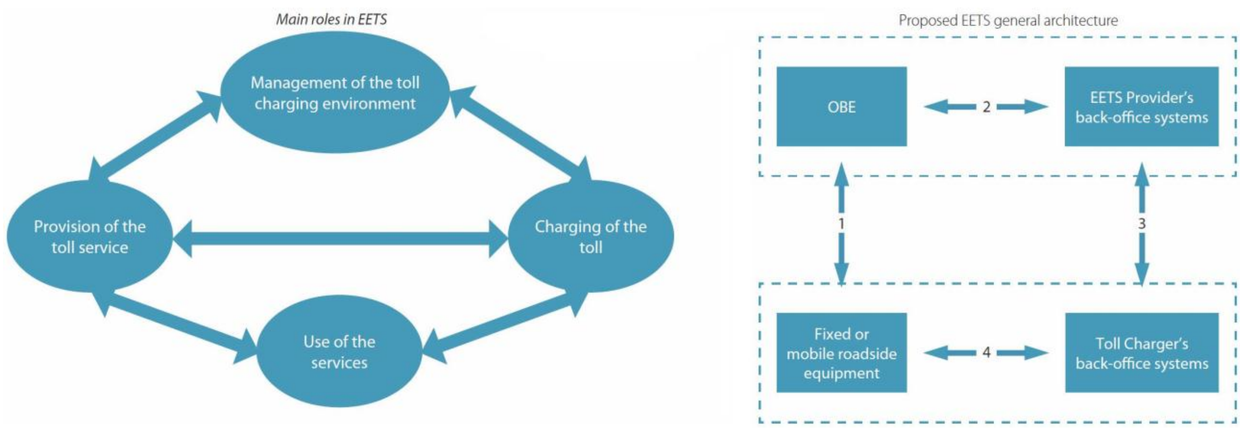
Three main stakeholders are identified within the EETS model (EC, 2011) as illustrated in Figure 1:

- The users may subscribe through a single contract with the EETS provider of their choice, and will not have to know the requirements of each national electronic toll system they encounter.

- EETS providers are required to build full service coverage for all EETS domains (ETC systems). They may implement different technological solutions according to their needs which may include “intelligent clients” – allowing for real-time price calculation – or “thin clients” (EC, 2006). Furthermore, EETS providers will enter into agreements with each Toll Charger to ensure that there are contractual relationships between all parties. Finally, a management framework governing the EETS service is necessary.

- The Toll Chargers levy tolls for the circulation of vehicles. They enter into contractual agreements with EETS providers. They have no direct contact with EETS users, except for enforcement purpose if necessary (European Commission, 2012).

Figure 1: Main stakeholders and proposed EETS architecture according to the CESARE III project[1]



Source: European Commission (2011).

Pursuant to Directive 2004/52/EC, EETS should have been available to heavier vehicles from October 2012 at the latest, and should be offered all other types of vehicles by October 2014. It appears however that EETS has not been deployed so far.

In its communication of August 2012 on the implementation of the European Electronic Toll Service (COM(2012) 474 final) the European Commission clearly states that 'this failure to implement EETS and to do it in the foreseen timescale is not due to technical reasons.' This

[1] The CESARE III project (Common Electronic Fee Collection System for an ASECAP Road Tolling European Service) is a project established by ASECAP and co-financed by the European Commission. It aims at specifying, designing, developing, promoting and implementing a common interoperable Electronic Fee Collection System (EFC) on European toll roads.

implementation would rather be 'hampered by a lack of cooperation between the different stakeholders groups' and the limited efforts of the Member States. In its Report of April 2013 on a strategy for an electronic toll service and a vignette system on light private vehicles in Europe (A7-0142/2013), the European Parliament took the same position and 'agrees with the Commission that the technology for interoperable systems already exists'.

1.3. Legislative framework

While some European countries – such as France, Italy and Spain – have long levied tolls on parts of their high capacity road network, EU legislation related to pricing mechanisms on road infrastructure only appeared with Directive 1999/62/EC and, more recently, Directive 2011/76/EU, which can be considered the key milestones towards the adoption of the "user pays" and "polluter pays" principles in Europe. As pointed out by Walker (2011), the implementation of road user charging presents a number of advantages:

- It promotes more efficient use of vehicles and infrastructure
- It constitutes an effective tool to manage road traffic demand
- It encourages the use of more environmentally friendly transport modes
- Pay-per-use schemes reduce the dependency on state funding for roads expenditure

EU transport policy has promoted not only road charging but also the adoption of electronic toll collection systems as a means to pay charges and tolls throughout Europe. Recent research studies (Yang et al., 2012; Gordin et al., 2011; Venigalla et al., 2006) have analysed the positive impacts of ETC systems on road safety, congestion and air pollution. Additionally, the adoption of this policy can promote a more efficient use of the road infrastructure. It can also contribute to the harmonisation of road transport costs across the EU, as ETC technologies make it easier to charge for the use of roads and could therefore help to expand the consistency of charging schemes throughout the Union.

Directive 2004/52/EC sets out the technical, procedural and legal matters required for the definition and deployment of the European Electronic Toll Service. The Directive requires EETS availability across the whole EU road network on which road charges are collected electronically. The EETS should be defined by:

- A contractual set of rules enabling operators to provide the service.
- A single subscription contract between the user and the EETS operator, giving access to the service on the whole tolled network. The contract would be independent of the place of registration of the vehicle, the nationality of the parties to the contract, or the region where the toll/charge is levied.
- A set of technical standards and requirements, including technical, procedural and legal matters. Technical matters of the service include operational procedures (subscription, instructions for use, customer assistance, etc.), functional specifications, and technical specifications of supporting ground-based and on-board equipment. Procedural matters include covering verification of technical performance of the system, parameters for vehicle classification and procedures for dealing with particular cases. Finally, legal matters include validation of the chosen tolling technology, setting common rules and minimum requirements for EETS providers, and harmonisation of rules on enforcement.

Further guidance on the application of the EETS was set out in **Decision 2009/750/EC**, especially in relation to the rights and obligations of each stakeholder in the system.

EETS Providers need to meet a number of requirements including ISO certification and be able to demonstrate an ability to provide ETC services. They are also obliged to maintain coverage of all EETS domains at all times, provide users with a suitable On-Board Unit (OBU), publish their contracting policy, and provide service and technical support. Toll Chargers must ensure EETS interoperability of the toll system, develop and maintain an EETS domain statement setting out the conditions which EETS Providers must meet to access their toll domains, and accept, on a non-discriminatory basis, any competent EETS Provider. Finally, EETS Users have the right to subscribe to EETS, must be adequately informed about the processing of personal data and the rights resulting from legislation, check that vehicle and user data provided are correct, and ensure that the OBU is operational.

Three main technologies were identified for electronic toll transactions: satellite positioning, GSM-GPRS mobile communication and CEN DSRC 5.8 GHz microwave technology. The Directive also observed that new on-board equipment should ensure access to future applications and services in addition to toll collection.

In the same year, the White Paper 2011 "Roadmap to a Single European Transport Area", **COM(2011)144**, called for definition and deployment of an open standard electronic platform for vehicle OBUs, performing various functions including road charging. The last document available, **COM(2012)474**, presented the progress achieved in its implementation and provided recommendations from the European Commission on the next steps towards making EETS operational.

At the end of 2013, the European Commission initiated a public consultation on charging for the use of infrastructure, in which stakeholders were asked to express their views on the electronic toll systems and the achievement of an EETS. Further to this, a 'Coordination Group' was created with the aim of certifying the suitability for use of EETS equipment.

Decisions relating to EETS and ETC also need to take into consideration related legislation. In particular, introduction of electronic toll systems entails the processing of personal data. This is dealt with in **Directive 95/46/EC** (the reference text on data protection in the EU) and **Directive 2002/58/EC** on ensuring an adequate level of protection with respect to the processing of personal data in the electronic communication sector.

2. REVIEW OF CURRENT TECHNOLOGY

KEY FINDINGS

- ANPR is a mature technology which does not require on-board units (OBUs) and needs "less costly" roadside equipment. If it was adopted for EU-wide tolling, it would need to be supported by a shared licence plate database and common transnational standardisation of licence plates.
- DSRC is the most widely adopted Electronic Toll Collection (ETC) technology in Europe, has CEN standards available and uses inexpensive OBUs. However, it requires the installation of costly roadside equipment and is a rigid scheme, which makes modifications difficult, and is not interoperable with other ETC systems.
- RFID achieves similar performance levels to DSRC and is a mature technology, but it has not been widely implemented in the EU and interoperability with existing ETC systems would require significant investment. Its main advantage is the cost of OBUs (~€1) which is significantly lower than for DSRC (~€5-10) or GNSS (~€100).
- GNSS requires minimal roadside equipment, and modifications to the tolled road network can be made easily. However it is expensive to install and operate.
- The tachograph-based technology avoids issues of users´ privacy and limits the roadside equipment needed to border crossings, but it is not commonly used and needs a complex and expensive OBU.
- Mobile phone and smartphone-based tolling do not require in-vehicle devices, allowing for lower initial investment costs when compared with other technologies. On the other hand, the technology is not mature and various issues still need addressing. In addition, the development of telecommunications-based technology is very volatile. Current systems based on GSM solutions are likely to become obsolete very quickly.
- DSRC, GNSS and GSM/GPRS are the only technologies proposed for the EETS by Directive 2004/52/EC. ETC technologies such as ANPR, RFID and tachograph present significant limitations and modifications are required to make them compliant with EETS.

This chapter presents the six main electronic fee collection systems currently in use. It summarises the most significant characteristics of each of them including performance, enforcement, accuracy, cost evaluation and interoperability. Special attention is paid to DSRC and GNSS options, which are two of the technologies proposed for electronic toll systems by Directive 2004/52/EC, together with satellite positioning.

This chapter sets out a high level explanation of the six technologies examined:

1. Video tolling (ANPR);
2. Short-range communication (DSRC);
3. Radio-frequency identification (RFID);
4. Satellite positioning (GNSS);
5. Electronic tachograph; and
6. Mobile communications (GSM and smartphones).

2.1. Video tolling (ANPR)

Using video cameras for vehicle identification in tolling is a mature technology. Automatic Number Plate Recognition (ANPR) has been used in urban congestion charging schemes, such as London, Stockholm and Milan, although other examples exist outside city centres, such as the ETR407 toll highway in Toronto. ANPR is generally implemented for charging and enforcement purposes. Some countries such as Australia, Chile and South Africa are considering it as an alternative to the DSRC schemes (Kapsch, 2013).

2.1.1 Admissibility of evidence

ANPR is useful for enforcement purposes as vehicle images are the most common strategy for identifying non-payers of tolls. As there is always a need to enforce payment of a toll or charge, the usual strategy is to rely on vehicle images to provide evidence for enforcement. Most legislation for enforcement relies on images that meet historic criminal requirements for "proof beyond reasonable doubt", even where non-payment has become a civil or administrative matter. Additionally, there is an established process for enforcing other traffic offences, such as for parking or speeding, which rely on a national vehicle and driver database which each Member State already has in place. The enforcement of non-payment of tolls or charges has therefore followed a similar process.

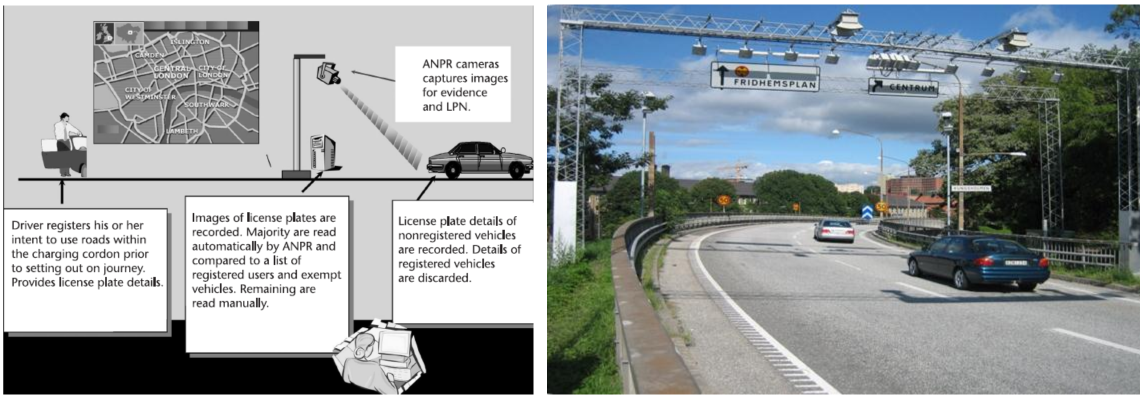
In addition, in most Member States the vast majority of vehicles are registered in that jurisdiction – for the majority of offenders it is therefore feasible to gather vehicle owner details from the national central database. However there has not been sufficient impetus to create an EU-wide vehicle and driver database yet. For example, in Stockholm, foreign vehicles are exempt from the congestion tax to simplify the enforcement process.

2.1.2 Performance & enforcement

This system works through cameras (mounted on poles or gantries at the roadside) taking a picture of the licence plate as the vehicle drives through the detection point. Optical Character Recognition (OCR) software reads the licence plate and the system then checks it against a list of registrations to identify the vehicle and apply a charge to the owner or driver. The user is charged without the need to install any OBU, either through a pre-registered account or individual payments per use.

The OCR process can be deployed either in the field (integrated camera and ANPR) or at a central site. In the first case, the entire process can be performed at the roadside in real time. Data can be stored in the camera or roadside cabinet for later retrieval or is sent to a back office for additional processing. In the latter case images from the cameras are transmitted to a central computer which subsequently carries out the OCR process. The back office process may also require an additional manual check, in order to improve the accuracy of number plate interpretation.

Figure 2 : Schematic of an ANPR scheme performance



Source: Pickford (2006) and Q-Free (2013).

ANPR generally requires users to register with the system before driving on the toll road to create a payment account, or to pay per trip. Tolls can be pre-paid or post-paid.

Enforcement against late payers or non-payers may take two main forms: additional fees for late payment and high penalties for non-payment.

Furthermore, tolling authorities may implement advanced video technologies, such as vehicle "fingerprinting" which creates a "master" vehicle image database which holds clear and high-confidence images of those vehicles previously captured by the cameras. Lower quality images are subsequently matched to these images through an automated system, with additional manual checks in some cases (Virginia Department of Transportation, 2008).

Notwithstanding the above actions, some forms of evasion remain, primarily in relation to cloned or altered licence plates. (Virginia Department of Transportation, 2008). As mentioned above, the lack of harmonisation of licence plate designs and ANPR standards[2] at the international level may lead to leakage of revenues, especially for foreign toll evaders. In these cases, identification of foreign licence plates may not be achieved electronically, making manual verification necessary and resulting in higher operating costs. DSRC or GNSS charging technologies could complement video tolling to avoid manual checking, but they are not usually cost-effective approaches, as potential additional revenues from violators do not compensate for the high level of investment required.

[2] Unlike DSRC-based technology, CEN standards for manufacturing ANPR equipment have not yet been provided.

Box 1: Congestion charging in Stockholm

The Stockholm congestion charging scheme became operational in 2007 following 6 months of trials and a referendum on the issue. The primary objective of the system was to reduce congestion in the city and not merely to raise funds. The system is based on 18 control points or "Betalstations" on the roads entering the city centre.

Vehicles are registered and identified by ANPR at each access point. A vehicle passing through the access point is detected by a laser, triggering cameras which take pictures of the front and rear licence plates. The vehicle's registration number is identified through the use of OCR technology. The success of the system led the municipality to remove the microwave technology previously used.

The ETR407 highway in Toronto, Canada, is the main example of a system of this type outside an urban environment. It uses a video tolling system to charge users without a transponder (see the box below). Within Europe, Hungary and Romania have implemented the "Electronic Vignette" system based on ANPR technology. Countries such as Australia, Chile and South Africa are also considering video tolling as an alternative to the DSRC-based schemes in free-flow tolling (Kapsch, 2013).

Box 2: ANPR outside the urban environment: the ETR407

The Canadian ETR407 was the world's first open-access electronic toll highway when it opened to traffic in 1997. From the beginning, the EFC system in the ETR407 highway was a mixture of two different technologies: DSRC and video tolling. Users were allowed to choose whether to install a DSRC based transponder within the vehicle (mandatory for Heavy Good Vehicles) or to be identified through the ANPR system.

Only about 20% of transactions are captured through the OCR process. Evasion has been minimised through the use of "fingerprinting" technology which also allows for a reduction in the number of manual checks.

2.1.3 Accuracy & data protection

The most advanced cameras currently achieve an automatic read rate up to 99% when mounted on gantries over unidirectional carriageways. However, read rates can be lower. Thus, 98% is the minimum permissible reading service level at Dartford Crossing (Highways Agency, 2012); 97% in Stockholm (Q-free, 2013); or better than 90% in London (TfL, 2009). In order to improve the detection rate and read accuracy, some technical challenges have to be addressed:

- Reflective licence plates – not all are retro-reflective
- Dirty licence plates, particularly on the back of trucks
- Poor weather, including fog, rain and snow
- Licence plates of different types, fonts, and colours due to the lack of standardisation within and between countries
- Similarities between some letters and numbers on licence plates
- Insufficient control of ambient light at camera positions

These challenges make ANPR less than 100% reliable, making secondary OCR processes and manual checking of licence plates a necessity to correct those errors. Use of confidence measurements, vehicle classifiers, the "fingerprinting" method and post-processing of images can reduce the need for manual intervention. To ensure that no errors are made, however, it is usual practice that images of the offending vehicle are manually checked before issuing an enforcement notice – this can create a synergy with enforcement operations and reduce the extent to which manual checking has additional costs.

There is a data protection issue that drivers (and passengers) could be identified through this system. There are different requirements in Member States, so no single approach suits all. For example, in Germany the picture needs to capture who is driving, but in the Netherlands the driver may not be captured. In the UK the evidence requires the location around the vehicle also to be captured within an "overview image" for the evidence to be robust; this means that it is not feasible to reduce the image only to the area surrounding the licence plate. The key issue is inconsistency in standards and requirements between Member States. However, as cameras are always required for enforcement, it is impractical to ignore the role of ANPR within the ETC system or treat it separately.

2.1.4 Life cycle & evaluation of costs

Using video tolling as the main ETC system involves no in-vehicle devices and no additional gantries for enforcement. Furthermore, the system is mostly automated, with labour effort primarily depending on the extent of back office manual checking. Video tolling technology generally involves lower operational costs than other ETC systems, as less roadside equipment (RSE) is required. However, depending on central data registration quality, the need to keep the national vehicle and driver registration database up-to-date may increase operational costs. The lack of a 'pan-European' vehicle and driver registration database is probably one of the greatest barriers to using video tolling on a Europe-wide basis. Nevertheless, for Member States where there are only a few foreign vehicles, the business case for resolving this issue may not be significant.

According to Prud´homme et al. (2005), the initial investment for the congestion charging scheme in London was estimated at €115 million.[3] This investment was recovered very quickly as annual revenue is almost equal to the initial investment cost (net revenue was €100 million in 2009/2010). In Stockholm, initial investment costs (€380 million) were recovered after the first few years of operation, with annual revenues estimated at about €96 million (Pardo, 2007). The Canadian ETR407 highway, in 2012, had total toll revenues of €1 billion[4] compared to annual operating costs of €170 million.

2.1.5 Interoperability & adaptability to EETS

The ETR407 shows that video tolling is easily interoperable with other electronic tolling technologies when all the tolling operations are managed by a single entity. However, the lack of licence plate standardisation, and the challenges for Member State cooperation involved in establishing an international licence plate database, make video tolling a more difficult means of achieving international interoperability. In contrast, other existing technologies such as DSRC have CEN standards available which makes interoperability easier to achieve.

3 €1= £0.68
4 €1 = $1.36

Moreover, adaptability to EETS may not be possible, since ETC systems based on ANPR technology are currently outside the scope of Directive 2004/52/EC, which identifies only the systems set out in Chapter 1 above. However, in the interurban context, video tolling is recommended as the best technology for enforcement purposes due to its proven effectiveness worldwide. Additionally, ANPR is generally only used as an ETC technology in urban pricing schemes.

2.1.6 SWOT analysis

Video tolling is a mature and highly automated technology. Its operation does not require in-vehicle devices or costly gantries, allowing for lower sunk investment costs when compared to other technologies. Due to the advanced development of camera technology, video tolling is not limited to operating at certain speeds. Furthermore, technological developments have allowed for a greater volume of traffic to be monitored simultaneously. For this reason, ANPR is a tolling technology working well in urban environments, specifically in "area" or "cordon pricing"[5] schemes, such as in London, Stockholm or Milan. It is especially suited to controlling toll areas where the tolling authority only needs to detect movement within an area or at entry/exit points. Distance-based charging can only be done between defined points, for example on expressways, similarly to a DSRC/tag scheme. As the technology is able to perform vehicle detection and enforcement at the same time, ANPR does not need the two separate functions required by other ETC systems.

However, this technology has significant limitations and it has not been proposed by Directive 2004/52/EC for EETS. There are no current standards regarding evidence requirements, privacy impacts or licence plate design across Member States. Video tolling technology is suitable when access to an area or zone needs to be charged, as in the case for the congestion charging systems in London or Stockholm. It can also be deployed on expressways. In both cases the key limitation relates to having access to vehicle registration data for charging or enforcement. ANPR can also complement other ETC technologies for interurban tolling, for enforcement purposes, subject to the costs involved.

[5] Cordon pricing is a road charging system in which vehicles entering a defined geographic area, typically a city centre, are assigned a fee (SFCTA, 2014). The fee can vary to best manage traffic flow, especially in peak travel hours, but is generally set at a flat rate.

Table 1 : SWOT analysis of the ANPR tolling technology

STRENGTHS	WEAKNESSES
• Mature technology in congestion charging and expressway tolling schemes	• Requires good quality licence plates
• No need for in-vehicle device or costly enforcement infrastructure	• Susceptible to poor lighting and adverse weather conditions • Access to up-to-date vehicle data needed by operators – local scheme registration or national vehicle database
• Can deliver cost savings for automatic handling processing, subject to fine tuning and secondary processing methods used	• Cost of manual checking can increase operational costs
• Most successful when combined with other technologies, subject to the additional costs of the other technologies	• Requires careful tuning and camera site setup to deliver high quality performance – other electronic systems typically need less tuning
• The system can be implemented gradually. • Early generation of revenues • No performance restrictions regarding vehicle speeds	• Suitable for supporting relatively simple charging policies
OPPORTUNITIES	**THREATS**
• Continuous improvements in video camera quality	• Lack of standardisation of evidence requirements and privacy laws in Member States
• Greater volumes of traffic supported, as technology develops	• Technology not proposed by Directive 2004/52/EC for EETS. • Lack of standardisation of licence plates
• Always required for enforcement	• Manual verification needed for full effectiveness subject to level of "tuning"

Source: Authors' analysis.

2.2. Dedicated short-range communication (DSRC)

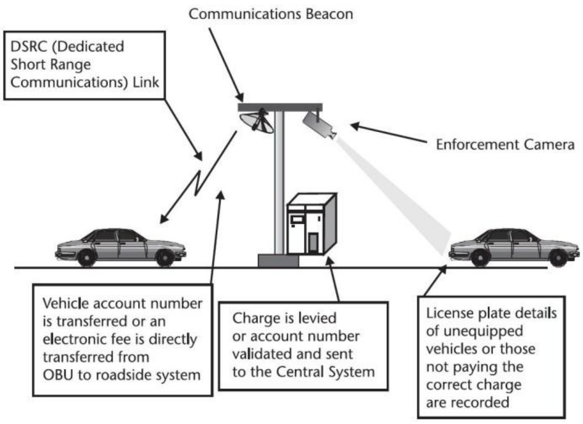
Dedicated short-range communications (DSRC) technology is based on bidirectional radio communication between fixed roadside equipment (RSE) and a mobile device (OBU) installed within a vehicle. It has been the most common approach to implementing electronic toll collection on toll roads since late 1980s. Today, DSRC is the most widely-used ETC system worldwide, and can therefore be considered a proven and mature technology. Its applications have been extended to urban area and cordon schemes and, more recently, to nationwide heavy goods vehicle tolling. Like ANPR, however, it cannot measure distance travelled, except between two points on an expressway.

2.2.1 Performance & enforcement

DSRC technology consists of the microwave transmission of data between an in-vehicle device and roadside tolling infrastructure, mainly comprising DSRC gantries installed along the tolled road (see figure 3). It is typically used as the primary method for tolling the crossing of specific points, such as a toll plaza or a location on an open road. DSRC enables wireless communication between RSE and the OBU in a range of around 20 metres, making possible two different practical applications: dedicated lanes (with/without barriers) and free-flow tolling approaches.

The On-Board Unit uses microwave technology (DSRC 5.8 GHz) to trigger raising the barrier and levying the tolls electronically. The device is associated with a registered user's tolling account which can then be used to charge the user either pre-pay or post-pay. The OBU can also store some vehicle-specific data, including licence plate details and vehicle category, which can be used to calculate the toll to be paid. However, the cost of programming such data into the OBU can increase the cost of operation and make changing vehicles more complex. The advent of the EN15509[6] standard meant that DSRC could be made more interoperable. DSRC can also be used at relatively high speeds but has more speed-related limitations than ANPR.

Figure 3 : Examples of DSRC tolling technology



Source: Pickford (2006) and Czako (2004).

The RSE includes tolling gantries over the carriageways with DSRC antennae to enable wireless communication with the OBU. Additionally, vehicle classification sensors can be used to aid vehicle categorisation where, for example, trailers or multiple axle vehicles are involved. When the vehicle drives under the gantry, the OBU is detected by the antenna and its identification code is read and checked. Once the vehicle is identified, the charge is applied to the account and sent to the Central Data System which processes the transaction. RSE is often complemented by cameras which check that the licence plate of the vehicle is consistent with the DSRC OBU for the vehicle and register potential toll evaders and unequipped vehicles.

Two different tolling approaches exist: open tolling and close tolling. In the open scheme, several tolling points are installed throughout the road network, so that the vehicle is detected each time it crosses these points. In a closed scheme, the user is registered when entering in the tolled area, and only needs to pay once, when leaving the tolled network. The distance travelled, and hence the toll, is calculated from the entry and exit points used. As with ANPR, the ETC system must properly register where the vehicle enters and leaves the system.

[6] CEN standard 15509 provides a basis for industry to manufacture interoperable solutions for DSRC-enabled road charging systems. It comprises a coherent set of requirements that may serve as a common technical platform for EFC interoperability.

The tolling process using DSRC technology can be fully automated as read accuracy for an OBU typically exceeds 99.999%. The only failures occur if the OBU is misplaced or if its battery expires. This generally provides a reliable means of detecting and charging a vehicle each time it passes under a tolling gantry. The driver is informed that the toll transaction has been carried out through a "beep" emitted by the OBU when passing under the gantry.

DSRC can be used either in toll plazas or in multi-lane free flow schemes. As with other ETC systems, DSRC needs to be complemented with other technologies to establish the classification of the vehicles passing through the tolling points. This is required to check that the vehicle data recorded in the OBU (determining the amount of the toll to be paid) has been properly declared. Enforcement can be strengthened by combining vehicle classification with images captured by cameras to identify toll evaders.

2.2.1.1 DSRC in toll plazas

Toll roads have traditionally collected charges from users through manual payment with physical barriers. As an evolution, DSRC-based systems have been introduced to pay for the use of a tolled road without needing staff to collect the tolls. Before using the ETC service, a contract is established between the Toll Operator and the owner of the vehicle, so that a non-cash means of payment (usually through a bank account or credit card) is agreed. When the vehicle approaches the toll plaza, an electronic reader receives the information from the OBU and the toll barrier (if one exists) is automatically raised. This configuration does not constitute free-flow tolling, since vehicles are often required to reduce their speed and, consequently, traffic may be affected. For this reason, despite being usual in high-capacity metropolitan ring roads, toll plazas approaches are rarely used in urban pricing schemes, where open road tolling with DSRC or ANPR technology is more widely used.

Numerous toll roads have implemented DSRC technology in toll plazas. They are mainly seen in southern European countries such as Italy (Telepass), Spain (Via-T), Portugal (Via Verde) and Greece (e-Pass). DSRC in toll plazas is also used in other European countries such as France (Liber-t), Slovenia (ABC) and Scandinavia (Easy-GO), as well as non-European ones such as Argentina (Autopista del Sol), Mexico (Red Nacional Concesionada) or Chile (Red Nacional de Autopistas Interurbanas).

Private concessions in many European countries apply DRSC in toll plazas with physical barriers (see figure 4). This ETC technology is generally applied at a frequency of 5.8GHz, in accordance with CEN DSRC standards. This is for instance the case in France, Greece or Spain, which applies the so-called VIA-T approach.

VIA-T is a fully interoperable ETC system, available for any kind of vehicle, and valid for all the Spanish tolled facilities (including some car parks) since 2003. Users can cross the tolled point through mixed or reserved VIA-T lanes, where electronic systems located on the toll plaza detect the on-board unit and raise the barrier automatically if the transaction is successful. The maximum permitted speed at the automatic toll barrier is 40 km/h. At higher speeds, there is the risk that the barrier will not lift in time.

Figure 4 : DSRC in toll plazas

Source: de la Fuente (2008) and Traffic infratech (2013).

DSRC technologies can also be operated in toll plazas without installing physical barriers, as is the case in Portugal. In contrast to the common European DSRC standards, Italy deployed a differing approach to DSRC (TELEPASS) based upon UNI-10607[7] specifications. Initially, the TELEPASS technology did not comply with the European spectral standards. The Italian specifications were later updated and currently mirror the communication architecture of the European standards for ETC and DSRC. TELEPASS is based on 5.8 GHz beacons and an OBU.

As vehicles are not always required to stop in the plaza when using DSRC technology, enforcement equipment, such as physical barriers and/or ANPR technology, are installed to avoid toll evasion. Toll plazas with and without barriers typically use ANPR to identify vehicles. ANPR or similar systems able to record licence plates are also recommended in toll plazas with physical barriers. Legislation in some countries does not allow Toll Operators to carry out enforcement directly, as it can only be done by the relevant public authorities – for this reason most private operators typically retain toll barriers, as even with video evidence they may not be able to recover the toll or penalty from a non-payer.

The e-Pass system on the Attica Tollway (Greece) is an example of both barrier and ANPR enforcement systems. It uses DSRC technology in toll plazas equipped with lifting barriers. Although these are the main enforcement tools, a Violation Enforcement System (VES) is also used to reduce evasions in e-Pass lanes. The VES records the licence plate of the evader and determines whether the vehicle is correctly registered. In addition, uniformed Toll Staff complement enforcement duties by randomly checking licence plates. As a result, evasion rates have fallen significantly to around 0.16% of ETC traffic (Thibaut et al., 2009).

2.2.1.2 DSRC in multi-lane free flow (MLFF) tolling

DSRC in toll plazas does not require a vehicle to stop to pay the toll but, primarily for safety reasons, it does require the driver to reduce speed or to pick a specified lane. Multi-lane free flow technology overcomes this restriction as the traffic flow is not affected by toll plaza infrastructure. As illustrated in table 2, free-flow technology can greatly improve vehicle flow and effective road capacity and reduce congestion on toll roads with high traffic volumes.

[7] Public standard available in 1996 from the Italian National Standardisation Agency (UNI), adopted to establish the Italian Telepass ETC system. UNI-10607 infringes the European frequency band requirements. It was flanked afterwards through the European Regulation ETSI ES 200674-1, but needed updating to reflect the Radio and Telecommunications Terminal Equipment (R&TTE) Directive.

Table 2 : Road capacity depending on the DSRC technology applied

Source	Road capacity (Vehicles/hour per lane)		
	ETC with barriers	ETC without barriers	Multilane free-flow
Villalonga (2010)	650-750 vehicles/hour per lane	1,200 vehicles/hour per lane	n.a.
Dancso (2008)	500-600 vehicles/hour per lane	1,000 vehicles/hour per lane	3,000 vehicles/hour per lane

Source: Villalonga (2010) and Dancso (2008).

DSRC technology in MLFF is capable of locating single OBUs, without limiting communication to a single vehicle within a tolled lane. The communication between the OBU and DSRC antennae installed on gantries is carried out while the vehicle moves freely. The information received by the RSE is then stored and transmitted to the Central System, where the toll is levied on the user.

For distance-based schemes, the road network is divided into sections defined by entry and exit points. A tolling gantry is installed within each road section, so that the toll for each section is collected separately for each tolling point. The Central System is able to identify which gantries have been crossed by each vehicle and charge each section of road to the driver’s account or remaining balance.

Many interurban toll highways worldwide use this ETC technology: ETR407 (Canada), Highway 6 (Israel), Northern Gateway Toll Road (New Zealand) and the national toll system in Japan. It is also widely used in Europe, and currently in use for the nationwide truck tolling approaches in Austria, the Czech Republic and Poland, as well as in the Portuguese SCUT roads.

Free-flow DSRC technology has also been successfully implemented in city centres. For example, Singapore represents a pioneer case of congestion charging that uses dedicated short-range communication. Its Electronic Road Pricing (ERP) scheme was implemented to alleviate daily congestion when entering the city centre. The ETC system uses OBUs provided with smart cards to store all transactions. Toll gantries are equipped with the following facilities: microwave antennae; optical sensors to detect the passage of vehicles; and cameras to cover the road section and to photograph toll evaders. As the charging scheme was implemented to manage road demand, charges are adjusted with traffic conditions. The Melbourne CityLink, in Australia, was the first case of implementing a DSRC system in a metropolitan area. Other examples of DSRC free-flow approaches in tolled ring roads can be found in Ireland (M50 Motorway Ring) and South Africa (Gauteng Open Road Tolling), as well as the Urban Concessions in Santiago, Chile (which follows a different approach).

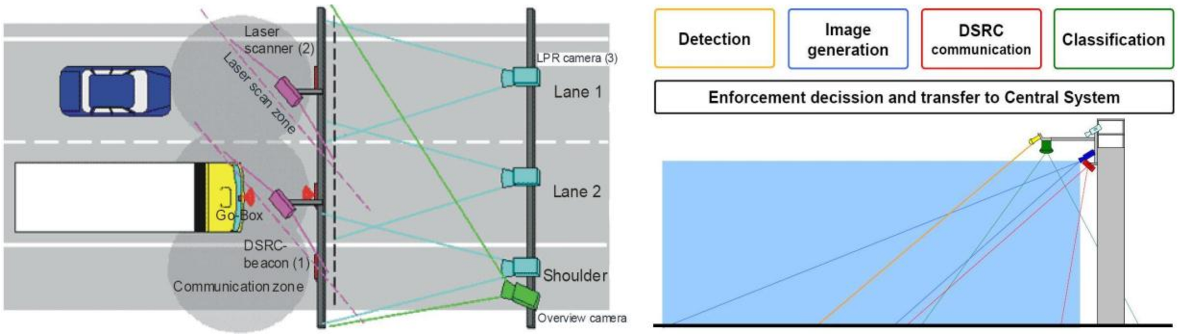
Initially, MLFF technology could only operate with low vehicle speeds and very limited exchange of data between the OBU and the RSE. After more than 20 years of continuous development, vehicle speeds up to 180 km/h and integration with high-performance camera enforcement systems is now considered the norm.

Depending on scheme rules, road users may choose between pre-payment and post-payment. With pre-payment – typically used by occasional users – the OBU is charged by cash or by credit card, and then the toll is deducted from the balance by the ETC system.

With post-payment – more convenient for frequent users – a contract is entered into with the Toll Operator and a detailed invoice is issued, typically on a monthly basis, linked to a bank account or credit card payment means.

Toll enforcement represents one of the most important parts of an open road electronic toll system to guarantee revenues. Toll evasion is generally controlled through enforcement gantries equipped with Automatic Number Plate Recognition (ANPR), as shown in figure 5, and following the general approach set out in the section on ANPR. Some toll roads also use portable control facilities and mobile control units to improve enforcement further (Box 3).

Figure 5 : Functioning of enforcement gantries in a DSRC tolling approach



Source: Cerny (2008).

Box 3 : Enforcement in the Czech Republic and Austria

According to Dancso (2008), an appropriate level of enforcement is achieved through: fixed control facilities, portable enforcement installations and mobile control equipment. The tolling systems in the Czech Republic and Austria represent two different ways of achieving these appropriate levels of enforcement.

In the Czech Republic, existing tolling infrastructure is also used for enforcement. In Austria, more than 100 stationary enforcement gantries equipped with ANPR are located at strategically important points with high traffic volumes. Both countries have implemented mobile enforcement, managed by toll officers/police forces that patrol the road network, provided with OBU mobile readers.

In the case of Austria, the mobile and stationary enforcement are closely interconnected. Toll officers receive data from the central system and are informed of vehicles which have not paid their toll correctly and therefore need to be stopped.

The German DSRC system

DSRC technology for enforcement is usually based on 5.8 GHz CEN standards. Nevertheless, the German scheme can be considered a special case since it uses Infrared (IR) DSRC technology based on ISO CALM[8] standards. IR DSRC provides similar functionality to 5.8 GHZ standards, but instead of microwave signals uses infrared light as a means of communication (FELA, 2014). IR DSRC presents some advantages over 5.8 GHz

[8] Wireless communication protocols and air interfaces for a variety of communication scenarios and methods of transmissions regarding Communications Access for Land Mobiles (CALM).

DSRC, such as higher data rates and vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) support. However, the cost of IR DSRC integration into the OBU is still much higher than the alternative option.

2.2.2 Accuracy & data protection

DSRC systems are based on simple technology and have been widely used to collect tolls electronically worldwide. Their high performance and reliability, including in extreme weather conditions, is appreciated by toll authorities and private concessionaires as a means to secure revenues. Successful transactions tend towards 100%, as observed in Austria (99.9%), the Czech Republic (99.7%), Poland (99.9%) and Santiago (99.5%).

DSRC systems are not significantly affected by privacy/data protection issues, as the location of the vehicle is only known when crossing a tolling gantry. Therefore, microwave technology does not provide the position of the vehicle in real time. However, the system requires the user to add personal data to the OBU (only when it is not done by the back office) to ensure compliance with local laws on data protection. For example, Austria has developed its DSRC toll systems in compliance with its Data Protection Acts as they were in place before the system was introduced. In the Attica Tollway (Greece), the Personal Data Protection Authority gave private concessionaires the authority to retain records (video and pictures) of toll violation events for 3 months, and up to 5 years if needed for legal purposes.

2.2.3 Life cycle & evaluation of costs

DSRC systems generally use inexpensive OBUs (circa €5 to €10), in comparison with GNSS based systems (where the OBU can cost €100 or more), with an average lifespan of 5 to 10 years. The cost of the viaBOX device in Poland is around €30 (RDW, 2012) and it is expected to have an operational life of 5 years on average before needing replacement, primarily related to battery life. Similar lifespans are observed for the Chilean OBUs and the Austrian GO-Box.

In contrast, DSRC technology requires the installation of costly RSE for both tolling and enforcement purposes. This is especially critical in free-flow approaches, since a significant number of tolling points need to be installed. Initial investment and operation costs can vary significantly, depending on the length of the tolled network. For example, the investment cost in Austria was €750 M for a tolled network of around 2,000 kilometres, while revenues currently amount to about €1,000 M (more detail is included in Table 3). Lower figures are observed for the nationwide heavy goods vehicle tolling scheme in the Czech Republic: length (1,200 kilometres), investment (€900 M), and yearly revenues (€245 M). The implementation of the 160 kilometre urban concessions network in Chile required an initial investment of $2,150 M (Sánchez, 2007).

Table 3 : Key data on the Austrian truck-tolling scheme

ITEMS	Source
• INITIAL INVESTMENT (2004)	€750 M
Tolled length (kilometres)	2,180
OBUs initially distributed (2005)	533,000
Initial revenues collected (2005)	€780 M
• Operating costs per year (2008)	€90 M
• Total collection costs (2011)	10-11% revenue
• OBUs in operation (2008)	900,000
• Toll segments in operation (2013)	800
• Enforcement gantries (2013)	Around 100
• OBU unit charge for the user (2013) when signing up for an account	€5/unit
• Collected revenue (2010)	Around €1,000 M

Source: Authors' analysis from several reports.

The profitability of the tolling system can also vary substantially. Collection costs are between 7% and 12% of revenue in Austria, but up to 40% of revenue in the Czech Republic (Wondracek, 2012). In contrast, the initial investment of the Polish system was repaid in full in just 18 months. These differences are due to investment costs, which are highly dependent on the length of the tolled network and the traffic volume. DSRC-based systems require high capital expenditures on roadside tolling gantries, while the unit cost of the OBUs is low. Therefore, DSRC technology is especially profitable when the tolling scheme is used by many vehicles and few road segments need to be covered (Q-Free, 2013). In contrast, it is difficult to modify the tolled network without high capital expenditure.

2.2.4 Interoperability & adaptability to EETS

Except for some specific cases (TELEPASS in Italy and Via Verde in Portugal), interoperability within national borders was until recently not a key issue. In Spain, an agreement between private operators in 2003 established the VIA-T service that enabled interoperability over the tolled network. In France, interoperability at a national level for heavy vehicle traffic (TIS-PL) was not achieved until 2007. The creation of the GRITS system in Greece is one of the most recent steps taken in Europe towards the implementation of fully nationally interoperable systems.

Despite limited improvements to date in this field, interoperability between different Member States will soon be made possible by common technical standards for DSRC-based systems. Currently, a significant percentage of tolling facilities throughout Europe follow the same DSRC standards (EN15509). This has enabled the establishment of transnational interoperability agreements in recent years as a result of pilot projects in cross-border areas (see Box 4). However, a more integrated approach is needed to ensure interoperability across the EU.

Box 4 : Transnational interoperability within the EU

Spain has emerged as one of the Member States most active in seeking to achieve DSRC interoperability with neighbouring countries. The adoption of common DSRC standards allows Spanish OBUs to be used on the French A-63 and A-64 toll roads. French OBUs also work in the Spanish Basque region. A recent agreement (2013) with Portugal has extended the reach of Spanish OBUs to the entire Portuguese toll road network. Furthermore, interoperability between the Spanish and Italian DSRC is available when using the TELEPASS OBU.

Another example is the EasyGo system, implemented in Scandinavia in 2007. The service allows users to pay (through their OBUs) for the tolled facilities in Norway, Sweden and Denmark, as well as ferries between Denmark and Germany. More recently, the Austrian national tolling system for trucks has been included in the system, leading to the creation of the EasyGo+ system.

DSRC Systems offering transnational interoperability are limited to these examples. However, this technology has been identified by the European Commission as one of the most suitable for EETS. It may be feasible to treat Member States that have adopted CEN DSRC as part of a Regional EETS community (see Chapter 4).

It should also be noted that DSRC two-way interoperability[9] with other tolling technologies has still not been achieved, though the RCI project[10] sought to demonstrate how interoperability could be delivered through a single payment account (RCI Final Report 2008).

2.3.1 SWOT analysis

DSRC systems have a number of advantages, including that they are based on a well-known and simple technology, with great reliability, and not significantly affected by privacy/data protection issues. For these reasons, DSRC is one of the ETC technologies proposed by Directive 2004/52/EC for EETS.

Other advantages include that both tolling infrastructure and OBUs may be shared with other applications and provide new added-value services. Furthermore, DSRC technology enables greater liberalisation regarding OBU providers and an early generation of revenues, since the system can be installed gradually. Further integration of European DRSC systems is feasible through the existence of common CEN standards. It is also important to consider that more than 10 million of OBUs are already in operation in Europe, so the cost of changes these units would be significant.

[9] Only one-direction interoperability has as yet been achieved. That happens when an OBU initially created for one national ETC system can be used to pay charges electronically in a second country, but the unit in the second country cannot be used to pay charges in the first country.

[10] The RCI (Road Charging Interoperability) project was launched by the European Commission. It aimed to make it possible to carry out any road charging transaction in Europe with a single, in-vehicle piece of equipment.

In contrast, the system requires the installation of costly roadside fixed infrastructure (gantries) for both tolling and enforcement purposes. This greatly limits its flexibility to modify the tolled network and makes it profitable only on roads with high traffic levels. Additionally, significant capital investment is needed to cover the road network correctly, especially when it has many entrances and exits.

DSRC technology presents several threats in relation to the implementation of EETS. Two-sided interoperability with other ETC technologies has still not been achieved due to DSRC OBU limitations. Additional material threats to further development are different enforcement laws across Member States and the fact that in some cases DSRC transactions are not accepted as evidence.

Table 4 : SWOT analysis of the DSRC tolling technology

<table>
<tr><th>STRENGTHS</th><th>WEAKNESSES</th></tr>
<tr><td>• Widely adopted, simple and tested technology</td><td>• Necessity to install road-side infrastructure (gantries) along the road</td></tr>
<tr><td>• Technology proposed for EETS by Directive 2004/52/EC</td><td rowspan="2">• High capital expenditure and maintenance cost of tolling infrastructure</td></tr>
<tr><td>• High reliability & performance, low signal interference</td></tr>
<tr><td>• Inexpensive OBUs and low operation costs (compared to GNSS)</td><td>• Difficult to modify the tolled network once implemented</td></tr>
<tr><td>• Large number of DSRC OBUs currently in operation</td><td>• Costly for roads with many intersections</td></tr>
<tr><td>• CEN standards available</td><td rowspan="2">• Monitoring gantries take up land and it is difficult to find space in non-motorway environments</td></tr>
<tr><td>• Available for subterranean facilities (parking and tunnels)</td></tr>
<tr><th>OPPORTUNITIES</th><th>THREATS</th></tr>
<tr><td>• Ability to provide/support other value-added services through the OBU</td><td>• The creation of a centralised tolling system may be politically and economically unviable</td></tr>
<tr><td>• Easier interoperability with existing private concession toll roads</td><td>• Coordination issues as electronic transactions may not be considered evidence in some Member States</td></tr>
<tr><td>• Closer control of the tolling system and revenues by Member States</td><td>• Less profitable in low traffic volume roads</td></tr>
</table>

Source: Authors' analysis.

2.3 Radio-frequency (RFID)

The term "Radio Frequency Identification" (RFID) refers to those technologies that use radio waves to identify devices automatically. In recent decades, RFID has been used mainly for Electronic Toll Collection in the United States (US). As shown below, the performance and characteristics of RFID are, at least in practice, very similar to those of DSRC technology, as both are microwave-based approaches. As a result, the analysis in this section is brief.

2.3.2 Performance & enforcement

Toll collection on US roads is carried out with RFID technology at Ultra High Frequency (860-960 MHz). The RFID-based tolling system consists of an OBU or "tag" installed in the vehicle, a reader/writer antenna on a gantry or toll plaza over the carriageways, and a central computer system. The performance of the RFID-based system is similar to DSRC-based schemes (DSRC systems can be considered as a subset of RFID technology). As a vehicle approaches a toll plaza or a tolling gantry, the radio-frequency (RF) field emitted from the antenna activates the transponder. It subsequently transmits a signal back to the antenna with information about the passing vehicle. The information is sent to the central database, where the user's information is checked for confirmation and the charge is calculated and levied.

The enforcement equipment for RFID-based systems also uses cameras with ANPR technology, located on control gantries or at toll plazas, to identify violators. The cameras are usually equipped with laser or automatic triggers to aid the identification of evaders (in the past, trigger loops to detect evaders were installed under the road surface, but this is now being phased out as the maintenance cost is too high and requires the closure of the lane). RFID has been primarily used for barrier-based systems. Only recently has the advent of more accurate RFID detection technology (Sirit ISO 18000 6C tag) allowed open road tolling (ORT) with RFID.

In a RFID-based system, the tag is the main component just as the OBU is in DSRC technology. The tag is a microchip containing memory and logic circuits to receive and send data to the reader. Tags may be either active or passive, which have different reading ranges. Active tags require an internal power source, i.e. a battery in the transponder that allows a longer reading range (~100 metres) than passive tags. Passive tags or "stickers" are affixed to the vehicle windscreen and require no internal power source. This makes them less expensive and complex than active tags but offers only a shorter reading range (~10 metres) (Fundación CETMO, 2012).

2.3.3 Accuracy & Data protection

The antenna transmits and receives data from the tag and contains a decoder and an RF module. Since no "line of sight" contact is required, antennas are able to read multiple tags simultaneously (Kathawala et al., 2008). The data is then transmitted to the central system.

Once the central system receives the information from the antenna, the user's account is verified. If a transaction is possible, the toll is deducted and, in the case of toll booths, the barrier (where present) rises. A green light is generally also shown so that the driver can proceed. If the information does not match that declared, or the vehicle is not equipped with a tag, the enforcement system takes a photo of the vehicle and its licence plate.

RFID technology is used either in specific lanes at a toll plaza, where for safety reasons vehicles must slow to a maximum of 5-15 mph (8-24 km/h), or in ORT lanes (usually called "express lanes") with no need to slow down. In some cases, toll plazas mix both ORT lanes and cash toll booths lane (see figure 6).

Figure 6 : RFID approaches: I-Pass mixed ORT/Cash toll plazas (Illinois) and E-ZPass specific lanes in toll booths

Source: Courtesy of OMEGA website and MTA of New York.

RFID can be less accurate than DSRC, but the performance of the new 6C tag is becoming comparable with DSRC (>99%). Failure rates in RFID technology can be higher than DSRC when operating in ORT lanes (see Table 5).

Table 5 : Comparison of DSRC & RFID technologies

TECHNOLOGY	FREQUENCY RANGE	READ RATE	WEATHER	TAG PRICE (AVERAGE)
DSRC	Microwave (2,45-5,9 GHz)	>99%	Not sensitive	Medium (10€)
RFID	UHF (868-956 MHz)	>99%	Not sensitive	Low (1€)

Source: Authors' analysis based on several reports.

Many examples of RFID-based approaches exist in the United States. The most relevant RFID-based tolled networks in the country are: E-ZPass (operating in 14 states), Sun-Pass (Florida), FasTrak (California) and TxTag (Texas).

Only a limited number of these systems exist outside the United States. One is the Salik toll collection system in Dubai, launched in 2007, which is a free flow system with passive tags and the latest RFID technology.

2.3.4 Life cycle & cost evaluation

The costs of RSE for RFID systems are very similar to those of DSRC. The main cost difference lies in the cost of the tag which is often significantly lower than that of a DSRC OBU.

2.3.5 Interoperability & adaptability to EETS

A distinction should be made between technological and geographical interoperability. On the one hand, partial technological interoperability has been achieved, as many RFID-based systems within the US operate, at least in part, in combination with ANPR technology. As an example, in the SunPass network, the option "Toll-by-Plate" has been introduced on the HEFT (Homestead Extension of Florida's Turnpike) from Florida City to Miramar in Miami-Dade County. On this section, RFID and ANPR work in parallel, allowing users to choose whether to be charged through the SunPass tag or through the use of licence plate recognition. On the other hand, geographical interoperability has been achieved at a regional/state level but has not yet been addressed at the national level.

Box 5 : RFID INTEROPERABILITY IN THE UNITED STATES

Regional interoperability in the US has been achieved within individual states, as well as between neighbouring states, as is the case with the E-ZPass network.

The E-ZPass network operates in 14 states and comprises a total of 24 toll agencies in the E-ZPass Interagency Group (IAG). IAG processes most of the toll transactions in the US and E-ZPass has become the world leader in toll interoperability, with more than 21 million E-ZPass devices in circulation (Lawson, 2012). The states of Florida, Texas and California have also achieved interoperability within their respective regions.

The current challenge is the creation of a nationwide interoperable system. According to Stone (2013), the system should take advantage of the existing investment in roadside equipment, vehicle and back office technologies and infrastructure. For this to work, a number of technical and institutional barriers need to be overcome. These include multiple brands (more than 100 North American toll agencies), lack of common technical standards, scarcity of funds and the absence of a national system. A significant step in the right direction was made in August 2013, when SunPass and NC-Quick Pass achieved interoperability between their systems, and now drivers can travel on toll roads in North Carolina and Florida using a single prepaid electronic transponder.

No RFID-based systems exists in Europe, but they will be introduced in 2014 on the Mersey Gateway Bridge and the Mersey Tunnels in the UK, and are considered an improvement on the DSRC systems currently in operation at these locations, because of the substantial cost savings for the tags and readers while ensuring comparable performance with DSRC based systems.

Despite this, RFID technology has not yet been implemented in Europe. Its adoption would result in high investment costs and would force the replacement of existing technologies. Additionally, DSRC technology implemented in Europe has benefits over RFID and is a more mature and well-known ETC system. There is no apparent opportunity for RFID in Europe.

2.4 Satellite positioning (GNSS)

Increasingly accurate and reliable satellite positioning systems have enabled the applicability of General Navigation Satellite Systems (GNSS) technology for toll collection purposes. Currently Germany (2005) and Slovakia (2010) use electronic toll systems based on GNSS technology and, in future, this technology will also be extended to Russia (currently planning a truck tolling scheme) and Belgium (where the VIAPass truck tolling system is planned to go live in 2016). The planned French Ecotaxe truck tolling scheme also uses GNSS, but its go-live date (due in 2013) has been put on hold for political reasons. In the US, the state of Oregon has also piloted GNSS based distance charging, and in 2012-13 Singapore conducted GNSS trials seeking a next step technology for the ERP scheme. In practice there are few examples of operational GNSS-based charging schemes worldwide. In the EU there are only 2 schemes in operation and 2 schemes pending.

2.4.1 Performance & enforcement

Satellite-based or GNSS electronic tolling systems involve the vehicle’s position data being used to measure the use of the road in order to calculate the charge. GNSS systems determine the vehicle´s position from a network of orbiting satellites, currently through the use of the US GPS, and in the future also through the Russian GLONASS system and the EU’s planned Galileo system.

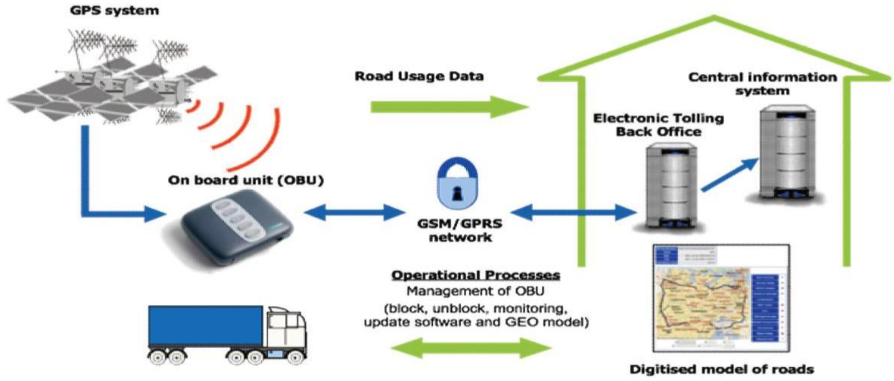
This technology requires the use of three different components: a GNSS OBU, mobile data communications equipment, and a back office (see table 6). To limit toll evasion, the system is complemented with enforcement equipment typically using ANPR and DSRC technologies. The satellite-based OBU is typically equipped with DSRC to enable interrogation on status by roadside equipment and by mobile inspection units (VIAPass 2012, LKW Maut 2005).

Table 6 : GNSS technology components

GNSS TECHNOLOGY COMPONENTS	
Satellite (GPS/GLONASS/GALILEO)	GNSS and DSRC (for enforcement purposes) receivers
Mobile data communication equipment (GSM/GPRS)	On- board unit (OBU)
Back office	Enforcement equipment

A bidirectional communication (CN/Cellular Network) is established between the OBU and a fixed telecommunications network, usually through the use of commercial cellular services such as the GSM mobile telephone network. This allows the OBU to connect to a Central Processing Centre or back office, where vehicle information is received and processed.

Figure 7 : Schematic use of GNSS systems



Source: Slovak National Highway Company (2010).

The satellite-based OBU is a complex device and has a relatively high unit cost compared with a DSRC OBU. The OBU records the vehicle's movements by downloading satellite time-stamped location coordinates, typically each second, and associating them with road sections which are typically a minimum of 90 metres in length. The OBU integrates several components: a GNSS module for localisation purposes; a GSM module for securing GPRS data communication from the OBU to the back office and vice versa; and finally a microwave module (DSRC transceiver) to communicate with fixed and mobile enforcement points as well as for interoperability. The back office handles customer and administration-related data, such as payment information and personal data of the user.

GNSS-based technology requires the creation, maintenance and continuous updating of a digital map of the chargeable road sections or areas. This map allows the system to accurately determine the position of a vehicle for charging purposes. The charging system can, in theory, be applied to any road without the need for costly RSE (gantries). In practice however, gantries are needed for the enforcement cameras and most schemes allow vehicles without OBUs to pass through, relying on ANPR detection along a pre-determined route. Unlike DSRC technology, it offers the possibility of charging without setting up any tolling plazas, extra lanes or speed restrictions. Only predefined sections or points on the tolled road network, called "virtual charging points", need to be identified. These virtual charging points are included in the digital map and replace tolling gantries used in DSRC approaches. Charging parameters or any feature of the tolled network can easily be modified by simply redefining the "virtual charging points". That provides the ability to adapt quickly and easily to changes in road or vehicle type, emission classes, or enlargement of the tolled network (see Box 6). These features result in a great flexibility for GNSS technology to define what is to be tolled and how it is to be tolled.

A transaction is generated when the vehicle passes through the virtual charging points and is automatically recorded on the OBU. The GSM network then transfers the charging data to the Central System where the invoice is generated. Additional GPS beacons and repeaters may need to be installed at points where the GPS signal is low or in locations which cannot be charged by GPS, such as tunnels.

The electronic tolling equipment and infrastructure can also provide other tracking-based functions and value-added services such as navigation, emergency response services, fleet and vehicle engine management systems and pay-as-you-drive insurance. Tolls can either be paid in advance (cash or credit card payments), or by post-payment such as using a fuel card or bank account.

Box 6: GNSS PERFORMANCE IN THE SLOVAKIAN TOLLED NETWORK

On the 1st January 2010, the Slovak Republic introduced a GNSS-based free flow tolling system on all motorways and some national roads, with a total of 2,400 kilometres of network tolled. All commercial vehicles weighing more than 3.5 tonnes must pay the toll. GNSS technology was chosen because of its advantages in charging in a dense road network, maximising toll revenue collection from lower category roads and because of its short implementation time (11 months) compared to other alternative technologies.

Given the success of the system in its initial years, the Ministry of Transport has decided to enlarge the tolled network in 2014 extending it by an additional 15,000 kilometres, including first, second and third category roads, making it the largest such network within the EU. This extension is expected to be implemented within one month, which would represent an implementation record.

GNSS-based enforcement is similar to the DSRC-based approach. Enforcement equipment is necessary to detect non-compliance, prevent violations and assure revenue recovery. The GNSS-based tolling systems usually consist of fixed stations, portable stations and mobile enforcement.

Fixed enforcement stations consist of control gantries provided with DSRC and/or ANPR technologies. They are established at different points along the tolled network, especially in sections with high traffic volume. DSRC allows wireless communication with OBUs to determine if they are correctly installed and operating. When crossing the enforcement gantry, vehicles are scanned to determine their main characteristics (including weight, number of axles, etc.).

Finally, as mentioned above, fixed enforcement is carried out with ANPR technology in order to capture the licence plate of each vehicle. Vehicle information is sent to a back office where it is checked and compared with the registered licence plate and trip information. If the vehicle is registered no enforcement action is taken. If it is not registered the relevant authorities are notified.

Portable enforcement stations are set up at the roadside and can be moved easily. They use the same technology as fixed enforcement systems. Users cannot avoid them to evade penalties. Even though enforcement stations can be easily automated, there is usually a manual inspection system as a backup to analyse critical data.

Mobile enforcement units consist of vehicles equipped with DSRC technology. These units can detect evaders while on the road, standing at the roadside, or at border crossings. The equipment identifies suspicious vehicles, which are then stopped to be inspected. Mobile units can detect whether the OBU has been installed correctly and works properly. They also check that pre-payers have enough credit remaining. Among other features, enforcement units are also immediately informed if a control gantry finds any discrepancy.

Countries using the enforcement scheme described above generally show low levels of evasion. For example, the fraud rate in the German nationwide truck tolling system is lower than 2%, according to Rodríguez et al (2011).

2.4.2 Evidence standards & approvals

GPS position is not currently regarded by courts as sufficient evidence of the location of a vehicle, and most EU jurisdictions still require photographic evidence. In addition, as GNSS OBUs are complex, their testing and approval process is also complex and expensive. Hence, the billing process for using tolled roads is driven by the commercial contract between the road user and the tolling operator, as with any typical utility or telecommunications service contract.

2.4.3 Accuracy & data protection

The level of satellite visibility is the main parameter that determines the accuracy of the GNSS-based electronic tolling system. Satellite signals are influenced by factors such as time of day, atmospheric disturbance and the local environment (tunnels or trenches). Moreover, cellular networks do not always have 100% coverage or accuracy. This could affect tolling when nearby roads are charged differently.

A low level of satellite signal may be mitigated through the provision of additional local land-based equipment at difficult locations on the road network. For example, special beacons have been installed in some road segments in the German truck tolling system to provide a satellite signal in tunnels.

Despite these weaknesses, the technology is becoming more reliable as satellite coverage improves how erroneous measurements are detected and discarded. The Slovak system boasts an accuracy level of 99% for measuring distance driven (as opposed to vehicle positioning) based on the road network's virtual charging point structure. Furthermore, the Galileo satellite system being developed in the EU is expected to improve the performance of satellite-based functions. According to Norbert Schindler (2012), positioning accuracy levels of around 5 metres are expected with Galileo after 2016, but it has yet to be concluded whether that level of accuracy will apply to a moving vehicle. For example, vehicles moving at 110 km/h move 30 metres each second, which may be the maximum granularity required to check passage through a 90 metre virtual tolling point.

Tolling systems may also have to cope with weak or even absent GSM signals. This can be solved either by caching the data or by reducing the information that is transmitted through GSM, as pointed out by Numrich et al. (2013).

Data privacy, as well as accuracy is a critical issue for GNSS-based systems. Because of the amount of personal information collected, it is necessary to guarantee users data protection. To mitigate public concerns, only essential positional information should be stored and processed.

The issues identified above can be addressed in different ways depending on the type of OBU and its performance. Two kind of GNSS OBU can be used:

- "Thin OBUs" which calculate the position of the vehicles and send positional data via GSM to the central system. This type of OBU can create privacy problems as it enables the generation of "movement profiles"[11].

- "Thick OBUs" collect position data from satellites and store them until the charging information is sent to the back office for fee calculation. This alternative secures personal data from being revealed, since the system does not need to know where

[11] Given data from the GNSS OBU, the detailed itinerary of the vehicle can be identified.

the vehicle has been, but only what to charge. Additionally, a backup is stored on the OBU for a limited time (if needed) as legal evidence. Thick OBUs provide a higher degree of privacy protection but also require larger amounts of data, since digital maps have to be repeatedly downloaded every time a charge is calculated. This can limit the degree of interoperability when a vehicle enters a new or foreign system. The correct digital maps must be provided for downloading, so operating costs may rise due to roaming costs in foreign countries.

In order to avoid unnecessary "movement profiles", pilot schemes developed by Spitscoren (in 2009) and Spitsvrij (in 2012) in Holland suggested stopping position data transmission once the vehicle leaves the tolled areas or roads. As pointed out by Numrich et al. (2013), the use of an Anonymous Loop-Back Proxy (ALP) would be another means to ensure privacy. With this approach, the OBU sends encrypted trip data to the ALP, where the charge is calculated and sent back to the OBU. The ALP can neither store nor access any trip data, which remains only in the vehicle. A legal framework to protect privacy is also required.

Box 7: Data protection in a mature scheme: German protection policy

The data protection policy in the German tolling system for trucks is continuously coordinated with the Federal Office for Goods Transport (BAG) and the Federal Commissioner for Data Protection and Freedom of Information (BfDI). Permission to process data for the toll system is provided by the BfDI and the Truck Toll Regulation. BfDI also establish data deletion deadlines for the toll operator, and processes user data and acts on behalf of the BAG in accordance with data protection guidelines and exclusively for the legally prescribed purpose of toll collection (Persad et al., 2007). Vehicle information recorded by enforcement equipment is also processed according to legislative guidelines. Photos and images of those drivers not suspected of evading the toll are automatically deleted.

2.4.4 Life cycle & cost evaluation

GNSS-based systems need both the installation of roadside infrastructure and a back office to create digital maps and distribute on-board units and for organisational and administrative purposes. Back office costs are higher for satellite-based technology than other ETC systems, but roadside infrastructure costs are lower since they are only used for enforcement purposes (apart from the GPS beacons and repeaters needed in areas where the satellite signal is low/non-existent). For these reasons, GNSS-based tolling systems are more suitable for area-wide tolling.

According to the Austrian government, operating costs in GNSS systems are generally around 10-15% of revenue. In Germany, operating costs were about 20% of revenue in the first year of operation (German Ministry of Transport, 2005), although these figures may exclude costs related to back office enforcement. These costs declined in following years. While GNSS-based systems involve less paperwork and lower transaction costs than other tolling schemes, they involve additional operating costs from GSM communications.

Table 7 : Key data on the GNSS-based systems in Germany and Slovakia

Issue	Germany	Slovakia
Investment costs (€M)	700	800
Annual revenues (€M)	4,500	1,550
Operation costs (% revenues)	12	15

Source: Authors' analysis based on several reports.

GNSS OBUs, costing about €100, are around ten times more expensive than DSRC units. However, the costs are declining, mainly due to wider adoption and the development of other applications, such as usage based insurance, driver and vehicle monitoring and e-call. Common standards and mass production should bring the unit costs down further. Moreover, once common standards for GNSS OBUs are developed, it will be possible to have them integrated into vehicles by the manufacturer, allowing further cost reductions. Most vehicle manufacturers are currently finalising their GNSS platforms to meet e-call requirements and the related value-added services.

According to the results of the GINA project[12], developed in 2009, GNSS-based tolling systems appear to be the most cost-effective alternative. The project estimates the development cost of different tolling technologies in a defined area. The results show that the more complex the system, the less cost-effective the DSRC or ANPR technologies, whereas with GNSS-based tolling systems the costs do not increase as rapidly. The Slovakian approach confirms this statement, since its implementation can be considered as being fairly cost-efficient. As remarked by Walker et al. (2012), the initial investment was recovered in just 4 years.

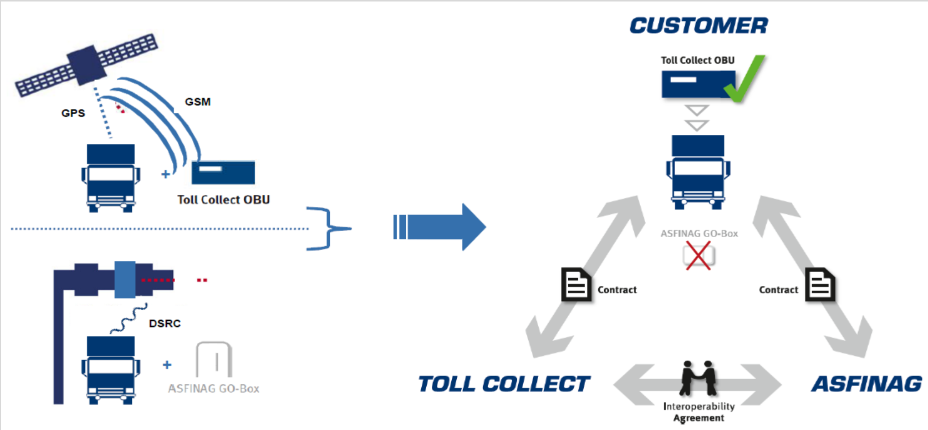
2.4.5 Interoperability & adaptability to EETS

Common standards between different existing systems are needed to achieve interoperability, and the GNSS-based system has already succeeded in this point. The GPS-based German scheme (Toll collect) achieved interoperability with the DSRC-based Austrian system in 2011 through the Toll2Go service (see Box 8). The French scheme "Écotaxe", mentioned above, has been designed to be interoperable with existing DRSC-based tolling systems, although a new hybrid OBU will be required. This shows that interoperability between GNSS and other existing ETC technologies is now technically feasible.

12 The GINA project (GNSS for InNovative road Applications) was a GSA/EC co-funded project to address the obstacles preventing a large scale adoption of road pricing and other services using EGNOS/Galileo. It proposed a realistic use of EGNOS/Galileo in road pricing and value-added services applications, developing a solution close to commercialisation.

Box 8 : GNSS integration with DSRC-based systems

The TOLL2GO service, established in September 2011, is the first toll system based on both satellite and microwave technologies. It is offered by the Austrian toll operator (ASFINAG) and Toll Collect in Germany, and allows users to pay tolls in both countries using a single OBU. Separate contracts are maintained with both toll operators and toll invoicing by the two companies remains completely independent (see figure below). The TOLL2GO service is currently used by more than 60,000 vehicles (Toll Collect, 2013) and can be seen as one of the first examples of achieving interoperability between different systems.



Standardisation is being addressed by the GNSS Metering Association for Road User Charging (GMAR). This association has developed the GMAR Performance Analysis Framework (GPAF), which provides a standard for the performance analysis of different ETC systems, including GNSS technology. In addition to this work, the European Committee for Standardisation (CEN) and the International Organisation for Standardisation (ISO) have developed standards covering GNSS-based tolling systems (Numrich et al., 2013). However, no standard has yet been finalised. Although GNSS is one of the technologies proposed by Directive 2004/52/EC, standardisation issues must be addressed before it can be implemented for EETS. Nevertheless, significant progress is being made in this field and GNSS standardisation is expected to be solved in the near future.

SWOT analysis

The most significant strengths of GNSS technology are its flexibility to define and modify the features of the tolling network, and the limited need for roadside equipment. GNSS is therefore well-placed to ensure interoperability, which has led the European Commission to propose it as one of the ETC technologies suitable for EETS.

GNSS's main weaknesses lie in the high start-up costs, issues regarding data protection, coverage and signal loss, and that there are no agreed common standards to make transnational interoperability possible for GNSS devices. In addition, the technology is not widespread and, although there have been some positive examples, further work is needed to ensure interoperability with existing DSRC schemes.

Table 8 : SWOT analysis of GNSS-based tolling technology

STRENGTHS	WEAKNESSES
• Flexibility to define and modify what is to be charged and how is to be charged	• Higher start-up costs (OBUs, back office, etc.) than other technologies • Less used and mature technology than other technologies
• Technology proposed by Directive 2004/52/EC for EETS • Little need to invest in roadside infrastructure	• Higher operation costs due to GSM communication • Detailed and careful planning is needed before starting to operate the system
• Once installed, less costly to maintain	• Data protection is strongly required due to the amount of information collected from the users • Accuracy errors in certain sections of the tolled network, such as parallel free roads and intersections.
• Easily expandable to other roads and regions	• Interference, not entirely reliable as the satellite signal may be lost: mountainous regions, urban/metropolitan areas and during storms. Additional roadside devices need to be installed.
• Possible to create a single centralised electronic toll collection system at the European level • Ability to provide/support other value-added services through the OBU: traffic information, speed control, etc.	• Interoperability with existing tolling schemes need to be pursued
• Better performance and accuracy are expected with the implementation of the GALILEO navigation system • Interoperability with other tolling technologies (DSRC) has already been achieved (TOLL2GO) • Once implemented, tolling low traffic volume is less costly	• Potential reluctance of Member States if a centralised tolling system is created

Source: Authors' analysis.

2.5 Tachograph

Tachograph-based technology records the mileage of a user through an OBU connected electronically to the vehicle´s odometer. Switzerland, the first country to introduce a fully-electronic nationwide tolling scheme in 2001, is the only European country that uses this technology to collect road charges on freight traffic. The State of Oregon on the United States has developed a number of pilot projects to implement road charges using an ETC system based on digital odometers. A tachograph system is also in place in New Zealand, but this system requires manual, rather than electronic, data collection.

2.5.1 Performance & Enforcement

Vehicles are fitted with an OBU which is coupled to the tachograph and records the distance travelled. The pay-per-use system in Switzerland fits with *area charging* schemes (Rapp et al., 2003), since tolls are levied not only on specific links but on all roads within a defined area. The whole Swiss road network (covering 72,000 kilometres of national, cantonal and local roads) is tolled for commercial vehicle traffic. The so-called Emotach OBU (see Box 9) is a complex electronic device, with GPS and DSRC technologies incorporated for enforcement purposes. Mileage data is copied to a special chip card, provided by the tolling authorities, housed within the OBU.

Box 9 : The Swiss OBU - Emotach

The Emotach OBU is the key element of the Swiss road charging scheme. The variety of functions and technological requirements demanded by the tolling authorities makes it complex and costly. In order to record the mileage covered within the country, the Swiss OBU is electronically linked to the tachograph. The road charge is calculated from mileage and other data, such as maximum weight and EURO emission class, stored in the OBU.

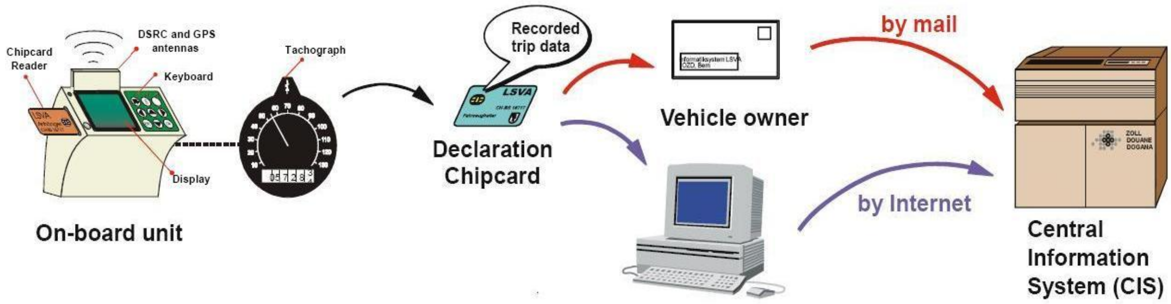
The vehicle´s position is determined by a movement sensor and GPS technology to ensure that the tachograph signal has not been intentionally tampered with. Finally, the OBU enables DSRC communication for enforcement purposes, and to allow activation and deactivation when crossing borders.

The second-generation Emotach OBU has been upgraded to allow for an enhanced chip card data transfer and Bluetooth communication.

The tolling system is complemented with roadside equipment (RSE) at border control stations. These facilities are provided with DSRC "airlinks", which activates and deactivates the OBU when crossing the border so as to charge only for mileage driven within the country. Radio beacons are installed over the lanes and enable free-flow traffic.

The Swiss tachograph technology is based on user´s self-declaration, and data recordings must be sent to the tolling authority's central information system (see figure 8). Mileage covered by the vehicle is automatically recorded in a declaration chip card inserted in the OBA. This information must be transmitted to the Swiss authorities every month, either by chip card (by mail) or electronically (by Internet). The data is then fed into the Central Information System, where it is verified and corrected if necessary. Finally, the billing centre calculates the road charge and invoices the owner. Occasional users, not provided with a Swiss OBU, can pay tolls manually by using self-service machines at borders.

Figure 8 : Process of trip data recording and transmission to the authorities in the Swiss tachograph-based system



Source: Schibler (2009).

Several security functions have been implemented to ensure that mileage declarations are accurate. In addition to motion sensors and a GPS connection, fixed enforcement gantries and mobile monitoring points, spread throughout the country, use a DSRC connection to check that the data declaration is correct. Foreign vehicles are recognised by their licence plate with ANPR technology. Enforcement duties are assisted by the cantonal police which conducts random checks on vehicles.

Although the potential for evasion with this technology is limited (Felix et al., 2002), erroneous vehicle declarations or manipulation of the tachograph are possible. According to Balmer (2006), observed offences in the Swiss system are nevertheless marginal, as evasion rates are below 1%.

2.5.2 Accuracy & Data protection

The tachograph-based approach has a lower level of accuracy than other systems, with errors of ±4% on data recordings (Engdahl, 2013)[13]. However, this is the only technology legally recognised in Switzerland.

Issues of data protection and user privacy are deliberately avoided in this system, as mileage data is the only parameter recorded by the OBU: the system only knows whether a vehicle is moving or not, and the exact position of the user is never known by the tolling authorities. Mileage data is retained by the Swiss authorities for enforcement purposes for at least 5 years.

2.5.3 Life-cycle & cost evaluation

The Swiss pay-per-use scheme for heavy goods vehicles was implemented in 2001. The lifespan of the first-generation OBU (called TRIPON) was estimated at 7 years. After a wide operational field-test, replacement of the TRIPON OBUs by second-generation devices (Emotach) began in 2009.

According to Rapp et al. (2003), a total investment of CHF 290 million was needed to implement the truck tolling system. Detailed data on the Swiss tachograph-based technology are included in table 9. The largest share of the initial investment related to

[13] This is not significantly lower than other systems, as vehicle speedometers have the same level of accuracy, and speed cameras only trigger at 10% above the speed limit to account for these vehicle variabilities.

roadside equipment, since an area tolling scheme requires the installation of numerous control stations at borders. As can be seen, OBU costs were also high (€800 each). This cost was borne by the Swiss authorities, as the OBU was distributed free of charge to road users. However, maintenance and installation costs (around €200-450) were borne by vehicle owners. The price of the second-generation OBUs, ranging from €300 (Oehry, 2011) to €750 (FCA, 2013), is lower than that of the previous unit, but is still significantly higher than OBUs used by DSRC and GNSS systems. The Swiss system made it easy for users of foreign vehicles to comply by allowing them to buy a vignette at the border.

Table 9 : Key data on the Swiss truck-tolling scheme

ITEMS	Source
• INITIAL INVESTMENT (2001)	€190 M
Background system & roadside equipment: beacons, sensors, etc.	€100 M
Recording devices (OBUs)	€60 M
OBUs initially distributed	52,000
OBU unit cost (covered by the State)	€800/unit
Others: planning, development (system, OBU, data processing)	€30 M
• Operating costs per year (2012)	€19 M
• Total collection costs: operation, maintenance, staff (2012)	5-6% revenues
• OBUs in operation (2013)	55.500
• OBU unit cost (2013)	€300-750/unit
• OBU installation cost (2013), assumed by users	€200-450
• Collected revenues (2011)	€1,200 M

Source: Authors' analysis of several reports.

Investment and collection costs were rapidly recovered from road charges. The Swiss government levied a total of €590 M during the first year of operation (Balmer, 2003) and raised revenues of around €1,200 M in 2010 (RDW, 2012).

2.5.4 Interoperability & Adaptability to EETS

While no nationwide truck-tolling scheme had been implemented in Europe by 2001[14], the Swiss authorities considered allowing some form of interoperability with other technologies in bordering countries. The first-generation OBU was designed in accordance with the CEN DSRC 5.8 GHz standards, which allowed for one-sided interoperability with the Austrian system from 2004. The second-generation OBU included DSRC technology allowing transactions to be carried out according to EN15509 standards and thus allowing technical interoperability with the Italian TELEPASS system (although this is not currently in operation). Nevertheless, two-sided interoperability is not feasible in Switzerland, as the additional functionality and complex technical requirements could not be incorporated into existing OBUs. As a result, full interoperability is impossible and this technology was therefore not chosen as one of the options included in the EETS Directive.

As pointed out by Schibler (2009), no institutional or contractual issues prevent the implementation of EETS in Switzerland. The Swiss authorities have recently published an EETS Toll Domain Statement which defines the commercial conditions and service level requirements of the service. The Statement includes conditions regarding recording the distance travelled from the tachograph, a requirement not present in tolling regulations in any other country. The Swiss authorities have participated in several interoperability projects and it is expected that recording devices envisaged for the EETS will also be used in Switzerland in the future. Nevertheless, the adoption of tachograph-based systems for EETS would require high investment costs, as it is not a common technology (it is used only

[14] After the Swiss experience in 2001, Austria was the second European country to implement a nationwide truck-tolling system, in 2004, in accordance with Directive 1999/62/EC.

in Switzerland) and is technically complex. Furthermore, with the exception of one-direction interoperability with DSRC Austria, interoperability with existing ETC technologies has not been achieved, making tachograph technology unsuitable for EETS.

2.5.5 SWOT analysis

The main strengths of the tachograph-based technology are absence of privacy/data protection issues and low collection costs. Furthermore, the system works best with area tolling schemes. Tolling infrastructure investment is limited to border stations and enforcement gantries, but the total cost is highly correlated to the shape of the area subject to tolls.

In contrast, this technology has several significant weaknesses: complexity, cost of the OBU, and low accuracy in recording data. Moreover, tachograph-based systems are not commonly used, and there is no technical standard. Additionally, two-sided interoperability with other tolling technologies, even DSRC systems, has still not been reached. Tachograph-based approaches, as currently implemented, will be difficult to adapt to a European strategy on ETC and do not seem suitable options for EETS. Tachograph technology was not included within the technologies proposed by Directive 2004/52/EC.

The system also makes it difficult to modify the tolled area, as border stations need to be replaced. Furthermore, it is not possible to limit charging to certain roads within the defined area, or to establish variable tolling depending on parameters such as type of road or level of congestion. Finally, the tachograph technology cannot provide new value-added services to road users, as proposed by Directive 2004/52/EC, since the vehicle´s location is not identified.

Table 10 : SWOT analysis of the tachograph-based tolling technology

STRENGTHS	WEAKNESSES
• Absence of privacy and data protection issues	• Rigidity in defining and modifying what is to be charged and how it is to be charged within the tolled area
• Investment on tolling infrastructure is relatively independent of the tolled network within the area	• Low accuracy of the tolling technology (±4%)
	• Complex and costly on-board unit
• Low toll collection costs	• Two-direction interoperability with DSRC technology is still not available
• Maintenance of tolling infrastructure is limited to cross-border control stations	• High start-up costs of cross-border control stations
	• Not commonly used technology. Lack of standards. Not compatible with EETS.
OPPORTUNITIES	**THREATS**
• One-sided interoperability with existing DSRC tolling technologies is feasible in the short-term	• Difficult/complex adaptation to EETS schemes due to excessive technical requirements
• Close control of the tolling system by Member States	• Additional position services cannot be provided through the OBU
	• Not proposed by Directive 2004/52/EC for EETS

Source: Authors' analysis.

2.6 Mobile communications (GSM and smartphones)

Mobile phones and smartphones are expected to play a significant role in the ETS system in the near future, but their role is still embryonic at the moment. The combination of mobile phone penetration, technological progress in the field of Near Field communication (NFC)[15] and growing cellular network coverage have led to a number of trials of integrating mobile phones with ETS.

2.6.1 Performance & Enforcement

Integration with ETS can be achieved at a number of levels. The handset can be used to monitor toll payments during a journey, to update a personal account and user data, or to select the method of payment. An example of this *is AfriGis Navigator Logbook*, a mobile application developed by AfriGis that automatically creates a logbook while driving. The application records the distance travelled and other journey information. The user can also receive suggestions on alternative routes if required. Similar services are provided by North Texas Tollway Authority (NTTA). The *Tollmate* application allows its customers to use their mobile phones to access their accounts, view the balance, top up credit, and create a logbook of their journeys.

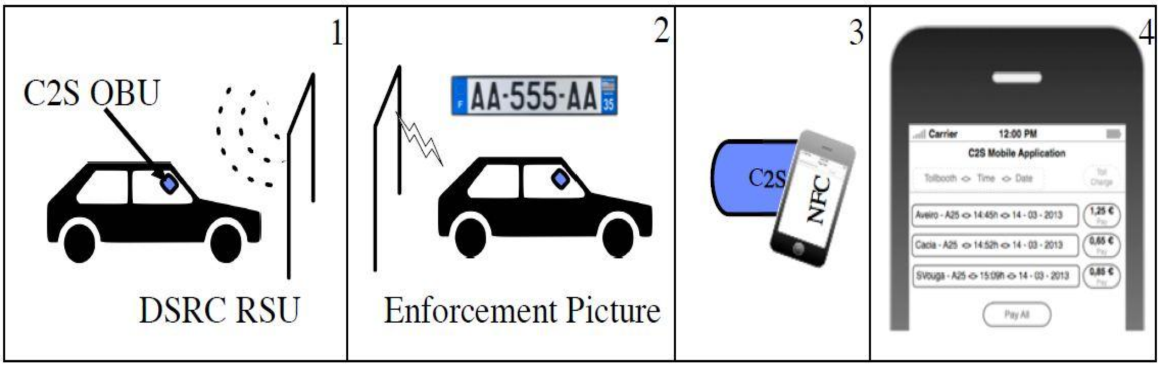
A second example of mobile and smartphone integration with ETS is the model proposed by the project *C2S,* a pilot project being developed in Portugal by the Institute of Communication of the University of Aveiro. The technology for this system is built around an OBU that integrates DSRC and GNSS with a smartphone mobile application using NFC technology. This technology provides:

- A mobile application with a user-friendly interface, which offers information including best routes, tolls to pay, payment method, etc.)
- A payment method by which the user touches the OBU with a smartphone to pay the bill

As *C2S*-enabled vehicles have an OBU that is not recognised by the conventional DSRC system, the vehicle is detected by ANPR and the driver is then required to pay within a certain period. The user can transfer all the toll logs to a smartphone with NFC by a simple touch, and pay the tolls with a mobile application (Diaz et. al., 2013).

[15] Near Field Communication (NFC) is a set of standards for smartphones and similar devices to establish contactless communication with each other by bringing them into proximity.

Figure 9 : Functioning of the C2S System

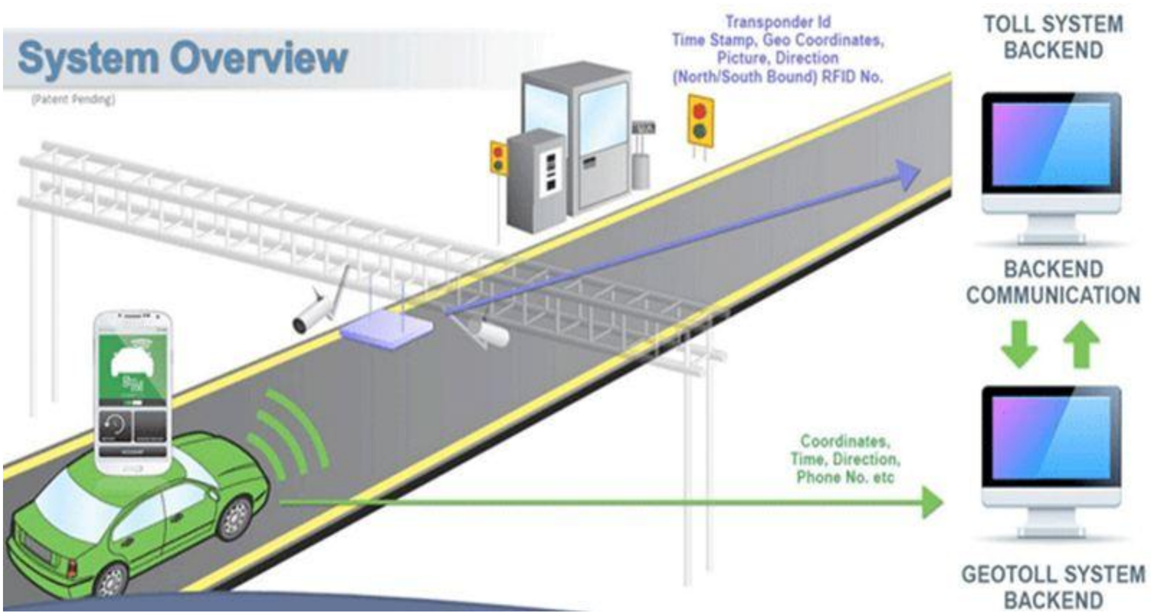


Source: Vehicular (2013).

The model aims to address the issues of flexibility (allowing the user to choose how to pay the toll), interoperability (the smartphone can integrate with different OBUs and different operators) and transparency (the user can see the tolls and charges in real time).

Another approach to integration is proposed by GeoToll, a technology based on RFID-equipped smartphones with the capacity to interface with a wide variety of electronic toll collection systems to pay tolls. GeoToll users pay automatically as they pass a toll gantry, using a combination of NFC, RFID and GPS technologies. GPS is used to "wake up" the dedicated GeoToll application on a driver's smartphone when approaching a toll plaza. A RFID chip embedded in a standard toll tag fixed to the smartphone is identified by the toll gate or gantry. Finally, NFC is used to allow the toll tag to communicate with the smartphone, enabling payment to be taken from the user's prepaid account. The application also allows users to obtain a receipt of the toll paid (NFC World, 2013). However, this service is currently only available in Florida.

Figure 10 : Functioning of the GeoToll System



Source: NFC World (2013).

The advantages of this technology are that each user can have different vehicles registered to one account, the scope for users to add rental vehicle information to their account, and the availability of a Back Office System (BOS) which manages a user's account, handles payments and creates reports upon request. The system is extremely flexible as no OBU is needed.

A further example of mobile and smartphone ETC integration is the *m-Toll* project. *m-Toll* relies on the use of smartphone WiFi connection to authenticate, validate and debit toll road users without the need for any dedicated hardware for the end user.

Figure 11 : Functioning of the m-Toll system

Source: NFC World (2013).

Servers installed at the toll plaza can detect the smartphones from a distance of 600 metres and deduct the toll from the connected account through NFC. The system includes provisions to allow for there being more than one enabled phone in the car. *m-Toll* also includes the facility of "connect to user" where the toll user(s) can be contacted remotely to facilitate dynamic traffic management and communication during emergencies. m-Toll is being tested from November 2013 in a pilot project in India, on the Tumkur-Chitradurga (Karnataka State) highway, and in 2014 will also be introduced in Brazil, Indonesia, US, and South Africa (GeoToll, 2013).

Table 11 : Mobile phones and smartphones integration with ETC technologies

Category	Countries of implementation	Example
Mobile phones and smartphones used to monitor toll expenses	South Africa US (Texas)	AfriGis Tollmate
Mobile phones and smartphones used to pay tolls integrated with a OBU through NFC integrated with DSRC or GNSS/GSM infrastructure	Portugal	C2S Project
Mobile phones and smartphones equipped with RFID tag residing on the phone	US (Florida)	GeoToll
Mobile phones and smartphones used as a tag through WiFi connection	India (Karnataka State) (Brazil, Indonesia, US, and South Africa in 2014)	m-Tool

Enforcement for smartphone-based systems is similar to that for DSRC or GNSS-based systems. It uses both fixed and mobile enforcement centres on control gantries provided with DSRC and ANPR technologies.

2.6.2 Accuracy and data protection

Given the limited take adoption of this technology to date, there is little evidence on data protection and accuracy. The main suppliers report accuracy rates of 100%, although some issues still need to be addressed:

- Vehicle classification: user-based contracts makes vehicle classification more difficult (Nijhuis, 2012).
- Battery life: compared to a tag, with a lifespan of around five to seven years, a smartphone's battery can be depleted in just a few hours. There is therefore a greater responsibility on the user to keep the phone working (Nijhuis, 2012).
- Proliferation: while smartphones are becoming increasingly popular, penetration has not reached 100%. Any application based on the use of smartphones must therefore be backed up by an appropriate toll collection scheme. This adds cost and complexity to the technology (Schnacke, 2012), as extra base stations are needed in areas where coverage is insufficient. Other technologies based on entry and exit points or satellite coverage have fewer of these types of costs.

Data protection is another issue, as cellular networks can determine the location of a smartphone through triangulation. Several recent trials have explored the potential use of cellular networks to monitor driver behaviour and to facilitate toll payment. Pilot projects have confirmed that the technology can provide a feasible alternative to other positioning-based systems. This has raised concerns about how the use of mobile phones for ETS could affect how personal information may be collected. To mitigate public concerns regarding being tracked, only essential positional information should be stored and processed.

2.6.3 Life cycle & cost evaluation

A benefit of smartphone use in ETS system is that no OBUs are needed. This could lead to savings per user of from €30 (in case of DSRC, RFID) to €100 (in case of GNSS). Using cellular networks to determine user locations could lead to additional savings, avoiding the installation of toll plazas, although this approach does raise concerns regarding privacy.

2.6.4 Interoperability & adaptability to EETS

Interoperability is an important issue for this technology, and it can be guaranteed more easily than other systems because mobile technology is already interoperable across Europe. It has been included in Directive 2004/52/EC and is thus compatible with EETS requirements.

Mobile telephone technology provides a superior interface to existing ETC systems and provides improved memory, greater processing ability and cross-border use. It also allows users and chargers to manage users' accounts more easily. Mobile phone tolling also has advantages for the toll operator, in particular avoiding outlay on equipment procurement or distribution (Burden, 2012) and allowing continuous contact with their customers.

In order to facilitate interoperability, GeoToll is developing a smartphone application to allow its users to pay tolls to operators outside the State of Florida (GeoToll, 2013).

2.6.5 SWOT Analysis

Mobile phone and smartphone-based tolling does not require in-vehicle devices, allowing for lower initial investment costs than other technologies. Mobile phone ETS services can offer a user-friendly experience, flexibility to define and modify methods and time of payments, and easy integration with other tolling technologies and driver services. Furthermore, it is one of the technologies compatible with EETS.

On the other hand, the technology is not mature, and various issues remain to be addressed including battery life, the proportion of the population with such phones, lack of standards and the inability of the system to identify the type and category of vehicles. A possible obstacle to the development of mobile phone ETS services is the data management issue related to the ability of cellular networks to track the user's position.

Telecommunications-based technology is very volatile due to rapid technological development. Current systems based on GSM are likely to become obsolete quickly and, when considering this technology, allowance must be made for the pace at which the industry moves. Tolling solutions must be developed with the aim of allowing for low cost upgrades when equipment becomes obsolete.

Table 12 : SWOT analysis of mobile phone and smartphone-based tolling technology

STRENGTHS	WEAKNESSES
• Flexibility to define and modify what is to be charged and how it is to be charged	• Device battery duration • Less used and mature technology than other options
• Little physical tolling roadside infrastructure investment	• Detailed and careful planning is needed before starting the system
• No need for in-vehicle device or costly enforcement infrastructure	• Can become obsolete quickly, given technological developments in the sector
• Compatible with EETS	• Variable proliferation of mobile and smart phones in different areas
• User-friendly interface	• Some areas do not have appropriate GSM coverage
• Interoperability with other tolling technologies	• No proven data about accuracy on certain sections of the tolled network, such as parallel free roads and intersections
• Low maintenance costs	• Not able to classify vehicles • No standards currently available
OPPORTUNITIES	**THREATS**
• Possible to create a single centralised electronic toll collection system at EU level • Continuous technological improvements in mobile phone and smartphone industry	• Data protection issue in relation to the cellular network used to track user position
• Possible to integrate toll payment with other user services	• Potential reluctance of Member States if a centralised tolling system is created

Source: Steer Davies Gleave analysis.

3. REVIEW OF EMERGING TECHNOLOGIES

The review of technologies that may play a part in the future EETS is driven by the following questions:

- Are existing technologies becoming obsolete?
- Is there a significant opportunity to reduce the cost of collection?
- Will the technology enable improvements in interoperability?
- Is technology within the same sphere also evolving and able to support or improve how EFC operates?
- Are there technological developments which provide better function, performance or accuracy?
- What is the timeframe for the existing technologies becoming mature and when might new technologies be able to integrate or play a role?

Each of these questions is addressed below.

3.1 Obsolescence

To assess which technologies could play a role in future EETS provisions, it is important to understand the degree of obsolescence of current technologies, which can be summarised as:

- **DSRC** is the most widely-adopted and mature ETC technology, and shows little sign of obsolescence.

- **GNSS** is still in its early stages of development, with first generation technology solutions in a number of Member States. It is also still developing through better signal processing and improved satellite coverage. Levels of adoption are still growing. This is expected to be boosted by the re-procurement of the German LKW Maut operation and the Belgian ViaPass GNSS scheme, which should substantially drive down OBU costs. These costs are expected to reach maturity between 2016 and 2020 at about €100. Once Galileo is fully operational (after 2020) data quality for tolling should reach optimum levels and reduce billing inaccuracy and back office handling costs. This would enable a greater degree of automation. The OBUs will benefit from wider developments in telematics for commercial vehicles related to driver monitoring, vehicle monitoring and usage-based insurance (through the use of Event Data Recorders).

- **ANPR** is not part of the EETS, but is required for non-electronic tolling (in local schemes as defined within the EFC Directive[16]) as well as for enforcement. There have been no substantial developments in how evidence of vehicle location is established within national legal frameworks. Given the increasing adoption of ANPR technology, and its use in enforcement, it is unlikely to become obsolete as a system. Improvements in camera technology may render some of components obsolete, but they could be replaced when life-expired.

[16] The Electronic Fee Collection Directive, 2004/52/EC, 29 April 2004.

- **GSM** - Analysys Mason forecast[17] that, by 2017, 40% of mobile subscribers in Western Europe will be using fourth generation mobile phone technology (4G LTE - Long Term Evolution), with the vast majority of others using third generation mobile phone technology (3G), and less than 10% of users will have GSM phones. GSM spectrum in the 800 MHz and 900 MHz bands is being redeployed to support 4G/LTE[18] and the remaining GSM (at 1800 MHz) is being focused on voice, with data migrating to 3G and 4G. The business case for 4G development depends on GSM spectrum reduction affecting the economies of scale for GSM data devices, increasing their costs and increasing the risk of obsolescence. There is therefore a high risk that GSM and GPRS components will be high cost to source and maintain, and that GSM may only be used in Europe for voice services. Limiting OBU technology to GSM therefore introduces a substantial risk to the system, as data transmission migrates to 3G- or 4G-based systems, where OBU unit costs are currently high but falling.[19]

The main EETS technology which is potentially obsolete is GSM/GPRS. The majority of mobile communications traffic in Europe is now using 3G, and 4G is being adopted in most Member States. The table below summarises the evolution of mobile communications technologies and indicative data transmission capacity.

Table 13 : Summary of mobile communications technology evolution

Technology	What is it?	Data speed	When introduced
First generation mobile '1G'	Diverse technologies such as Nordic Mobile Telephone, Total Access Communications System, Advanced Mobile Phone Service	Analogue – no data capacity	1981 onwards
Second generation '2G' mobile – GSM	Groupe Special Mobile (now Global Standard for Mobile)	Low speed data < 10 kbps	1992 onwards
2.5G - GPRS	General Packet Radio Service – a data service operating over the primarily voice-based GSM	10-80 kbps	2003 onwards
Third generation '3G' UMTS	Universal Mobile Telephone Service (UMTS)/Wide-Band CDMA created by the 3rd Generation Partnership Project	200 kbps-42 Mbps	2001 onwards
Fourth generation '4G' LTE	An enhanced 3G service with a new radio interface developed by the 3G PP	100Mbps – 1 Gbps	2009 onwards
Fifth generation '5G'	A future generation of technology still being researched and with no standards	1 Gbps +	Expected to emerge ~2020

17 July 2013 - http://www.analysysmason.com/About-Us/News/Newsletter/LTE-USA-Europe-Aug2013/
18 KPN Position Paper on Spectrum in the Netherlands, following Dutch spectrum auction, 14 Dec 2012.
19 References: AT&T announce shutdown of 2G networks by Jan 2017, August 2012, Wall Street Journal, Aug 2012, (http://online.wsj.com/news/articles/SB10000872396390443687504577567313211264588).

GSM and GPRS components are becoming less available and their support costs are increasing (unsupported software, out of date Printed Circuit Board modules). Telecoms companies are also reallocating their 2G resources to 3G and 4G. In addition, 5G is currently being planned, and it is likely that this evolution will continue, effectively raising the costs of 2G operation. Given this likely obsolescence, a review of the current EFC Directive and EETS Decision should be considered, with the aim of removing reference to GSM technology and inserting a more general statement about using available, mature, area-wide mobile communications to transmit EFC-related data securely from the OBU to the proxies and back office.

Other technologies do not seem to be approaching obsolescence.

3.2 Cost reduction

The most significant cost aspects of ETC schemes are associated with:

- **OBU costs** – there are still significant opportunities for GNSS and DSRC OBUs to be available at lower costs. RFID 'sticker tags' also have the potential to reduce costs substantially. Significant developments in vehicle telematics are also driving down the cost of technology.

- **Road-side equipment** – this equipment, including DSRC/tag readers, vehicle classifiers and cameras, is still expensive, although unit costs will fall with wider deployment.

- **Wide area communications** – migration to 3G and 4G provides lower unit costs per data packet transmitted. There is also potential for using WiFi-based technologies, primarily in urban areas. Mobile internet access has driven down costs and increased volumes for all types of applications; EETS can also benefit from these cost reductions.

- **Back office** – the operation of customer payment channels and billing, the wider adoption of digital channels for billing and payment, and reduced payment in relation to service provider/merchant acquirer fees, all mean that costs can fall further and make all systems cheaper to operate and maintain.

- **Enforcement operations** – the key opportunity here lies in sharing vehicle and driver registration data on a pan-European basis and adopting common approaches to the datasets required for enforcement. However, given the slow pace in relation to harmonising enforcement arrangements, the benefits may only emerge in the long term.

3.3 Improvements in interoperability

Evidence from the US shows that lack of interoperability across States leads to significant costs and increases the risk of not capturing all drivers. This is being overcome in the US through ANPR-based number plate identification, which works in parallel with existing technology and processes payments through the various back offices. This solution has been adopted as the best option to ensure simple and cost effective interoperability.

The main opportunities in the EU relate to the adoption of common technologies between Member States. For example, the current method by which both the CEN[20] and UNI DSRC[21] communications protocols must be supported means that there are additional testing and certification costs. The current use of Infra-Red DSRC in Germany and Microwave DSRC in other Member States also complicates matters and increases the cost of achieving interoperability. These are primarily issues of how individual MSs want to control their own solutions, and technology supply chains, to the detriment of unit costs and the easy exchange of data for EFC. No technology-driven enablers for better interoperability are expected in the EU, although identical ANPR technology is already available in many Member States.

3.4 Emerging related technologies

The main areas where technology is developing are:

- In-vehicle Intelligent Transport Systems (ITS) technology, for example within the Cooperative Vehicle Information Systems (CVIS) and Communications Access for Land Mobiles (CALM) areas

- In-vehicle applications such as telematics for vehicle and driver management, eCall, usage-based insurance (UBI) and different types of Event Data Recorders (EDRs)

- Low cost combined GNSS/accelerometer devices to track movements even where satellite visibility may be poor – they are serving the fitness and leisure market as well as vehicle navigation and measurement

- Mapping standards, map quality, highway section asset management and algorithms for determining when a vehicle has passed a "virtual tolling point" or similar "toid" (Topographic Identifier)

- Cloud-based storage and processing, which reduces operating costs and improves the speed of calculation of distance driven, toll due, and cleaning of erroneous data.

All these developments have a direct impact on how vehicles interact with their environment. It is unlikely that these devices will conflict with each other as they are based on common standards and, where necessary, different frequencies, but the way they interact and work together is important. The cellular network developments discussed earlier show how developments in other areas or sectors need to be fully understood before proposing technical standards.

Of the technologies mentioned above, eCall should in future be mandatory on all new cars, and UBI and EDRs are becoming more popular and are being installed in a growing number of vehicles (although there are no fixed standards for EDRs at the moment). These two types of devices alone will be a fundamental component of vehicles before many more road tolling schemes come online. Bringing these different technologies together into "one box" would have a significant impact on costs for all systems. Our research indicates that platforms able to provide driver behaviour profiling, UBI and, potentially, road pricing may be available at a CAPEX of €100 with OPEX of less than €10/month, associated primarily with data communications to a back office. Recent reports suggest that approximately 50

[20] CEN DSRC as defined by TC 278 adopted in most of Europe.
[21] UNI DSRC Conforming to ETSI standard UNI 10607 adopted in Italy by Telepass.

million vehicles in Europe will have adopted UBI by the end of 2017.[22] As a result, before technology developments in the EETS field are considered in more detail, it will be necessary to understand how other technological developments can best be exploited to ensure common, interoperable and low cost EETS OBUs.

3.5 Improvements in function, performance and accuracy

3.5.1 Usage based insurance (UBIs) and event data recorders

Adoption of usage based insurance is forecast to grow, and estimated to reach approximately 50 million vehicles in 2017 (Telematics Update, Sept 2013). UBI relies on simple GNSS devices that plug into the On-Board Diagnostics (OBD) port and enable a wide range of vehicle services, including toll collection. The cost of these units is declining, with an OBU (including a GPS unit, GSM module and accelerometer) currently costing about €75,[23] although in some cases this can be as high as €150.[24]

3.5.2 RFID sticker tags

RFID technology can potentially match the performance levels of DSRC on interurban and motorway networks. Sticker tags can also be significantly cheaper and their low profile makes them suitable for delivery by post, allowing distribution costs to fall. They are also cheap to manufacture, and could almost be considered disposable, unlike DSRC tags which at a cost of about €10-€30 each need to be maintained and managed.

In the US, RFID sticker tags, operating at 915 MHz and meeting ISO 18000 6B standards, have long been used by the US E-ZPass[25] toll system. With the new ISO 6C standard, there is an opportunity for better detection performance. This is coupled with an almost insignificant unit cost, which is declining to less than €1, with some Chinese suppliers quoting as low as €0.1 to €0.2 per tag. These tags are also available for the European market and have already been implemented on parts of the Turkish toll road network.[26]

3.5.3 Roadside equipment

Roadside equipment generates the largest costs of interurban tolling. Unit costs are also falling with technology developments, but the steel and concrete gantry infrastructure and related earth and building works still has a substantial cost and can dominate the overall budget for equipment. Individual 'man–access' gantries can cost €50,000-€200,000 to install. Initiatives which enable gantries to be shared between signage, road pricing equipment and traffic management systems are some of the most effective ways of reducing these investment costs. Technological developments in this field are having a further impact on the following costs:

- With smaller and higher density charge-coupled devices (CCDs), cameras have falling costs, while providing higher definition and more accurate pictures, and are able to process images faster, improving recognition rates. Cameras rely on the quality of optical components to perform ANPR and they typically require 3-4 pixels

[22] See https://www.abiresearch.com/press/europe-to-lead-insurance-telematics-market-with-mo
[23] Cognizant, 2012. http://www.cognizant.com/InsightsWhitepapers/The-Telematics-Advantage-Growth-Retention- and-Transformational-Improvement-with-Usage-Based-Insurance.pdf.
[24] Casualty Actuarial Society, Weiss and Smollik, 2012 http://www.casact.org/pubs/forum/12wforumpt2/Weiss-Smollik.pdf.
[25] E-ZPass tag account – see https://www.e-zpassny.com/en/about/howit.shtml
[26] Toll road news, Oct 15 2012 and Eric Redman's presentation to IBTTA in March 2012, http://www.ibtta.org/files/PDFs/Redman_Eric1.pdf.

across the 'stroke width' of a licence plate character to read it. Costs are heading towards €3,000-€4,000 per lane camera for interurban tolling. Other developments include Astucia, which has developed as an alternative mounting option a road stud with an ANPR camera embedded in it, but this does not provide the same level of read rate quality. However, further development may improve performance.

- The costs of RFID Tag readers are falling towards €2,000-€3,000 per reader.
- The costs of DSRC beacons are falling towards €5000, including an embedded lane controller which dispenses with the need for a roadside cabinet.
- The use of broadband technology at the roadside, with encryption over the internet, is also reducing the telecommunications costs related to transferring information from detection sites to the back office.
- The cost of a detection site with camera and beacon technology is falling towards €30,000-€40,000, depending on complexity and installation needs.

3.5.4 Digital payment channels and mobile payments

There are substantial advances in the adoption of digital payment channels, as mobile internet becomes the primary medium for customer payments and communications in Europe. This development is driving down the costs of charge card and bank card transactions as micro-payment service providers develop. Customers are also more familiar with account-based usage of utilities, and telecommunications services, with payment linked to a bank account or credit card.[27]

In addition, contactless payments from a card, or through a mobile phone emulating a contactless card using Near Field Communication (NFC), enable better cashless transactions in which a person's identity does not need to be disclosed. This development has the benefits of removing cash handling and reducing the transaction costs of micro-payments, enabling those without tolling accounts to pay per use at a physical location. Visa Europe reported in May 2013 that contactless transactions grew by 46% in the first 3 months of 2013 compared to transaction volumes in 2012.

The combination of mass-market devices and their protocols, typified by smartphones with NFC, creates new opportunities in toll charging. Recent pilot projects confirm that contactless toll charging is becoming a reality.

Contactless transactions by mobile phone are not new. Different examples have emerged over the last few years in Japan and Korea ("Wave and pay" systems) and in regions of Africa where mobile-to-mobile money transfers are already common. This contrasts with the low penetration of smartphone payment systems in countries such as the US (Cantinelli, 2012).

Many experts claim that smartphones using NFC technology will complement and help to accelerate the current trend in tolling, by moving towards all-electronic toll collection. Smartphones offer new possibilities for users of the tolled roads because their memories and processing capabilities exceed those of vehicle tags and OBUs. Consequently, users would be able to benefit from new services during the trip. The smartphone's ability to roam between regions and countries also means that it can quite easily pass through

[27] Ingenico report on Electronic Payments in Europe, October 2012, www.ingenico.com/zee_uploads/all/all/gallery_gallery/3760/electronic-payment-and-trends-in-europe.pdf.

different charging and tolling schemes, which cannot necessarily be achieved by a tag or OBU. Furthermore, mobile phone applications provide a superior interface to existing ETC systems, and offer the possibility of seeing and managing user accounts. Mobile phone tolling also has advantages for the toll operator, in particular in relation to eliminating equipment procurement or distribution costs (Burden, 2012), as well as a 24 hour connection to customers.

As for security issues, users tend to have their smartphones with them, so cloning rates will be lower than other means of payment such as credit cards. In contrast, toll operators would have to deal with several operating systems and different telecoms suppliers. There may, however, be privacy issues associated with this system (Larraondo, 2012).

According to Wurmser (2012), ETC technology could replace cash and credit card transactions, but its short range requires ‘stop and go’ at the toll plazas, limiting its free-flow application. NFC-enabled smartphones have already been implemented at some toll plazas. In contrast, using NFC technology as an OBU operating in free-flow/open road tolling conditions is not yet technically possible. It is possible to use smartphone applications jointly with ANPR technology to provide occasional non-registered users with access to a free-flow charging schemes. This is the case for the Tehran (Iran) congestion charging system, in operation since 2011, and has been used in London for payments since 2003.

3.5.5 eCall

eCall should be put into service in the coming years. It uses a GNSS device to provide location data to emergency services through ‘112’ - the pan-European emergency services number. The eCall platform could also be used to provide GNSS-based road pricing. The vehicle manufacturers are finalising their eCall packages, many of which have additional communication services that enhance the basic eCall function (for example, Ford offers SYNC, General Motors offers Onstar).

3.5.6 Mapping, processing and storage

Mapping providers now operate on a global basis and have largely standardised the quality and technical content of mapping and Geographical Information System (GIS) information. Providers are able to offer a common reference framework for maps, in both an OBU and a back office, to enable more accurate location services and distance measurement. ‘Map-matching’ for interurban journeys is now a mature and established service. Map updates and downloads can be provided dynamically, enabling both thick and thin client OBUs. The falling costs and size of storage technology means that in-vehicle mapping components are continuing to develop. This means that GNSS-based charging still has significant potential both in interurban tolling and within cities.

Wide adoption of satellite navigation devices, and their generally reliable operation, mean that with relatively simple ‘virtual tolling points’ or zones, the devices should be able to charge accurately in an urban environment. With effective zoning and mapping technology, interurban and potentially urban areas can be tolled with GNSS technology, subject to costs.

Box 10: GNSS urban trials

In 2007-2008, Transport Research Laboratories conducted a trial for the Dutch Government of the operation of distance-based charging with 11 suppliers of OBUs and back office systems. The main challenge concerned the potential inaccuracy of GNSS within an urban environment for distance-based charging. Therefore, the objectives included:

- to establish the accuracy and reliability of satellite systems for KMP - the national time, distance, place (TDP) road pricing scheme for the Netherlands.

- to use the outcomes of the technology performance trials to provide input to the development of tariff zones for an eventual national road pricing scheme. The design of the tariff zones and their relationship with mapping data is key to accurate distance measurement.

The research evidence suggested that GPS-based road pricing technologies were sufficiently accurate, reliable and cost-effective to support the Netherlands' desire to introduce the first national (all roads, all vehicles) GPS-based road charging system. (This road pricing project was not implemented due to the Government of the time being voted out over a separate policy matter.)

This contrasted with similar trials in London between 2004 and 2007, which concluded that GNSS suffered from mapping and zoning issues and the limited accuracy of the OBU positioning capability.

In Singapore there have since (2011-2013) been GNSS based trials with four suppliers, seeking a successor to the existing system. The results of the trials have not yet been made public by the Land Transport Authority.

3.5.7 Satellite coverage

Better satellite coverage due to a greater number of satellites in the sky is likely to improve GNSS performance significantly. For GNSS to work effectively, the OBU needs to have visible a minimum of 4 satellites. With the existing GPS system this is not always possible, and, in urban areas, lack of visibility can increase to minutes the 'time to first fix' following initial power up of an OBU. The use of GLONASS and the future Galileo system will reduce the number of erroneous location data-points and thereby improve the overall accuracy of GNSS.

3.5.8 Cellular location tracking

Location and cell tracking of mobile objects can be done by cellular communication-based positioning systems. This technology uses the existing base stations of cellular communication networks to locate a vehicle. A device similar to a mobile phone chip could be installed within a vehicle. It has been suggested that this could be used to determine the distance travelled by the vehicle and to calculate the toll to be paid. However, base stations are not designed to provide accurate locations; even pico-cell technology[28] only identifies an area with a radius of 100-200 metres as a location. This technology may only

[28] Pico-cell technology is a more concentrated cell network that uses smaller transceivers, providing a greater ability to locate mobile devices within the network. By using this type of network, it is possible to locate properly-equipped vehicles with a high degree of accuracy.

be practical on expressways, motorways and interurban roads with minimal intersecting roads and where the distances between cell-based virtual tolling points can be rounded to set values.

In recent years, several trials have explored the potential usage of GSM for toll charging (see box below).

Box 11: Cellular positioning trials

Trials performed in 2008 in Maryland and California involved cellular networks to gather traffic data information.

They were based on a static network of motes connected to bus stops and mobile motes placed on buses. The system trials were used to provide position information collected from the buses.

Other trials involved the use of pico-cell systems based on a dense network of low-cost and short-range transceivers, located on roadsides and within vehicles. Trials of this type of technology were undertaken in the United Kingdom (Newcastle and London) to test the feasibility of the technology for congestion pricing. The trials in London (2004-2008) concluded that the technology was not accurate enough for congestion charging detection, because pico-cells were too small to register a phone reliably as it passed through an area (like a DSRC transaction), and there was insufficient accuracy to determine whether a vehicle was inside or outside the zone.

Mobile phones are already widely used to generate 'floating vehicle data' for traffic measurements. The system works by collecting the signals between the mobile phones and the phone towers to map traffic flows and congestion patterns. It is yet to be seen whether this technology can be applied for location determination in distance-based toll systems.

3.5.9 CVIS/WAVE/5.9 GHz for V2V and V2I

We understand that the EC's current position is that CEN DSRC at 5.8 GHz is to be used for tolling and that 5.9 GHz/WAVE is a separate development in vehicle telematics, though we cannot identify a formal policy document that states this position. However, 5.9 GHz may provide a future platform for tolling through an integrated solution.

New services in vehicles include dynamically assisted navigation (traffic status, etc.), dynamic user information provided during the trip, dynamic safety measurements, real time driving assistance, intermodal planning, parking assistance, and wide area high-speed data access to the internet to provide onboard information (Lamy, 2013). The current limitations are imposed by the inadequate bandwidth available to provide these ITS services to a moving vehicle.

To address these issues, a number of projects are being developed worldwide by different organisations and partners of the automotive industry. These projects are mainly aimed at increasing road safety and efficiency by integrating ITS and vehicle-to-vehicle (V2V) communication supported by vehicle-to-infrastructure (V2I) communication. As an example, the 'European Car 2 Car Communication Consortium' (C2C-CC) is an industry-driven organisation set up by the European vehicle manufacturers and supported by equipment suppliers, research organisations and other partners. The objective of the consortium is to develop, harmonise and standardise technologies for V2V systems.

A new communication technology at 5.9 GHz is currently being developed and standardised worldwide. It consists of a wireless technology for point-to-point communication between vehicles and ITS infrastructure, as well as V2V communication (McNew, 2010). According to Lamy (2013), the main technical characteristics that make it possible are:

- It is a microwave media with an operating frequency of 5.9 GHz.
- The 5.9 GHz-based OBU is a transceiver, which can transmit and receive data at any time.
- Its range is greater than 5.8 GHz technology (up to a few hundred meters in line-of-sight) which leads to increased accuracy.
- High bandwidth: data rates (around 50 Mb/s) are higher than any current mobile network operator (MNO) service.
- It uses open standard IEEE 802.11 communication layers that are already widespread for Wi-Fi equipment.
- It can provide short range vehicle positioning.

The most innovative feature of this technology is the transceiver OBU, which allows V2V communication without the need for an external infrastructure network. The 5.9 GHz system can ensure transaction management with at least the same level of accuracy as the 5.8 GHz system (see box below), allowing the use of an OBU incorporating both technologies. In this scenario, the operating frequency of 5.8 GHz in DSRC-based common electronic systems would be kept available for toll collection, while 5.9 GHz would provide additional services to users, such as safety-related applications (collision warning applications), real time traffic information and payment applications. The benefits for the toll operator would be considerable, as the 5.9 GHz technology is fully interoperable with free-flow schemes and future related applications. Furthermore, it would provide lane localisation, which would facilitate the management of High Occupancy Tolling (HOT) lanes and congestion pricing approaches (McNew, 2010).

However, full migration to systems exclusively based on 5.9 GHz seems unlikely in the short and medium term because of their cost. While it would provide new value-added services and opportunities, toll operators are expected to retain the existing technologies, especially 5.8 GHz tolling infrastructure.

Box 12: Accuracy of 5.9 GHZ technology

In 2008, a performance evaluation test of a 5.9 GHz-based electronic toll system was conducted by the Southwest Research Institute of San Antonio (SwRI) and the company KAPSCH. The trials were carried out on the E470 highway in Colorado, where the Public Highway Authority allowed installation of the electronic toll technology on a beam over one set of open road toll lanes at Parker Road.

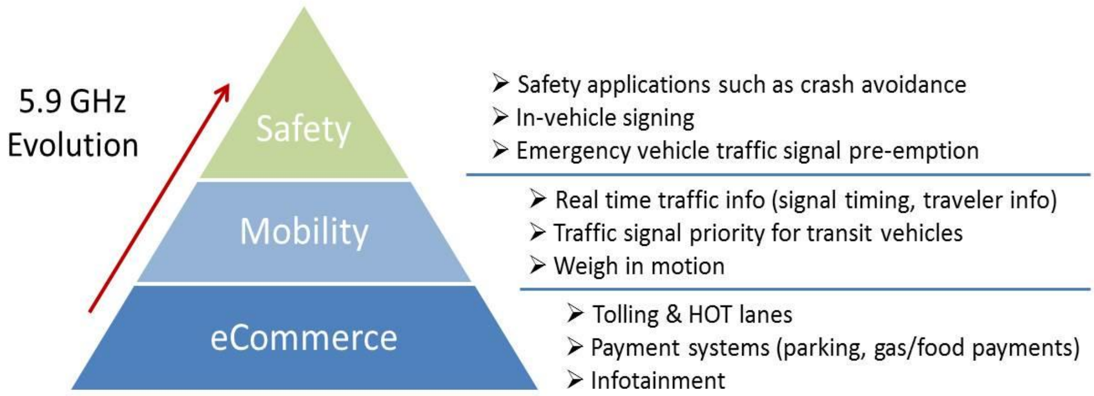
The system comprised 5.9 GHz reader antennas, vehicle detection and classification lasers, cameras and lights. A fleet of 27 test vehicles made approximately 11,000 passes under the KAPSCH reader antennas. The SwRI compared the records with a count of passing vehicles using a separate GPS system, concluding that the 5.9 GHz system had obtained a 100% level of accuracy (Toll Roads News, 2008).

This technology could operate jointly with GNSS technology by providing higher reliability where satellite signal may be lost, especially in urban areas or tunnels.

Costs related to OBUs and infrastructure equipment are the largest percentage of total costs. The 5.9 GHz-based OBU would probably not be expensive as it is based on existing open standards (IEEE 802.11) and would not require R&D costs. Furthermore, vehicle manufacturers might be interested in incorporating the technology in their vehicles, given increasing interest of the automotive industry in new "real-time" communications and safety. In contrast, infrastructure equipment would mean significant investment costs, especially if global coverage of the road network were planned. As a result, the deployment of 5.9 GHz technology is not expected to be widespread in the short term (Lamy, 2013). Its implementation is instead expected to be concentrated where value-added services may be particularly useful (frequent accident areas, urban centres, in conjunction with tolling, etc.).

Some experts (McNew and Kotsche, 2010) consider that there will be a gradual evolution of the 5.9 GHz system in relation to ITS services, as shown in figure below. They expect that the 5.9 GHz system will initially have eCommerce features, which will be gradually extended to mobility and safety services.

Figure 12 : Functional evolution of 5.9 GHz technology



Source: McNew and Kotsche (2010).

The technical performance of this emerging technology, its high level of accuracy, its potential interoperability with other systems, and its ability to enable new value-added services, make the 5.9 GHz system a real option to be considered for ETC communications in the near future.

Future developments of existing and emerging technologies will allow the provision to users of new in-vehicle services such as eCall, traffic status, Pay As You Go (PAYG) insurance and real time driving assistance. The majority of them could be addressed by GNSS technology, as well as by emerging technologies such as 5.9 GHz systems and other telecommunications-based systems. These value-added services would greatly influence the choice of a tolling technology if they were declared mandatory, as will happen with eCall services. In this situation, the technology installed by car manufacturers to meet legal requirements would need to be considered when promoting tolling technology. The table below summarises the impact of the main new technological developments.

Table 14 : Indicative impact/benefits of technology developments

Development Area	Cost reduction	Performance	Operator & customer access to data	Acceptance of privacy	EFC collection rate	Likely timeframe
DSRC OBU Development	X				X	2014-2018
GNSS OBU Development	X				X	2014-2020
RFID Sticker tag development	X					2014-2030
RSE	X					Ongoing
Wide area communications	X	X		X		Ongoing
Digital payment channels	X		X		X	Ongoing
Enforcement ops	X				X	Not likely before 2020
Rationalisation of DSRC standard	X	X				EU decision
In-vehicle cooperative ITS solutions		X	X	X		2020
e-call/usage based insurance	X		X	X		From 2015
Combined GNSS/accelero meters	X	X				From2014
Mapping quality	X	X			X	From 2014
Data processing & storage developments	X	X	X			Ongoing
Satellite coverage		X			X	From 2016
CALM, 5.9 GHz		X			X	2020

4. THE WAY FORWARD

4.1 Purpose of this chapter

This chapter draws on the preceding analysis of ETC technologies to summarise both technological and non-technological issues regarding the way forward for EETS. It also identifies the principal questions relating to harmonisation and proposes some policy recommendations.

4.2 How can technological developments contribute to progress in non-technical areas?

While this report focuses primarily on technical issues, developments in technology also contribute to progress in other areas creating barriers to adoption of EETS, such as cost, privacy and demand for interoperability, which we discuss below.

Table 15 : Indicative impact/benefits of technology developments

Challenge Area	Impact on ETC and EETS
Cost of Ownership	Capital and operating costs of technology for the tolling service provider and end user dominate many of the issues affect the adoption of ETC and EETS, particularly the costs of GNSS OBUs.
Demand for Interoperability	Where there is little demand for OBU-based tolling, there are significant diseconomies of scale of implementing electronic toll collection methods, which then have a consequent impact on EETS.
Privacy	End user privacy is a critical factor which can deter users from adopting OBUs, irrespective of their other merits. Even though the EU's preferred way forward is for national road pricing using GNSS (see GNSS/CN Migration Study, DG TREN, Sept 2009) there are concerns about having all road journeys tracked. Technical work on the EFC Security Framework has only recently been completed by the CEN TC 278/WG1 technical committee, and such standards take time to become adopted in solutions and service provider contracts. Where there are Privacy options for the end user to choose - technology can make the end user autonomous in selecting the privacy settings, based on relative value and costs of the options.
Operating Model and Risk Transfer	How a MS operates and governs the implementation and operation of a tolling scheme. Transfer of delivery and revenue collection risk to a private sector operator is often treated with greater priority than technical interoperability. Implementation of road pricing is seen as a more complex and risky undertaking than other services which are technically more mature.
Political Challenges	In many cases new road pricing schemes that will raise taxes also meet strong political opposition unlike, for example, developments in new telecommunications service provision which are view positively by consumers. Political priorities may be ranked higher than technical interoperability.

Challenge Area	Impact on ETC and EETS
Stakeholder Acceptance	When a new scheme is in the planning stage, opponents can undermine the case for it by referring to privacy, technical complexity, cost and operating risk. This means that Member States tend to focus more on these issues than on technology standards or interoperability.

The most significant challenge for tolled and charged roads is minimising the set-up and operation costs in order to:

- Attract users through an affordable tariff, or generate more net revenue.
- Gain political support for a scheme: if operating costs are a high proportion of revenue, it is less efficient than other forms of revenue or tax collection.

There is therefore substantial pressure to adopt the lowest cost technology so that the local business case for tolling or charging is accepted. The EETS operating model may be perceived as imposing a cost premium on the toll charger, except where there is a high volume of visiting users who need interoperability and adopt an OBU with a payment account. Each MS and tolled road has different vehicle mixes and trip patterns – the business case for each project is typically decided on a case-by-case basis. This means that the following factors have a large impact:

- Frequency of trips by foreign vehicles – low volumes may not justify the additional costs of requiring the installation of OBUs by all local users.
- Enforcement process and driver/vehicle registration may require ANPR as a default for open road operation – the additional costs of DSRC OBUs, readers and controllers may not be justified.

In addition, when a tolling operation or a concession is tendered, the transport authority involved usually seeks to transfer maximum technical and operational risk to the operator and procure a lowest cost solution, making the cost issue even more fundamental. This means that any factor that increases operating costs will be resisted by the transport authority and the operator or concessionaire. This may occur if adopting an interoperable technology or business model increases costs, or implementing a model with multiple service providers (such as a separate main service provider and EETS provider) increases both costs and risks. It is therefore likely that the EETS model will only work well where there is a high 'demand for interoperability', which is likely to be primarily on a regional basis, because the 'demand for interoperability', and the pressure to introduce interoperable systems, are both higher at this level.[29]

In summary, this means that some stakeholders can easily make the case for not adopting either ETC or EETS. The following case studies show how EETS has been adopted or rejected, the issues affecting adoption, and whether technical developments could have improved the outcome. The key is adopting the technology that most benefits end users and provides them with a business case. This has occurred in the road freight sector where truck tolling now operates in much of Europe and:

[29] Non-uniform demand for interoperability and high cost of setting up EETS in low demand nations – ASECAP, Eurotoll, Toll2Go (Fleet Telematics, 28 Jan 2013).

- There is a strong case for road pricing for heavy goods vehicles, because of the disproportionate level of damage to the roads.
- Vehicle tracking and privacy impacts are accepted as part of a commercial operator's role.
- There is a strong case for interoperability to ease the flow of goods.[30]
- The cost of operation is absorbed into the cost of transporting goods and people.

This chapter therefore also explores other in-vehicle applications that could enable wider adoption of EETS.

4.3 Case studies on current and recent tolling schemes

4.3.1 Belgium

Belgium has adopted a single service provider model in its procurement of the ViaPass system, which is due to go live in 2016. This does not involve establishing an independent EETS provider.[31] This option was chosen mainly to deal with cost and delivery risk, and responsibility for working with the three regions in Belgium, which may have different charging policies and approaches to enforcement. The political imperative in Belgium is that the scheme successfully goes live, that the levels of charge are accepted by drivers, and that costs of collection are not a high proportion of the toll, which could lead to criticism.

Could developments in technology have changed this situation? We suspect that if road pricing technology for distance-based charging of trucks was more of a commodity, then the EETS multi-service provider model would have been considered as lower risk.

4.3.2 Denmark lorry charging

The lorry charging scheme was intended to go live in 2015, but has been cancelled primarily for reasons of cost as set out by the government in its July 2012 statement:

"Altogether the Government is not convinced that benefits from Lorry Road Pricing in Denmark compare favourably with the associated administrative cost. On this basis the Governments has decided to refrain from introducing Lorry Road Pricing, as planned, from 2015."[32]

4.3.3 France - Ecotaxe

The proposed "Ecotaxe" in France was due to go live in late 2013, but is now on hold due to pressure from the road haulage lobby and other parties, primarily in relation to the costs of tolls. "Ecotaxe" was officially suspended on 29 October 2013 following a statement from the French Prime Minister.

[30] Michael Nielsen, IRU, presentation to the EC, 5 Dec 2012, on 'What transport operators do and don't want' and the main challenges (http://ec.europa.eu/transport/modes/road/events/2012-12-05-road-pricing_en.htm

[31] http://www.viapass.be/fileadmin/viapass/documents/download/Viapass_Final_Architecture_kilometre_. charge_for_HGVs.pdf.

[32] http://www.skat.dk/SKAT.aspx?oId=305&vId=0.

We suspect that technology developments might have improved this if, for example, road pricing functionality was included with other on-board telematics with which the haulage industry was already familiar, such as within a tachograph, or bundled with eCall.

4.3.4 Dartford Thurrock river crossing - UK

This crossing will be changing from a toll plaza barrier based operation to open road operation in late 2014. The approach adopted requires minimum technical compliance, leaving the choice of technology to the operator. This satisfies the risk transfer objective and seeks to make the operator responsible for all costs including the customer relationship and toll recovery.

Could technology developments have changed the outcome? The costs of DSRC tags (>€10) and of managing them was considered to be high. There are few tag-based tolling schemes in the UK, reducing demand for interoperability. If tag unit costs had been lower (say ~€1) the outcome might have been different.

4.3.5 Humber Bridge - UK

The approach adopted at the Humber Bridge is to minimise the committed cost, for example, to enable interoperability for the quoted 'few vehicles that may require it'. A budget has been set aside to enable compliance, should it be required.[33] The system is due to be switched on in 2015.

The key issue here is low demand for interoperable ETC, making it difficult to justify the additional costs of the EETS model.

4.3.6 A14 - UK

In the UK, tolling on the A14 has been cancelled primarily because of political pressure following consultation and the potentially high cost of tolling operation relative to the toll collected.[34] Introducing additional costs to enable interoperability would probably have further reduced support for the toll.

4.4 Technology and scheme "fit"

To date the most successful and mature interoperable ETC technology is CEN DSRC, but even that has significant CAPEX and OPEX and is therefore only deployed where there is a good fit with the roads to be tolled, the charging policy, the intended traffic management outcomes and the business case. For example, DSRC tags have not been adopted in Stockholm, London or Milan, as ANPR has been deemed sufficient to meet the local requirement, primarily on the grounds of cost and net revenue. The total cost of the system generally comprises planning and design, back office cost, the acquisition and distribution of OBUs (if required), roadside tolling infrastructure, data transmission and enforcement equipment. In this case, CAPEX is mainly influenced by OBU and RSE costs, while the level of OPEX is determined by the payment channels, back office needs, and the management of exception processes such as occasional users, potential toll evaders and enforcement. The levels of CAPEX and OPEX, and their contribution to total costs, will vary with the

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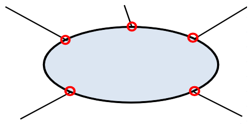
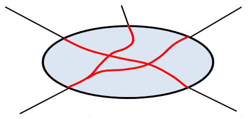
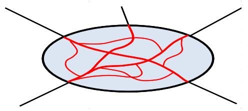
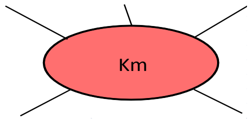
[33] Interoperability for One, Tim Gammons, ITS International, November 2013, http://www.itsinternational.com/categories/charging-tolling/features/european-ideal-poses-local-problems-for-toll-companies/.

[34] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/265311/A14_Cambridge_to_Huntindon_Consultation__2_.pdf.

context. As a result, each ETC technology may be more suited for a specific tolling situation, as illustrated in the table below. However, there are no set rules, as each scheme may have quite different cost, revenue and policy outcomes.

Table 16 : Illustration of typical ETC technologies suited to tolling

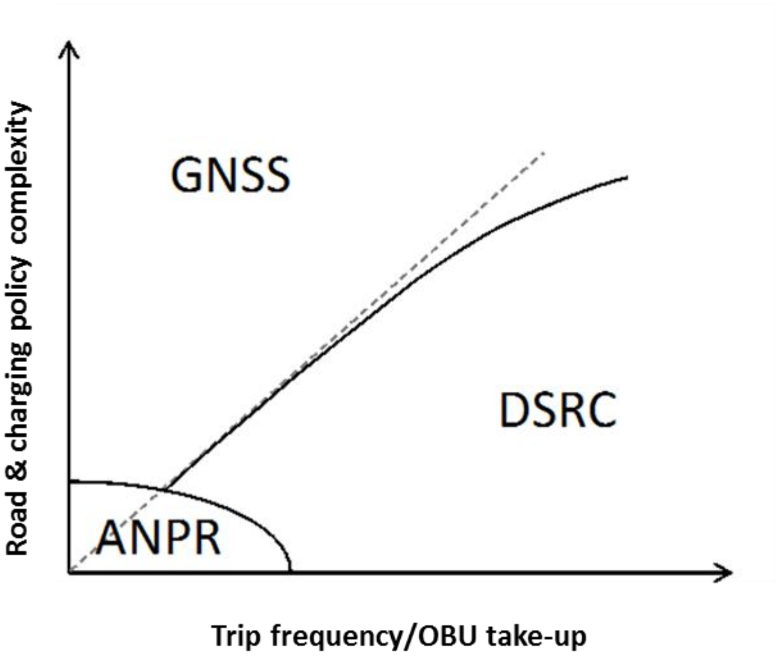
		Tolled road, zone, object, specific infrastructure	TOLLED VEHICLES	
			Heavy goods vehicles	All vehicles
Tolling scheme	Nationwide tolling scheme	High capacity roads	DSRC (GNSS possibly)	DSRC
		National roads	GNSS (DSRC)	DSRC/ANPR
		Rural/all roads	GNSS	GNSS
	Cordon, Zone or Area charging	Typically urban roads	DSRC/ANPR	DSRC/ANPR
	Specific infrastructure tolling	Special tolled sections: bridges or tunnels	DSRC/ANPR	DSRC/ANPR
Charging concept	Access or area charge		ANPR/DSRC (GNSS only where part of a larger scheme)	
	Tolls in high capacity roads		ANPR/DSRC/GNSS	
	Tolls on complex networks		GNSS, DSRC subject to segmentation	
	Charges on all distances		GNSS, Tachograph	

Source: Authors' analysis from Jáuregui (2011) and Oehry (2006).

The analysis in this report has shown that ANPR and DSRC technology is primarily suited to zone or area environments, or where the road network is subdivided into discrete sections of toll road.

These factors are illustrated graphically in the figure below, which plots the level of "road and charging policy complexity" (composed of the length of the tolled network and the number of entry/exit points in the road) against trip frequency/OBU take-up.

Figure 13 : Suitability of ANPR, DSRC and GNSS



Source: Authors' analysis of several reports.

The maturity and reliability of the different types of technology are among the most important drivers in the decision-making process. The possibility of offering new value-added services to the user, and the potential of each technology to do so, should also be considered. The impact on privacy needs to be addressed fully, as the user´s perception of tolling has traditionally been the main concern in achieving a successful implementation. The choice of ETC technology may also be influenced by a decision to create a centralised European registration or tolling system, or to establish transnational enforcement regulation and cooperation.

From our research, we believe that the ETC technology should be chosen after detailed analysis of the costs and business case objectives, taking into account the tolling policy, user base and topology of the road network, and depending on the context and the goals of the tolling authority.

4.5 Implementation of a harmonised ETC approach

Although several pilot projects have been conducted in the last few years (for example RCI[35]) to overcome technical barriers, interoperability (either transnational interoperability between charging schemes using the same ETC technology, or interoperability between different ETC systems) is still limited. EC communication COM(2012)474 suggested a stepwise approach, beginning with establishing regional EETS blocks. Regional EETS[36] (REETS) emerges as a kick-start deployment of EETS, which could facilitate the global implementation of electronic toll collection across Europe.

[35] See http://www.ertico.com/rci
[36] Interoperability of electronic road toll systems in the EU - The European Electronic Toll Service (EETS) Directive 2004/52/EC & Decision 2009/750/EC, Charles Surmont, 29 November 2012 TEN-T Info Day.

At some locations, international traffic represents a significant share of the total revenue of the tolling system, so limiting toll evasion by foreign users is an important challenge. Current regulations and national laws make it difficult to penalise foreign evaders, because of limited cooperation between national authorities in enforcement, and evidence gathered in one Member State is not always legally sufficient in another Member State. As a result, greater coordination of enforcement actions at the transnational level will be necessary in future. There will be a need to promote the exchange of information on toll evasion at an international level and to give greater power to the different tolling authorities for the identification of violators and enforcement processes (as proposed by VERA III and the European expert group).

Harmonisation is also lacking in the legal nature of tolls, which have varying status across the EU. National legislation can define them as a fee, tax or charge. To solve this problem will require greater EU harmonisation of fiscal legislation in relation to tolls.

Achieving sufficient penetration of ETC technologies is also fundamental to the adoption of EETS. The installation of ETC technologies as an additional service provided by car manufacturers, bypassing the need to obtain an OBU independently, would help greatly. Additionally, the legal requirements to achieve the mandatory provision of new in-vehicle services (such as eCall) should be coordinated with a European tolling strategy.

Similarly, it will be necessary to develop legislation to promote the installation of these new services in new vehicles, even if it did not apply to existing vehicles. This policy would enable the creation of a European vehicle fleet equipped with this technology in the near future.

4.6 Framework for progress

Given these challenges, enabling EETS may require the recognition of the local business case and cost impact of the EETS model, particularly where 'foreign' vehicle volumes will be small. It may also require a greater emphasis on reducing the operating costs of the model, including the technology-related costs. This may, for example, involve considering an EETS Service Provider 'of last resort':

- Where the local business case for spend on interoperability is weak.
- Which may be subsidised by Government, but operates in a manner that does not undermine existing operators – a shared service across Member States may meet this in the most economic manner.
- Once the market is more mature this entity could be commercialised.
- Where the key objective might be to meet the freight industry (> 3.5 T) need for interoperability within a predictable timescale across the most 'needy' parts of the trans-European transport network (TEN-T).

Enabling EETS may also require the adoption of a regional model, where the business case for interoperability is simple to demonstrate (as stated by the European association of toll operators [ASECAP])[37], and/or a gradual expansion of interoperability at marginal cost as technology and the operating model matures.

[37] http://www.ibtta.org/files/PDFs/Dionelis_Kallistratos.pdf

The EU should therefore consider technology options for interoperability based primarily on their cost to the operator or transport authority, and the ease with which customers can be persuaded to sign up for an account (implying a minimal cost OBU). In addition it may be necessary to help individual Member States or schemes to design and cost interoperable solutions, potentially through a 'toolkit' of sample solutions and reference costs.

To summarise the discussions in chapters 2 and 3 about the technology itself:

- The most mature ETC technology in place enabling interoperability is currently OBU-based CEN DSRC, but efforts should be made to reduce its cost of ownership – other tag technologies may be able to reduce such costs.
- GNSS is still a developing technology, is yet to mature, and is far from obsolete.
- GSM may be close to becoming obsolete.
- ANPR is also still developing and is required for evidential purposes, even though it is not an electronic tolling method.

Emerging technologies should be reviewed and selected on the basis of how they enable the reduction of system costs, as well as giving users adequate control over their privacy.

4.7 Policy recommendations on a European EFC strategy

This section sets out a number of recommendations to be considered going forward.

4.7.1 Main objectives

The following objectives should be considered in the coming years:

- Generalised and harmonised implementation of road charging across the EU.
- Make the ETC the most utilised means of payment for tolls and road charges within Europe (potentially making it mandatory in the long-term, even for local schemes).
- Set up one single contract and one single OBU valid for the whole EU tolled network.
- Minimise the life-cycle cost of toll collection systems.

4.7.2 Specific areas for policy development

Policymakers should consider the following:

- Implementation of EETS requires an egalitarian and harmonised introduction of tolling devices to users.
- Making the installation of an in-vehicle device, during either the manufacturing or registration process, both attractive for the end user and potentially compulsory, to facilitate EETS take-up. Outside factors may influence the tolling technology to be implemented, especially when an in-vehicle service becomes available in the market (such as usage-based insurance) or mandatory (such as eCall). As a result, in-vehicle technology installed by car manufacturers, or retrofitted, should be considered as an opportunity to coordinate both a harmonised European approach on ETC and the provision of new value-added services.

- Coordination within a car of all the on-board devices, and interfaces for retrofitting, would make EETS implementation easier.
- Coordinated use of the OBU with other navigation and communication systems would facilitate user acceptance of ETC.
- To ensure a harmonised approach to data privacy, adopting the EFC Security Framework, agreement must be reached on what information should be made available and what should remain confidential.
- The potential constraints of existing ETC standards on future measures should be considered on a case-by-case basis; not all solutions may continue to be compatible, though it is desirable that new measures should be interoperable with existing ETC systems.

4.7.3 Practical aspects

The following practical aspects should be reviewed:

- Current technologies (including ANPR) can meet most of the requirements needed to toll roads in Europe at a technical level, but do not deliver the right cost outcome. However, some additional steps are still missing:
    - Enable a more competitive market with regard to the design, manufacturing and distribution of current ETC technologies, to achieve the lower unit costs anticipated in this paper
    - Establish public standards to regulate the use and characteristics of these technologies (including relating to privacy)
    - Establish a common certification scheme for evidence for enforcement
- Operators and users should have the right to choose the simplest and most economical technology to pay tolls electronically throughout the EU. Elsewhere (US, Turkey, Mersey Gateway in the UK) there has been a wider adoption of the new 6C standard RFID OBUs as they have a low, almost disposable, cost.
- Efficient back office, inter-operator settlement and enforcement systems need to be implemented to guarantee toll payments without generating significant additional collection costs for toll operators or EETS service providers.

4.7.4 Weaknesses and recommendations to overcome them

From the analysis conducted in this report, we have identified the following weaknesses:

- Most vehicles in Europe do not have devices installed for paying tolls electronically.
    - Recommendation: promote a generalised introduction of ETC devices across the EU.
- Even though current ETC technologies are compatible with EETS requirements, additional factors need to be addressed to reach interoperability throughout the EU.
    - Recommendation: promote a liberalised market for the manufacture and distribution of ETC technologies. This should be accompanied by promoting a more coherent standard for suppliers to follow.

- ETC technologies still require the implementation of reliable enforcement mechanisms to identify toll evaders and guarantee the payment of electronic tolls within the EU.

  - Recommendation: promote sharing of data on registration and evasion through a secure pan-European registration database with evader/nonpayer details, secured through measures set out in the EFC Security Framework.

REFERENCES

- Artemio J. (2008), *Determinación del Estado del Arte en el cobro electrónico de cuotas,* Secretaría de Comunicaciones y Transportes, Publicación Técnica No. 132, Instituto Mexicano del Transporte.
- Balmer U. (2006), *Kilometer Fee for Heavy Goods Vehicles - The Swiss Experience*, Federal Office for Spatial Development.
- Balmer U. (2003), *Practice and Experience with Implementing Transport Pricing Reform in heavy goods transport in Switzerland*, Federal Office for Spatial Development.
- Cantinelli M., Burden M., Larraondo I., Wurmser E., Nijhuis J., Schnacke D. (2012), extracted from *Debating contactless toll charging by smartphone,* ITS International News, website http://www.itsinternational.com//
- Car2Car Communication Consortium (2014), website: http://www.car-to-car.org/
- Cerny K. (2008), Electronic toll collection in the Czech Republic, Kapsch Telematic Services.
- Cosmen J., Gutiérrez S. (2013), *Precio vs prestaciones en las diferentes tecnologías para el pago de peajes*, IV Jornadas sobre ITS en las autopistas de peaje, GMV, Madrid.
- Dancso L. (2008), *Truck Tolling Solutions – Technological Possibilities for implementation*, Kapsch TrafficCom AG, Eurovignette Congress in Barcelona.
- D'Artagnan Consulting LLP (2011), *Lessons Learned from other Vehicle Road User Charging Systems,* ODOT Flexible Services Agreement 29142/ WOC1: Task 9, Oregon Department of Transportation.
- Datler B. (2011), *The ASFINAG enforcement system, Tolled infrastructures for safe, smart and clean transport.* ASECAP Technical Communications, Brussels 2011.
- Engdahl J. (2013), *Implementation of the EETS in Switzerland*, SIS 18 regional tolling, 9th ITS European Congress – Real Solutions for real needs, Dublin.
- European Commission (2012), Implementation of the European Electronic Toll Service, COM(2012)474, Communication from the Commission.
- European Commission (2012), The European Electronic Toll Service (EETS) ensures interoperability of road toll systems – frequently asked questions, European Commission Memo, Brussels 7 September.
- European Commission (2011), The European Electronic Toll Service, Guide for the application of the Directive on the interoperability of electronic road toll systems, Directorate-General for Mobility and Transport, Publications Office of the European Union, Luxembourg.
- European Commission (2011), White Paper "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system", COM(2011)144.
- European Commission (2009), Commission Decision of 6 October 2009 on the definition of the European Electronic Toll Service and its technical elements, Decision 2009/750/EC, Official Journal of the European Union, L268/11-29.
- European Commission, Expert Group 9 (2006), Specification of the EFC application based on satellite technologies, Report of Expert Group 9 working to support the European Commission on the work on Directive 2004/52/EC, Version 3.2.

- European Commission (2001), White Paper "European transport policy for 2010: time to decide", COM(2001)370.
- European Parliament (2004), Directive 2004/52/EC of the European Parliament and of the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community, Official Journal of the European Union, L200/50-57.
- European Parliament (2002), Directive 2002/58/EC of the European Parliament and of the Council of 12 July 2002 concerning the processing of personal data and the protection of privacy in the electronic communications sector (Directive on privacy and electronic communications), Official Journal of the European Communities, L201/37-47.
- European Parliament (1995), Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data on the free movement of such data, Official Journal of the European Communities, L281/31.
- Federal Customs Administation, FCA (2013), *HVF Overvie: Performance-Related Heavy Vehicle Fee*, Federal Department of Finance FDF.
- FELA (2014), FELA Management AG website http://www.tripon.ch/de/electronic-tolling/base-technologies/infrared-dsrc
- Felix A., Neuenschwander R. (2002), "*WP3: Case Studies, Task 3.2: Case Study Switzerland*", DESIRE project, Design for Interurban Road pricing schemes in Europe, Project funded by the European Community under the Competitive and Sustainable Growth Programme (1998-2002).
- Fuente B. (2008), *Vía-T Sistema de Telepeaje Interoperable en España,* IBTTA Toll Road Summit of the Americans, ASETA.
- Fundación CETMO (2012), *Tarificación vial: aspectos clave y situación en diversos países.*
- Gordin E., Klodzinski J., Dos Santos C. (2011), *Safety Benefits from Deployment of Open Road Tolling for Main-Line Toll Plazas in Florida*, Transportation Research Record 2229, pp. 85-92.
- Jáuregui M. (2011), *Electronic Toll Collection*, Kapsch TrafficCom.
- Kapsch (2013), *Soluciones para el peaje*, ITS Spain 2013.
- Kathawala Y., Tueck B. (2008), *The use of RFID for traffic management*., International Journal of Technology, Poliy and Management, Vol 8., No. 2.
- Kotscher C. (2010), *Intelligent Transportation for a Greener Georgia,* Kapsch TrafficCom US Corp.
- Lamy, B. (2013), *5.9 GHz Which future in Europe?*
- Lawson J.W. (2012), *E-ZPass Virginia: Operational Overview and Challenges.* Virginia Department of Transportation.
- McNew J. (2010), *5.9GHz Tolling Systems,* Kapsch TrafficCom US Corp.
- NFC World (2013), *GeoToll uses NFC to manage RFID road toll payments,* website http://www.nfcworld.com/2013
- Numrich J., Ruja S., Voß S. (2013), *Global Navigation Satellite System based tolling: state-of-the-art,* Netnomics, Springer.

- Oehry B., Haas L., Mahieu V., Scheer S. (2011). *Possible Application of Short Range Communication Technologies in the Digital Tachograph System to Support Vehicles Filtering during Road Controls*. JRC Scientific and Technical Reports. Institute for the Protection and Security of the Citizen. Joint Research Centre. European Commission.
- Oehry B. (2011), *Swiss Heavy Vehicles Fee LSVA – Implementation and Experiences*, Rapp Trans AG.
- Oehry B. (2006), *Charging technology and cost effectiveness*, Rapp Trans.
- Persad K., Walton C.M., Hussain S. (2007), *Toll Collection Technology and Best Practices.* Project 0-5217: Vehicle/License Plate Identification for Toll Collection Applications. Research and Technology Implementation Office, Texas Department of Transportation.
- Pickford A. (2006), *Technology Options for Charging.*
- Prud´homme R., Bocarejo J.P. (2005*), The London Congestion Charge: A Tentative Economic Appraisal*, Transport Policy 12:3, pp. 279-287.
- Q-Free (2013), *Technology comparisons – Systems based on DSRC, GNSS and video (ANPR)*.
- Rapp M., Balmer U. (2003), *The Distance-related Heavy Vehicle Fee in Switzerland*, World Road Association (PIARC).
- RDW (2012), *Road Pricing in Europe, Second version*, Association of European Vehicle and Driver Registration Authorities.
- Rodríguez de la Rubia J., Rodríguez A., García A., Velasco A., López J.C., García J., Santamaría B., Temboury M., de la Fuente B. (2011), *Claves para la introducción de la Euroviñeta en España.* ASETA.
- Salik (2014), website: http://www.salik.gov.ae/en/, Roads & Transport Authority, Government of Dubai.
- San Francisco County Transportation Authority, SFCTA (2014), website: http://www.sfcta.org/
- Schibler S. (2009), *Swiss Heavy Vehicle Fee (LSVA) Electronic Fee Collection System*, Federal Customs Administration FCA, Federal Department of Finance FDF.
- Schindler N. (2012), *The Ascent of Satellite-Based Tolling Systems in Europe and Beyond,* IBTTA Symposium on Mileage-Based User Fees & Transportation Finance Summit, Jersey City, 2012.
- Slovak National Highway Company, Národnádiaľ ničnáspoločnosť (2010), *Multi-lane free-flow electronic tolling in the Slovak Republic.*
- Stone M. (2013), *The path to toll interoperability,* IBTTA Vancouver 2013.
- Thibaut F., Mandalozis D. (2009), *ETC-pioneer services need strong support. The case of Attica Tollway, Athens (Greece),* Violations Enforcement Summit, Boston, Massachussets, IBTTA.
- Toll Collect (2013), *Interoperability with Toll2Go in Austria,* Toll Collect GmbH, Kom, Berlin.
- Toll Roads News (2008), *Kapsch report accuracy of 100% in electronic toll tests with 5.9GHz- SwRI tests,* website http://tollroadsnews.com/news
- Traffic Infratech (2013), website: http://www.trafficinfratech.com/

- TransCore (2014), website: http://www.transcore.com/literature
- Venigalla M., Krimmer M. (2006), *Impact of electronic toll collection and electronic screening on heavy-duty vehicle emissions*, Transportation Research Record: Journal of the Transportation Research Board, 1987(1), 11-20.
- Villalonga E. (2010), *Infraestructuras del Transporte*, Aumar-Abertis.
- Virginia Department of Transportation (2007), *Technologies for toll facility mobility enhancement,* Report to the General Assembly of Virginia.
- Walker J. (2011), *The Acceptability of Road Pricing*, Royal Automobile Club Foundation for Motoring Limited.
- Walker J., Pickford A. (2012), *Moving towards Pay As You Drive.*
- Wondracek C. (2012), *Overview of the current situation and outlook of the tolling market*, Congress Zilina 2012.
- Yang H., Ozbay K., Bartin B. (2012). *Effects of Open Road Tolling on Safety Performance of Freeway Mainline Toll Plazas*, Transportation Research Record 2324, pp. 101-109, Intelligent Transport Systems Committee (AHB15).
- Zabic M. (2011), GNSS-*based Road Charging Systems. Assessment of Vehicle Location Determination,* DTU Transport, Department of Transport, Technical University of Denmark.

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