Study on "State of the Art of Electronic Road Tolling"
MOVE/D3/2014-259

Report
October 2015

European Commission
DIRECTORATE-GENERAL FOR MOBILITY AND TRANSPORT
Directorate D – Logistics, maritime and land transport and passenger rights

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Executive Summary

Introduction and objectives

The principal objective of this study is to provide an overview of those electronic tolling solutions that are available at the current time and those that have potential for the near future. Those solutions are placed in the context of their use in different types of scheme, and to analyse them against a number of different criteria. This provides – for each solution – an evaluation of their cost and relative strengths.

The secondary objective is to analyse the reasons why interoperability between electronic tolling schemes has not yet been achieved on a pan-European basis, and to propose recommendations for toll chargers and the European Commission to move towards the objectives of EETS.

Current state of play

At the present time, the European tolling market is characterised by a diversity of solutions which are based on a legacy of development to meet different technical requirements and to be compliant with differing local legislative contexts.

Tolling schemes are not homogenous - each Member State and Toll Charger has its own legislative context, objectives for establishing a scheme, local context and traffic conditions, and funding landscape.

These varying contexts mean that it is extremely challenging to compare the implementation of a tolling solution in one country to another. Nevertheless, for the purposes of this study, a **range of technologies have been reviewed** in the context of their deployment.

A benchmark among different technologies to be used for tolling and enforcement purposes can be reasonably performed only by taking into account the whole life cost (and therefore not only the investments) of a system.

From this analysis, a set of key themes have emerged that can assist future toll chargers in developing and implementing successful toll schemes. Additionally, concluding considerations have been provided, that are aimed at helping the European Commission to realise their ongoing support for realising the European Electronic Tolling System.

Assessment of the existing tolling market

Tolling related technologies have made tremendous progress over the past decade, and today developing and implementing a nationwide solution presents fewer technological risks than was the case 10 to 15 years ago. Additionally, the technologies are able to make use of ever greater performance from mobile telecommunication networks which make operational processes such as online registration and account top-up far more straightforward.

Nevertheless, the CAPEX (Capital Expenditure[1]) and OPEX (Operational Expenditure) are still significant. The decision about which technology to adopt is often informed by the number of segments to be tolled, the type of road infrastructure, the targeted type of vehicles and their volume, and the expected scalability of the system.

[1] Please note – a full glossary can be found in the Appendix

The research that has fed into this study has illustrated that if a scheme is looking to toll a fleet of more than 500,000 vehicles, and the tolled network consists of fewer than 2,500 tolled segments, then DSRC (Dedicated Short Range Communication) is typically more cost-effective. However, if the same number of vehicles are subject to the toll, and the number of tolled segments rises to above 5,000, then GNSS-based (Global Navigation Satellite Systems) solutions become the more viable option. In addition to this, GNSS-based solutions are typically more scalable and flexible due to the absence of a requirement for physical roadside infrastructure. This was demonstrated by Slovakia in 2014, when the GNSS-based national tolling scheme was extended in three months.

For local tolling applications, the opportunity to use solutions based on emerging technologies such as RFID (Radio Frequency Identification) could be an opportunity to develop optimized solutions. Turkey decided to introduce a mandatory ETC (Electronic Toll Collection) and demonstrated the efficiency and the cost effectiveness of RFID technology as an alternative to existing DSRC solution.

In terms of enforcement, the fact that technology providers have enhanced the performance of their solutions enables operators to better detect and identify violators by automatic means. However, two major issues remain:

- The ultimate efficiency of the enforcement is still reliant on the human resources in the back office, and this has an impact on the operating costs of the scheme.
- A second point highlighted by several interviewed actors who have implemented free flow solutions is that whilst it is possible to identify the number plate of foreign users who contravene the scheme rules, it is not possible to enforce the penalty, unless the user is stopped in the country, or unless there is a bilateral agreement between the respective countries.

The lack of an agreement among the different European Member States for the handling of toll violations also has a limiting effect on the development of video tolling solutions and in general of the deployment of free-flow solutions for all vehicles.

Potential for other tolling technologies

This study has demonstrated that there are a number of technologies that are either already being used for tolling purposes, or could be in the future.

ANPR or video tolling is already a mature tolling solution, and has been used in a number of free-flow schemes around Europe. It offers distinct benefits to schemes, particularly those involving significant numbers of occasional users. At the present time ANPR does not fall within the scope of the EETS Directive as a tolling technology in its own right.

RFID is emerging as a strong technology thanks to its low OBU costs, and has demonstrated its capabilities across other markets and other tolling contexts in the US, Turkey and beyond.

Smartphones and other mobile communications devices show great potential to be used for tolling purposes due to their proliferation in the user community, their platform structure for additional applications, and their flexible nature. However, there are limitations that would need to be overcome before they could be adopted as tolling solution. This includes ensuring that the smartphone could exchange data with the vehicle to guarantee its proper functioning in a secure mode, and that it could be plugged to an energy source. It would mean a complex integration of multiple products which have different life cycles and the benefit for the carmakers is not obvious.

As **autonomous and connected vehicles** emerge commercially, it is likely that vehicles would be equipped with additional short range communication devices that use V2X (Vehicle to anything) communications protocols (include Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications) in the 5.9GHz frequency band. These could feasibly be used to support tolling in the future, although there is no critical mass in the market yet.

Realizing a future for EETS

European interoperability for tolling has not yet been achieved. The REETS initiative is an important step and will help the stakeholders to get a better understanding of the benefits of the including EETS providers into the value chain. The business dimension must be taken into account for any potential evolution of the EETS directive.

A key component of the business dimension relates to the future prospects for potential EETS Providers. There are key challenges facing prospective EETS Providers that need to be addressed before a clear and viable business case can be realized. These include:

- The requirement to agree contractual terms with all Toll Chargers;
- The certification process;
- The uncertainties in relation to the business model for EETS providers and the potential remuneration available from Toll Chargers; and
- The limited ability to enter markets due to local decisions.

Implementing a nationwide toll solution for a country is challenging due to the presence of legacy tolling schemes, their own legal constraints and the need to comply with relevant EU legislation. Interoperability can be a source of savings and the introduction of a third party provider of electronic tolling services can be an asset because the latter typically has more expertise than the local toll charger, as well as the necessary tools to manage complex customer relationships with vehicle owners coming from all over Europe.

Engagement with the tolling community as part of this study has highlighted a number of areas that if properly addressed, could serve to accelerate the realization of EETS. These include:

- The need for the European Commission to proceed with Member States (and/or Toll Chargers) to the development of a harmonised set of specifications for a European GNSS OBU/Proxy (including functionalities, performances and services), to be used as the reference on which any new tolling scheme would be based;
- Stronger and clearer guidance on the interpretation of the relevant EU legislation;
- Amendment of the EETS Directive to allow the use of additional tolling technologies;
- Sustained support for regional-EETS;
- Guidance on privacy and engendering trust between key stakeholders; and
- Business case support for EETS Providers entering the market.

To date, the European Commission has played a key role in supporting the development of interoperability in the tolling sector. However, given the evolution of the market, and the continuous developments in technology, it is our view that there are further opportunities to progress and optimise the market for interoperable tolling in Europe.

Acknowledgements

Many thanks to the many organisations who have been interviewed as part of this study and have provided valuable insights that have helped to shape this study and report. 32 interviews were conducted with Toll Chargers and Operators, ETS Providers, and Technology Providers. These have included:

- 3M
- AETIS
- AGES MAUT GmbH and EETS GmbH
- Asfinag Maut Service GmbH
- ASFA
- Autostrade per l’Italia S.p.A.
- AXXES
- BVMI and BAG
- EFKON AG
- Eurowag
- MEDDE – DGITM – French Ministry of Ecology, Energy and Sustainable Development
- National Toll Payment Services
- NDS
- Sanef ITS
- Shell Deutschland
- Thales Communications & Security S.A.
- Toll Collect GmbH
- Vendeka Defense Industry and Trade Inc.
- Vinci Concessions
- Telepass S.p.A.

Additionally, thanks go to Ondrej Zaoral of Inoxive and Nick Patchett from Pillar Strategy for their contributions and inputs to this study.

1 Introduction to the Study

The European tolling market is today characterised by a diversity of solutions, from both the technical and the operational perspective. Depending on the context (typically the length and the topology of the road infrastructure, the volume and the characteristics of the concerned vehicles, the need to be interoperable with other existing schemes, and others) the road infrastructure operator can decide among different options on the basis of their effectiveness. The convenience of one or another solution strongly depends on the context in which it must be implemented and operated.

The objective of the study - that we have been carrying out on behalf of the European Commission - is to provide an overview of the available and prospective electronic tolling solutions, for the different typologies of scheme and vehicle types, and to analyse them against a number of different criteria, finally providing – for each different solution – an evaluation of their performance.

The scope of the study is on the electronic toll collection (ETC) solution whether based on barriers or open-road vehicle detection. Our focus is the ETC technology used and its suitability for different types of schemes, for this reason in this report we do not address the wider issue of customer care channels, which are generally call centre and web-based back office.

Our main focus is on solutions serving primarily national road pricing schemes, though we also explore single City schemes.

We recognise that the operational design of a toll system has a huge impact on the overall cost and revenues collected. Technology is a substantial part of this; an informed choice of the solution for a scheme can go some way to reducing the burden on the operational responsibilities but technology should not be considered in isolation.

Many other factors affect the cost of implementation and operation of a road pricing scheme, including:

- Whether the driver population is likely to be compliant;
- Quality of vehicle registration databases and accessibility between member states;
- Local legal framework;
- Communications programme used to publicise the scheme;
- Planning and consultation processes that need to be followed within each jurisdiction;
- Commercial structure for the charging operation, procurement and contracting approach, and risk share/ownership between toll chargers and contractors;
- Labour costs which vary widely across Europe;
- Maturity of the local banking and payments industry.

These latter factors vary substantially between member states and for each charging scheme, as a result it is extremely difficult to provide a direct cost/benefit comparison between different schemes and technology systems.

Our approach is therefore to provide an overview of the process for the ETC selection, the different costs through the life cycle of the project and an analysis from the Scheme Owner/Toll Charger/Operator perspectives.

The Report is structured as follow:

- Chapter 2 provide an overview of the EETS directive and the Toll Schemes across Europe (WP1);
- Chapter 3 describes and evaluates the different Toll System (WP2);
- Chapter 4 provide a performance assessment of the different tolling systems and technologies (WP3);
- Chapter 5 summarise an high level analysis on Costs and Benefit (WP4);
- Chapter 6 reports the main conclusions and recommendations.

2 WP1: Market review of toll schemes in Europe

Introduction

Europe is characterised by a significant number of road charging schemes. The charge concept, types of vehicle charged, charged network, and the length of the network all have significant impacts on the design of a scheme, and in the context of this study, the toll systems that are used to detect the charge liability. This is set against a back drop of other factors that also have significant impacts on the scheme design such as a varying set of objectives, tolling policies, commercial arrangements, operating models and scheme characteristics.

In many cases, tolls vary with time of day, direction of travel, category of user and vehicle characteristics to encourage drivers to change their driving behaviour; tolls are not only applied for the purpose of paying for the infrastructure.

As a consequence of that, the existing road charging schemes in Europe are not homogeneous, both from a technical and an operational perspective.

In order to solve the problem of throughput of the traditional toll plazas, therefore to reduce the congestion that the tolling infrastructures were sometime causing, some toll chargers started to deploy electronic toll collection schemes. Electronic toll solutions were deployed as an alternative to more traditional mechanisms, therefore proposed to a subset of the customers as an alternative to more conventional means.

These schemes had been integrated by using technical solutions mostly derived from other applications and without any specific harmonization among the different schemes.

The way these charging schemes are implemented and operated is very different, not only in terms of technologies:

- Distance-based charging schemes: the charge is calculated on the base of the distance travelled by the vehicle and then modulated by other parameters characterising the vehicles;
- Time-based charging schemes: the charge is calculated on the base of the time for which the users is paying, with the charge being again modulated along with the vehicle characteristics;

- Access-based charging schemes: the charge is applied to a specific geographic area, typically part of a city, but could equally be applied to specific infrastructure or other zone (e.g. an airport perimeter).

The first category of schemes is widely adopted across Europe; most charging schemes are based on the principle that a charge is paid by the road user on the base of the effective use of the concerned road infrastructure. A vehicle is charged proportionally on the effective use of the road infrastructure, by using different technical means.

The second category of schemes is referred to as Vignette-based schemes. A vehicle, either a light vehicle or a heavy good vehicle, needs to purchase a vignette that allows him to make use of a certain road infrastructure for a specific amount of time (typically few days, rather than few months or a full year). The fee to be paid is independent from the actual use of the road infrastructure.

The third category of schemes are principally applied to urban areas and specific infrastructure where the user is charged a toll for crossing a cordon, or driving in the liable zone at a particular point in time.

This chapter explores:

- The **legislative framework** for electronic tolling schemes in Europe;
- **Case studies of tolling schemes** in Europe, observing their key features, and operating models; and
- The **issues associated with the realisation of EETS** in its current form.

Legislative Framework

The proliferation of technologies for electronic toll collection systems and the related business models have been limiting interoperability at many national borders, thereby hampering the internal market. The various European electronic toll collection (ETC) systems introduced at local and national levels from the second half of 1990s onwards are generally non-interoperable and each requires vehicles to be fitted with a different electronic tag or on-board unit (OBU).

Figure 2.1: Challenge facing EETS - one user, multiple OBUs

Source: DIRECTS/Mackinnon

International hauliers currently need many different on-board units and tolling contracts, in addition to a certain number of vignettes, to cover the whole network. The variety of road charging agreements in Europe means that users do not receive, across the EU, consistent price signals and incentives to more sustainable use of the infrastructure.

In order to speed up the complex process to establish technical, procedural and legal interoperability, and following the efforts realized by different players across the European market, the European Commission published in 2004 the Directive 2004/52/EC, aiming to achieve interoperability of the electronic road toll systems in the European Union, by setting-up of a European Electronic Toll Service (EETS), complementary to the national electronic toll services of the Member States.

This Directive sets out the different aspects required for the definition and deployment of the European Electronic Toll Service (EETS) and 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 Provider, giving access to the service on the whole tolled network; the contract would be regardless 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; and
- a set of technical standards and requirements, including technical, procedural and legal issues; technical issues cover aspects such as operational procedures of the service (subscription, instructions for use, customer assistance, etc.), 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.

Commission Decision 2009/750/EC defining the European Electronic Toll Service entered into force on 8 October 2009 upon its notification to the Member States. This implementing decision established the essential requirements of this service valid over the entire EU and sets the mandatory standards, technical specifications and operational rules. The key obligations include the following:

- Member States have to keep national electronic registers of their tolled networks, toll chargers and toll service providers they deemed eligible for registration, and make them electronically accessible to the public. They shall also set up a Conciliation Body in charge of facilitating the contractual negotiations between toll chargers and EETS providers.
- Toll chargers must set their electronic road toll systems in conformity with the technical standards referred to in the legislation and make public their contracting conditions; they must accept any registered EETS provider on a non-discriminatory basis.
- EETS providers have to be registered in a Member State where they are established. They are to reach full European coverage of all the road infrastructures tolled electronically within 24 months of their registration. EETS providers are in competition: every road user is free to contract with the provider of his/her choice.

EETS Providers need to meet a number of requirements including ISO certification and be able to demonstrate the 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 need to adhere to access their toll domains, and accept, on a non-discriminatory basis, any competent EETS Provider.

Three main technologies were identified for electronic toll transactions: **satellite (GNSS) 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.

The EETS should have been in place three years after the came in force of the Decision 2009/750/EC as far as heavy vehicles are concerned. Unfortunately, in spite of the different efforts of the European Commission as well as of other public and private players, the EETS has not been put in force yet. A number of developments have taken place or were supposed to:

- Member States have set up their national electronic register listing the tolled road infrastructures falling under the scope of Directive 2004/52/EC within their territory. The Toll Chargers were supposed :
    - Publish their EETS Domain Statements which set the general conditions for delivering EETS on their infrastructures and constitute the basis for the contractual relationships between toll chargers and EETS providers.
- Propose financial conditions for EETS to operate in the value chain. The potential EETS provider have set up an European association, AETIS, to organize themselves and jointly defend their interest
- New projects launched such as Ecotaxe in France (ultimately this did not go into operation, despite being completed at a technical level) and the Viapass toll solution in Belgium (to be in operation in April 2016) were defined accordingly to the European Directive. The evolution of the Czech Republic toll scheme and the German LKW toll scheme should introduce ETS provider (future EETS provider into the value chain)

Professional stakeholders are becoming increasingly aware of their respective rights and obligations. They generally agree that momentum has been gained to put into place EETS and many elements essential to EETS have already been established. Manufacturers are increasingly contacting the Commission services for additional information or clarifications and contractual negotiations between potential EETS providers and toll chargers have started.

To gain experience in technical as well as contractual interoperability, some toll chargers have established joint solutions offering to customers on-board units that can be used on all the networks under their responsibility:

- "EasyGo", a contractual interoperability service currently in implementation, combining the various DSRC technologies used in Denmark, Sweden, Norway, Austria and two ferries lines in Germany
- "TOLL2GO", a technical interoperability service already in operation, ensuring DSRC/satellite interoperability between Austria and Germany).
- Other toll chargers went even further: both technical and contractual interoperability is operational between TIS-PL, VIA-T and Via-Verde (and a few tunnels in Europe), which allows ETS Provider to offer electronic toll services covering toll domains in France, Spain and Portugal.

In compliance with and in support of the existing EC legislation regarding the interoperability of electronic road toll system (Directive 2004/52/EC and the subsequent Decision 2009/750/EC) the proposed Project (REETS TEN) aims at deploying EETS compliant services in a cross-border regional project. The Project shall cover the electronically toll network of 7 Member States (Austria, Denmark, France, Germany, Italy, Poland and Spain) and Switzerland.

State of the Art in Europe

This section introduces the main principles upon which toll schemes have been and are being implemented around Europe, with focus on schemes that fall within the scope of the EETS Directive as well as for other scenarios that are considered as significant in light of the objectives of the study.

In particular a certain number of case studies have been selected as they are representative of the diversity of the European market, aiming at outlining how the current schemes are different, not only in terms of technologies but also in terms of transaction and operational models.

For each scheme we are also providing a high-level analysis of the charging and enforcement solutions in use.

Distance-based tolling schemes – heavy vehicles

The table below provides an overview of the distance-based tolling schemes for heavy vehicles in Europe.

Table 2.1: Overview of distance-based tolling systems, Heavy Vehicles

Tolling Schemes	Technology used	Country
Free-flow	GNSS with ANPR, and/or DSRC	**Hungary**, **Slovakia**, Belgium (2016)
Free-flow	GNSS with Infrared and/or DSRC	**Germany**
Free-flow	DSRC	Austria, Belarus, **Czech Republic**, Poland, **Portugal**, Turkey, UK(Dartford Crossing)
Free-flow	ANPR	UK (Dartford Crossing)
Free-flow	ANPR and DSRC OBU	Portugal (A22, …, A25)
Free-flow	Tachograph	Liechtenstein*, Switzerland
Free-Flow	RFID	**Turkey**
Networks with toll plazas	DSRC	Bosnia and Herzegovina, Croatia, **France**, Greece, Ireland, Italy, Norway, Poland, Portugal, Serbia, Spain, UK

* Performance-related heavy vehicle charge LSVA

Table 2.2: Distance-based tolling systems for Heavy Vehicles - Selected Case Studies

Case Study	Main characteristics
LKW Maut - Germany	• First GNSS-based tolling solution using a thick-client OBU; • The OBU is not mandatory and there is a manual booking alternative for occasional use; • The operating model is based on a public-private partnership model
"eMyto" - Slovakia	• GNSS-based scheme where the scheme rules have been amended to extend the network coverage; • Enforcement is not-based on a real-time interrogation of the OBU (it relies on a post-processed ANPR method).
Czech Republic	• Free-flow tolling scheme using DSRC
TIS-PL - France	• First country to introduce an Electronic Toll Service Provider into the value chain (in 2007) and reflects nationwide interoperability between tolling concessionaires.
HU-GO - Hungary	• The newest GNSS-based free-flow tolling scheme in Europe.

	• The scheme enables HU-GO-certified telematics providers to offer tolling services to their customers using in-vehicle equipment that is not-dedicated to tolling.
HGS - Turkey	• Available for Heavy Vehicles and Light Vehicles • Large scale tolling solution based on RFID sticker • The enforcement relies on ANPR technology

Key details about the schemes are presented in Tables below:

Characteristic	Toll Collect (LKW-Maut) - Germany	"eMyto" - Slovakia
Type of technology	GPS/GSM	GPS/GSM
Type of network subject to the toll	Federal motorways (12 864 km), trunk roads (1 135 km), some national roads,	Highways, Motorways and selected 1st class national roads
Liable vehicles	>7.5t exclusively for goods transportation	>3,5t including buses
Network length	14.136	2.275
Number of distribution points / service points	3.500 terminals	N/A
Number of enforcement points	300 fixed gantries, 278 control vehicles	N/A
Revenue per / year (€)	4.460 mln	159 mln

Characteristic	Kapsch – Czech Republic	TIS-PL - France
Type of technology	DSRC	DSRC
Type of network subject to the toll	Highways (54%), Motorways (32%), National Roads (14%)	Highways
Liable vehicles	All vehicles >3,5t, incl. Buses	All vehicles>3,5t/>3,5m high
Number of vehicles subject to the toll	686.000	658.000 TIS-PL subscribers (12/2015)
Network length	1.421	9.053
Number of distribution points / service points	250 distribution points and 15 contact centers	Via ETS Providers

Characteristic	Hu-Go – Hungary
Type of technology	DSRC+GPS
Type of network subject to the toll	Highways, motorways
Liable vehicles	HGVs>3,5t
Network length	1.157
Number of distribution points / service points	500
Number of enforcement points	101
Revenue per / year (€)	678 mln

Characteristic	HGS – Turkey
Type of technology	RFID
Type of network subject to the toll	Highways, motorways, bridges

Characteristic	HGS – Turkey
Liable vehicles	HGVs and Light Vehicles
Network length	2.300 and bridges
Number of distribution points / service points	More than 5.000 post offices
Number of enforcement points	97 toll plaza equipped
Revenue per / year (€)	415 mln (around)

Germany – LKW Maut system

Germany was the first country to have introduced a tolling system that uses a GNSS position to establish a liability for charges on existing motorways.

The decision of implementing a free flow solution was based on its flexibility for later extensions without any infrastructure installations (no tolling gantries or toll plazas which was complex on existing highways). So a functional open tender was carried out.

LKW-Maut has been applied to trucks with a gross vehicle weight equal or more than 12 tons since 1 January 2005 and is to be extended to trucks with a gross vehicle weight equal or more 7.5 tons from October 2015. The toll levied is based on the distance driven, the number of axles and the emission class of the vehicle. Germany's toll road network measures around 12.800 km motorway and some 1.200 km federal trunk roads (Source Toll Collect – Date 31st of December 2014). Some 1.100 additional kilometers of Federal roads have recently been added (1st of July 2015).

The system was innovative due to its combination of GPS with GSM networks (CN/GNSS). The toll collection is based on two types of booking solution 1) the automatic system using an OBU and 2) a manual booking solution – a driver can reserve a trip either through terminals (3500 payment terminals in Germany and abroad) or through the Internet. The OBU is provided free of charge by Toll Collect and remains its property but the installation costs are borne by the user.

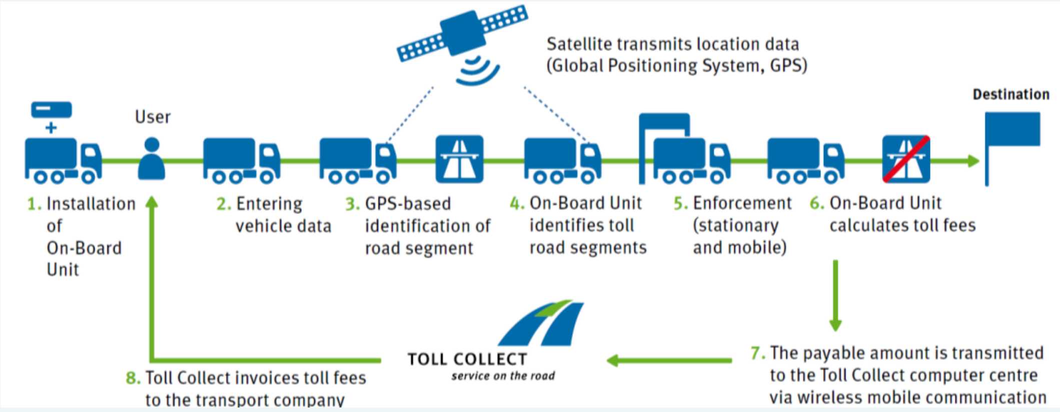
The OBU receives satellite signals via GNSS and references a digitized road map to determine whether the vehicle is travelling on a tolled section of a road. All calculation of the toll liability is being processed inside the OBU and the declaration is then sent securely via mobile communications to the Toll Collect central system. The OBU also contains DSRC technology using Infra-Red (CALM) for interrogation by enforcement facilities. With regards to European standardization, the enforcement system will progressively migrate from infrared technology to microwave-DSRC. Based on the PPP model implemented, BAG is responsible for overall enforcement, using technical equipment and systems provided/operated by Toll Collect:

- Mobile enforcement troops (currently 278 vehicles) to perform an log-on via communication with the OBU, BAG is allowed to stop vehicles in case of fraud detection;
- Manual log-on checked by scanning HGV registration numbers and communication with the Toll Collect central system;
- Portable enforcement equipment that can be used flexibly on the entire toll network;
- 300 fixed gantries with scanners to detect vehicle type and toll liability, ANPR cameras to capture number plates and DSRC sensors to communicate with vehicle's OBU.

On 31st of March 2015 (source: Toll Collect GmbH and BAG), there were:

- 1.080.000 registered vehicles
- 169.500 registered users
- 832.700 mounted OBUs
- 28.030.000.000 toll kilometres (annual figure 2014)
- 93% quota of automatic booking system
- 99,9% availability / level of automatic system
- 10% of tolled traffic is being enforced and 99% is the accuracy rate of the enforcement solution
- Around 12.000.000 controlled vehicles per year.

Germany Automatic log-on



Source: Toll Collect

Toll Collect GmbH operates as the contractor in a Public Private Partnership (PPP) signed with the Bundesamt für Güterverkehr BAG (Federal Office for Goods Transport) a subordinate agency of the Bundesministerien für Verker und Digital Infratruktur BVMI (Federal Ministry of Transport and Digital Infrastructure). Toll Collect has designed, financed, and implemented a satellite-based truck tolling system (CN/GNSS technology) and operates it.

The distance-based truck tolling scheme is a major building block of the federal government’s efforts to improve adequate and fair financing of road infrastructure by means of road user charging. In this context the LKW-Maut is also a major source for financing the so called “A-Modell” scheme which allows the inclusion of private parties into financing of infrastructure investments.

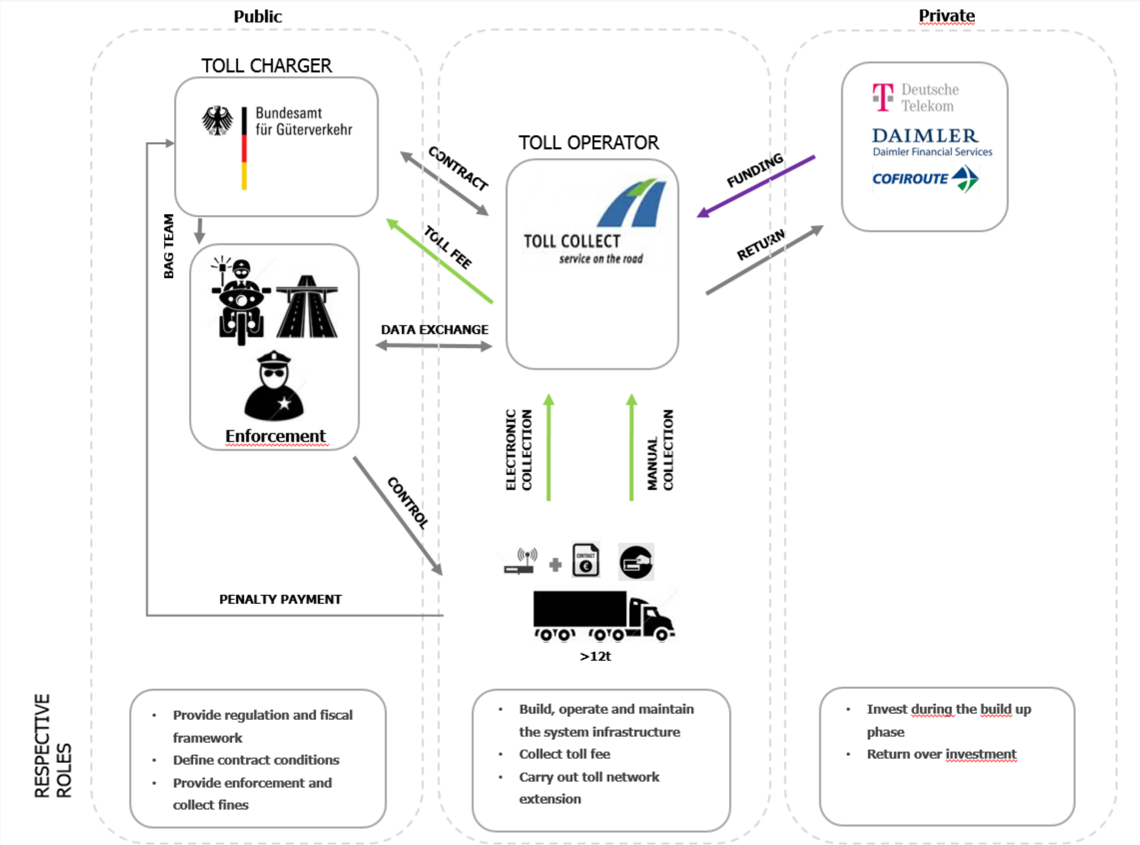
“A-Modell” and “F-Modell” are both PPP-models for road infrastructure available in Germany.

The “A-Modell” addresses projects where a private concessionaire takes over the extension of existing road infrastructure. Typically such projects involve the conversion of four lane motorways into six lane roads. The private concessionaire is reimbursed by user fees generated by a toll levied on heavy goods vehicles. The contracting authority may also provide start-up funding. The “F-Modell” applies to projects where a private concessionaire builds, operates, maintains and finances capital intensive infrastructure like bridges and tunnels and special roads (e.g. mountain passes). The principle is based on the law ”Fernstraßenbauprivatfinanzierungsgesetz“ (Law for private financing of trunk road infrastructure). The private concessionaire is allowed to collect user fees from HGVs and passenger cars in order to re-finance its investments. Formally the fee is a public fee which is regulated in a public decree.

Current PPP for operations of the truck tolling will terminate 31st of August 2018 (including three years of contract prolongation). BVMI is currently preparing the future of the toll collect system with respect to various scenarios, which concern different types of subjects (not officially confirmed yet):

- Extension of the tolled network to up to 39.000 km of federal roads (preparation presumably to be started before end of current contract)
- Tender process in order to find new shareholders for Toll collect and sign a PPP for the next decade or more may also include technological upgrades on the current system)
- Opening of the value chain to EETS-provider

German LKW-Maut based on a PPP Model:



In Germany, the Toll Operator is responsible for the full revenue to be collected. Thus for any reason the system is not running, Toll Collect GmbH has to pay all lost revenue caused by Toll Collect GmbH. The concrete impact is that if the value chain is opened to EETS-providers, they will have to be compliant to strict technical requirements and to assume a high level of guarantees.

For the next PPP contract, the future stakeholder will have to take into account the existing system, which has already a high value and a handover and new migration towards the next toll operator will have to be anticipated.

Slovakia – «eMyto»

Slovakia was the second country to introduce a GNSS-based service in Europe.

The service “eMyto” was launched on January 1st, 2010. The main goal was to toll main national and transit routes - as the Slovak highway network is far from completion, selected 1st class (“national”) roads were tolled as well. The distance based tolling was introduced for all trucks and buses with a gross weight 3.5t+, the vignette system for these vehicles was abolished and remains only for passenger cars (up to 3.5t). Tariffs are differentiated by the number of axles, type of vehicle (truck / bus), emission class of the vehicle, weight of the vehicle (3.5-12t, 12t+) and type of road (highways / 1st class road). The service is nationwide and uses GPS/GSM technology. Starting with January 1st, 2014, the system was significantly extended and covers more than 17.700 km of roads, but toll is being levied only on 2.275 km of highways, motorways and 1st class roads. The rest of the network is being “monitored” mainly for the drivers bypassing of the paid roads.

Technical operator of the system is SkyToll, a.s. The company won a 13 year PPP operations tender for the period 2010 - 2023. Skytoll is tasked with design, building, financing, operating and operating of the system under the DBFOT (Design, Build, Finance, Operate and Transfer) sourcing model. At the end of the contracting period, the system shall be transferred to NDS. Contract extension option for operation until 31.12.2027 can be called by NDS on 31.12.2022 at the latest.

Number of tolled kilometres:

Year	Highways	Motorways	1st class roads	“Monitored” roads
2010	391.155	172.350	1 385.161	0
2011	394.355	225,799	1 379.444	0
2012	393.000	225.828	1 414.393	0
2013	393.000	240,003	1 423.476	0
2014	395.479	238.334	1 635.951	15 466,094

The GPS/GSM system uses a “thin” client OBU, which is compulsory for all vehicles liable to toll. The OBU sends position fixes to the central system where toll is calculated. Pre-paid and post-paid products are available to customers.

As the Slovak highway network was far from its completion when the toll project was launched, it was already in the beginning foreseen, that the toll network will comprise of a large portion of 1st class roads. As these roads had many exits and interchange points, the decision was taken to adopt a GNSS solution.

The system has proven to be scalable. In 2010, the toll collection was “extended” to the Czech Republic for demonstration purposes (this took just 16 days to apply). The system was extended to more than 17.700 km covering almost all roads in Slovakia, using the same technology, just with a performance upgrade.

The scheme started on January 1st, 2014, and it was mandatory for all liable users to have an OBU. The “ticketing scheme” was initially operated on major transit routes (CZ - SK - HU- PL). Toll tariffs are the same for prepaid as well as postpaid users, only the choice of payment methods varies:

- Prepaid (cash (EUR only), bank card and fuel card)
- Postpaid (fuel card and invoice with a bank guarantee)

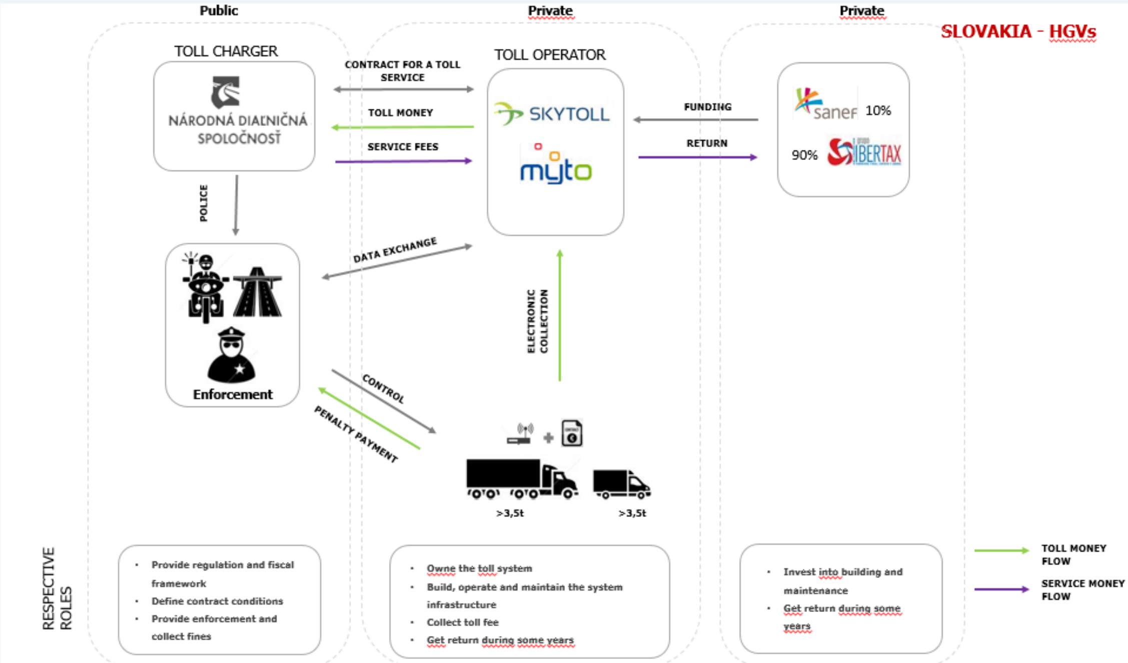
The sole objective of the enforcement is the control of the toll payment liability fulfilment and of other liabilities. These liabilities are defined by the Act on toll collection which includes the documentation of toll incidents and the remedies applied to toll offences.

The enforcement subsystem uses the DSRC communication interface of the OBU. The fixed and portable roadside control stations verify the vehicles technical data and compares it with the vehicle registration data in the central system and the OBU settings. Any suspicious findings ('toll incidents') detected by control stations are sent automatically to the central supervision office where they are processed, classified and verified again. The confirmed incidents are classified as toll offences and then treated in compliance with the applicable legislation.

The Toll Police vehicles are equipped with similar control technical devices as the control stations. The Toll Police also pursues specific vehicles based on the documents from the central supervision office. The Toll Police is entitled to sanction the vehicles in respect to which the toll liability violation is found by high financial punishment – a fine either directly at the point within fine administration proceedings or administrative proceedings at the appropriate Traffic Office.

For 2014: 6.574 incidents were detected and total fines EUR 91.000 were collected (share of Slovak vehicles on incidents 24%). 20.3 millions of vehicles controlled by the fixed enforcement and 4.2 million by the mobile enforcement. The fraud treatment team of Skytoll is around 89 persons.

Here is the operating model of "eMyto":



Czech Republic – DSCR in multilane free flow

Initially, the tolled network was 968 km length applied to the trucks over 12 tonnes. On 1st January 2010, vehicles with a maximum permissible weight exceeding 3.5t had to pay a toll to use 1.345 km of road in the Czech Republic

The toll is collected electronically using the Premid Unit, a small electronic device (OBU) that communicates with the electronic toll system.

Consortium Kapsch was awarded the contract to build and operate the Electronic Toll Collection scheme by the Ministry of Transport. The electronic tolling system in the Czech Republic is based on DSRC technology, applied in multi-lane free flow tolling.

A charge liability for the use of a specific tolled section of a road is detected when a vehicle passes through a toll gantry. Tolling stations (gantries and road side equipment) are built on the tolled road network and are equipped with DSRC transceivers that enable communication between the tolling station and Kapsch's Premid OBU product.

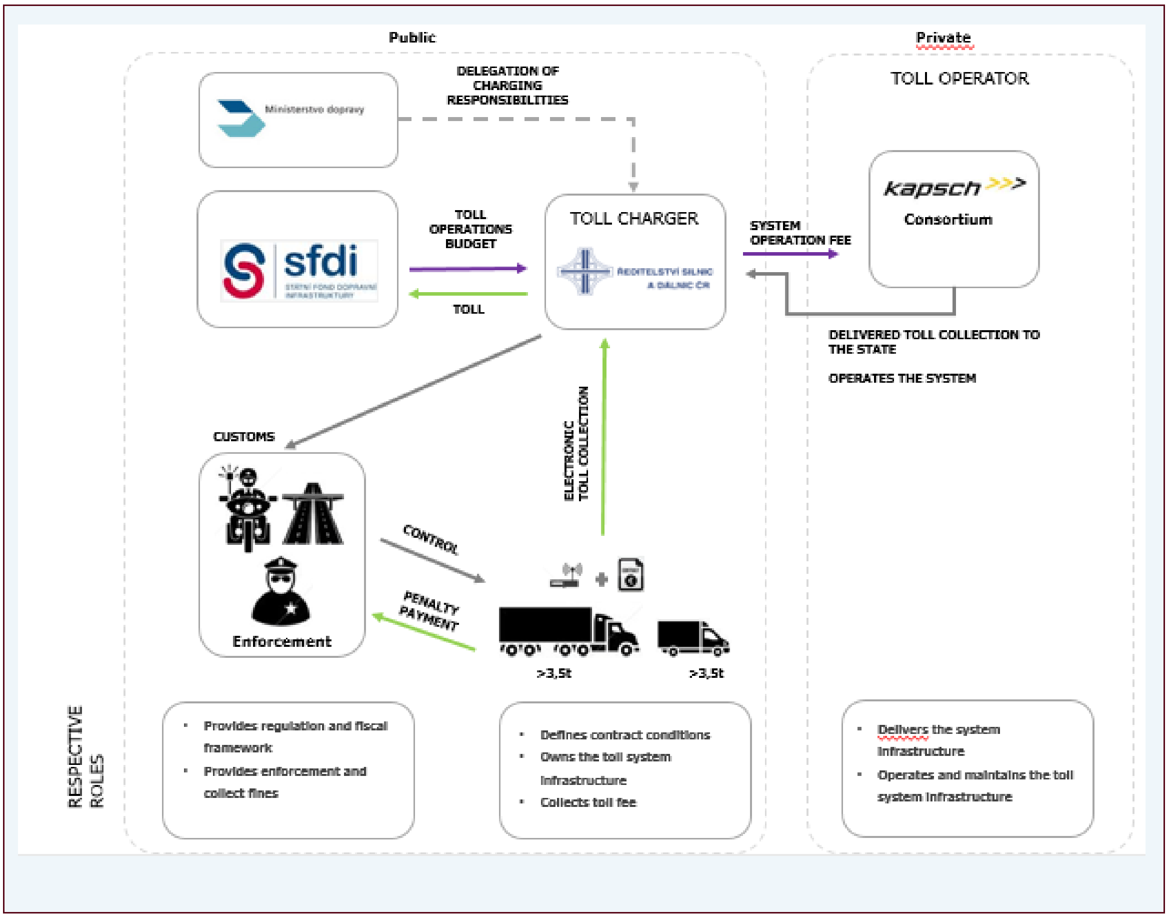
The Czech Republic has two ways of paying the toll: the pre-paid system, where payment is made in advance charging the Premid Unit before entering a tolled road and a post-paid system that requires the signing of a contract between the vehicle owner and the toll system operator, with payment triggered by the user receiving an invoice for their tolls.

Toll gantry in Czech Republic

Source: Road and motorway Directorate, Myto

At the end of 2014, there were more than 712.000 OBUs active in the Czech Republic and 1.425 km of tolled network. (Source: Inoxive).

One major issue on the Czech Republic State is the evolution of the existing scheme with the launch of new tender to allocate the delegation of charging responsibilities. Czech Republic plans to extend its tolled network to secondary roads as Czech Republic is a transited country but is blocked by the former technical choice. Moreover the handover and migration between the existing toll charger and the future one has not been clearly defined yet.


Public
Private
DELEGATION OF CHARGING RESPONSIBILITIES
Ministerstvo dopravy
TOLL OPERATOR
sfdi
TOLL OPERATIONS BUDGET
TOLL
TOLL CHARGER
SYSTEM OPERATION FEE
kapsch
Consortium
DELIVERED TOLL COLLECTION TO THE STATE
OPERATES THE SYSTEM
CUSTOMS
ELECTRONIC TOLL COLLECTION
CONTROL
PENALTY PAYMENT
Enforcement
>3,5t
>3,5t
RESPECTIVE ROLES
Provides regulation and fiscal framework
Provides enforcement and collect fines
Defines contract conditions
Owns the toll system infrastructure
Collects toll fee
Delivers the system infrastructure
Operates and maintains the toll system infrastructure

France – Interoperable DSRC toll domains

In France, the levying of tolls was first introduced in 1955. The Motorway system is based on the principle of works and public services' concession. A concession agreement is a contract by which the State (the granting authority) leaves to the concessionaires companies all the responsibilities for financing, building and operating the motorways. The French concession network is operated by 23 private operators that manage more than 9.053 kilometres of network between them.

The road toll system is based on the distance travelled and depends on the type of vehicles, number of axles and the costs incurred before and after the building of the stretch of road. The tariff, also varies by section of road and operator. Depending on the infrastructure, the toll system is open (payment lanes) or closed (entry lanes+ payment lanes). The motorways network is interconnected between several (until 6 for a given trip) toll concessionaires.

Tolls can be paid

- with automatic equipment by cash, credit card, fuel card
- with ETC Equipment, handling On Board Equipment (DSRC OBU – compliant with CEN DSRC standard) without stopping (30km/h speed limit).

TIS (Télépéage Inter Sociétés) encompasses two interoperable ETC contexts: TIS Liber-t (since July 2000) – 3.5 tons and less - and TIS PL (since January 2007) - equal and more than 3.5 tons. Both contexts are designed in order to allow the concept of one OBU (per vehicle), one contract customer/ETS provider, one invoice, one payment. Any OBU (certified and accredited), delivered to a customer, is accepted by all toll chargers.

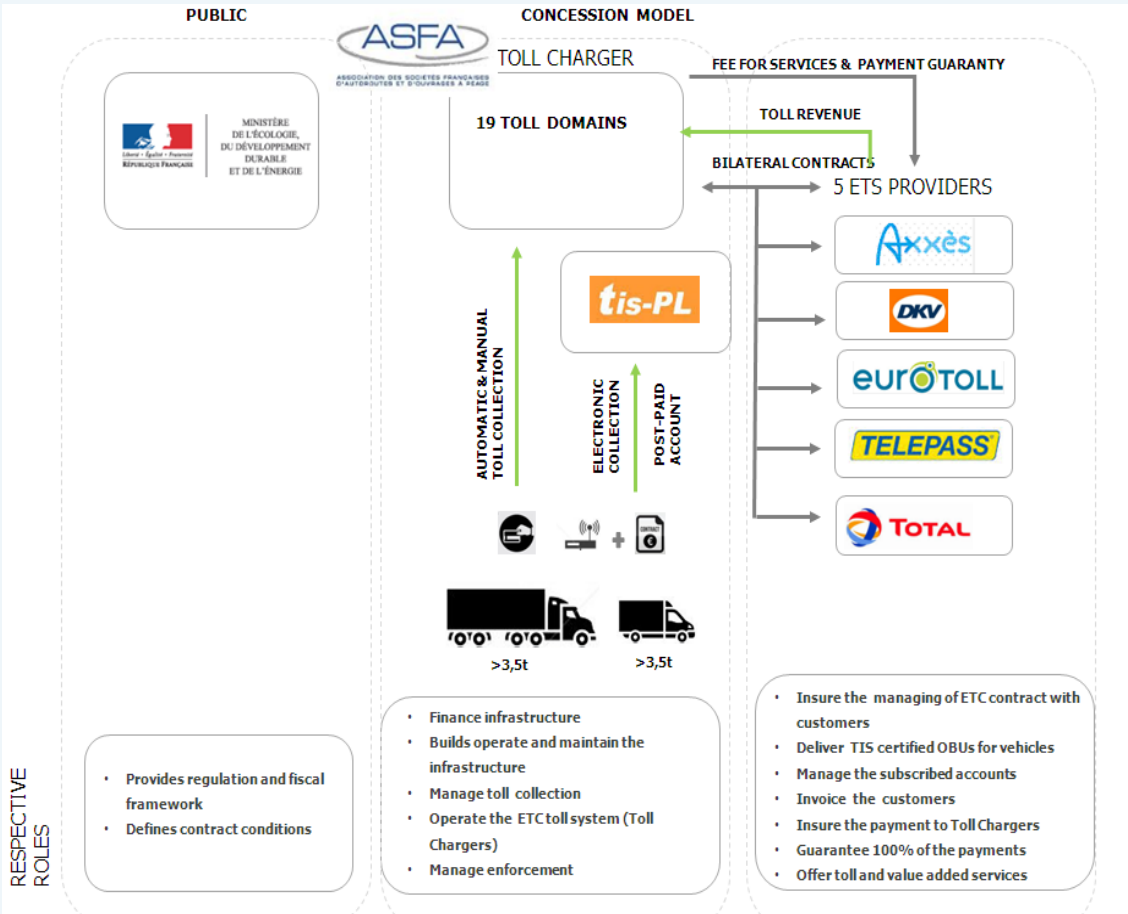
The TIS system allows the use of EN 15509 standard OBUs, with both security levels (with or without Access credential). TIS is the largest interoperable toll collection system in the world, on motorways, bridges, tunnels and parking. It encompasses (figures at end of 2014 – Source ASFA):

- 11 ETS Providers accredited for Liber-t and 5 accredited for TIS PL;
- 4 633 ETC toll lanes, including 577 lanes at 30 Km/h;
- 19 Toll Chargers for motorways, 400 light vehicle parking, 12 secured heavy vehicles secured parking;
- Annually, 567 millions of Liber-t transactions, 151 millions of TIS PL transactions;
- ETC usage rates are 45 % for light vehicles and 85 % for heavy vehicles;
- Annual amount collected by ETC ; more than 5 billion Euro;
- The number of OBUs exceeds 6 million.

The Concession model was selected by the State to finance, build and operate the highways (more than 9.000 km), bridges and tunnels in France. As it's a concession model, the traffic risk is partly relying on the concessionaire. A consequence is that to finance the project, a concessionaire has to secure his lenders and takes the assignment to perform internally the toll calculation.

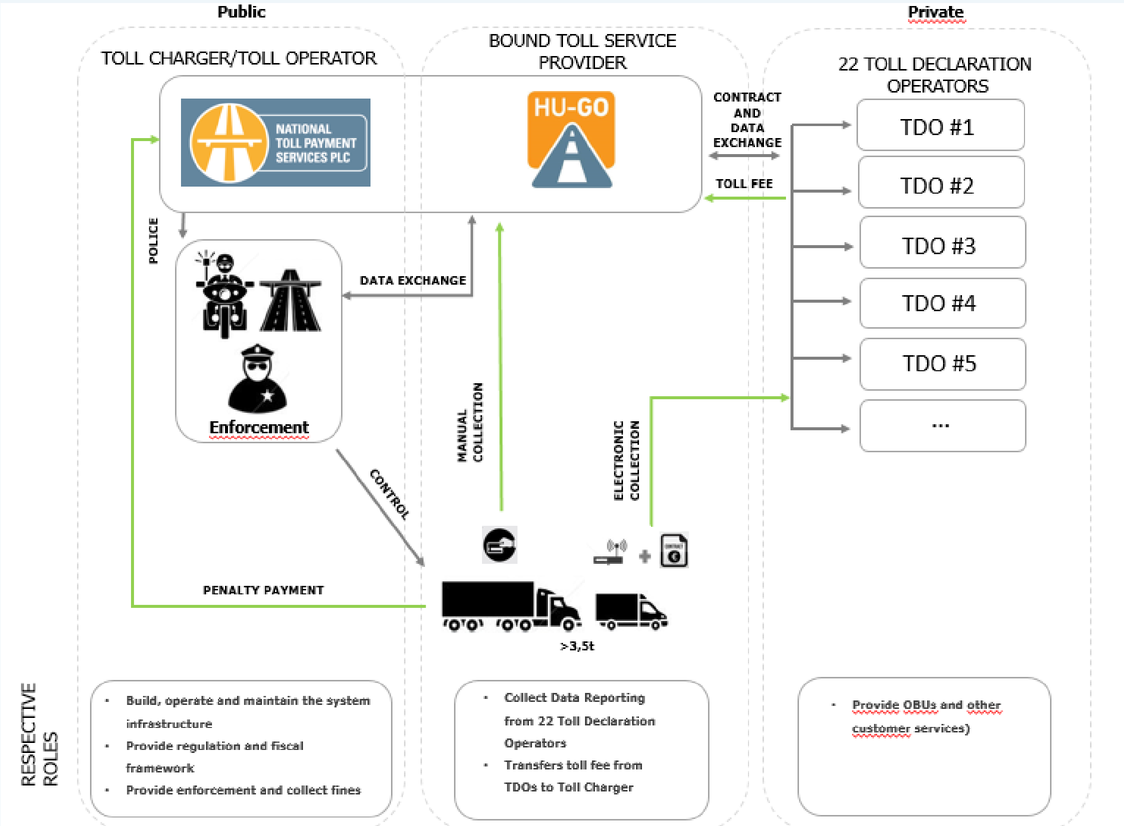
When it launched the Ecotaxe project (2007-2014), the French Ministry of transport had to take into account the existing toll domains and insure a full interoperability and secure the fact the ETS Provider could be also part of the Ecotaxe value chain.

TIS PL Organisation



The OBUs delivered by the above ETS Providers, accredited for TIS, are also accredited in Spain (VIA-T), in Portugal (VIA Verde) and three tunnel in Belgium (1) and in Germany (2).

The Hungarian Toll Scheme

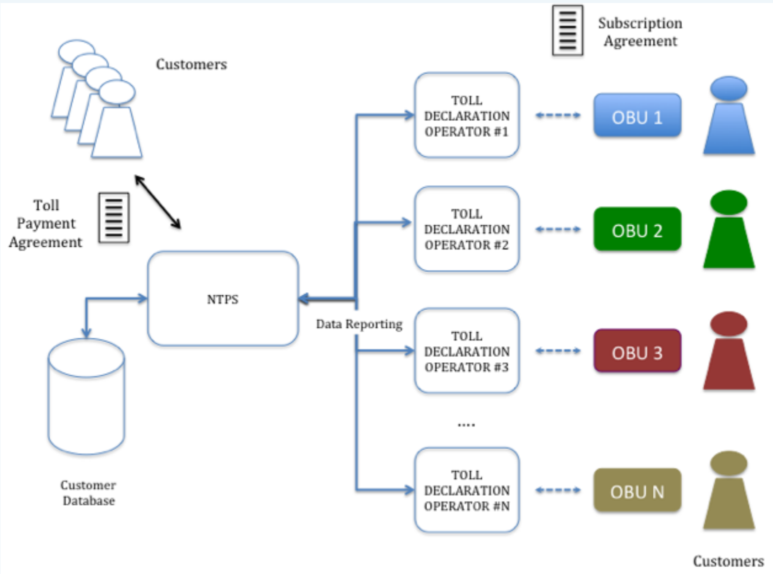


The block diagram above shows the different players involved in the operation of such system (in particular in the recording of the road usage and in the detection of the travelled road sections) and the relations among them all.

In particular the following players are involved:

- Customer, the road user eligible for the payment of the toll along the concerned road network in Hungary;
- Toll Declaration Operator, one of the several service providers that provide the Customers with an OBU recording the road usage in the frame of a service contract (Subscription Agreement);
- Bound Toll Service Provider, who collects from the different Toll Declaration Operators the Data Reporting with all the travelled toll sections;
- Toll Collector (or Toll Charger), that accounts the travelled sections onto the relevant user account and performs the actual charging.

Functional scheme of the HU-GO system



Source: HU-GO

In the specific cases of an OBU mode, the Toll Declaration Operator provides the Customer with a GNSS OBU (unless this OBU was already being used for other services), that is recording the raw element in regards to the usage of the concerned road network and transmits these information to a data processing unit (operated by the relevant operator).

The data processing unit of each Toll Declaration Operator makes use of the elementary road usage data collected by each OBU to detect the toll section travelled by the vehicle, by means of map matching mechanisms. The entire road network is divided into the 2 243 toll sections.

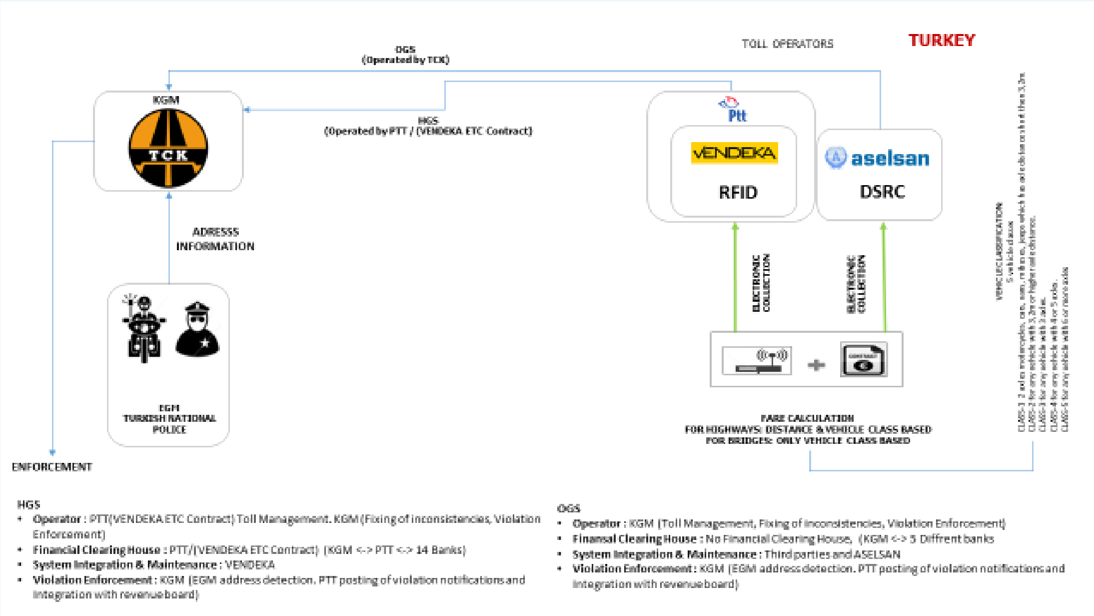
The information about the travelled toll sections are sent over to the Bound Toll Service Provider within a data set referred to as Data Reporting. Specific service level agreements exist between the Toll Declaration Operators and the Toll Charger, to ensure that the Data Reporting are transferred within the shortest time possible and that the Data Reporting includes all the toll sections that have been actually travelled by the user.

In particular the terms and conditions ruling the relations between the Toll Charger and the Toll Declaration Operators specify that the Data Reporting sent by a Toll Declaration Operator shall cover at least 99.8% of the number of the theoretical data reporting within a month (and 94% after 15 minutes). HU-GO has defined an algorithm that can measure the time elapsed between the sending (ITS – means insert time stamp) and the use of time (ETS – event time stamp) in among of all the tickets (source: DTO guidances).

The Police are acting as the Enforcement Agency, detecting, identifying and enforcing road users who travel along the concerned network without having purchased the necessary rights. Violation cases. The action is supported by 101 enforcement gantries and 45 data collection vehicles).

According to those examples, we notice that the existing schemes are different and that any initiatives of unification which could be a facilitation for interoperability requires time and a necessary consideration of the existing toll schemes.

The Turkish Toll Scheme



Turkey introduced a DSRC-based electronic tolling solution in 1999 on existing toll plazas. The number of DSRC users remained low, whilst the level of traffic increased. More than 300.000 vehicles cross the Bosphorus each day and Istanbul has more than 2 million visitors per day.

The General Directorate of Highways (KGM/TCK) decided to introduce a new ETC solution that will run in parallel with the existing one. One requirement was to equip all vehicles so that the toll payments could be administered using ETC solutions. RFID technology was chosen due to the fact that it was cost effective – less than 2 EUR for a RFID tag – and for ease of distribution (an RFID tag can be sent by post in a classic letter). Additionally there is no maintenance (no batteries compared to DSRC OBU).

The block diagram above shows that RFID and DSRC are operated in parallel by two separate operators. Today, there are more than 11.5 million ETC OBUs in Turkey:

- 9.5 million RFID (65% of which use prepaid accounts)
- 1 million DSRC

The pricing is distance-based for light vehicles and based on the distance travelled and the number of axles and for heavy goods vehicles.
The CAPEX and OPEX of DSRC and RFID toll lanes are similar.
The enforcement in Turkey is performed by ANPR.

Time-based tolling schemes – heavy vehicles

In terms of time-based tolling schemes for heavy vehicles, the schemes in Europe are summarised below.

Table 2.3: Overview of time-based tolling systems, Heavy Vehicles

Tolling Schemes	Technology used	Country
Vignette	e-Eurovignette	Belgium, Denmark, Luxembourg, Netherlands, Sweden
Vignette	Electronic vignette	UK
Vignette	Sticker	Bulgaria, Latvia, Lithuania (paper), Romania

Distance-based tolling schemes – light vehicles

The following table provides an overview of the distance-based toll schemes that apply to light vehicles around Europe.

Table 2.4: Overview of distance-based tolling systems, Light Vehicles

Tolling Schemes	Technology used	Country
Free-flow	DSRC	Belarus, **Portugal**
Free-flow	ANPR	**Austria**
Network with Toll Plazas	DSRC	Bosnia and Herzegovina, Croatia, Denmark, France, Greece, Ireland, Italy, Norway, Poland, Portugal, Serbia, Spain
Network with Toll Plazas	RFID (based on 6C tags)	Turkey

A case study has been provided for Portugal and Austria. Portugal was the first country to introduce free-flow DSRC-based tolling for light vehicles. The Video-Maut scheme in Austria enables light vehicles to pay for their access to a series of roads using an ANPR-based solution.

Key details about the schemes are presented in Tables below:

Characteristic	Via Verde - Portugal	Characteristic	Video Maut - Austria
Type of technology	DSRC	Type of technology	DSRC
Type of network subject to the toll	Highways, motorways	Type of network subject to the toll	Highways, Motorways, tunnels, bridges
Liable vehicles	HGV>3,5t Buses	Liable vehicles	all vehicles >3,5t
Network length	2479	Number of charge points	800 charging points
Number of charge points	156 toll plazas	Number of enforcement points	100 stationary gantries, 20 portable, 25 mobile
Number of distribution points / service points	171	Revenue per / year (€)	1.135 mln
Number of enforcement points	102		

Portugal : All Electronic Tolling (AET)

Most the motorways in Portugal have been subject to the payment of a toll, along with a closed tolling architecture. Since 1991 DSRC-based electronic tolling has been introduced and widely applied across the whole network of Portugal, with a very high market penetration in terms of OBUs (today more than 3 million subscribers, 50% of the vehicles are equipped with an OBU). The motorway network includes approximately 2.900 kilometres of road, some of which are toll free. A part of this network was initially managed by means of shadow tolling mechanisms. This network, as well as other section of motorway in Portugal, have recently being upgraded to an All Electronic Tolling (AET) system, referred to as ex-SCUT roads (*Sem Custos para o Utente*, "No Cost to Users").

Portugal has then become one of the first countries in Europe to introduce a free-flow system for paying tolls of all vehicles. On the ex-SCUT, the user is charged in a multilane free-flow environment, using:

- either a DSRC OBU (mainly post-pay but also in pre-pay mode)
- or a video tolling mechanisms (pre-pay and post-pay modes).

There are no toll booths or physical barriers and as a result, the traffic flow is not affected.

SCUT roads map

Source: Estradas de Portugal S.A.

Austria : Video Maut system

In Austria vignettes are compulsory on all motorways and expressways, except special toll routes, on the A 9, A 10, A 11, A 13 and S 16, where special toll tickets can be paid either directly at the respective toll station or paid in advance by purchasing a video toll card. These road sections are tunnels and special alpine roads. The tolling scheme used is an ANPR-based video tolling system. With the video tolling system, special toll tickets can be purchased before commencing the journey. When the user buys the ticket, the number plate is registered and approved. As soon as the registered car travels trought the automatic processing lane the number plate is identified, the barrier opens and user passes without stopping.

Austria Special Toll (in blue)

Source: web site Asfinag

Time-based tolling schemes – light vehicles

The table below summarises the time-based tolling schemes that apply to light vehicles within Europe.

Table 2.5: Overview of time-based tolling systems, Light Vehicles

Tolling Schemes	Technology used	Country
Vignette	Sticker	Austria, Bulgaria, Czech Republic, Hungary (e-vignette), Romania (paper vignette), Slovenia, Slovakia, Switzerland
Toll with physical barrier, or free-flow	DSRC, ANPR – differs by scheme	UK

Access-based tolling schemes – all vehicles

The following table provides a summary of the access-based schemes that are applied to all vehicles around Europe.

Table 2.6: Overview of access-based tolling systems, All Vehicles

Tolling Schemes	Technology used	Country
Access-charge (cordon charge)	ANPR	**Sweden (Stockholm)**
Access-charge (vignette)	ANPR	UK (London Congestion Charge), Milan (Area C charge)

A case study is provided for the Stockholm Congestion Charging scheme as:

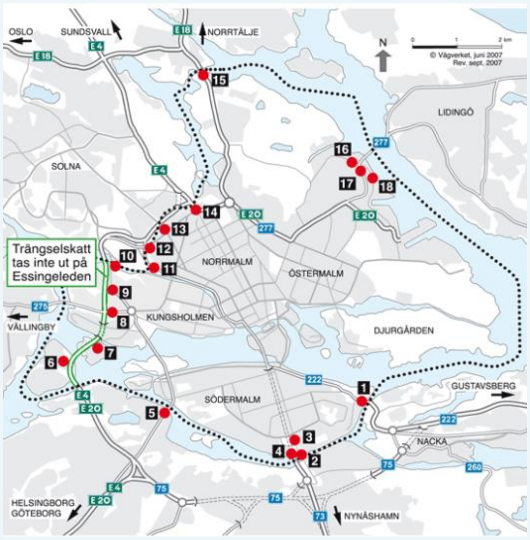
- It is an urban tolling scheme
- It initially used a DSRC-based approach to detect the liability but then changed to using ANPR.

Stockholm Congestion Charging system

After a trial period, in 2007 a system for administering a congestion tax in the city of Stockholm was introduced on a permanent basis. The primary purpose of the congestion tax was to reduce traffic congestion and to improve the environmental situation in central Stockholm.

The system is based on 18 control points on all roads that lead to the inner city, as shown in the map below. Passages in and out of central Stockholm are automatically registered, during the periods when the congestion tax is charged, by capturing an image of the vehicle's number plate. The traffic flow is not affected by the control points, as drivers do not have to stop or slow down for the liability to be detected. A bill is sent to the vehicle owner at the end of each month.

Stockholm: Location of Control Points

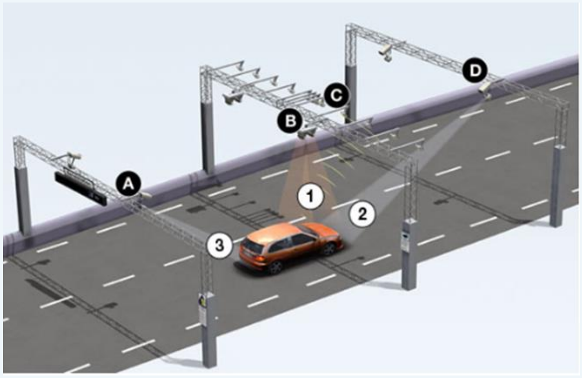


Source: Swedish Transport Agency

The control points are identified by a sign displaying "Betalstation" that also shows the current amount of the congestion tax. The tax is charged from Monday to Friday between 06.00 and 18.29. There are no charges on Saturday and Sunday, public holidays or days before a public holiday or in the month of July. Each passage cost SEK 10, 15 or 20 depending on the time of the day.

Vehicles are registered and identified by ANPR at each control point. A vehicle passing through the control point is detected by a laser (1 in figure 4 below), triggering cameras which capture an image of the front (2) and then the rear (3) number plates. The vehicle's number plate number is immediately identified in the camera using OCR technology (Optical Character Recognition).

Technology in Stockholm

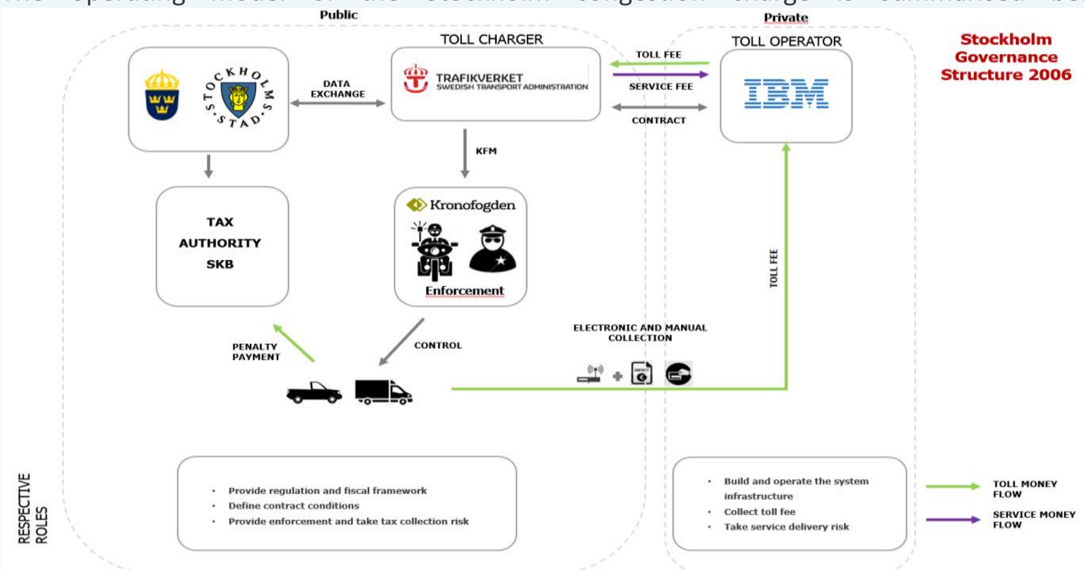


Source: Swedish Transport Agency

Information registered at control points (date, time, control point, number plate number and amount) and the tax decision made is stored until the tax has been paid and the processing of the matter completed.

The system was built by a consortium consisting of many different companies with the main contractor IBM. It was a build and operations contract with the ministry as the principal. The contract had a period of 3 years and could be extended for one year. During this period some of the activities were sourced from "Vagvarket" (Swedish Road Administration).

The operating model of the Stockholm congestion charge is summarised below:



EETS: Main issues and prospects

Because of the complexity and the diversity of the schemes, technologies, contexts and objectives, a significant number of challenges exist that represent a barrier to the realisation of EETS across Europe.

A the outset, the initial assumptions used to form the Directive and subsequent decisions seems in fact to be now inconsistent with the current commercial framework:

- The percentage of transport companies that deliver pan European services is relatively low.
- Due to the increased presence of logistic operators, the transport of goods has fundamentally changed and the route definition is now optimized by tracking the fleets. The availability of a single OBU for Europe is not necessarily a main priority for the final user;
- The pan European solution for tolling for the passenger car does not seem to be a priority for most of the travellers.

In addition, even if signing up agreements within 24 months (as requested by the Directive) with the more than 140 toll domains can be feasible, from the business case prospective is rather challenging for a provider to establish a business case setting themselves up as a pan-European EETS Provider.

Toll Charger

From the Toll Charger prospective, in a number of cases the core features are yet to be defined or published by the relevant Toll Charger:

- Toll Statements;
- The role of EETS in their Toll Domain and any related remuneration;
- The type approval or certification process for engaging with the scheme.

Introducing ETS Provider into the value chain requires the technical adaptation of an operational system.

The major issue for the existing Toll Chargers is how to finance the introduction of a new player into the value chain. There are a few possible options available to the Toll Charger:

- They could increase the toll rates paid by the final user;
- They could decrease the current level of remuneration to the incumbent toll operator (who in term would likely look to reduce its activity and limit its risk exposure with the final user). This could present significant issues from a contractual and commercial perspective as such a case was not contractually anticipated. Furthermore, it is unclear how the value brought by the ETS Provider could be calculated;
- The Toll Charger could wait until the next evolution of the national toll scheme before looking to introduce an ETS Provider into the value chain.

The French concessionaires introduced the TIS-PL solution and the TIS-PL issuer (ETS Provider) because they considered that managing the relationships with transport companies from all over Europe was not their business. Thus, the ETS Provider layer was introduced in 2007 and the concessionaires paid a fee to the ETS provider for guaranteeing the toll payment. Not all current Toll Chargers have evaluated the benefits of such an approach like in France, Spain and Portugal with their interoperable DSRC solution.

EETS Provider

The current ETS provision market consists of different actors, each with their own business interests and motivations. This varied set of business drivers means that there is not a one size-fits-all approach to engaging with EETS Providers.

- Companies like AirPlus, Axxes, DVB, Eurotoll, Eurowag, Ressa, Telepass, etc. are organisations whose main business is the providing tolling service and VAT recovery. Most of them are operating in several countries in direct or through alliances and local commercial agreements. For these firms, directly entering into new market areas all over Europe is unlikely to represent a positive return over investment (ROI). Recent attempts at creating a service provision model for a national road tolling scheme (specifically the Ecotaxe in France) involved very significant investments (around 50 million EUR for an ETS provider option 3.). The cancellation of that programme meant that there were commercial consequences for the ETS providers that will be long to overcome. The result of this is that some providers are more wary of similar investments in the market area.
- Fuel card player like BP, DKV, Shell, Total, UTA … where the provision of tolling services is complementary to their core business. Investing into EETS is not therefore their priority
- “Applicant to be an EETS” like AGES EETS which is the first player to be registered as EETS (May 2015 in Germany). It positions itself as an interface between the European Toll domain and the players that are managing the relationships with the hauliers.

The toll domains are including some local requirements that the EETS provider has to support and this makes the type approval process complex and expensive to manage. Any subsequent evolution of the OBU, requires the EETS Provider to partially or totally re-perform the type approval process which means that there would be additional costs and delays to the deployment.

Some Toll Charger will also require exceptional requirements that may inadvertently block ETS Providers (e.g. the ‘Trusted Element’ in Netherlands during their most recent attempt at introducing nationwide tolling in 2010 which would have been a certified component within the OBU that protected the users privacy and sent an aggregated declaration to the scheme owner relating to the users charge liability).

The aggregated costs for assessing interoperability and carrying out “suitability for use” tests required by certain Toll Chargers from an EETS Provider may constitute a barrier to business entry.

A number of existing **concession contracts may need to be amended**. For instance Toll Chargers may need to adjust the toll rates to be able to finance the necessary investments they must do to adapt their infrastructure. In the case of road tolling, concession contracts for levying tolls are between a Toll Charger and the Member State or an agency working under direct control of public authorities. Therefore the responsibility for making possible the implementation of EETS on their territory lies primarily with the Member State concerned who can amend the existing concession contracts if necessary.

3 WP2: Toll Systems Evaluation

Introduction to toll systems

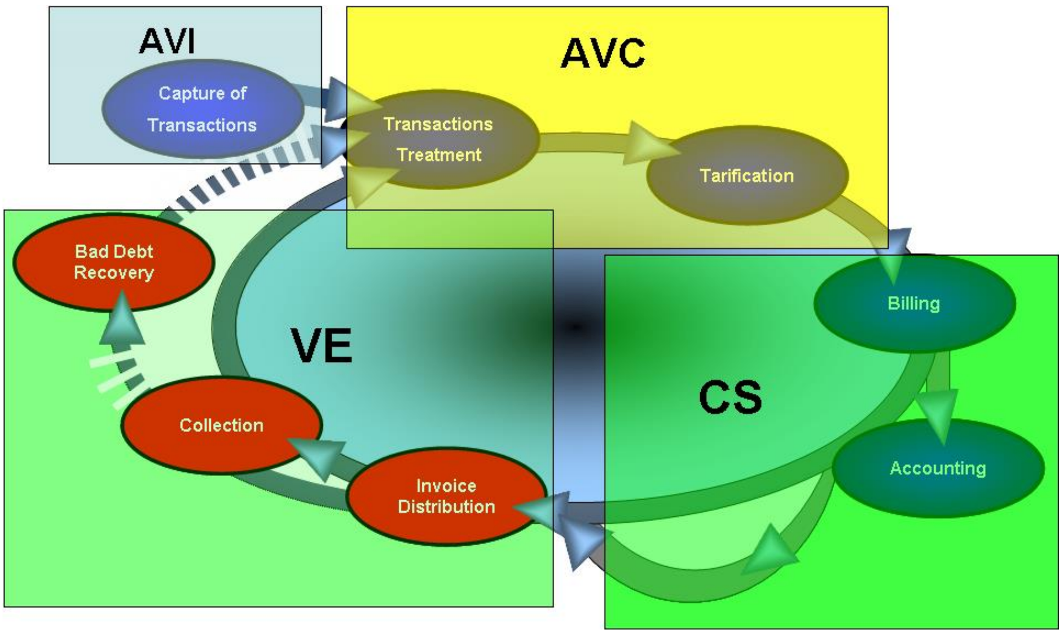
We have seen that across the different countries, depending on the local or national context, different charging schemes are implemented along with different operational approaches.

Different technical solutions and technologies have been deployed in Europe to support the different tolling schemes. The initially adopted proprietary solutions have gradually been replaced by more standardised technologies and solutions.

However, the toll system is a combination of different components either technical or operational that must be combined to provide the most cost-efficient system for the specific requirements and environment.

Every tolling systems incorporate four major components, namely *Automated Vehicle Identification*, (AVI), *Automated Vehicle Classification* (AVC), *Customer Service*, and *Violation Enforcement*. Each component is described below.

Figure 3.1: ETC System



Automated Vehicle Identification

The automatic identification of a vehicle involves the transmission of an identification code between an in-vehicle device and a roadside reader. For ETC, the vehicle identification number is linked to the customer’s account from which the appropriate toll is automatically deducted.

Automated Vehicle Classification

The number of axles is the most common vehicle toll classification scheme, although a range of other parameters can be used including vehicle length and height of vehicle above front axle. AVC equipment can provide a check and determine the proper vehicle classification for electronic toll collection

Customer Service

Customer service may be provided at a physical customer service centre, by telephone, or over the Internet. The functions of the customer service centre include:

- Creation and Maintenance of Customer Accounts.
- *Issuing Transponders*: The customer service centre assigns a transponder to each vehicle under a given account. These transponders must be requested from the toll authority’s tag warehouse and tracked as inventory. Once assigned to an account, the status of the transponder (active, inactive, lost/stolen, etc.) becomes part of a customer’s account history.
- *Accounting*: Customer account balances are constantly fluctuating in real time as a result of toll transactions, automatic replenishment via credit cards and/or bank account transfers, customer invoicing, and in-person transactions at the customer service centre.

Violation Enforcement

The primary goal of enforcement is to ensure that there is an acceptable level of compliance, and enforcement efforts are considered to be fair and consistent. The following are the key elements of violation enforcement:

- License Plate Image Capture.
- Name and Address Acquisition.
- Violator Payment:
- Legal System Interfaces: In some country, toll violations become a citable offence, generally under traffic or parking laws and regulations. New tolling authorities must work with local courts to determine the legal, technical, and resource-related issues surrounding toll enforcement, in terms of how toll violations will be processed in the court computer system, what are the evidentiary requirements, and what is a reasonable violation penalty. The penalty must effectively discourage violators without being so harsh as to potentially tax the resources of the courts with a large number of appeals.

While on most systems Automatic Number Plate Recognition is related to violation enforcement, on some systems it is also a means of verification that a vehicle has paid. For example, in London the Congestion Charge does not have any transponders and consequently users register a number plate when they pay. On some other systems “virtual” day passes can be bought that always travel on the toll road without an account or a transponder.

In both these cases, the non-violator users are identified as “non-violators” using number plate recognition.

Inevitably, such processes are linked with violation enforcement as they both rely on the ANPR system.

The focus of this Chapter is to provide:

- An **overview of the different Technical Solutions** that are presently deployed, or could be used in the near-future;
- A description of the **key cost-components** associated with the sub-systems of different tolling scenarios, enforcement techniques, customer relationship functions, and the payment solutions; and
- A discussion on the **future technologies** in this area and the factors that will influence their evolution.

Technical solutions

Today the existing toll schemes in Europe mostly make use technologies that are compliant with the ETC Directive (i.e. GNSS, DSRC, or GSM) but still legacy solutions are operated in some cases and countries. This applies to both charging and enforcement.

Where customers are signed up to accounts, it is generally the “liability for the toll” that is processed electronically, where the actual collection of funds is still operated through a pre-pay account being debited or post-pay mechanism as for more traditional schemes.

Here below the key technologies that are currently used and/or that appear as promising solutions for the near future are detailed:

- Automatic Number Plate Recognition (ANPR) also referred to as Video tolling;
- Dedicated Short-Range Communications (DSRC) technology;
- Radio Frequency Identification (RFID);
- Global Navigation Satellite Systems (GNSS) technology;
- Tachograph-based technology;
- Mobile communications (GSM and smartphones) tolling systems.

Here below these alternative solutions are detailed. These are technologies that are generally used to identify the vehicles, either for tolling or for enforcement purposes.

Automatic Number Plate Recognition (ANPR) is a technology that uses cameras and optical character recognition for vehicle identification. It does not require on-board units (OBUs) and involves “less costly” roadside equipment. A vehicle is recognised by means of its license plate number, for either tolling or enforcement purposes. However, an ANPR-based scheme typically requires either

- a national number plate database to enable Toll Chargers to issue users with their bill; or
- a system that enables users to register for an account so that the Toll Charger is aware of their number plate and has a link to a payment account.

Mostly used for enforcement purposes, ANPR technology is currently used in urban congestion charging schemes, such as London, Stockholm and Milan, as well as for charging on interurban infrastructures where video tolling mechanisms are offered to the users. The use of such technology for tolling purposes is not really covered by Directive 2004/52/EC for EETS.

Dedicated short-range communications **(DSRC)** technology is the most widely adopted across Europe, and it is also mentioned within the EFC Directive. It is based on bidirectional radio communication between a fixed roadside equipment (RSE) and a mobile device (OBU) that is installed in a vehicle; 5.8 GHz ISM communication channel is mostly used, even if in some specific cases legacy systems make use of other proprietary solutions. By means of such communication, the road user (and its vehicle) are identified by the roadside infrastructure, in order to trigger the payment. Depending on the complexity of the technical implementation, the on-board unit can be represented by a simple identification tag or storing more information supporting the vehicle classification and the identification of the travelled path. The DSRC technology is used either in a single lane environment (as in the case of the systems operated in Italy, France and Spain, among others) or in a free-flow environment (as for the cases of Austria, Czech Republic and Poland).

Radio Frequency Identification **(RFID)** technology uses radio waves to automatically identify on-board devices, very much like for the DSRC technology. But operating on a different frequency bandwidth (in the range of 915 MHz) RFID-based tolling systems still make use of a “tag” installed in the vehicle, which is detected and identified by means of a reader antenna installed within a toll plaza or over the carriageways. More recent RFID technology achieves similar performance levels to DSRC, although the lower frequency and the limitations on the emitted power imply a certain reduction of service level, especially in a free-flow multilane environment. This solution is widely used in the USA, it has been recently deployed in Turkey and it is being considered in the UK. Interoperability with existing ETC systems may require significant investment.

Another technology cited by the Directive is the joint use of ***Global Navigation Satellite Systems*** **(GNSS)** in conjunction with GSM for communications. GNSS systems allow to determine the vehicle´s position on the base of the signals received from a network of orbiting satellites (part of the GPS, GLONASS and in the future Galileo scheme). In this case the on-board unit (OBU) is more complex, since it needs to identify its location and to collect and process the necessary information to measure the road usage, without the aid of roadside units. This is the technology that has been selected for the national tolling systems for heavy vehicles in Germany, Hungary and Slovak republic system. This will also be used in Belgium as part of the Viapass system (to be introduced in 2016). In all the cases above GSM and its successor technologies (GPRS, 3G and 4G) are used to pass data between the OBU and back office computer systems used for billing.

Tachograph based tolling – only used in Switzerland to collect road charges for heavy good vehicle traffic – is based on the registration of the mileage driven by the vehicle within a toll domain by means of an OBU connected electronically to the vehicle´s odometer. Mileage data is copied to a special chip card, provided by the tolling authorities and integrated within the OBU. At the end of each month, the information recorded within the chip card are transferred to the operator for billing purposes. The tolling system is complemented with roadside equipment (RSE) at border control stations, which activate and deactivate the OBU when crossing the border so as to charge only for mileage driven within the country.

Mobile communications (GSM and smartphones) is generally only an adjunct to support data collection from an OBU, or customer access to internet-based payment. However, as mobile cell sizes and location-based services have developed and improved their capabilities, it has become more feasible to use cellular-based location services for the purposes of detecting a vehicle journey and therefore to calculate and apply a charge. These tolling systems are still underdeveloped but may have significant potential in the near future. This tolling system could potentially share its role with a phone and may not necessarily require a dedicated OBU, potentially allowing lower initial investment costs when compared with other location based technologies such as GNSS. On the other hand, the technology is not yet mature and there are still many data accuracy issues that need addressing. In addition, the development of telecommunications-based technology is very volatile. Systems based on GSM – stipulated by the EFC Directive in 2004 – have become obsolete very quickly due to developments in the mobile phone and cellular network industries. As GSM has been included in Directive 2004/52/EC we review its capability in this study – in practice we suspect GSM should be substituted for the preferred communications technology at the time.

The following chapters analyse different technical and operational approaches with respect to:

- Toll collection technologies and solutions, i.e. solutions used to collect the data on the use of the road infrastructure and to charge the corresponding toll;
- Enforcement technologies and solutions, i.e. solutions used to verify the compliance of the road users with respect to the charging schemes and to collect the related evidence;
- Central System and IT solutions, i.e. the processing of the tolling and enforcement data, the invoicing and payment flows
- Customer Relationship and Assistance solutions, i.e. solutions to let the road user register themselves with the appropriate schemes and, where applicable, to obtain the relevant on-board unit.

Tolling sub-Systems

A summary of the key cost components of different tolling technologies are set out in the table below.

Table 3.1: Supporting infrastructure

	Technologies					
Supporting infrastructure	**DSRC**	**GNSS/ GSM**	**ANPR**	**Sticker tag**	**Mobile phone**	**Manual collection**
In-vehicle equipment	Yes	Yes	No	Yes	Yes	No
Roadside Equipment	Yes	No	No	Yes	No	Yes
Roadside Infrastructure	Yes	No	No	Yes	No	Yes
Roadside Communications	Yes	No	No	Yes	No	Yes
Roadside Power	Yes	No	No	Yes	No	Yes
Back office/central system	Yes	Yes	Yes	Yes	Yes	No
National number plate database	No	No	Yes	No	No	No
Toll Plaza (land)	No	No	No	No	No	Yes
Toll Plaza (barriers, booths, canopy etc.)	No	No	No	No	No	Yes
Local payment collection (e.g. cash handling, staff costs, card handling)	No	No	No	No	No	Yes
Back office billing and payment processing	Yes	Yes	Yes	Yes	Yes	No

Further detail on these cost components relative to the type of tolling scenario are provided in the sections below.

Manual Toll Collection

This is the most traditional means that toll chargers have been used over time to collect a charge for the use of a road infrastructure. In this case a charge is collected in cash (or eventually by means of payment cards) by a toll collector when a vehicle is crossing a charging point, with the tariff being calculated (as a minimum) on the base of a distance travelled and of the characteristics of the vehicle, in both an open and closed environment. Manual and/or automatic vehicle classification schemes may be integrated within the toll system, in order to support the work of the toll collector as well as to monitor it.

This method of collecting tolls is widely used throughout Europe, in particular in those countries that have use toll collection as a means of financing the construction and the operation of toll motorways under a concession regime; toll motorways in Italy, France, Spain, Portugal, Greece, Slovenia, Croatia are largely using them, although most countries in Europe have adopted this approach in at least few facilities. Besides the local currency, in some cases also foreign currencies are managed; checks are accepted in some countries (e.g. in France). At the same point of collection, the toll collector is usually able to accept also private cards (issued by the toll charger itself), debit cards, credit cards and in some case fuel cards.

Vehicles are typically constrained to travel across a toll lane, within a toll plaza, both in entrance and exit from the road facility; therefore vehicles are forced to significantly slow down when passing through the toll lanes and stopping in front of the toll collector to handle the payment, so that the throughput of vehicles over time gets significantly reduced (down to 250 to 300 vehicles per hour). In order to handle all vehicles, it is often necessary to allocate a significant ground, and therefore a number of parallel toll lanes, to a toll plaza.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Civil works for toll plazas	Personnel costs
Land expropriation	Cash handling
Tolling equipment	Tolling equipment maintenance

In this particular case toll collection is performed by means of toll plazas (more or less extended in function of the level of traffic to be managed) and toll collectors who do classify the vehicles (when no automatic pre-classification is implemented), calculate the tariff in accordance to the specific vehicle category and to the origin-destination ratio, and collect the toll by cash or by payment cards.

As far as the main cost elements are concerned, it is in this case difficult to provide information that can be representative of the set-up and of the operating costs of such a solution, as they strongly depend on the specific context. Every tolling system and every country are different and the cost that have been faced by one or another concessionaire and/or operator cannot be considered as representative of a general case.

From the investment perspective, the civil works necessary to build the toll plazas (including the cost for land expropriation, the set-up of the canopy, the toll booths and other) represent the main cost element. In addition to that, each toll plaza has to be equipped with one or more toll lanes, both for entry toll lanes in a close toll environment (where the user collect a ticket) and for exit lanes.

Although the characteristics that these tolling equipment are requested to fulfil can vary from country to country and from domain to domain, the typical cost for the procurement of such tolling equipment can be in the range of:

- 25.000 to 40.000 EUR for a manual toll collection exit lane;
- 45.000 to 105.000 EUR for a toll plaza supervision and operation system, depending on the complexity and on the level of intelligence that is delocalised from the back-office towards to the toll plazas.

These costs do not include the procurement and the installation of the toll booths (25.000 EUR per lane in average) and of the relevant air conditioning systems, as these are typically procured as part of the toll plaza civil works.

With regards to the operation and maintenance costs, the personnel costs – linked to the toll collector managing the physical collection within the toll plazas – represent the main cost factor, together with the cash handling (either internalised or externalised). The maintenance of the tolling equipment is then driving yearly maintenance costs that are in the range of 15% of the corresponding investment.

The table below provides a summary of the toll collection costs that are typically associated with manual tolling schemes.

Table 3.2: Manual tolling cost components summary

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Land costs	Yes	1.000.000	4.000.000	per toll lane	N/A	N/A	N/A
Toll collection	Labour costs	Yes	N/A	N/A	N/A	210.000	300.000	Covering 24/7/365 staffing per lane
Toll collection	Roadside Infrastructure	Yes	45.000	105.000	Per lane	15%	15%	% of CAPEX
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Self-service collection

The automated processing machine was a significant improvement in toll collection technology. Many of these machines have been in place for over 40 years. They replace a human toll collector with an automated machine that accepts payment cards, tokens or cash, even exact change coin transactions. The automated machine offers the ability to process tolls at a significantly higher rate than manual toll collection. The methodology still requires the automobile to fully decelerate and the driver to interact with the machine or to deposit the coins or tokens in the basket prior to proceeding.

This is the natural evolution of manual toll collection mechanisms, whereas automatic machines are handling the whole process of toll collection without any involvement of personnel for the toll collection. Also in this case a charge is collected by means of cards and in some case of cash by means of a self-service machine, with the tariff being calculated (as a minimum) on the base of a distance travelled and of the characteristics of the vehicle, in both an open and closed environment. Automatic vehicle classification schemes (more or less complicated) need to be integrated within the toll system.

This method of collecting tolls is widely used throughout Europe; toll motorways in Italy, France, Spain, Portugal, Greece, Slovenia, and Croatia are largely using them, although most countries in Europe have adopted this approach in at least few facilities. At the same point of collection, the self-service machines are usually able to accept also private cards (issued by the toll charger itself), debit cards, credit cards and in some case fuel cards.

Again vehicles are typically constrained to travel across a toll lane, within a toll plaza, both in entrance and exit from the road facility; therefore vehicles are forced to significantly slow down when passing through the toll lanes and stopping in front of the toll collector to handle the payment, so that the throughput of vehicles over time gets significantly reduced (down to 300 to 350 vehicles per hour). In order to handle all vehicles, it is often necessary to allocate a significant ground, and therefore a number of parallel toll lanes, to a toll plaza.

Toll authorities report a further significant improvement in efficiency in the hourly processing rate when exact coin or token machines are used. Specific scenarios of this kind have demonstrated to achieve a range of 750 to 800 transactions per hour for exact change machines.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Civil works for toll plazas	Tolling equipment maintenance
Land expropriation	Cash handling
Tolling equipment	Commissions for card payment

This case is very much similar to the Manual toll collection system as the tolling equipment that are necessary to collect the tolls in a self-service mode are to be installed within the same environment (toll plazas) where the manual toll collection lanes are installed. Self-service toll lanes (accepting or not cash) are installed in parallel to manual toll collection lanes.

Therefore the same considerations made for the manual toll collection case, with regards to the significant investments necessary to set-up the toll plazas, apply in this case.

With respect to the necessary tolling equipment, the cost for the procurement and installation of a self-service lane can be significantly higher with respect to the manual toll collection lanes, in particular when these equipment are able to accept and return cash. These costs can be in the range of 50.000 to 200.000 EUR.

As the toll is collected in a full automatic mode, the personnel costs do not play a major role in this case, besides for the cash handling operation and especially in the case that this service is internalised by the system operator. The yearly maintenance of the relevant tolling equipment is still estimated in the range of 15% of the investment costs.

Under the assumption that the use of payment cards (debit, credit and fuel cards) is significantly higher in this case, the commissions paid by the concessionaire or by the operator for the acceptance of the cards start to play a role in the operation and maintenance costs. The typical commissions that are applied, although vary from country to country, are in the range of 1 to 4 %. These rates may be significantly reduced by establishing an online authorisation, so reducing the risk level associated to the operation.

The table below provides a summary of the toll collection costs that are typically associated with traditional tolling schemes using self-service machines.

Table 3.3: Cost component summary for traditional tolling using self-service machines

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Land costs	Yes	1.000.000	4.000.000	per toll lane	N/A	N/A	N/A
Toll collection	Roadside Infrastructure	Yes	50.000	200.000	Per lane	15%	15%	% of CAPEX
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Vignette-based solution

The vignette is the typical time-based toll collection mechanism, by which a road user (either private or commercial) purchases in advance the right to travel across a road network by purchasing a vignette (i.e. a sticker) that is valid for a certain period of time.

The purchase of a vignette, that typically needs to be installed on the windscreen of the vehicle, gives the road user the possibility to travel without limitation across the concerned network for the corresponding period of time. The purchasing value of the vignette depends on the duration of the rights (either few days, or few months or a year) and on the category of the vehicle; the charge is therefore not at all related to the actual length of road travelled by the user.

Different countries in Europe still make use of vignette-based time related charging schemes, either for private or for commercial vehicles. The most important cases that it is worth to mention include Switzerland and Austria for light vehicles, and the countries that are still part of the Eurovignette scheme for heavy vehicles such as Belgium, Netherlands, Luxembourg, etc.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Purchase of vignettes	Distribution costs
User registration (where applicable)	Enforcement

This solution has been mainly adopted for time-based toll collection systems.

In general terms, the road users that are subject to the payment of such a toll, are required to purchase a physical vignette (the electronic vignette case is detailed by the following section) before using the road network. The distribution of the vignettes is performed by means of an extensive distribution network, on a 24x7 basis and both along the borders and within a specific country. The activities of distribution of the vignettes and – when applicable – of the registration of the road user into the schemes are typically managed by the concessionaire or the operator by outsourcing to other third party operators.

The purchase and the distribution of the physical vignettes (stickers) represents the key investment when establishing such a system**. The distribution costs represent a significant part of the operating costs of such a system, as the concessionaire or the operator need to maintain and operate (though by means of third parties) a service network where a vignette can be procured whenever necessary. The distribution of a vigne**tte is typically made at marginal costs, as it is distributed by means of existing points of sales such as petrol stations, shops and others. Still these third parties charge the concessionaire in relation to the time spent by its personnel in handling the sale of the vignette and eventually the registration of the road user.

The unit cost for the procurement and the distribution of a vignette (including the commissions paid to the distribution partners) is in the range of 1 EUR.

The other key cost elements is represented by the enforcement operations. In most cases enforcement is performed by means of personnel deployed on the road to verify that the vehicles travelling along the road have actually purchased a vignette for the relevant period. In some cases the concessionaires make use of dedicated personnel, in other cases the police is taking care of such operations.

Again the estimation of such costs is very difficult and it depends on the local context. It is difficult where impossible to quantify such costs in a way that is representative of the way such solution is operated across Europe.

The table below provides a summary of the toll collection costs that are typically associated with tolling schemes using vignettes.

Table 3.4: Summary of cost components for tolling using vignettes

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Vignettes	Yes	1	1	Per vignette	N/A	N/A	N/A
Central system	Central system	Yes	10.000.000	25.000.000		1.200.000	3.000.000	
CRM	Distribution	Yes	N/A	N/A	N/A	1	1	Per vignette per post
Central system	Payment handling	Yes	N/A	N/A	N/A	N/A	N/A	N/A

Electronic vignette-based solution

During the last few years, certain time-based tolling schemes have replaced the physical vignette (the sticker to be applied on the windscreen) with an electronic vignette, referred to as e-Vignette.

The e-Vignette is based on the electronic storage of rights of use. This authorization to use the roads is acquired via the Internet, mobile via smartphone, at a point-of-sale, e.g. petrol station or other sales partner.

All purchasing options are also available to foreign road users, so that the system is non-discriminatory. Several payment means are accepted to procure the e-Vignette, such as cash, debit, credit and fuel cards. Alongside the registration number, only the data relevant to the toll charge is registered during the booking process.

The advantage of the new technology is that the e-Vignette can be purchased online and is immediately valid if required. Sending the vignette and sticking it on the windscreen is no longer required.

After purchase of the electronic vignette, all the necessary data, such as the relevant validity and vehicle data, is stored and encoded centrally by the toll system operator and is immediately available for control purposes.

The controls to enforce compliance of the e-Vignette are similar to other compliance measures utilising fixed or mobile number plate recognition means, as well as manual controls. The registration of the vehicle under control is registered automatically, encoded and compared with the centrally stored rights of use. If there is no violation, the data is deleted immediately. No movement profiles need to be created, protecting driver privacy and observing data protection laws.

In the case of unauthorized road use, proceedings to issue a penalty notice can be initiated without delay. Stopping is only necessary in the case of foreign vehicles, which may otherwise be able to escape such proceedings.

This kind of scheme is already used in Hungary (for the e-Vignette for the light vehicles) and is planned to be introduced in Germany (again for the e-Vignette for the light vehicles).

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Purchase and deployment of automatic enforcement means	Distribution costs
User registration	Enforcement

The use of an electronic vignette has a positive impact in terms of investments, as no physical vignette need to be procured and distributed to the eligible road users, as well as on the operating costs, as the road users can make use of diversified and modern means to register themselves into the scheme and to obtain their e-Vignette without stopping by a point of sale.

A central system, with customer relation management capabilities, is required to support the registration of the road users, the purchase and the payment (via different channels) of the e-Vignette and the registration of the rights of use of the road network to the relevant vehicle. The setting up of such a system, for which operators can access to existing products available on the market, can cost few millions of Euros; it is also possible to make use of third parties solutions by means of a service contract.

From the operational point of view, the other key cost elements is represented by the enforcement operations. In most cases enforcement is performed by means of personnel deployed on the road to verify that the vehicles travelling along the road have actually purchased a vignette for the relevant period. In some cases the concessionaires make use of dedicated personnel, in other cases the police is taking care of such operations.

Again the estimation of such costs is very difficult and it depends on the local context. It is difficult where impossible to quantify such costs in a way that is representative of the way such solution is operated across Europe.

The table below provides a summary of the toll collection costs that are typically associated with tolling schemes using electronic vignettes.

Table 3.5: Cost component summary for tolling using electronic vignettes

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Enforcement	Roadside Infrastructure	Yes	N/A	N/A	N/A			
Central system	Central system	Yes	20.000.000	40.000.000		2.400.000	4.800.000	
CRM	Customer relationship services	Yes	3.000.000	6.000.000	Call center & Training	1.500.000	3.000	For 200 people
CRM	Distribution	Yes	N/A	N/A	N/A	3600	6000	Per vending machine
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Single lane DSRC solution

This technical solution makes use of an On-Board Unit associated with a user's account and installed within the vehicle to manage a tolling transaction when the vehicle is passing within a dedicated or mixed lane within a toll plaza, by means of a short-range radio communication with one or more readers. This solution is generally referred to as ETC (Electronic Toll Collection).

The readers are typically integrated within an overall lane architecture, where a lane controller manages the vehicle detection, the vehicle classification, the toll transaction and exception handling.

From a technological perspective the European market has been characterized over time by the use of different short-range communication technologies, working on different ISM frequency bands (respectively 915 MHz, 2.45 GHz and 5.8 GHz) and along different protocols (mainly proprietary in the early stages, standardized later on). Nowadays the market has moved towards the use of a common technology, working at 5.8 GHz on the base of the communication protocol developed by the CEN TC278 standardization committee widely referred to as DSRC (Dedicated Short Range Communication).

The throughput of a single lane DSRC solution is significantly higher than the one of manual and self-service systems; the experience shows that – depending on the overall architecture of the lane – vehicles can travel across at a speed that can go up to 70 km/h, and therefore these lanes can be characterized by a throughput of up to 1.000 vehicles per hour. In order to handle all vehicles, it is still necessary to allocate a significant ground, and therefore a number of parallel toll lanes, to a toll plaza.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Civil works for toll plazas	Tolling equipment maintenance
Land expropriation	Distribution of on-board units
Tolling equipment	Billing and invoicing
On-board units	

In terms of investment for the setting up of the system, a part of the costs are the same as for more traditional manual and/or self-service toll collection solutions, as such solution is still integrated within a toll plaza environment. There is still a need to build a toll plaza (involving land acquisition and civil works), except that the throughout that is associated with an ETC lane is such that the number of lanes of a toll plaza can be reduced.

The road users are equipped with a DSRC based OBU, whose procurement cost is in the range of 10 to 15 EUR, depending on the procured quantities and on the design of the OBU, especially in terms of HMI.

This OBU can be distributed to the users either by means of a retail network, directly managed by the toll operator or outsourced to existing retail service providers. Depending on whether the OBU needs to be personalised (configured with vehicle and user related data) or not, the distribution network needs to be equipped or not with a DSRC reader.

The handling of the toll collection and enforcement operations are managed in a very similar way as for the manual and toll collection. The same lane architecture is in fact typically adopted, with the functions of vehicle detection and classification integrated with the radio communication with the OBUs. Depending on the specific solution adopted by the toll operator, in particular in terms of redundancy, the cost for the procurement and installation of an ETC only lane can be in the range between 20.000 and 50.000 EUR.

A central system is required to manage exception lists and user accounts, process transactions, and support the billing function. The required level of investment associated to the set-up of such system is in the range of 1 million EUR.

From the operational point of view, the main elements of cost are represented by:

- the maintenance of the equipment that, as above, can be estimated in about 15% (on a yearly basis) of the investment costs;
- the distribution costs, for the continuous registration of the users and the distribution/maintenance of the OBUs, that strongly depends on the way distribution is managed and cannot be easily compared;
- the billing/invoicing costs, that strongly decreases as soon as invoices are sent electronically only to the users.

The table below provides a synthesis of the toll collection costs that are typically associated with tolling schemes using Single Lane DSRC solution.

Table 3.6: Cost component summary for single lane tolling using DSRC

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Land costs	Yes	1.000.000	4.000.000	N/A	N/A	N/A	N/A
Toll collection	OBU	Yes	10	15	Per OBU	N/A	N/A	N/A
Toll collection	Roadside Infrastructure	Yes	20.000	50.000	Equipment cost per lane	15%	15%	% of CAPEX
Enforcement	Roadside Infrastructure	Yes	Included in toll collection		Per station	15%	15%	% of CAPEX
Central system	Central system	Yes	1.000.000	1.000.000	Central system set up	15%	15%	% of CAPEX
Central system	Payment handling	Yes	Included within central system		N/A	1%	4%	% of revenue from card transactions

Free-flow DSRC solution

This is the natural evolution of the above mentioned "single lane DSRC solution" as in this case the same technology is used in a free-flow environment, i.e. without any limitation onto the speed by which the vehicles can travel through the charging point.

Each charging point is equipped with a physical infrastructure (gantry) where a certain number of DSRC readers are installed, providing for the communication with the OBUs installed within the vehicles. The DSRC readers are installed and characterized in a way to ensure the proper coverage of the entire carriageway, therefore to perform a DSRC transaction with the OBUs whichever is the position of the vehicle. Depending on the solutions proposed by the different suppliers, one or more readers per lane are used.

Vehicles who are equipped with a valid OBU are detected and identified by the roadside equipment that collects all the information that are required to calculate the tariff, to charge the account and then to produce a bill. The vehicle category (including any type of applicable parameters) is typically retrieved by reading out the content of the OBU. Both Pre-pay and Post-pay schemes are deployed by means of this technology; in case of Pre-Pay, it is possible to envisage either an on-board account or a central account, depending on the specific requirements.

Examples of the use of such technical solution exist today in Austria, Czech Republic, Poland, Portugal, Ireland and United Kingdom. Wherever this solution has been adopted for heavy vehicles only, toll charger has opted for a mandatory OBU; on the other side, where all type of vehicles are charged, the OBU is not mandatory and the road users are allowed to be charged by means of alternative means.

If it is not mandatory to use an OBU, additional roadside equipment may be required to detect and classify vehicles without the assistance of an OBU. In this case the unequipped liable vehicles are charged by using ANPR toll collection and is described later in this document.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Civil and steel works for roadside infrastructure	Tolling equipment maintenance
Central processing system	Distribution of on-board units
Tolling equipment	Billing and invoicing
On-board units	Handling of exceptions (e.g. enforcement)

A free-flow toll collection system, compared with previously described toll plaza based solutions, is characterised by a completely different cost structure, for both the set-up of the system and for its operation and maintenance.

A DSRC-based free-flow system is still characterised by a significant amount of roadside equipment, as toll transactions are registered on the base of the elements recorded by a radio communication occurring between a roadside equipment (in this case installed on a physical gantry) and the OBUs. Each charging point is characterised by a gantry across the carriageway, on which DSRC beacons (with read/write capabilities) are installed to establish a communication with the OBU passing by.

Depending on whether the schemes are based or not on a mandatory OBU, and on the extension of the concerned network, the roadside installation can be supporting:

- the tolling-only functionality, i.e. the capacity of detecting and communicating with the DSRC OBUs passing by;
- the tolling and the exception handling functionalities, i.e. the capacity to identify vehicles by means of either the DSRC OBU or the number plate (for video tolling and/or enforcement purposes).

OBUs for free-flow DSRC schemes tend to cost between 10 and 15 EUR each.

Assuming that the roadside equipment covers two lanes plus an emergency lane, the costs of a tolling-only station can be in the range of 100.000 to 150.000 EUR each. This cost can increase up to 300.000 EUR and above when the station include both tolling and exception handling devices. These costs could rise to over 1 million EUR for a joint free-flow tolling and enforcement station depending on the configuration of the solution.

The development, testing and customisation of central systems to support free-flow tolling systems can be subject to significant costs (in the region of 30 to 50 million EUR).

Moving to the operation and maintenance of the system, the main cost components include:

- the maintenance of the roadside equipment;
- the operation and maintenance of the central system;
- the distribution of the on-board units;
- the billing and invoicing;
- the operation of the exception handling processes, including the enforcement;

The annual costs for the *maintenance of the roadside equipment* can be estimated to be approximately 12 to 15% of the initial investment.

The annual costs for the *operation and maintenance of the central system* include the cost for the housing and hosting of the central system, for the maintenance of the hardware and software components as well as for the application maintenance; the use of third party software packages trigger within this cost also the maintenance costs for the software license. Depending on the complexity of the system and of the business processes as well as on the size of the system (e.g. number of accounts), this cost can vary between 4 and 7 million EUR per year.

The next significant component of the yearly operation and maintenance costs is represented by the *registration of road users and OBU distribution costs*.

Different schemes will have different requirements regarding the nature of the registration and distribution networks.

The distribution costs[2] are characterised by a fixed component and a variable component. Fixed costs include land leasing, maintenance and operating costs for the equipment; variable costs include transaction dependent fees whenever distribution equipment is attended.

In schemes which require mandatory OBUs, the number of distribution points is driven by the requirement to provide non-discriminatory access to OBUs and the network, rather than the actual demand. It includes the maintenance and operation of the necessary equipment (up to 5,000 EUR per year per equipment in case of an automatic self-service machine distributing OBUs) and the fee required for the rental of the space required to operate them (typically between 100 and 300 EUR per month per site). Staffing costs for manned distribution points are subject to local labour rates, but typically a cost of 1 to 2 EUR per transaction can be estimated.

Unmanned vending machines installed in a partner facilities (gas station, restaurant, etc.), can involve the following annual OPEX:

- Site rental: 2500 EUR
- Telecom (SDL Line) : 2000 EUR
- Power : 1000 EUR

If the use of an OBU is optional, the number of distribution points can be reduced and optimised on the base of the estimated levels of demand.

Another significant component of the operating costs is represented by the *billing and invoicing costs*, or better by the cost that are required to collect the money from the road users along with the different payment methods. In recent years the actual billing and invoicing costs have decreased; the main cost is therefore now linked to the collection costs, i.e. to the commissions that the operator pays to the payment means providers (debit, credit and fuel cards) that collect the toll and transfer it to the account of the toll concessionaire and/or operator. A commission is applied onto the different transactions, in the range between 1 and 4%, for the handling of the relation with the end user and for the undertaking of the risk of insolvency.

Finally the last of the most significant cost components in the operation and maintenance of such a system is represented by the *handling of the exceptions* and/or of the enforcement. This element includes all the cost necessary to process the evidences recorded by the roadside equipment when vehicles are detected to pass through a charging point without having the

[2] The focus is made on Service Points installed on the premises of a partner (gas station, restaurant, garage, etc.). Installing an unmanned service point in a desert zone is subject to the vandalism risk due to the cash handling. Moreover most of desert zones have no electricity source or telecommunication connection which means a CAPEX that can reach a few hundreds of thousands EUR.

necessary rights of use (i.e. without the OBU, without an account or without sufficient balance in the account).

It includes basically personnel costs for the people that are asked to manually validate the evidences (i.e. the pictures of the license plate number and the contextual picture of the related vehicle) detected on the road and corresponding to potential violations.

The associated level of cost depends on:

- the number of cases to be validated, as a function of the level of traffic, the violation rate, the number of control points and the activation rate of the different control stations;
- the legal framework, in particular when it requires that all exceptions (including the enforcement cases) need to be manually validated by means of human interventions;
- the required performances in terms of time allowed to the processing of each case from the time it has been recorded;

These elements influencing the number of cases (pictures) to be manually validated within a certain time (e.g. 24 hours).

The number of cases to be manually validated, each one requiring (depending on the verifications to be performed) between 5 and 20 seconds each, and the time limits within which these cases need to be processed result into a number of Full Time Equivalent (FTE) resources that are required to operate the scheme, and therefore in a yearly cost.

The table below provides a summary of the toll collection costs that are typically associated with tolling schemes using free-flow DSRC.

Table 3.7: Cost component summary for free-flow tolling using DSRC

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Land costs	No	N/A	N/A	N/A	N/A	N/A	N/A
Toll collection	Labour costs	No	N/A	N/A	N/A	N/A	N/A	N/A
Toll collection	OBU	Yes	8	15	Per OBU	N/A	N/A	N/A
Toll collection	Roadside Infrastructure	Yes	100.000	150.000	Could be up to €1m for a MLFF tolling & enforcement station	15%	15%	% of CAPEX
Enforcement	Roadside Infrastructure	Yes	150.000	200.000	per station	15%	15%	% of CAPEX
Central system	Central system	Yes	30.000.000	50.000.000		3.600.000	6.000.000	
CRM	Customer relationship services	Yes	3.000.000	6.000.000	call center + training + progressive sourcing	1.500.000	3.000.000	For 200 person
CRM	Distribution (unmanned)	Yes	25.000	35.000	Per vending machine	2.500	10.000	per site per year

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Free-flow GNSS solution

Vehicles are equipped with complex on-board equipment, integrating different technologies, such as satellite-based positioning (GNSS), and mobile communication (GSM/GPRS). The OBU is therefore able to register (by means of the GNSS receiver) to continuously register its positions along a road network, that can be used (either locally or centrally) to recognize the trip and the crossing of the charging points. The OBU is able then to detect and register the path travelled by the vehicle, and then to detect when the vehicle is using a section of road that is subject to a charge.

The existing free-flow GNSS systems (for example in Germany and in the Slovak Republic) are section-based charging schemes, in the sense that the GNSS sub-system is detecting when the vehicle crosses a charging point associated to a specific toll section; other schemes may use the GNSS signals to measure – with an error of up to 5% - the distance actually travelled by the vehicle.

The performance of this solution strongly depends on the performance and of the robustness of the GNSS receiver, in particular in conditions of reduced visibility of the GNSS satellites (such as in urban canyons). The topology of the road network may require in some case the deployment of DSRC augmentation beacons, replacing the GNSS satellites.

Different schemes - in terms of architecture - are implemented, differing on the base of the processing being done within the OBU. In particular we are talking of a "Thin Client" when the data processing is mostly performed within the central system, rather than of a "Thick Client" when the data processing is mostly performed within the OBU.

Depending on the selected scheme, it is possible to perform the detection of the charging point, the calculation of the tariff and the accounting within the OBU (in the case of the Thick Client) or in the central system (in the case of the Thin Client).

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
On-board units	Distribution of on-board units
Central processing system	Telecommunication
	Billing and invoicing
	Handling of exceptions (e.g. enforcement)

This technical solution is characterised, with regards to other distance-based tolling schemes, by a significantly reduced roadside infrastructure.

The cost for the procurement of such an OBU has decreased during the last few years down to 90 to 150 EUR. The exact cost can vary as a function of the data processing capability (in particular whether a thin client or thick client architecture is adopted), the size of the memory, the complexity of the Human Machine Interface (HMI) and the mobile communication technology (a significant price different exists between GPRS and UMTS modems).

In some specific cases, and depending on the functional requirements and on the required performance levels, DSRC Augmentation Beacons (LAC) must be deployed in order to ensure that the OBU can correctly detect the passage through the charging points even with a poor visibility of the GNSS satellites. These LAC beacons can be deployed by using different (existing or not) roadside infrastructure, and the related cost can vary between few thousands Euros (e.g. installing beacons overhead within a tunnel where energy) to several tenths of thousands of Euros (in the case a steel gantry needs to be installed).

If enforcement stations are required as part of the scheme then some roadside equipment may be required. Assuming that the roadside equipment covers two lanes plus emergency, the costs of a station supporting the exception handling functionalities can be equal to up to 300.000 EUR and above. As in the free-flow DSRC environment, these costs can rise to over 1 million EUR per station depending on the complexity.

A central system is required to support a GNSS tolling solution, and subject to the caveats described in the free-flow DSRC solution, the costs are significant and can fall in the range of 30 to 50 million EUR.

The operational costs for a free-flow GNSS scheme are typically consistent with the costs set out in the previous section for free-flow DSRC. There are some cases where the operational costs differ – these particularly relate to the communication costs for the transfer of charge declarations to the central system.

The communication costs vary depending on the solution being adopted (thick or thin client).

In the case of the Thin Client approach, the communication cost can be estimated at about 1 EUR per month per OBU. A certain cost reduction can be achieved in the case of a Thick Client (with less data to be transferred) unless the data need to be recorded in the central system for auditing purposes (as it is often the case).

The autonomous vending machines used for distributing GNSS and DSRC OBUs are broadly the same. There are however some distinctions between the vending machines for GNSS and DSRC OBUs. If the OBU is purely DSRC-based, the vending machine will typically require a DSRC beacon to personalise the OBU. Additionally, vending machines have a greater capacity if the OBUs are purely DSRC-based, as DSRC OBUs are considerably smaller than GNSS-based OBUs (examples to date have shown that the capacity of a GNSS vending machine is approximately 20-25 OBUs).

The table below provides a synthesis of the toll collection costs that are typically associated with tolling schemes using free-flow GNSS.

Table 3.8: Cost component summary for free-flow tolling using GNSS

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Land costs	No	N/A	N/A	N/A	N/A	N/A	N/A
Toll collection	OBU	Yes	90	150	Per OBU	N/A	N/A	N/A

Tolling sub-system	Component	Applicable	CAPEX CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (per year) OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Enforcement	Roadside Infrastructure	Yes	150.000	300.000	Per station	15%	15%	% of CAPEX
Central system	Central system	Yes	30.000.000	100.000.000		3.600.000	12.000.000	
CRM	Customer relationship services	Yes	3.000.000	6.000.000	Call center + training	1.500.000	3.000.000	For 200 people
CRM	Distribution (unmanned)	Yes	25.000	35.000	vending machine	2500	10.000	Per site per year
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Tachograph

This is a specific autonomous solution that is currently used in Switzerland, in the frame of the LSVA system.

In this case vehicles subject to the payment of a charge are required to be equipped with an OBU that is connected to the vehicle odometer to establish the distance driven in Switzerland only. The OBU (at least the way the system is currently implemented) is not able to distinguish the different road sections and therefore to apply different tariffs depending on the road; but it is able to measure the travelled distance and therefore to trigger the charging of the road user on this base.

A GPS module, integrated within the OBU, is used to validate the odometer information (to protect against fraud) and to switch the OBU on and off at the borders when entering and leaving Switzerland. There is no map on-board, and the GPS isn't used to locate the vehicle.

Each month, the mileage driven is obtained from the OBU by means of a "smart card," which is read on a PC to transmit the vehicle data and mileage to the Swiss Customs Authority's central site. No mobile communication link is established between the OBU and the central system.

After obtaining the vehicle mileage from the multi- technology OBU, the Swiss Customs central site calculates the amount due using updated tariffs.

Enforcement is operated by means of both stationary equipment (installed on roadside gantries across the carriageway) and enforcement agents that can stop the vehicles in case of doubt.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
on-board units	distribution of on-board units
stationary enforcement equipment	billing and invoicing
central processing system	handling of exceptions (e.g. enforcement)

From an investment perspective, the key elements are represented by the purchase of the OBU and from the deployment of the stationary enforcement equipment.

The OBU being adopted in this case is much more complicated than DSRC and even GNSS OBUs, and its cost suffers also from the fact that it is used only in Switzerland. Initially the procurement costs were in the range of 800 EUR (when procured in the early 2000), they decreased down to about 350 EUR after a few years. The complexity of the solution is such that in any case the cost for such an OBU remains far higher than the others.

The cost for the deployment of enforcement stations is very much similar to those indicated for the other free-flow systems, both based on DSRC or on GNSS.

A central system is also required to process all the data that are recorded by the OBUs and that are transferred for the calculation of the charge on the base of the tariff, as well to process enforcement related and customer related management data. Independently from the specific case in Switzerland, where the central system is very much integrated with the existing tax processing system, the investment required to set-up from scratch of this system can be very similar to the one detailed for the other free-flow systems.

Moving to the operation and maintenance of the system, the main cost components include:

- the maintenance of the roadside equipment (estimated to be 15% of the initial investment annually);
- the operation and maintenance of the central system (between 4 and 7 million EUR);
- the distribution of the on-board units (consistent with the distribution costs for GNSS free-flow solutions);
- the billing and invoicing (consistent with the distribution costs for GNSS free-flow solutions);
- the operation of the exception handling processes, including the enforcement (consistent with the distribution costs for GNSS free-flow solutions);

The table below provides a summary of the toll collection costs that are typically associated with tolling schemes using a tachograph.

Table 3.9: Cost component summary for tolling using a tachograph

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	Land costs	No	N/A	N/A	N/A	N/A	N/A	N/A
Toll collection	Labour costs	No	N/A	N/A	N/A	N/A	N/A	N/A
Toll collection	OBU	Yes	350	350	Per tachograph	N/A	N/A	N/A
Toll collection	Roadside Infrastructure	No	N/A	N/A	N/A	N/A	N/A	N/A
Enforcement	Roadside Infrastructure	Yes	300.000	1.000.000	Per site (varying from 2 lanes to MLFF)	15%	15%	% of CAPEX
Central system	Central system	Yes	N/A	N/A	N/A	4.000.000	7.000.000	N/A

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
CRM	Customer relationship services	Yes	3.000.000	6.000.000	Call center + training	1.500.000	3.000.000	For 200 people
CRM	Distribution	No	N/A	N/A	N/A	N/A	N/A	N/A
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

ANPR solution

This is a solution being used for electronic toll collection where the vehicle is recognized by means of its number plate, rather than on the base of an OBU installed within the vehicle. A charging mechanism based on the recognition of a license plate is often provided as an alternative to the use of an OBU, in particular for occasional users.

The license plate number is registered and associated to the user account, together with a valid payment means, so that a toll transaction is produced and accounted onto the user account as soon as the specific license plate is recognised

In Europe there are both single lane and multilane free-flow schemes using ANPR for toll collection purposes.

For example a so-called Video-Maut system has been operated for years in Austria by Asfinag, allowing registered road users to be identified at the toll plaza by means of their previously registered number plate. At the same time certain urban congestion charging schemes (e.g. in London, Stockholm and Gothenburg) rather than toll motorway schemes in the United Kingdom and in Portugal make use of this technology for tolling purposes in a multilane free-flow environment.

In both types of environment (single lane or multilane) a roadside equipment is deployed on the charging point (within a toll plaza rather than using a physical overhead gantry) with a certain number of cameras with ANPR capabilities.

The cameras collect the evidence of the passage of each vehicle, and in particular the picture of the area around the number plate (the front or the rear plate depending on the local regulations) from which the ANPR mechanism derives the number plate and the nationality of the vehicle.

When the ANPR mechanism is not able to retrieve – with the sufficient confidence level – the number plate of the vehicle, the evidence collected by the roadside equipment needs to be transferred centrally and manually decoded (if possible).

The performance of this scheme is dependent on the capacity of the ANPR mechanism to properly recognize and decode a license plate number.

The experience made by different system operators in Europe show that a significant performance (with an automatic recognition rate of about 85% of the plates) can be achieved in most cases, where the performance can be significantly improved when a system is characterised mostly by local vehicles (same nationality and same type of license plate). The performance also depends on the operational context within which the vehicles are to be charged: in a single lane environment the situation is more comfortable as vehicles are passing always in the same place, whereas a multilane environment is characterised by a higher complexity.

The key cost elements of this solution are summarised below:

Main Investments costs	Main Operational costs
Civil and steel works for roadside infrastructure	Number plate recognition
Tolling equipment	Maintenance of roadside equipment
Central processing system	Billing and invoicing
	Handling of exceptions (e.g. enforcement)

In terms of investments, this system is very much similar to a DSRC free-flow system, exception made that:

- no OBU is used by the users for the payment of the toll;
- all the roadside equipment are able to collect the evidence of the passage of the vehicles.

The key cost elements for the setting-up of such a solution are then the following:

- the roadside infrastructure and equipment (300,000 EUR);
- the central system (30 to 70 million EUR).

In a toll plaza environment, an ANPR camera is installed within a toll lane, very much the same as for a DSRC reader, with or without a vehicle detection module (used also to trigger the camera) and a classification module. The investment is limited (estimated in few tens of thousands of Euro).

The table below provides a summary of the toll collection costs that are typically associated with tolling schemes using ANPR.

Table 3.10: Cost component summary for tolling using ANPR

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection and enforcement	Roadside Infrastructure	Yes	300.000	1.000.000	Could be up to 1m for a MLFF tolling & enforcement station	15%	15%	% of CAPEX
Central system	Central system	Yes	30.000.000	70.000.000		15%	15%	% of CAPEX
CRM	Customer relationship services	Yes	3.000.000	6.000.000	Call center + training	1.500.000	3.000.000	For 200 people

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Sticker tag solution

This solution is very similar to the DSRC solutions referred by the previous sections of this document. In this case, in fact, the OBU is replaced by a simple RFID sticker (to be stuck on the windscreen of the vehicle) with short-range communication capabilities.

The system architecture is very similar to the one used for DSRC schemes, whereas the short-range communication technology and frequency are different. Sticker tags are operating in the 915 MHz bandwidth, which is still an ISM bandwidth but that is not specified in Europe for electronic toll collection applications. At the same time, with respect to the DSRC technology used in Europe, tags are read-only, in the sense that the application can be based only on the reading out of the tag identifier that needs to be associated to an account.

This solution is widely used in the United States, where sticker tags are gradually replacing tags being previously distributed. The same solution has been deployed in Brazil and in Turkey.

Both single lane and multilane free-flow schemes can be theoretically implemented by using this solution. The possibility of implementing high-speed schemes, in particular in a multilane environment, strongly depends on the emission power that the readers can produce. In particular the maximum emission power admitted in Europe within this frequency band is significantly reduced with respect to what is allowed in the United States, with the consequence that a multilane free-flow scheme is very difficult to implement.

The key cost elements of this solution are therefore:

Main Investments costs	Main Operational costs
Civil and steel works for roadside infrastructure	Tolling equipment maintenance
Tolling equipment	Distribution of tags
Tags	Billing and invoicing
Central processing system	Handling of exceptions (e.g. enforcement)

From a cost perspective the main difference between this solution and DSRC-based alternatives is represented by the cost of the tag itself, which is significantly lower than the cost to procure a DSRC OBU. The cost of a sticker tag is in fact in the range of 1 EUR to 1.20 EUR.

Besides that the technical architecture is very similar to the one used with the DSRC technology, whereas an RFID reader is used instead of a DSRC reader. As the cost of the readers are similar, the investment costs that can be expected for an RFID solution are similar.

In reality, as the performance that can be expected when using RFID technology is slightly lower than the one characterising a DSRC technology, the investment costs to be faced with RFID systems becomes slightly higher when the same level of performance needs to be achieved, especially in a multilane environment.

The different characteristics of the RFID technology with respect to the DSRC technology (because of the frequency bandwidth, a larger communication area characterises the RFID-based systems) affects also the operation and maintenance costs, in particular the costs necessary to process the evidences of passages recorded by the roadside equipment for the exception handling.

As the communication area is wider, it is in fact more complicated (and therefore less systematic) to correlate the result of the RFID communication between the sticker and the reader with the result of an ANPR process, with the consequence that more potential violations are recorded by the roadside equipment and need to be manually processed. The operational costs associated to exception handling of passages of the vehicles can be 10 to 20% higher than in the case of a DSRC-based system.

The other costs, both in terms of investments and of operation, are similar.

The table below provides a synthesis of the toll collection costs that are typically associated with tolling schemes using RFID.

Table 3.11: Cost component summary for tolling using RFID

Tolling sub-system	Component	Applicable	CAPEX			OPEX (per year)		
			CAPEX (low estimate) (€)	CAPEX (high estimate) (€)	Unit	OPEX (low estimate) (€)	OPEX (high estimate) (€)	Unit
Toll collection	OBU	Yes	0.80	1.20	Per tag	N/A	N/A	N/A
Toll collection	Roadside Infrastructure	Yes	100.000	150.000	Could be up to 1m for a MLFF tolling & enforcement station	15%	15%	% of CAPEX
Enforcement	Roadside Infrastructure	Yes	150.000	200.000	Per station	15%	15%	% of CAPEX
Central system	Central system	Yes	30.000.000	50.000.000		3.600.000	6.000.000	
CRM	Customer relationship services	Yes	3.000.000	6.000.000	Call center + training	1.500.000	3.000.000	For 200 people
CRM	Distribution	Yes	N/A	N/A	N/A	5.000	10.000	Per site per year or 1 euro per post
Central system	Payment handling	Yes	N/A	N/A	N/A	1%	4%	% of revenue from card transactions

Mobile communication solution

This solution has never been implemented in real operation, and only pilot systems have been deployed.

Under this scenario, a mobile phone (or an equivalent mobile communications device) is used as the on-board device that identifies the road user and the vehicle. The mobile phone, by correlating the different signals that it receives from the GSM base stations, is able to identify the path taken by the vehicle and can therefore generate the corresponding toll charging elements.

The different tests performed to validate the feasibility of this approach have outlined that:

- specific (in terms of software and hardware) mobile phones may be required to achieve the necessary performance of the solution in terms of path recognition;
- the capacity (for the mobile phone) of correlating the signals coming from the different bases stations depends on the availability of the mobile operators to provide the configuration data of the different base stations.

Using mobile phones as a platform for tolling has potential, given the high-level of market penetration. There are already various examples of mobile phones being used to support financial-grade systems in the usage-based insurance industry, where insurers are using smartphone apps (and a smartphones GPS module) to monitor users driving style and movements in return for a different premium. However, as noted above, there are substantial challenges that would need to be overcome relating to the hardware, software, user attitude, security and other factors if a toll scheme wished to seriously investigate the technologies potential use.

The key cost elements of this solution are therefore:

Main Investments costs	Main Operational costs
Mobile phones	Distribution of mobile phones
Central processing system	Telecommunication
	Billing and invoicing
	Handling of exceptions (e.g. enforcement)

This solution would be economically interesting in the case that the road users might make use of their own mobile phone. In that case a similar solution might be implemented and operated at marginal costs and would become very interesting.

In reality the existing mobile phones, although they (nearly) all integrate the capacity of positioning themselves, are not exactly suitable for being used for tolling applications, and therefore a significant investment is required to procure and distributed the mobile phones, even higher than what is now required for a GNSS solution (as a mobile phone can require an investment of some hundreds of Euros).

In the same way, as the mobile phone are not equipped with a DSRC interface for compliance check purposes, the operational costs of such a solution would be significantly higher in terms of enforcement. In order to implement automatic enforcement solutions, it would be necessary to collect – for each enforcement station – the evidence of passage of each eligible vehicle and to implement a complex correlation between the passage and the data collected via the mobile phone.

Enforcement techniques

Introduction

This section provides an overview of the different approaches that are used and that could be used to detect non-compliance and enforce road users to respect the rules applying to the use of a road infrastructure subject to a charge.

The key activities involved in the compliance checking and enforcement value chain are illustrated at a conceptual level in the figure below.

Figure 3.2: Compliance checking and enforcement activities

The activities set out in Figure above are not specific to any particular solution. For example, the detection of a suspected violation could be based on reading a number plate or interrogating an OBU using DSRC or RFID, or by observing an incident at the roadside. The evidence processing will vary by the local requirements and legislation. If a violation is confirmed then a process is followed (again, varying by the legal basis for a Scheme) to enforce the penalties for non-compliance.

The different solutions may differ in terms of business model, in terms of technology and in terms of operational model. In some cases, in particular in the frame of more conventional charging schemes, very basic enforcement schemes are used; in manual, self-service and partly with electronic toll collection methods, a physical barrier is systematically used as enforcement means, with the road user that is allowed to leave the toll plaza only once the toll transaction has been finalised.

Over time and with the adoption of more sophisticated technologies, also enforcement schemes have been further developed. The identification of the vehicles on the base of their license plate numbers has been widely integrated within the enforcement schemes and more statistical approaches have been adopted, where controls are performed on the users in a way to optimise the ratio between the operational effort and the result.

Very often toll chargers make use of a combination of the different solution in order to maximise effectiveness.

A short description of each of the relevant options will be provided, as well as some of the associated key cost driving elements. The analysis will comment also on the maturity of the technology, the availability of the technology, potentials for interoperability and other characteristics such as scalability, adaptability, flexibility and safety.

Use of physical barriers

At the very early stages of the road tolling, physical barriers were used as the only enforcement means in the frame of tolling schemes. The road user was allowed to cross the toll plaza only when the toll transaction was finalised; the physical barrier was raised and the vehicle was allowed to pass through.

The same type of approach is still widely used nowadays in the frame of more conventional manual and self-service tolling schemes, as well as for some single lane electronic toll collection schemes (based on DSRC and/or ANPR technologies).

This solution is clearly effective, in particular from a psychological point of view, as the user is aware of the presence of the barrier and therefore tends to comply with the rules.

At the same time, this enforcement method has a significant impact on the level traffic and can generate congestion, because of the reduced throughput.

Fixed enforcement with ANPR on free-flow networks

When moving towards multilane free-flow environments, enforcement-related controls need to be performed without affecting the traffic flow, therefore by means of roadside equipment that are able to detect and verify vehicles while they are freely moving along the road network.

Vehicles are in this case detected, classified (in particular to filter those vehicles that are eligible to the payment of the charge) and verified by means of a set of equipment that are installed on an overhead gantry.

These equipment include typically:

- vehicle detection sensors (such as laser camera, radar or else) to detect the passage of the vehicles and trigger the capture of any necessary evidence;
- vehicle classification sensors to measure the parameters (such as the number of axles and the overall dimensions) characterising the vehicles with respect to the tariffing scheme;
- short range communication reader (DSRC) to detect and communicate with the OBUs eventually present within the vehicles for retrieving of the configuration data;
- evidence capture devices (cameras) that, triggered by the detection sensors or directly from the images, collect the image of the license plate number and the overview image of the vehicle.

Figure 3.3: ANPR example

Source: www.traffic-tech.com

Depending on whether the charging system concerns all vehicles rather than a part of them (e.g. only vehicles above 3,5 tons), the enforcement equipment has also the task to differentiate (by means of the vehicle classification devices) the vehicles that are eligible for the payment from the vehicles that are not eligible. This is a particularly complicated task, and a final decision on that cannot be always taken at the roadside.

The performances of such type of equipment are normally measured in terms of:

- detection of the vehicles;
- classification of the vehicles (including the identification of the eligible vehicles);
- communication with the OBUs;

- recognition of the license plate number (including ANPR).

More basic type of enforcement can also be implemented, by reducing the complexity of the equipment; for example a DSRC reader can be removed in those cases where no OBU is foreseen, or the detection of the vehicles can be performed by means of free-running cameras. All this has a clear impact on the performances.

Performances are also affected by the configuration of the equipment and for example by whether the equipment are installed overhead or on the side of the carriageway.

An overhead installation ensures higher performances but it is more expensive and less flexible. In some case enforcement equipment are installed on the right end side of the carriageway, so that they can be easily moved from site to site. Working solutions exist on the market, guaranteeing a higher flexibility and therefore effectiveness, but they come with a reduction of the performances.

Whereas some basic processing (including the recognition of the license plate number) is done locally, some of the automatic verification can be or must be done centrally in order to improve the quality of the data (so reducing the manual intervention) and to respect the local regulations.

A further data processing in the central system allows to improve (in some case significantly) the level of performances that can be achieved, by means of automatic and manual processing. In particular the vehicle classification and the license plate number recognition can be significantly improved.

Mobile enforcement

In free-flow environment, and in particular where enforcement is not implemented on a systematic base, mobile enforcement become very effective to control and enforce the road users.

The road users can be controlled both on the move and on parking areas in order to verify whether they are registered into scheme, whether they are equipped with an OBU and whether their OBU is properly configured.

Mobile enforcement is typically performed by means of vehicles that are equipped with devices allowing to communicate with the OBU (in case it is present), to collect the evidence of the license plate number, to recognise the plate number by means of an ANPR mechanism and finally to access the central databases to perform verifications.

Level of penalties for non-compliance

In addition to the process of detecting and gathering evidence of non-compliance, a key part of the compliance and enforcement process relates to the penalties that can be applied for non-compliance. It is recognised that no system can be 100% accurate, and that the cost of identifying and enforcing all non-compliant vehicles can be disproportionate to the level of revenue that could be brought in. Therefore a powerful tool to encourage compliance with the scheme rules is to set the penalties for non-compliance in such a way that it deters opportunist drivers from evading the toll.

The basis for applying penalties for non-compliance varies by scheme and the legal basis for the scheme. For example, if evasion of a toll is considered to be a civil issue rather than criminal, then the penalties are typically applied on a monetary-basis. However, depending on the legal basis of a scheme other penalties for non-compliance could be applied (e.g. the threat of suspending a haulier's operator licence for non-payment of tolls in a tax regime).

The balance of risk and reward (i.e. non-payment of tolls) for users who evade a toll can therefore be re-aligned if the level of penalty for non-compliance is at a sufficiently high level.

The enforcement process

As mentioned above, all enforcement techniques are deployed with the aim of detecting and identifying those vehicles that violate the rules. The effectiveness of a charging scheme strongly depends on the capacity that a toll charger has to detect violations and to implement processes to enforce them. This is particularly true in a multilane free-flow environment.

In order to achieve the effectiveness and the economic efficiency of a scheme, it is necessary to make use of performing equipment as well as of an effective operational process so to maximise automatic processing.

The use of a knowledge database, which is continuously integrated with the data regarding the vehicles that have been detected violating the scheme, can allow improving performances (e.g. by quickly recognising previously detected vehicles by means of fingerprinting techniques) as well as reducing and optimising the resources required to process an enforcement case (e.g. by retrieving information concerning registered vehicles).

The performance of the enforcement equipment is sure important to achieve effectiveness, but the legal framework and the operational processes are part of the whole picture.

The legal framework must be such to allow a toll charger (rather than someone on its behalf) to properly enforce violating vehicles, both national and international. This may involve the right to stop vehicles and to enforce them on the road, but also the possibility to obtain their identification and implement a process to recover the unpaid tolls and any other administration fee.

The absence of a common and harmonised vehicle register at European level, rather than the possibility for a toll charger to access to all national register, represents today a significant limitation to the deployment of innovative and economically efficient charging schemes.

The following model Illustrates the violation process based on a certain hypothesis of volumetric and other configurations that can be adapted, depending on the real situation:

ASSUMPTIONS AND PARAMETERS		
Road Network		
Length	2 000	km
Toll sections	900	
Enforcement sections	100	
Average length of toll section	4,44	km
Traffic		
Annual Average Daily Traffic (HGV)	1 893 230	passages/day
Annual Average Daily Traffic (LGV)	13 500 000	passages/day
Distance Travelled on the Network (HGV)	8 414 355	km/day

Distance Travelled on the Network (LGV)	60 000 000,00	km/day
Average Trip Length	60,00	km
Number of Toll Sections per Trip	13,50	
Average Number of Trips per Day (HGV)	140 240	trips per day
Average Number of Trips per Day (LGV)	1 000 000,00	trips per day
Number of Enforcement Points per Trip	2,50	
Number of Enforcement Points per Day (HGV)	350 600….	
Number of Enforcement Points per Day (All)	2 850 600	
Pre-Pay OBUs	30%	
System Configuration		
Activation Rate	35%	
Task Duration		
License Plate Verification	10	sec
Vehicle Category Verification	5	sec
Eligibility Verification	5	sec
Final Verification	10	sec
Performances		
ANPR Error Rate (no LPN)	15%	
ANPR Error Rate (Wrong LPN)	10%	
ANPR Error Rate (1 wrong character)	5%	
DSRC Error Rate	0,03%	
Classification Error Rate (not eligible vehicles)	0,2%	
Classification Error Rate (eligible vehicles)	4%	
User Behavior		
Violation Rate (No OBU)	0,01	
Violation Rate (Wrong Declared Category)	0,02	

On the basis of the above hypothesis, a roadside infrastructure (fixed and portable) registers daily, a certain number of potential violations, both real violations and violations related to errors made by the equipment (e.g. when classifying a vehicle). The following section provides for the types and for the amount of enforcement cases that are registered, arranged per category.

The volumetrics are:

VOLUMETRICS OF ENFORCEMENT CASES		
Enforcement Cases "No OBU"		
Number of Vehicles with "No OBU"	1 227	
Man Hours	**8,52**	**hours**
Enforcement Cases "Defect OBU"		
Number of Vehicles with "Defect OBU"	37	
Man Hours	**0,26**	**hours**
Enforcement Cases "Classification Error"		
Number of Vehicles with "Classification Error"	1 995	
Man Hours	**8,31**	**hours**
Enforcement Cases "Not Recognised Exempted Vehicles"		
Rate of Exempted Vehicles (out of all crossing eligible vehicles)	0,00	
ANPR Error Rate (overall)	0,30	
Number of vehicles with "Not Recognised Exempted Vehicles"	37	
Man Hours	**0,10**	**hours**
Enforcement Cases "Wrong Declared Category"		
Number of Vehicles with "Wrong Category"	2 454	
Man Hours	**20,45**	**hours**
Enforcement Cases "Wrong Classification"		
Vehicles without trailer	0,50	
Number of Vehicles with "Wrong Classification"	2 454	
Man Hours	**13,63**	**hours**
Enforcement Cases "OBU in Black List"		
Rate of vehicles with "OBU in Black List"	0,01	
Number of Vehicles with "OBU in Black List"	614	
Man Hours	**3,41**	**hours**
Enforcement Cases "Pre-Pay OBU with No Balance"		
Rate of Vehicles with "Pre-Pay OBU with No Balance"	0,05	
Number of Vehicles with "Pre-Pay OBU with No Balance"	1 840	
Man Hours	**10,23**	**hours**

Each case, whether it is related to a real violation or not, requires automatic and manual processing. A different processing time is required to annually validate the different cases, as the verifications to be performed are different.

It will require 65 man hours to treat more than 10.000 cases of which more than 6,000 violations per day are confirmed.

The number of employees should be between 8 and 12 FTE (depending on whether the toll charger requests that cases be treated within a maximum of 24hrs). Then depending on local workforce regulations, the number of employees can be between 12 and 22.

Out of the 6.000 violations per day, we estimate that on average 3000 different vehicles will be registered. The business rules that are usually adopted by Toll Chargers implies a certain level of aggregation of the violations performed by a certain vehicle over a certain time window (e.g. 4 hours). This can have a significant impact on the number of violations that will be actually formalized to the users.

Finally we estimate that a toll operator will be able to recover the unpaid tolls and eventually the applicable fines from a majority of the local users but only from a small % of the foreign ones.

These figures must be treated carefully because the context may change even significantly during the operation of a specific tolling system. The violation rate for example can be high during the first few months of operation, due to a lack of awareness regarding the regulations, but then should be reduced over time; also in a similar way, the performance of the equipment and the efficiency of the process should increase over time (including the knowledge of the exempted vehicles if any).

All the toll chargers we met during the study informed us that they could improve the rate of detection for violators but subsequently are unable to identify the violators and/or recover the fines for all vehicles.

In conclusion, the enforcement policy must be clearly defined. Even if the estimated figures can let the toll charger imagine significate complementary revenue the results are far from those estimations. The main issues are:

- the capacity to recover the fines whenever the truck is not registered in the country except if this truck returns to the country and is stopped by the authorities ;
- the number of employees requested to treat the potential violation. Even if the enforcement KPI are high, human support is needed;
- the case is even worse if the specifications require a violation treatment within a time limit. Some control/enforcement must thus work 365/7;
- the enforcement equipment are producing data but their processing and the low capacity to obtain payment from foreigners is a major drawback.

Central System

The central system is a core component of any toll system, supporting the key business processes and providing services to most of the other sub-systems and to the system operators.

The central processing unit (in short referred to as the central system) includes all the central processing components, typically manages the interface with peripheral elements (for example tolling and enforcement equipment, rather than the distribution points), processing data and providing services with regards to the key business processes (registration, toll collection, enforcement, customer care, payment etc.), storing and archiving business and operational data.

The complexity of the central system can vary depending on the characteristics of the tolling system. These can range from very basic central systems that support the setting tariff tables in manual toll collection schemes, through to elaborate schemes that involve complex business processes and interface management to support wide scale free-flow GNSS schemes.

The following costs are to be considered for the set-up, operation and maintenance of a central system:

ID	Cost Element
1	Business Processes Design
2	Software Specification
3	Software Development and Customisation
4	Testing (Component Testing and Subsystem Testing)
5	Hardware IT Infrastructure Procurement and Installation
6	Base Software Licenses (Set-Up Cost)
7	Technical Documentation

Table 12: Central system set-up cost elements

ID	Cost Element
1	Housing of IT Infrastructure
2	Hosting of IT Infrastructure
3	Hardware IT Infrastructure Maintenance
4	Base Software Licenses (Maintenance Costs)
5	Application Software Maintenance
6	Data Mining

Table 13: Central system operation and maintenance cost elements

Most of the above cost elements, in particular all those regarding the IT infrastructure and the base software, apply to all the different environments of the central system that are typically usually required (development environment, testing environment, integration environment and production environment).

Customer Relationship and Assistance

This section provides an overview of the different approaches that are used and that could be possibly used to register road users into the charging schemes and to distribute them – where necessary – the on-board unit required to respect the rules applying to the use of a road infrastructure subject to a charge.

The registration of a road user and the distribution of an on-board unit (or something equivalent, such as a sticker) are fairly new concepts and problematic characterising the road charging systems since the introduction of electronic toll collection schemes.

The registration and the distribution of on-board units have gradually become one of the most delicate issues to deal with when deploying a road charging scheme.

In some cases, the use and access to a road facility require the user to mandatorily register itself and to equip the vehicle with an on-board unit; in order not to discriminate and to interfere with users, in particular occasional users, an expensive distribution network has to be implemented, ensuring anyone to quickly register and obtain an OBU whenever is required, and without major impact in terms of delay.

In other cases, the OBU is not mandatory and alternative means of accessing the scheme are provided. Nevertheless the user needs to register itself into the scheme, either before travelling or shortly after, so avoiding to be handled as a violator.

The different solutions may differ in terms of business model, in terms of technology and in terms of operational model. The economic impact associated with either one of the different approaches is different and no solution can be considered as the perfect solution; the solution to be adopted for registration and distribution needs to be defined on the base of the specific context.

A short description of each of the relevant options will be provided, as well as some of the associated key cost driving elements. The analysis will comment also on the maturity of the technology, the availability of the technology, potentials for interoperability and other characteristics such as scalability, adaptability, flexibility and safety.

Mandatory use of an OBU

Certain charging schemes, in particular those involving only heavy commercial vehicles, it is mandatorily required to make use of an on-board unit. This OBU needs to be obtained and installed within the vehicle before accessing the road network that is subject to the payment of a charge.

Although the toll chargers provide the possibility to register into the scheme and to obtain the OBU several months ahead of the operation of the new scheme, the problem of handling the occasional users and of not discriminating the international users with respect to the local ones exists.

This constraint obliges the toll charger (rather than the operator of the system) to establish and operate on a 24x7 basis an extensive network of service points, so ensuring that anyone can obtain an OBU when necessary.

The experience with the existing systems has shown that often this extensive infrastructure is not efficiently used, beyond some specific locations (mainly along motorways with high traffic) and beyond the first few weeks of operation of a system (after which most of the road users are equipped).

For this reason, system operator tend to deploy the distribution network by using existing facilities (e.g. petrol stations) and service providers (e.g. logistic partners), rather than establishing its own service network with its own personnel. Existing service providers are charging for the service on the base of a fixed monthly fee per site plus possibly a transaction fee when their personnel is involved.

Where the charging scheme regards a primary road network (such as a motorway) there are high probability to find existing service providers, operating on a 24x7 basis in the proximity of the access to the road network. Nevertheless, during the night and during the weekends, when these service providers are not active, an automatic machine needs to be used to ensure the necessary level of service.

Potentially it is also possible to make use of self-service machines only, with the involvement of any personnel, but this concept needs still to be proven from an operational perspective. It represents a significant investment, but sure it is more effective than establishing a dedicated service point network.

Alternative means to access charging schemes

In alternative to the tolling systems based upon the use of a mandatory OBU, certain charging schemes offer the use of the OBU and in alternative other means to register itself and to pay, without installing an OBU.

Different examples can be outlined, such as:

- the Manual Booking approach implemented in Germany for the LKW-Maut system, whereas the occasional users can declare and pay upfront for the exact trip they plan to travel within Germany;
- the Video Tolling option supported in different multilane free-flow schemes (both in urban and inter-urban environment), where occasional users may register themselves within the system and charge the passages onto an account on the base of the license plate number;
- the use of a Smart Card to declare and register the travelled kilometers upon the entrance and the exist in Switzerland that is offered to foreign HGVs in the frame of the LSVA system.

Each of these approaches is valid and adapted to the specific constraints.

The most appropriate approach needs to be defined by taking into account the characteristics of the network, as well as the characteristics and the volume of the concerned vehicles.

Payment schemes and solutions

This section provides an overview of the different approaches that are used and that could be possibly used to handle the payment of the charge associated to the use of the road infrastructure.

The more conventional road charging systems that were implemented since the 60s and that are still in operation, accepting different payment means, namely cash, private cards, debit cards, credit cards and fuel cards. In some case other technologies are being used, such as RFID or NFC cards in order to improve the user experience during the payment.

The introduction of electronic toll collection mechanisms, and in particular the use of on-board units or of alternative means to identify the vehicles and the users, has made necessary to establish a payment architecture that is associated to the OBUs and that allows to associate to each user account a specific payment means for the transfer of the money from the user to the toll charger.

In general terms there are two main options that are offered:

- a Pre-Pay method, whereas the user account is charged with an amount that is then decreased over time as long as the user is travelling across the network;
- a Post-Pay method, whereas the toll transactions are accounted in near real time and then they are billed at the end of a reference period (on a monthly basis rather than on a weekly basis).

The different solutions differ in terms of business model. A short description of each of the relevant options will be provided, as well as some of the associated key cost driving elements. The analysis will comment also on the maturity of the technology, the availability of the technology, potentials for interoperability and other characteristics such as scalability, adaptability, flexibility and safety.

Pre-Pay mode

The Pre-Pay mode allows a road user to pre-pay, or better to charge its account with a specific amount that is then decreased by accounting the different toll transactions in accordance with the actual use of the road.

The pre-pay account is re-charged by means of one of different payment means, i.e. by using cash or one of several cards (debit, credit o fuel cards). A payment transaction is therefore performed by using a payment card, and the corresponding amount is charged onto the user account.

A commission is then paid by the toll charger to the issuer of the relevant payment means for the use of the card. The commission is clearly applied only when a payment card is used.

Post-Pay mode

The Post-Pay mode allows a road user to pay the toll after the transactions being actually registered. The user account is in fact associated with a registered payment means, towards which all the transactions performed within the reference time period are accounted.

The post-pay account is associated to a registered payment means, such as a debit card, a credit card or a fuel card. At the end of each reference period (typically a month) all transactions that have been accounted onto the post-pay account are invoiced and charged onto the payment means that is associated with the account.

A commission is charged by the card issuer to the toll charger in relation to the risk that the same issuer assumes with regards to the solvency of the user. The actual level of the commission is in the range of 2% of the transaction value.

Not all the payment means available on the market can be used as post-pay means, depending on the commercial strategy of the different issuers. In addition to that, the card issuers are ready to allow a user to set-up a post-pay account only if specific financial guarantees are provided. As a consequence of that, the post-pay method is not accessible to all users.

Direct Debiting

As mentioned above, not all the road users can have access to post-pay accounts, as the issuers of the cards on which these account are based are restrictive on the base of the financial capabilities of the user.

In order to partially solve this problem and so ensure accessibility to post-pay to a larger number of road user, certain toll chargers have implemented a so called Direct Debiting scheme, whereas the post-pay account is managed directly by the toll charger.

The road user is then establishing a post-pay contract with the toll charger only, by means of which the user is invoiced without the intermediation of a card issuer. The toll charger has also the advantage that he avoids the commissions on the toll transactions.

An example of this concept is represented by the DirectGo scheme that has been implemented by the toll charger Asfinag in the frame of the LKW-Maut system in Austria.

Technology Evolution

In terms of technology evolution, technologies are inevitably continually becoming obsolete. In particular, communications technologies in Western Europe:

- GSM is regarded as a fall back technology. There have been proposals to discontinue it and it risks being declared obsolete by 2020
- Components for GPRS for data communications are becoming more difficult to source as telematics units are more likely to adopt 3G or 4G data communications. In parts of Eastern Europe 3G may still be an emerging solution and the roads may not have the required covered, so GPRS obsolescence is generating some challenges.

The single unifying technology across all vehicles is still the vehicle number plate; hence vehicle detection using ANPR cameras is likely to be a common requirement across all scheme types. Therefore a common framework for data captured and quality measures which can be applied across member states without affecting local enforcement or subsidiarity, would be useful. For example, the following data fields in the ANPR record could have standard minimum content and quality.

- Vehicle in Context of its Surroundings/Overview Image
- Number plate image
- Interpreted Vehicle Registration Mark
- Confidence measure for interpreted VRM
- Affirmation the ANPR camera is working correctly/Diagnostic alarms
- Affirmation the evidence has been captured correctly
- Encryption/watermarking of the image and dataset
- Location name, code including direction of facing, lane number
- Date and timestamp to 0.01 second.

The primary emerging technology is the vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) standards that have adopted the 5.9 GHz WAVE standard for communications between vehicles and with the roadside. Tolling or charging is just one “app” amongst a wide range which V2V and V2I are expected to support in the next 15-20 years, summarised in Table 6 below.

Table 3.14: Summary of Applications which V2V and V2I are planned to Support

Safety • E-call to a tunnel control room or 111 service • Warnings on entering or leaving tunnels and at highway intersections • Obstacle discovery and alerting • Warning of sudden traffic braking and stopping • Reporting incidents and accidents • Lane change warnings • Highway edge/ tunnel wall impact avoidance **Traffic Management** • Variable speed limits and intelligent speed adaptation • Adaptive signal control/priority • Automated intersection control • Priority for ambulances, fire and police cars **V2V** • Collision avoidance (front to rear and front to front) • Spatial monitoring of the vehicle relative to other vehicles: trajectory, relative distances, speed of surrounding vehicles. • Recording accident details (black box)	**Driver Assistance** • Guidance to parking locations and destinations • Parking a vehicle • Cruise control • Support to keeping in lane • Electronic road sign recognition/repeating • Control and Enforcement • Traffic surveillance • Speed limit warnings • Access control and restricting entry • Checking vehicle/driver credentials/load details • Commands to pull over **Payments** • Toll collection • Parking payments • Freight/loading control • Usage based insurance **Information** • Maps and navigation • Fuel stations/electric charging points • Business locations • Car related services

Autonomous vehicles are currently emerging and are adopting V2V and V2I technologies and sensors.

In practice, V2V and V2I standards are some way from being widely implemented in vehicles available today and there is likely to also be a substantial legacy vehicle fleet on the road even when these solutions are fitted as standard to new vehicles. It has been proposed that such standards may become mandatory for vehicle OEMs in 2018-2020. The Amsterdam Group (CEDR, ASECAP, POLIS, Car-2-Car Communications Consortium) has defined a roadmap for Cooperative ITS in Europe, though to date, road pricing/tolling is not an identified application. The one element that may be relevant in the short term is the 5.9 GHz WAVE standard which some tag and beacon suppliers have adopted to increase the communications range between the tag reader/beacon and tag/OBU from the ~10 metres allowed by the CEN 5.8 GHz standard, towards 70m or more.

The EC Decision 2008/671/EC introduced throughout Europe a new frequency bandwidth (5 875 to 5 905 GHz) for safety-related ITS applications. They feature both inter-vehicle communication and roadside to vehicle communication. The introduction of this new bandwidth and the development of the on-board and roadside products, represents an opportunity to achieve a worldwide harmonisation of this spectrum range and of technical solutions for ITS applications. USA and Canada have assigned 5 850-5 925 for ITS with significantly lower spectrum range and usage restrictions. Thus, the European industry is at a disadvantage and deployment in Europe will be slower and more expensive due to this. The US has a time schedule that aims to legally require 5.9 GHz safety systems on all new vehicles from 2015/2016 onwards. European car manufacturers have indicated they will also follow this guideline for the European market. The 5.9 GHz spectrum range has been adopted for ITS in many other countries in Asia/Pacific and the Middle East. This is important for the industry due to economies of scale and also in reducing national test régimes for different markets. As with the USA, where 5.9 GHz solutions have started to be introduced to the market and toll agencies are considering using this technology for tolling as well, a migration of EU-based electronic toll facilities towards this new technology needs to be carefully considered. The EU market dimensions (with several million circulating OBUs) as well as potential interferences that are anticipated between the CEN DSRC 5.8 GHz (referred to as RTTT applications) and the ITS-G5 5.9 GHz applications make such a migration complicated. The evaluation of this technical implementation in Europe is expected by 2016/2017, in order to finally appreciate the impact of interferences between the two technologies.

The evolution of the mobile phone and its potential application to tolling can pose some interesting questions and challenges for the future. A summary of some of the key considerations in this debate are set out below, . On one hand:

- The smartphone can establish its position using the GNSS signal and the 3G/4G triangulation;
- The smartphone has an increasing memory capacity and CPU to run multiple types of applications in parallel;
- Updating an application is easy and can be done over the air via 3G/4G or wifi networks;
- Smartphones are often linked to a debit or credit card to purchase applications or content; and
- Users can easily create an account, update information, scan documents, top-up, etc.

Using a smartphone could obviously facilitate the customer relationship and make the tolling easier for the final user by reducing barriers such as dedicated equipment etc. However, there are some challenges that would need to be overcome before it could represent a viable tolling solution in its own right.

- The smartphone must be in an installed in an optimised position to receive the GNSS signal and be connected to the mobile network;
- The smartphone may need to be interfaced with the vehicle to guarantee a proper functioning for a tolling application (eventually to connect to the GNSS module of the vehicle, the odometer and the gyroscope), and a potential connection to an energy source;
- The interface with the vehicle which is a complex and long process. The products life time are different several years for a vehicle and several weeks for a smartphone. Up to now, the carmakers have no financial or marketing interest to develop a solution to interface a smartphone for a tolling purpose. The development of new telematics linked to the autonomous car may create opportunities for tolling application embedded into a smartphone. To our view, this is unlikely to be established until around 2030.

4 WP3: Performance assessment

We have seen that every scheme that is implemented is unique in its characteristics and nature. These differences may be a result of the scheme rules, the legal basis, the underpinning the technology choices, the actors involved or many other factors.

The result of this is that it is not possible to directly compare the performance of one scheme against another. What is instead possible to do is to comment on general scenarios, and whether a technology's characteristics lend itself to supporting a particular type of scenario.

To assist with this process a set of generic hypothetical scenarios have been generated. These have been created based on high-level scheme design characteristics that a prospective Toll Charger is likely to have a view on from an early stage (and can therefore potentially relate to). The high-level characteristics include:

- The types of vehicles that will be subject to a toll;
- The nature of the network to be tolled (e.g. motorways, all roads, a specific area);
- The length of the network to be tolled (and more specifically the number of charge points that are being considered);
- The nature of the toll (e.g. by distance, by time, or an access charge for a specific area).

Qualitative performance considerations

There are clearly a vast number of factors that affect the design and operation of a scheme, but generating hypothetical charging scenarios based on the key characteristics above enables this study to objectively discuss the merits of different technologies in supporting those hypothetical schemes without appraising existing real schemes or their technology choices.

The set of hypothetical scenarios that will be used in the initial part of this qualitative assessment are as follows:

- Distance-based motorway schemes, applying to all vehicles, on a network that is under 5.000 km in length;
- Distance-based motorway schemes, applying to all vehicles, on a network that is over 5.000 km in length;
- Distance-based motorway schemes, applying to only heavy vehicles, on a network that is under 5.000 km in length;
- Distance-based motorway schemes, applying to only heavy vehicles, on a network that is over 5.000 km in length;
- A distance-based scheme that is applied to all roads, applying to heavy vehicles only, on a network that is over 5.000 km;
- Time-based, all roads;

- Distance-based schemes that applies to all vehicles, with a network that is based on single roads/tunnels/crossings that are under 150 km in length;
- A zonal, time-based;
- A zonal, cordon-based scheme.

To help place the hypothetical scenarios in a real world context, a table has been prepared that identifies the way that real schemes could be grouped based on the hypothetical tolling scenarios.

Table 4.1: Example schemes grouped by hypothetical scenarios

Scenario		Examples of real schemes
1	Motorways; all vehicles; distance based; under 5.000 km	Portugal; Spain
2	Motorways; all vehicles; distance based; over 5.000 km	France; Italy
3	Motorways; Heavy vehicle only; distance based; under 5.000 km	Austria; Belarus; Belgium (from 2016); Czech Republic
4	Motorways; Heavy vehicles only; distance based; over 5.000 km	Germany; Hungary; Slovakia
5	All roads; Heavy vehicles only; distance based; over 5.000 km	Switzerland
6	All roads; Heavy vehicles only; time based; over 5.000 km	UK (HGV Levy)
7	Single Road/Crossing/Tunnel; All vehicles; distance; under 150km	Austria; France; Ireland (M50); UK (M6 Toll, Dartford Crossing)
8	Zonal; All vehicles; Cordon based; under 100km	Stockholm Congestion Charge
9	Zonal; All vehicles; Time-based; under 100km	London Congestion Charge; Milan Area C

The table below provides an overview of an initial assessment of each technologies capacity to support the hypothetical tolling scenarios.

Each one of these scenarios is differently characterised in terms of:

- Length of the network, with a consequence in terms of the number of necessary charging points;
- Characteristics and number of vehicles, with a consequence in terms of the number of on-board units;
- Road network topology, with a consequence in terms of complexity in the organisation of the charging policy;

Nevertheless, other parameters can influence the choice of a solution or another, such as the ratio between national and international traffic.

Table 4.2: Technology assessment against set of Scenarios

		Technologies					
	Scenario	**DSCR**	**GNSS/GSM**	**ANPR**	**Sticker Tag**	**Mobile Phone**	**Manual collection**
1	Motorways – all vehicles, distance based, under 5.000Km	YYY	YY	Y	YY	YY	Y
2	Motorways – all vehicles, distance based, over 5.000Km	Y	YYY	N	Y	YY	N
3	Motorways – HGV only, distance based, under 5.000Km	YYY	YY	Y	YY	Y	N
4	Single road/crossing/tunnel – all vehicle, time based over 5.000Km	YY	Y	YYY	YY	Y	YYY
5	Motorways – HGV only distance based over 5.000Km	Y	YYY	N	Y	YY	N
6	All roads- HGV, time based over 5.000Km	Y	Y	YY	Y	N	N
7	All roads- HGV, distance based over 5.000Km	N	YYY	N	N	YY	N
8	Zonal – all vehicles, cordon based under 100Km	N	N	YYY	Y	Y	Y
9	Zonal – all vehicles, time based under 100Km	N	N	YYY	Y	Y	N

KEY

***N**: Not suitable (eg. network length is too short to justify costly in vehicle equipment, or the network is too long to justify expensive roadside equipment and infrastructure)*

***Y**: Could be used for the Scenario but would not be suited to the technology strengths*

***YY**: Broadly suitable for the Scenario but there are certain characteristics that could limit the performance (eg. the need to proceed large number of images for a wide scale ANPR scheme, accuracy of read rate, ..)*

***YYY**: Strongly suited to the technology strengths (eg. scalability, robust, most appropriate for the traffic profile, most suited for network length, …)*

We have seen that each technology has its own strengths, and the suitability for use with a scheme is subject to a number of factors including the type of vehicles that are subject to the toll, the network length and charge point density, the road types being tolled, and the nature of the toll.

A summary has been provided below that comments on the merits and strengths of different technologies in responding to those core characteristics of these hypothetical tolling schemes.

Type of vehicles

The types of vehicle that are subject to a toll (e.g. heavy vehicles only [e.g. in the case of scenarios 3, 5, 6, and 7] or all vehicles [e.g. in the case of scenarios 1, 2, 4, 8 and 9]) has an impact on the choice of technologies that are best placed to support a particular scheme.

The vehicle type has an impact on different types of technology and their suitability of Classification and detection of relevant vehicles (alignment of cameras/classification equipment is more complex if schemes apply to both heavy and light vehicles; training of equipment for local traffic).

HGVs are very familiar with being tolled, particularly if they are engaged in long distance haulage in Europe. As a consequence they are used to dealing with in-vehicle equipment, especially DSRC tags, but also GNSS-based OBUs if they travel through applicable areas (e.g. Germany).

Whilst ANPR-based approaches require similar levels of roadside infrastructure to DSRC, it does receive a lower score for certain scenarios. This is for a number of reasons: firstly the camera equipment needs to be carefully configured to capture images at the correct angle and resolution for the local traffic (which is more time consuming if all vehicles are liable to the toll). Secondly, a national number plate database is required to enable any suspected violations to be processed. However, ANPR based solutions do offer the benefit of meaning that occasional users of a scheme do not need to have any dedicated equipment to pay their toll.

If the number of vehicles that are liable to the toll is particularly large, it can present issues for certain technologies in terms of the processing of transactions and detection of vehicle passages. This is specifically the case for ANPR where the manual processing of images can be high if the fleet is large, and the initial detection is insufficiently conclusive.

One of the key differences between tolling all vehicles and supporting only a subset of the overall fleet, relates to traditional manual collection. If the toll is only applicable to heavy vehicles, then a barriered manual toll collection would not be suitable as the traffic would be mixed, and the light vehicle traffic would need to be filtered out.

Network length

The length of the tolled network, and more specifically the number and density of the charged points or intersections has an impact on the choice of technologies for a given scheme.

The reason that the number of density of charge points is relevant is that different tolling technologies will handle the charging process in different ways, and may require road side infrastructure to support that process. For example, DSRC-based solutions require infrastructure on which the transceiver and other detection and classification equipment is mounted, roadside cabinets to process the collected data, communications equipment to transfer the charge data to a back office. This can represent a significant capital cost for a scheme, subject to the number or density of charge points.

DSRC-based solutions are considered to be effective for schemes that are broadly consistent with this type of scenario, particularly if the number of charge points or toll sections are towards the lower end of the spectrum (e.g. fewer than 1.500).

If the number of charge points would be lower, and if all vehicles were liable for the toll, the utilisation of the tolling scheme would be higher. Therefore the DSRC could be considered to be a viable option from a cost effectiveness perspective for this scenario 1. Whilst the CAPEX for the roadside infrastructure is high relative to some other technologies (e.g. GNSS), the OPEX is typically lower. Additionally, the cost of distributing the OBU (e.g. by having arrangements in place for users to acquire OBUs from shops, vending machines or some alternative fulfilment method) would be spread across a wider vehicle fleet.

GNSS-based approaches are flexible in the type of scheme that they support. They become a progressively viable option as the density of charge points/intersections and number of liable vehicles increase. In the context of a scenario where the network length is under 5.000 km, GNSS technologies could be used, especially given that all vehicles would be liable for a toll. One of the significant benefits that GNSS-based tolling solutions has is that it requires no roadside infrastructure and so the CAPEX costs are significantly lower than the alternative offered by DSRC, ANPR etc.

There are certain challenges that GNSS-based solutions face in the context of this scenario. If the network length is shorter, the benefit to cost ratio becomes smaller due to the significant OPEX costs. Additionally occasional users present a challenge if it is mandatory to be equipped with a GNSS OBU as they need to acquire and install an OBU prior to entering the charged network.

Nature of the road network

The nature of the tolled network is another key characteristic that a prospective Toll Charger is likely to be aware of from the outset, but will have significant implications for the technology chosen to support the scheme.

A scheme that tolls drivers for the use of all roads will likely have implications for the choice of suitable technologies. This is of course dependent on the nature of toll (e.g. whether the prospective Toll Charger intends charging users by time, distance, or access – these will be discussed in the section below), however this section discusses the implications in general terms.

If a distance-based toll is applied to all roads in a given area, then this would mean that a vast amount of roadside infrastructure would be required for schemes adopting DSRC, RFID or ANPR based solutions for detecting a toll liability. Under these conditions it would be difficult to consider those solutions as viable options. In this scenario, a GNSS-based solution would be more appropriate as the toll sections or distance driven does not require physical infrastructure to be in place for the liability to be detected.

Urban environments

In urban environments, greater consideration needs to be paid to the design and implementation of any roadside infrastructure such as mounting equipment, cabinets and so on. Typically, the full, cross road mounting gantries that might be used on interurban networks cannot be used in urban settings. Consequently significant steps are taken to find mounting infrastructure that is sympathetic to the surroundings and responds to residents/business needs to keep tolling equipment away from residences.

There are specific challenges for GNSS-based solutions in urban environments relating to urban canyoning. GNSS OBUs typically include a number of additional features such as accelerometers and dead reckoning that are combined with map matching to overcome some of the issues associated with constrained areas.

In urban environment there are also considerations to be made about the configuration and alignment of any fixed tolling equipment. Whilst the mounting infrastructure might be different to an interurban setting, it is still critical to ensure that the read angle is appropriate for the technology. A balance needs to be struck to limit revenue leakage in the system compared to intrusive infrastructure

Short stretches of roads

For standalone, short sections of road GNSS is not generally considered to be a suitable option due to the comparatively high OBU costs, plus the high operational costs. GNSS might be a viable option if the single road is interoperable with a wider set of schemes. Additionally, GNSS-based approaches could be a useful solution if the single tolled road is part of a patch work of schemes (especially if the scheme rules vary substantially as GNSS solutions offer a greater degree of flexibility in their ability to be adapted to support a range of scheme types).

There are many instances where DSRC-based solutions have been used in single toll lane environment as an alternative to cash or credit card payments at barriers. The OBU is significantly lower in price than GNSS, and for shorter sections of road with fewer interchanges/charge points the infrastructure costs can be acceptable. There are many factors that influence the effectiveness of such a solution such as the traffic flow, the local attitude to compliance etc.

Video tolling using ANPR based-solutions is being used frequently now, either as the primary method of detecting the toll liability or as an option for users with an account. E.g. Dartford/Austria. This is a viable option for single toll roads as it does not require any dedicated in-vehicle equipment. Video tolling needs to be carefully handled in certain environments, particularly in tunnels to take account of the enclosed environment with a higher level of pollutants and dirt/grime. However, it should be noted that there are challenges relating to number plate databases, and cooperation with authorities from other countries.

Traditional manual tolling with payments via cash, debit/credit/fuel cards are the dominant method of tolling in this scenario.

Flexibility (extension of the network; changes to the scheme rules…)…

Over the course of a schemes lifetime, the Toll Charger may plan changes to the scheme that affect its characteristics and can have an impact on a solutions capacity to support the scheme.

These changes to the schemes characteristics could include aspects such as the following:

- Extension of the scheme to a wider network or to reduce traffic report
- Interaction with other schemes and interoperability
- Changes to the scheme rules (e.g. type of charged vehicles, vehicle classifications,
- Changes to tariffs
- Introduction of different account types
- Changes to legislation (e.g. evidential requirements, data protection etc.)

A summary of the main characteristics of the different technical options in terms of flexibility and scalability is provided in the following Table:

Table 4.3: Technology Flexibility

Technology	Adaptability
DSRC	Relatively low levels of adaptability. There can be changes made to the tariffs at the roadside, or in the back office; but the scheme can be difficult to modify once it is installed. Extending a scheme can involve the installation of additional infrastructure at the roadside as well as extending the distribution network for OBUs. If the scheme is based on charging by road section/distance then DSRC requires a lot more infrastructure for roads with a large number of intersections; the installation of additional infrastructure can be challenging in areas with limited land (e.g. in urban areas) or with an absence of power, communications).
RFID	Similar considerations to DSRC regarding adaptability, but with the advantage that the OBU costs are typically significantly lower
ANPR	If the scheme is extended on a geographical basis then an ANPR based scheme will require additional infrastructure and tuning of the system to react to the traffic conditions; further issues relating to number plate standardisation and cross-border cooperation; and the volume of post-processing [NB – this can vary depending on the scheme requirements, and solution applied]).
GNSS	Highly adaptable. For example: • The OBU can be updated remotely to respond to changes in the users contract or the scheme rules; • The scheme itself can be extended without the need for additional roadside infrastructure, (e.g. virtual gantries can be added in the OBU or in central depending on the tolling mode) However, GNSS-based tolling solutions typically require a comprehensive communications network to exchange charge data and update OBUs so if the signal in areas or if the roaming close to the borders are poor, then redundancy solutions must be included

For example, the 17.700km extension in Slovakia (GNSS system) was performed in 3 months. The Capex and the Opex associated with the extension:

- Capex = 12.4 million EUR
- Opex (per year) = 5 million EUR

In terms of scalability, the GNSS solution offers the most cost effective opportunity in the shortest time.

Table below provides an example for the matrix and scoring for the technology options. The scoring for each technology type (or grouped solution) is relative to the other technologies. We have assumed that GNSS can be used only for national schemes, and ANPR, DSRC and RFID could serve both zonal and national schemes. At this stage we have not rated mobile communications as an ETC solution as it is not sufficiently mature.

The impacts that will be explored are between scheme types:

1. National schemes – all roads
2. National schemes - motorways
3. Motorways with few intersections per unit distance
4. Motorways with many intersections per unit distance
5. Zone based schemes – urban with residential street scape and public realm sensitivities
6. Zone based schemes – industrial/non-residential and no public realm sensitivities

The main differentiators between Scheme types 1-4 are costs – so an outcome from the costing element

The differentiators between Schemes 5 and 6 are also cost related. However, use of gantries and heavy structures may be impractical for type 5. For Scheme type 6 the differentiator is expected to be just cost.

Table 4.4: Example Matrix and Scoring for Technology Options

	Scenario	DSRC Only	GNSS Only	ANPR Only	DSRC + ANPR	GNSS + ANPR	GNSS + DSRC + ANPR	RFID Only	RFID + ANPR	RFID + ANPR +DSRC
	Charging & Enforcement									
1	Maturity of the technology	5	3	4	5	4	4	4	5	5
2	Availability of the technology	5	4	4	5	5	4	4	5	5
3	Suitability for Charging	5	4	4	5	4	5	4	4	5
4	Reliance on Mapping/GIS accuracy for charging?	5	1	5	5	2	2	5	5	5
5	Suitability for Enforcement	1	1	5	5	5	5	1	5	5
	Customer									
6	Safeguard personal data	5	3	4	4	4	3	5	4	4
	Operations, Maint and Cost									
7	Maintainability	5	3	5	5	5	4	5	5	5
8	Safety	5	5	5	5	5	5	5	5	5
9	Operates under power supply failure	5	2	5	5	2	2	5	5	5
10	Additional services to share technology costs	2	5	2	2	5	5	2	2	2
	Regulatory									
11	Approved/Recognised by EFC Directive	5	5	1	5	5	5	1	1	5
	Customer Channels									
12	Access to web-based internet account	5	5	5	5	5	5	5	5	5
13	Vending machines/Occasional User	4	2	3	4	2	2	5	5	5
14	Does not require user cooperation/ sign-up	1	1	3	1	1	1	1	1	1
15	Does not rely on end user installation	1	1	5	1	1	1	1	1	1
	Long Term Technology Future									

	Scenario	DSRC Only	GNSS Only	ANPR Only	DSRC + ANPR	GNSS + ANPR	GNSS + DSRC + ANPR	RFID Only	RFID + ANPR	RFID + ANPR +DSRC
16	Well defined roadmap for road pricing	5	3	3	4	5	4	5	5	5
17	Well defined use in future vehicles	3	4	5	5	5	4	4	4	4

KEY:

The scoring system adopted uses a scale of 1 to 5 with a qualitative grading with the aim of comparing relative quality, compliance or fit depending on the parameter assessment. Hence a score of:

5 indicates best, good, compliant, cost effective, accurate, good capability

1 indicates worst, poor, non-compliant, not cost effective, inaccurate, no capability.

Grades in between 1 and 5 indicate marginally better or worse in the context of the aspect being compared.

Technical key performance indicators

In addition to the more qualitative criteria detailed by the previous sections, the different technical solutions can also be assessed on the basis of more quantitative key performance indicators that are the subject of this section.

These key performance indicators are particularly important for the solutions that fall within the category of the tolling systems operating in a free-flow environment as they have direct impact on the business case of the toll charger as well of the toll operator, and therefore can influence a decision towards one or another solution.

They are less pertinent for the other technical options, even if they can be measured for electronic fee collection schemes in a single lane environment as well. In principle, and independently from the adopted technological solution, the performance of a free-flow tolling system can be measured on the basis of:

- The capacity to detect the passage of an eligible vehicle through a charging point;
- The capacity to recognise and identify eligible vehicles who are suspected to be non-compliant with the scheme rules.

These criteria are representative of the strategic objectives that characterise the operation of a tolling system, i.e. the maximisation of the income and the optimisation of the operating costs associated with the collection and with the handling of the exceptions.

If the tolling and enforcement solution is able to detect the charge liabilities, and identify suspected non-compliance effectively it reduces the requirement for manual processing for exceptions, and maximises the revenue collected.

The above criteria can be calculated in different ways depending on which technology and solution is being used. These criteria can be measured differently depending on the technology used, the business logic and the systems operational context. It is therefore challenging to provide an indication of the key performance indicators that the market is able to support at the present time.

Nevertheless, the following sections provide an overview of key indicators that can be used to measure the performance and capability of different tolling systems. A set of performance values are proposed in the context of a free-flow tolling scheme.

The performance indicators considered below are:

- Vehicle detection, corresponding to the capacity of roadside infrastructure to automatically detect the passage of a vehicle;
- Short range communication, corresponding to the capacity of a roadside infrastructure to properly communicate with the on-board equipment installed within the vehicles;
- GNSS transaction, corresponding to the capacity of a GNSS-based tolling system to correctly register the passages of the OBUs through a charging point;
- Vehicle classification, corresponding to the capacity of a roadside infrastructure to classify a vehicle by means of the measurement/detection of the key vehicle parameters;
- Recognition of the license plate of a vehicle, corresponding to the capacity of a roadside infrastructure to identify the license plate number.
- Location accuracy
- Billing accuracy

Each of these indicators contributes to the overall quality of a tolling system, although no single indicator should be taken as a gauge of the overall performance of the tolling system.

Vehicle detection

The performance of all tolling systems depends directly on the capacity of the system to detect the passage of eligible vehicles across a charging point. In electronic toll schemes, the detection of the charge liability acts as the trigger for the calculation of the charge that is due.

Depending on the characteristics of the tolling system and on the specific technical solution, the detection of the passage of a vehicle can be performed by:

- the simple communication with the on-board equipment installed within a vehicle (only vehicles carrying on-board equipment are detected in this case unless other detection mechanisms are integrated);
- the automatic registration of the passage across a charging point performed by the on-board equipment itself (in the case of autonomous tolling systems);
- the physical detection of the vehicle when it is passing across a charging point.

This section deals in particular with the third case, as the two other cases are dealt within subsequent sections below.

The physical detection of a vehicle is very important whenever evidence (such as an image) of the passage needs to be collected, for both tolling and enforcement purposes. This is the case in tolling systems that adopt an ANPR-based solution for detecting the charge liability rather than only being used to collect evidence of suspected non-compliance.

The detection of the passage of a vehicle is often used to trigger the collection of images (of the license plate and/or of the overall context) and to launch the vehicle classification process.

The performance of such a process is therefore very important for the overall system as an evidence is collected only when a vehicle is detected.

Different technical solutions can be used to detect the vehicles. In most cases laser devices (forming a vertical laser curtain that is intercepted by the front and/or the rear of a vehicle) are used, but magnetic loops under the road surface and volumetric detector can be used. Detection of vehicles on the base of the automatic triggering of the cameras on the license plate number of a vehicle can be also used, but it is typically characterised by a lower performance.

Most vehicle detection mechanisms can guarantee a very high level of performance. Vehicle detection in the range of 99.9% or better can be easily achieved.

Short range communication

In many electronic toll systems, an on-board equipment can be installed (either as a mandatory or as an optional solution) within the vehicle. ; The on-board unit communicates with a reader installed at the roadside.

This performance is subject to the communication between the roadside and the on-board unit. Therefore it depends on technical parameters such as EIRP power (as permitted by the frequency bandwidth and countries/regions of the world), orientation of the antennas and the size of the antennas. Read-only systems are characterised by higher performance than read and write systems as the transaction time is smaller and therefore the margin on the radio link budget is higher.

The theoretical performance can be significantly affected by the behaviour of the users. If the users do not install the on-board unit correctly or take steps to interfere with the on-board unit, then there will be negative consequences for the efficiency of the communication with the roadside equipment.

The operation of several free-flow electronic toll systems on the basis of 5.8 GHz DSRC technology has shown that a charging rate of up to 99.7 to 99.9 % can be achieved. Slightly lower performance levels are obtained by using RFID solutions.

GNSS transaction

A number of autonomous tolling systems make today use of a GNSS technology to register the position of the vehicles along their journey and to detect the passages across the charging points.

In these cases the passage of a vehicle across charging points rather than along a toll section are typically detected and recorded by means of so-called ‘virtual gantries’. The road network that is subject to the payment of a toll is divided into sections, and each section is coupled with a charging point. The passage of a vehicle across this point triggers the registration of a toll transaction.

Although different solutions are implemented by suppliers, in general each charging point is created using a polygon of coordinates that is referred to as a virtual gantry.

The passage of a vehicle across a charging point is recorded by continuously comparing the positions of the vehicles and these virtual gantries. The comparison can be performed either within the OBU (in the case of thick client approach) or in the back-office (in the case of a thin client approach).

The performance of these approaches can be improved by implementing software mechanisms (within the back-office) that allow the reconstruction of the toll transactions even when no communication with the on-board unit has been completed. This can be achieved by evaluating whether a vehicle is likely to have passed through a charging point on the basis of the transactions recorded at specific the charging points located before and after.

This indicator relies directly on the performance and reliability of the localisation and on the robustness of the detection mechanism.

The performance of the localisation approach depends on the characteristics of the OBU, in particular of the GNSS receiver and of any additional mechanism that increases the quality of the registered position. However, it is strongly affected by the topology of the road network and by the number of satellites that are visible to the OBU in the proximity of the charging point.

The error that characterises the localisation of the OBU becomes greater as the number of visible satellites gets lower, e.g. in dense urban areas and in particular in urban canyons (characterised as areas with high-rise buildings). As the positioning error increases, the detection of passage across a charging point is also affected by an error, and the system can register either positive or negative errors (registering the passage of vehicles that were travelling on parallel roads or not register the passage of vehicles that were actually travelling on the tolled network).

The opportunity to position the charging point with a certain flexibility, so reducing the possibility of errors due to complex road topology, and the use of performance map matching mechanisms can help to significantly increase the performance of such systems. Augmentation beacons may be used in those cases (e.g. tunnels) where no other alternative can be adopted.

Recently the technological evolutions has reached such a level that the charging performance of GNSS-based has become very similar to the one that characterises DSRC-based tolling systems. A charging performance in the range of 99.7 to 99.9 % may be achieved with the available solutions.

Recognition of the license plate number of a vehicle

The number plate of a vehicle is used in a number of schemes as a means of identifying a vehicle for both tolling and exception handling purposes.

For tolling systems that makes use of video tolling mechanisms the possibility of properly recording license plate numbers as a proof of passage is key to maximising the toll revenue. At the same time it is of utmost importance that the quality of the evidence is such to ensure a significant proportion of number plates are identified automatically. This limits the requirement for human intervention and reduce the overall operational costs. In a similar way, the license plate recognition is a key success factor also for the handling of exceptions and as a means to enforce violations.

The ANPR process is one of the most critical process in a free-flow tolling and enforcement system and its optimisation is often a key success factor for the economical effectiveness of systems.

The performance of the image capture and recognition process is subject to a number of factors including the quality of the cameras deployed, their correct installation, and on the efficiency and robustness of the ANPR process. The market for ANPR-based solution offers high-quality camera equipment and as a result, the efficiency and robustness of the process is the most important issue in determining the effectiveness of a scheme.

The possibility of creating the correct lighting conditions both during day and night and the capacity of recognising license plates of different nationalities are also very important.

Often the ANPR process can be maximised by integrating back-office image processing.

The performances of such a solution are such that a license plate number can be read out in the 96 to 98 % of the cases but, depending on the context the derived license plate number is correct in the 92 to 96 % of the cases.

The nature of the traffic has an impact on the efficiency of ANPR-based solutions. If a toll scheme is likely to involve a significant proportion of foreign vehicles the correct recognition of a license plate number becomes more difficult. This is because the cameras and the ANPR mechanisms need to deal with number plates with differing characteristics (e.g. reflective vs non-reflective plates, different colours, varying syntax). The performance of ANPR-based solution under these conditions can be significantly reduced, down to approximately 85 %.

Vehicle classification

The tariff applied to toll schemes is often subject to the vehicle classification.

The detection of the vehicle classification is particularly relevant to schemes that involve systems that do not read the vehicle class form an on-board unit, e.g. an ANPR-based solution. Under these circumstances it is important to:

- distinguish eligible from not-eligible vehicles (if applicable);
- verify whether a vehicle is declaring the correct category;
- perform the maximum possible verifications during the passage and therefore reducing the manual verification afterwards.

The classification criteria typically adopted in free-flow electronic toll systems involve one or more of the following:

- the maximum permissible weight;
- the number of axles;
- the environmental class (e.g. the Euro class of the vehicle engine).

Whereas the environmental class can be retrieved only by means of declaration, the other parameters can be measured in an automatic way, although with some limitations.

Most systems actually derive the number of axles from the size of the vehicle, on the basis of statistical information; the actual measurement of the axles is far more complicated, as it requires the analysis of the vehicle characteristics from a side view, that is not always possible or easy (especially in a multilane free-flow environment where the traffic is less constrained than it is in a toll plaza environment).

The classification process is also affected by the types of vehicles that are subject to the payment of the toll.

First of all there is often the need to distinguish whether a vehicle is or not eligible to pay; this is the case for all tolling systems for heavy good vehicles.

This analysis can be complex, particularly if the threshold for eligibility is fixed at 3.5t. This is because there are a significant number of vehicles that have physical characteristics close to those of the eligible vehicles even if the vehicle is below the 3.5t threshold. The consequence is that the roadside equipment is not always able to automatically filter out in-eligible vehicles from the tolling and enforcement process. This can therefore contribute to the generation of at least 10% more evidences of potential violations. These cases may be discarded only by means of manual validation, subsequently contributing to increase the operational efforts and costs.

Once the system has determined whether or not a vehicle is eligible for a toll, the next step is to identify the vehicles specific characteristics (e.g. maximum permissible weight or number of axles) and map these to the relevant toll categories. This typically involves the measurement of the overall volume of the vehicle and the mapping of such characteristics to one of the possible categories.

This process is not completely infallible, as the vehicles characteristics cannot be derived in all cases from the size of the vehicles. An example of this is a bus whose size is such that the system may assume them being vehicles with 4 axles or more, whereas they actually have only two axles. These cases cannot easily be automatically processed and require again a manual intervention.

The performance of an automatic classification process in a multilane free-flow environment depends on the classification parameters and on the vehicle characteristics. A correct classification can be measured in the 95% to 98%, whereas the actual measurement of the number of axles is typically captured at a lower rate.

There are many other factors that reduce the accuracy of vehicle detection, for example:

- DSRC OBUs may not be correctly fitted by a customer, or may be installed in an incorrect vehicle – these factors have been found to be the dominate element in detected billing inaccuracies
- Number plates may not be read correctly where they are obscured by other vehicles, dirty, broken and where lighting and weather conditions are not always at an optimum
- GNSS OBUs in many cases rely on connection to the "lighter socket" for power.

Billing accuracy

In terms of Billing Accuracy Target, there have been several attempts to set billing accuracy targets. For example, an often quoted reference uses telecommunications billing systems which may be accurate to 1 in 10^6. Given the other factors above, it seems unlikely that the technologies reviewed above will deliver that same level of accuracy across a whole estate of vehicles. Accuracy of the order of 0.1-1.0 in 10^2 may be a more realistic target. The contractual performance levels are usually significantly lower, for example, the KPIs for the Belgian Viapass operation were specified in 2012, based on a minimum tariff zone length of 150m as:

Table 4.5: Viapass Distance Accuracy Targets. Source ViaPass Technical Architecture Ver 2.7, 12/12/2012.

	Maximum Permitted Deviation from Kilometres Actually Driven for Vehicles with An Operational OBU		
Kilometer Registration Requirement	Urban	Non-Urban	Major Roads
Total Kilometres	4%	2%	2%
Deviation Upwards in Total Kilometres	1.5%	1%	0.1%
Deviation Downwards in Total Kilometres	4%	2%	2%

The key target concerns reducing the risk of "overbilling" distance driven on major roads.

5 WP4: Focus on cost considerations

Introduction

Conducting a cost analysis of a tolling scheme is a complex exercise. Each scheme is different and cannot be compared easily. These varying characteristics can include:

- Varying objectives;
- Network types;
- Interaction with bordering countries or schemes;
- Economic environment;
- Political environment;
- Legal context;
- Operating model;
- Traffic conditions;
- Local conditions etc.

Furthermore, the life cycle costs for a scheme are typically influenced by many factors such as the technology choice, scheme maturity, operating model and so on. **The expected costs of schemes are frequently underestimated during the scoping, design and procurement phase. It is therefore a question of how the cost efficiency of a scheme (across the systems lifecycle) can be optimised during the development phase.**

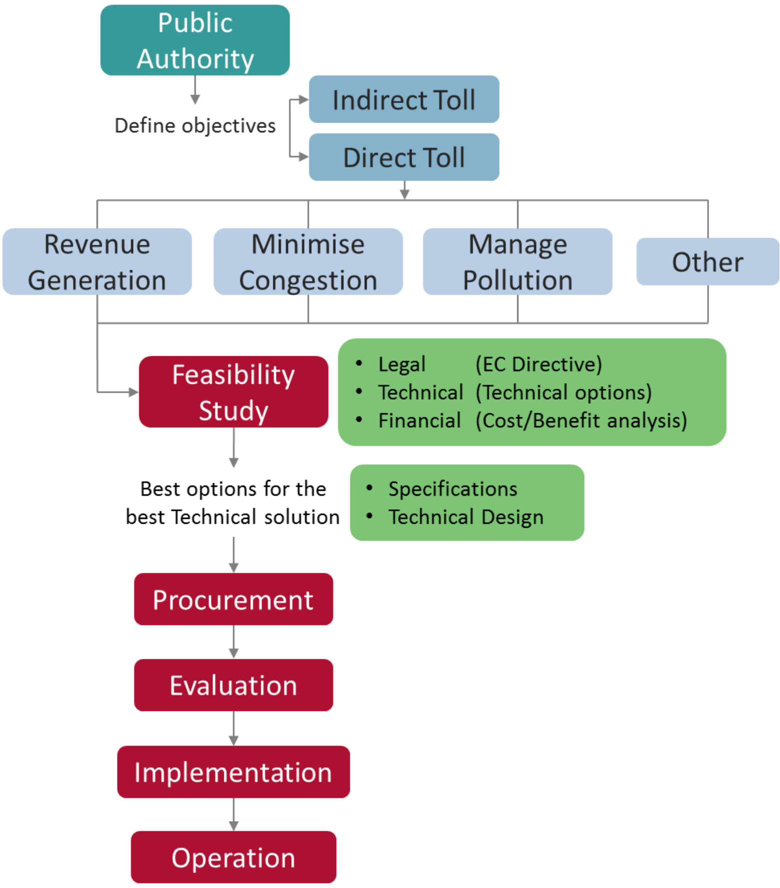
A suggested process for identifying and developing a scheme is set out during the first part of this chapter and includes a commentary on the key aspects that can drive the costs at each stage.

The second part of this chapter deals with the benchmarking of costs for some recent GNSS and DSRC schemes, as well as a comparison between RFID and DSRC solutions for a single lane tolling scheme.

Overall Cost Analysis

The diagram below illustrates the key steps involved in developing a new toll scheme from its initial conception, to the implementation and operation. The same set of principles apply to Toll Chargers embarking on making changes to an existing toll scheme. The key cost drivers and recommendations that can help the prospective Toll Charger to limit their costs during the development/amendment of a tolling scheme will be described in the context of this process.

Figure 5.1: Toll scheme development and cost analysis process



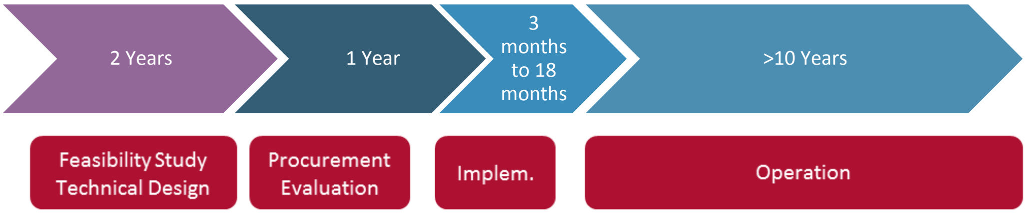
The section below provides more detail for each of the key stages depicted in Figure 5.1.

Initiating the toll scheme development

The first step in the process of the scheme identification and development process is for a public authority to take the **decision to investigate a toll programme** or make a change to an existing scheme. The reasoning for doing so ought to be framed by a set of objectives (this is expanded on in the next sub-section).

At this stage, the public authority should also take a realistic view of the **timescales** that could be involved in preparing for, developing and implementing a tolling scheme. This will help to set the expectations amongst key stakeholders, and will assist the budget planning process. An example timescale is provided below that is indicative of the phasing.

Figure 5.2: Indicative timescales for the development of a tolling scheme



Pre-design phase

Definition of objectives

Once the decision has been taken to investigate the feasibility of introducing a toll scheme, the public authority should typically look to **define the prospective toll schemes objectives** based on the local context and aspirations. This will help a Toll Charger to minimise the expenditures on unnecessary features to be implemented into the scheme, by recognising what is important and what is not important.

The objectives could include the following:

- Finance infrastructure;
- Minimise congestion;
- Manage pollution;
- Raise revenue etc.

The objectives play a key role throughout the lifecycle of a toll scheme. During the feasibility phase they are used to frame the analysis of the business case for different options; during the design and procurement phase they can be used to structure the evaluation of the different solutions and tenders; and during the operations phase they can be used to form the basis for any ongoing contractual mechanisms such as key performance indicators.

Recognition of local context

It is recommended that prospective Toll Chargers undertake a pragmatic and honest **appraisal of their local conditions** during the pre-design stage. There are certain factors that can have substantial impacts on the scheme design and can make certain solutions not suitable for the proposed scheme. These include elements such as the traffic profiles (e.g. the proportion of local vs national traffic, with regards to cross-border international traffic; the types of trips taken; the types of vehicles used etc.) or attitude to compliance locally (e.g. does the local community typically abide by traffic regulations, or flout them?).

Feasibility study phase

It is good practice to conduct a **feasibility study** to define context for scheme and identify the options for delivering the scheme. For each option the feasibility study should describe:

- The key legal considerations such as the application of relevant EU Directives, and impact on national/local legislation;
- Identification of the technical options and challenges;
- An appraisal of the financial situation by conducting a cost-benefit analysis on the different options.

The result of the feasibility phase is a preferred option that is taken forward to a detailed design phase.

There are a number of aspects that the prospective toll charger should consider as during the feasibility study (as well as during any subsequent detailed design work). Comment is provided on some of the key points below.

Technical considerations

When the prospective Toll Charger is first investigating the possibility of implementing a toll scheme, there are certain aspects that it is worth to consider at an early stage. These factors have proven to have a material impact on the performance and success of a scheme. These elements can be considered as part of an **early feasibility study** for tolling in the prospective Toll Charger region.

The following table sets out some of the key technical considerations relating to tolling that could be considered during the feasibility study phase.

Table 5.1: Technical considerations relating to tolling during the feasibility stage

Tolling consideration	Example impacts on the toll scheme design and feasibility
Local context	• The **network and road environment** will have an impact on the choice of solution that might be suitable (e.g. TTFF, multi-pathing, slow signal acquisition, absence of cellular signal for GNSS in urban and underground environments; dirty cameras and emissions for ANPR in tunnels; issues of overhead equipment in areas with height restrictions). Recognition of these conditions will help to identify appropriate technical options during the feasibility stage. • The **local attitude to compliance** will have an impact on the expected level of enforcement and associated processes (e.g. processing suspect violations, chasing bad debt etc.)
Anticipated changes to the system	• The **flexibility** that might need to be built into the system from the outset will have an impact on the choice of solution. Certain technologies are more suited to responding to changes to the scheme rules, or extent of the network. For example, if the size of the tolled network is extended, then a DSRC-based approach would require additional infrastructure to be constructed for the additional toll sections, whereas a GNSS-based solution can be amended based on virtual gantries or similar.
Interoperability with other schemes	• If it is anticipated that the toll scheme should be **interoperable** with neighbouring schemes then this should be considered from the outset as part of the feasibility study. There will be considerations such as creating an interface with other back offices for the transfer of toll records; potentially the interaction with other service providers and any associated certification process etc.
Complexity of scheme rules and charging policy	• The **complexity of the charging rules** will have a material impact on the choice of technical options during the feasibility stage. For example, ANPR is very efficient for very simple charging policies; GNSS is more suitable for more complex charging policies, and for those schemes that may wish to make amendments to the scheme in the future; DSRC is somewhere in between the two.

Tolling consideration	Example impacts on the toll scheme design and feasibility
Technology maturity	• The **maturity of the technology** can have a significant impact on the cost of the system. Early adopters can typically expect to face a greater burden of the development costs for an emerging technology than other schemes at a later stage. Therefore a balance needs to be struck between being at the cutting edge and enjoying the benefits that innovation can bring, relative to the issues associated with being an early adopter of systems that have not yet been tried and tested. This can help the prospective Toll Charger to determine how ambitious their scheme design can be, and which other processes they would need to consider as part of their overall strategy (e.g. testing procedures, system refreshes etc.).
Requirement for ongoing maintenance	• The identification of the **maintenance and operations costs** during the operations phase will provide a valuable input to the cost-benefit assessment. For example, manual tolling will involve significant staffing costs; schemes involving roadside infrastructure will need the equipment to be maintained etc.
Communicating changes to users	• A significant component that should not be underestimated is the cost of **notifying and educating prospective users about a new or changed toll scheme**. During the feasibility stage, this should represent one of the activities that should be accounted for.
Operational model	• There are multiple **operating models** that could be adopted for a toll scheme. The Toll Charger should consider which models would be most appropriate for the scheme and context. This should then be reflected in any design specifications.

The following table sets out some of the key technical considerations relating to enforcement that could be considered during the feasibility study phase.

Table 5.2: Technical considerations relating to enforcement during the feasibility stage

Enforcement consideration	Example impacts on the toll scheme design and feasibility
Local context	• High-**levels of non-compliance** amongst users will increase the costs of chasing bad-debt, will reduce the level of revenue collected and limit the systems effectiveness • Bribery and corruption can undermine the integrity of the tolling and enforcement process (if this is an issue, an alternative tolling scenario that prevents the user from entering the system if they do not have the means to pay may be preferable)
Local evidential requirements	• There may be overriding **local evidential requirements** that a tolling and enforcement process may need to subscribe to (e.g. capturing both front and rear images of the vehicle). These need to be considered at an early stage as they will dictate the solutions and technical options that may need to be considered/ruled out.
Enforcement strategy	• The balance between compliance and enforcement, compared to the **penalties for non-compliance** will have an impact on the solution design. Appropriate legislation and penalties may help to reduce the costs of checking compliance (i.e. the penalties associated with getting caught outweigh the benefits of not paying until you get caught).
Existence of a national licence plate database	• The presence of an **existing national number plate database** has a key influence on whether or not an ANPR based-solution (for either tolling or enforcement) is feasible. If there is no such database in place, the scheme would need to set up its own accounts based system where ANPR could be used as an optional payment measure alongside other techniques (e.g. a traditional barriered system).
Handling non-compliant users from other Member States	• The approach to handling **non-compliant users from other Member States** will have an impact on the design and effectiveness of a toll scheme if there is a high-proportion of overseas traffic. In the case of the Stockholm Congestion Charge (which uses an ANPR system to detect the charge liabilities) the city has had to set up agreements with other enforcement/licencing bodies to ensure that overseas users can be chased for payment and enforced as necessary. Brokering these types of agreements can be costly, and time-consuming.

Enforcement consideration	Example impacts on the toll scheme design and feasibility
Balance between system performance and operation processing	• The workload involved in **processing suspected violations** can require a substantial number of staff, and this can be very expensive as an ongoing cost. If the enforcement system detects a high level of suspected non-compliance and there is a requirement to process this data manually, then this can be a very costly exercise for the Toll Charger.

Detailed design and Specification

The section above outlines a number of key considerations from a Toll Charger perspective in relation to the technical, legal and financial aspects of a scheme during the feasibility stage. During the detailed design and specification phase, the preferred option will be worked up into a set of procurement and design documents.

Expressing requirements

One aspect that the prospective Toll Charger should be mindful of during the design and specification phase is the **approach taken to identifying and expressing their requirements**. There is a balance to be struck between having confidence that the resulting scheme will meet the original expectations in terms of design and function, and being overly prescriptive about their technology requirements and potentially constraining the market (along with the risk of paying a higher price for those bespoke services).

Unusual functional and technical characteristics should be carefully considered. The products and the solutions that are available on the market have been designed and developed on the basis of the requirements expressed by the market; the introduction of specific requirements, not fully in line with what the market has previously indicated, will oblige potential suppliers to a significant adaptation of their solutions. For example, DSRC tags are limited on memory space to keep the costs down. Therefore if any new parameters need to be added to satisfy the needs of a particular scheme, the tag may require a re-design. This is an example of an aspect that could increase the development costs for a supplier and therefore for the setting-up of the scheme itself.

Allied to the above point is the benefit of prospective Toll Chargers placing the **emphasis within their tender specifications on output requirements** compared to specific characteristics. These can be broken down into required elements, optional elements, and for information only.

Focusing on the output requirements within a tender specifications could include aspects such as specifying a minimum mandatory detection rate for charge liabilities, or the requirements for the charge declaration; these could be enhanced by more demanding “desirable” performance measures that suppliers can then respond to without being non-compliant. For example, the recent procurement for Dartford Crossing “Free-flow” specified a mandatory detection rate (including ANPR and DSRC tags) of 98%. The supplier market was quickly reduced as many decided they could not take that risk for open road tolling. In addition to output requirements, there may be certain elements that the prospective Toll Charger needs to specify, such as specifying key interfaces and evidence requirements.

It should be noted that the above should be balanced with the prospective Toll Charger having an awareness of the different factors that may mean that a particular technological solution is **adding a risk onto the deployment**. Those factors could include aspects such as the need for supporting infrastructure (roadside equipment, national number plate database, enforcement bodies), the attitude towards compliance in the community, the maturity of the technology, the land-use requirements (e.g. for equipping new users with OBU, distribution points for OBUs, toll plazas), future flexibility and scalability, the on-going support and maintenance requirements, future operational changes to the system, the customer service and logistics etc.

The prospective Toll Charger should also be aware that certain requirements can pose a challenge to prospective suppliers. An example of this relates to a requirement relating to the scalability of the solution. The word scalability itself is ambiguous, unless the Toll Charger qualifies it with their objectives (e.g. what it is they would want to deliver) and when they might expect to call upon that requirement. The issue being that to ensure that a solution is scalable, and without knowing the actual extent of the requirement, the Toll Charger may end up purchasing a solution that they will never actually use.

Risk allocation

Central to a prospective Toll Chargers obligations during the setting-up of a scheme is the consideration of the commercial terms for any contract with the entities designing, building, operating and maintaining the toll scheme. The Toll Charger may involve itself in some of these activities (so reducing the risks allocated to the market and in some cases the risk factor associated to the costs), but it is the balance of contractual responsibility between the parties and across the different project phases that can have a very significant impact on the cost of toll scheme.

The **risk allocation** between the prospective Toll Charger and their suppliers/operators has a direct the relationship to cost of a scheme. For example, the technology cost should not be considered by itself, as suppliers and providers will price risk into their offer. That risk can take many forms, e.g. delivery risk, the potential penalties for KPIs and SLAs, the operational responsibility, the risk of not being able to re-sell the solution again in the future etc. If the prospective Toll Charger places the majority of the risk on its delivery partners, or on particular project stages (e.g. on the operation phase compared to the build phase) then it should expect the price for those services to be higher than if the Toll Charger shoulders some of the burden of risk. The KPIs and SLAs should be adjusted to reflect the risk allocation, and should be consistent with the objectives of the scheme. Therefore, the Toll Charger should carefully consider which KPIs are critical to the contract, and those that are not.

Performance management requirements

All toll domain authorities and toll operators want to ensure that the system functions at the highest rate of performance and results in a user-friendly solution for the end customer. Fitting with all these objectives does have a technical and financial impact on the solution. The key challenge facing the Toll Operator is how the toll operator will measure such a **Key Performance Indicator** (KPI) and will it be possible to improve the quality of the solution and, if possible, what will the consequence be?

Toll Chargers as well as system operators and/or suppliers are continuously faced with a set of functional requirements and of KPI to be met during the operation of the corresponding scheme. Most of these requirements and KPIs are derived from the contractual terms upon which public tenders have been based. However, and especially in the case of the more traditional concessions, KPIs are defined directly by the Toll Charger as indicators for the operational efficiency of a charging scheme.

The adherence to these requirements and KPIs has an impact in terms of operational costs for the operator and therefore for the Toll Charger.

The two examples below illustrate this:

- KPIs relating to the enforcement process: Typically, it is expected that the enforcement system should provide a high level of vehicle detection (classification, number of axles, etc) with all the related pictures and documentary evidences. The solution is cost-effective due the high volume of data produced and sent to the IT control system. However, Toll Chargers should be mindful that operating the enforcement system requires operational expenditure and if it generates suspected violations, it may require human operators to validate the suspected violation or to treat the claim of users. The result of this can be that the activation rate of the enforcement solution and the number of resources potentially have a greater impact on the efficiency of the solution than the quality of the camera performance.
- KPIs relating to OBU fulfilment: "a User arriving at a service must get an OBU and be able to be equipped and leave the service point in a maximum of x-minutes". Many external factors can potentially impact the time that the user will spend (e.g. proximity to a fulfilment centre, user competence and speed, traffic levels, land availability etc.). A KPI such as this is reliant on so many other factors, how can this be properly measured?

It is often observed that Toll Chargers set KPIs at a level that is above the point that would typically be required to ensure the effective operation of a charging scheme. The consequence being that the Toll Charger is confronted with an operational cost that is inconsistent with the needs of the system.

In addition to this, the KPI cannot be always be easily measured in an automated fashion, as their definition is unclear and complicated. Each Toll Charger or authority has its own objectives and tries to translate them into requirements and KPI; in some cases it is very complicated to compare the KPI that different toll charger have defined for the same area of operation.

The key conclusion in this area is that Toll Chargers should take a pragmatic view on the level of performance required to effectively operate the system. Toll Chargers should also establish that the KPIs can be measured in a transparent and objective manner. Additionally, the Toll Charger should consider whether the level of KPI will have a corresponding effect on another area of the system. All of these will have an impact on the price of a solution, and may affect other areas of the system.

Procurement and evaluation

Prospective Toll Chargers can **engage with the market at an early stage** to understand the services, solutions and innovations that potential suppliers may be able to offer. This "soft market testing" would also enable the market to anticipate the emerging scheme's objectives and the broader context for its implementation.

The prospective Toll Charger should consider and **assess the whole-life costs over a suitable period** (e.g. 10 years). As mentioned earlier in this study, different tolling approaches incur costs at different stages of the lifecycle, especially if there is the scheme is extended. For example, some tolling systems based on DSRC require additional infrastructure if a distance-based scheme is extended, whereas the changes to a GNSS based solution are more focused on software and map updates and therefore the costs associated with the extension are likely to be much reduced. DSRC OBUs also typically only have a life of 6 to 8 years, hence an appraisal over 10 years would include a significant element of OBU refresh costs.

Cost Analysis : benchmark and focus

This section presents some benchmark examples of the costs associated with particular toll domains.

French Benchmark – GNSS versus DSRC solution for former Ecotaxe project

The first benchmarking exercise deals with the Ecotaxe project in France (2009-2014), specifically relating to the comparison of GNSS and DSRC-based solutions.

A summary of the key figures is provided below.

Table 5.3: Key figures for Ecomouv’ in France

	Key figures	Costs	Revenue
Network	• Taxed Network: 15.200 km • Virtual tolling gantries: 4.100 • Operation duration : 11 ½ years		
Total number of users (HGV >3.5t): 800.000 unit	• Users (Subscribers) through ETS Provider : 600.000 • Users (Non-subscribers) through Ecomouv’: 200.000 • Estimation : 550.000 French and 250.000 foreigners		

*Service Point Network**	• Total 420 POS (Point of sale for the Ecotaxe scheme) including:
	  ◦ 330 in France close to the taxed network (20 minutes isochrones from the network)
	  ◦ 50 in France on the conceded highways (start-up phase)
	  ◦ 40 abroad
		Capex Ca.20 Million EUR	

Enforcement	• Fixed gantries: 173 • Movable gantries: 100 (500 potential positions along the taxed network) • Manual Mobile enforcement equipment: 400 • Mobile enforcement installed in police cars: 200	Ca.200 Million EUR	
Tax revenue collected annually			1.2 billion EUR/year
Main operational costs		• 96 million EUR excl. VAT – Capex reimbursement • 47 million EUR excl. VAT – Operation and maintenance • 8 million EUR excl. VAT – evolution • 64 million EUR excl. VAT –ETS Provider remuneration	

**Including:*

- 139 equipped with BAUT (Automated Vending Machine) only (33%)
- 126 POD (Point of Distribution – equivalent to a PC and payment means) – staffed with employees only (30%)
- 155 both equipped with BAUT and staffed with employees (37%)

Table 5.4: Benckmark between GNSS and DSRC solution

	GNSS Solution (Million€)		DSCR Solution	
	Build	Run	Build	Run
Capex financing		96		120
Tax collection	180	18	500	10
Enforcement	200	24	200	24
IT-system	100	12	100	12
Distribution network	20	2	20	2
ETS Provider	20	64	10	25
Maintenance Evolution/replacement		8		8
Other	130		130	
Total	**650**	**224**	**960**	**201**
Run Period 11,5 year		2.576		2.311,5
Total . Project costs		**3.226**		**3.271,5**

Source: decrets” / Senat report and audition minutes – May 2014 / State information / press information

Based on the above benchmarking exercise, for such an extensive taxed network, the GNSS solution was resulting slightly more cost-effective than a DSRC-based solution. Furthermore, the GNSS-based solution offered the French state with flexibility if the state had subsequently decided to extend the size of the taxed network to include additional roads (e.g. to respond to congestion on the wider network caused by users trying to avoid the taxed network by driving on other roads).

Ecomouv’ proposed a challenging schedule of 21 months to implement the scheme. Implementing more than 4.000 DSRC gantries would have taken up to 36 months. This would have had a significant impact on the level of taxes collected.

Deploying more 4.000 gantries would have also likely caused significant disruption and generated reluctance and opposition from citizens. This would have represented a substantial challenge to the social acceptance of the scheme.

Looking into the details of the CAPEX for each of the solutions reveals that the DSRC solution would have been more expensive but the operating costs would have been lower than a GNSS solution.

The initial study (source French MEDDE – DGTIM) performed in 2007 were leading to the following results for 800.000 HGVs above 3.5tons:

Network length	Outcome for technology choice
Less than 10.000km	DSRC was more cost effective than a GNSS-based solution
Between 10.000km and 15.000km	The GNSS and DSRC solution were equivalent in terms of financial balance. The Capex of the DSRC solution was higher but the Opex was lower than for a GNSS solution
Over 15.000km / more than 4.000 toll segments	The solution based on GNSS was more cost effective than the one based on DSRC, and could handle the proposed network extensions for a lower cost

Distribution costs from Ecotaxe

If an OBU is mandatory for any vehicle then the distribution network will be highly used during the early part of the implementation phase and then its use will be more limited. The CAPEX is on average around 30.000 EUR for a vending machine (an autonomous machine connected to a video assistance service to support users if they were in need) and an average overhead of 10.000 EUR of CAPEX for installation (including power and communications).

The monthly OPEX is around 1.000 EUR. This covers the rent, telecommunications, power, OBU and cash logistics and maintenance (it should be noted that the vandalism risk is not included).

For a 10 year lifecycle period, 300 service point vending machines would equate to:

Cost type	Unit	Cost
CAPEX	Per service point	40.000 EUR
OPEX	Per service point per year	12.000 EUR
	Total (for 300 vending machines over a 10 year lifecycle)	**48 million EUR**

Homologation and type approval from Ecotaxe

In France, the 19 toll domains have set up a type approval procedures to enable new TIS-PL issuers to enter the market. There are three steps:

1. Initial approval of the candidate organisation
2. Technical interface and VABF (a step-by-step verification of the correct functionality of the solution in a test environment)
3. The verification of the correct functionality in an operational environment (VSR).

The overall procedure can last between 18 to 24 months. A team of 3 to 4 people will be involved on the issuer side with the support of legal and technical experts. The toll domains will require an initial fee to support all the tests to be performed. In total, the capex can be estimated between 1.2 and 1.8 Million EUR. During the VSR, the ETS Provider is operating a normal service but its fleet is limited.

Achieving interoperability with the Liefkenshoek Tunnel (Belgium) is around 100.000 EUR for ETS Provider (source: ETS Provider).

The TIS-PL issuer business was launched in year 2007. The market is stable and most HGVs over 3.5t that use French highways are already equipped. Therefore it is very challenging for new entrants to the issuer market, as achieving a significant market share requires a substantial acquisition effort. It is for this reason that the economic equation is difficult to solve given the high-level of market competition and that the toll domains pay the same commission to all TIS-PL issuers.

At the European level, if an ETS provider plans to be interoperable with all the European toll domain, it is estimated that it would require a CAPEX investment of around 15 million EUR (estimated figure base on 100KEUR per toll domain – around 150 in Europe), even before you take account of the costs associated with client acquisition and local operations.

Main conclusions and considerations from the Toll Charger perspective

This study has involved a significant level of evidence gathering from other reports, research and interviews with key players in the tolling market. This, combined with the study team experience, has illustrated that each toll scheme and implementation is unique in its objectives, operating models, requirements, and context.

Despite these differences, there are certain key lessons learnt that emerge from these schemes and the evidence gathered that are illustrate the ways that future prospective Toll Chargers can design and develop a more efficient scheme from the outset. The key concluding points from those lessons are set out below:

- Take account of the whole life system costs build and run, rather than considering only the initial capital investments;
- Avoid bespoke (as much as possible) requirements that could affect the cost of the charging solution:
    - Bear in mind the need to define requirements in a way that is proportional to the schemes objectives
    - Define KPIs that can be measured and anticipate the resources needed to meet them;
    - Define the scalability of the future system as precisely as possible to avoid the over-specification of solutions.
- Define a realistic schedule for the procurement and the implementation of a tolling system;
- Carefully consider the allocation of risk between the contracting parties and the associated operating model, as this will have a substantial impact on the system cost, and select a procurement and commercial negotiation approach that will allow for a balance between cost and performance to be achieved;
- Undertake an honest and pragmatic appraisal of the local conditions before embarking on a particular toll scheme; this could include the nature and level of the traffic, the general attitude towards compliance in the society, and others;
- Consider the wider context for a scheme at the outset – for example, is there a need for the scheme to be interoperable with any other schemes? Is there potential for the scheme to be extended at some stage?
- Take steps to understand the supply industry and the capabilities of the market to ensure that the solutions are available that meet the Toll Chargers needs in a cost effective manner; before starting the design or a procurement, complete an exercise in "soft market testing" with potential suppliers of ETC to understand the technical, performance and commercial questions they are likely to be raised and which may make some of your requirements more challenging or costly to achieve;
- Evaluate the potential impact of the EETS into the value chain and define their role and remuneration accordingly;
- Take a practical approach to the design of the non-ETC related business process areas;
- Ensure the scheme, its objectives and the benefits are communicated to all stakeholders to minimize the risk of unexpected opposition

6 Main conclusions and recommendations

Our research, experiences and the evidence base has shown that to date, the Commission has played a central role to progressing interoperability in the tolling sector. It has contributed in a number of ways, including the introduction of key Directives and supporting Decisions, the sponsorship of standardisation, certain research and other key initiatives, and the provision of political direction on a pan-European level. This, coupled with support from industry and other stakeholders, has enabled the market to progress to the place where it is today. However, given the evolutions in the market, the mobility sector, and the developments in technology, it is our view that there are further opportunities to progress and optimise the market for interoperable tolling in Europe.

This section sets out the considerations for European Commission in relation to the EUurope Directive (and the associated documentation) and its role in supporting electronic tolling in Europe.

Summary of key considerations for the European Commission:

- Proceed with Member States (or/and Toll Chargers) towards the development of a harmonised set of specifications for a European GNSS OBU/Proxy (including functionalities, performances and services), to be used as the reference on which any new tolling schemes would be based
- Consider wider technology trends and evolution (e.g. driverless and connected vehicles, urban tolling project) – potentially through separating the principle content of the EFC Directive from the list of approved technologies which are likely to need updating frequently
- Facilitate the exchange and cooperation between Member States by including the tolling violation
- Provide guidance on privacy and trust
- Provide guidance on the interpretation of relevant Directives and their application to different types of tolling schemes
- Support the business case for EETS Providers by supporting REETS initiative and analyse the evolution of the transport business in Europe

List of EETS compliant technologies

There are a number of recommendations relating to the choice of technologies that the EC could take forward, should it consider adapting the requirements for EETS.

The EC should consider **extending the list of technologies** that EETS compliant schemes would be able to accept.

The EC should also **consider wider technology** trends and developments in the automotive and personal mobility sectors. This study has commented on technologies and approaches that are either on the market or near market for tolling purposes, however there are a number of wider trends that could have a significant impact in the future. For example, the development of driverless and connected vehicles or the increasing number of restricted areas inner cities could present significant opportunities for identifying vehicles, and charging for their usage/movement. Additionally, other factors such as usage based insurance, mobility accounts, and opportunity to use non-dedicated technologies such as smartphones, or other in-vehicle devices should be monitored.

Allow for other tolling technologies locally

The interoperability directive (2004/52/CE) currently considers GNSS / DSRC and 2G (and over) to be compliant technologies for the collection of tolls. These solutions are optimized for certain tolling scenarios, and are best suited to schemes of a particular size, and involving certain number of toll sections, or users.

At this point in time, more and more cities in Europe are exploring the opportunity to implement Urban Tolling. The objectives are different: financing road infrastructure, dynamic traffic management, peak hour management, pollution reduction, congestion charge, etc. The constraints are numerous: user friendly, integrating discreetly into the city, flexibility, special social ratings, etc. GNSS or DSRC are not generally adaptable to these standalone environments due to the limited size and network of the urban area.

RFID-based technologies (increasingly used in Turkey for example) is less expensive than GNSS and DSRC (4icom average estimation for the in-vehicle technologies: GNSS OBU: 100 EUR, DSRC OBU: 12 EUR and RFID Sticker: 1 EUR). The application of RFID is a potential solution for urban tolling or local infrastructure. An example of this is the future bridge over the Mersey River in Liverpool, UK for which RFID technology was chosen. Another asset of RFID technology is that all the processing of the data is performed in back office (even if writing on a tag is feasible) that presents an opportunity from an interoperability perspective.

The EC could consider exploring the opportunity to establish local standards that enable tolling by RFID and to fix the criteria of interoperability between local and nationwide system.

Guidance on privacy implications

Due to the heterogeneity of toll schemes around Europe, they each have different requirements relating to privacy. This is extended further if Service Providers are able to offer users a range of packages, some of which may be more privacy-centric than others.

Given this backdrop, there appears to be value in the EC providing guidance on privacy in tolling and working with key bodies in each Member State (e.g. the Information Commissioners office, key user representatives). One aspect of this could be guidance on data protection and data security such as the trade-off between support for value added services and transparency vs. privacy.

Guidance on the interpretation of European Directives with relevance to tolling

Around Europe there have been examples of schemes interpreting Directives in different ways, with the consequence being that requirements are placed on suppliers that are more onerous than might be expected based on experience of schemes elsewhere.

An example of this is the implication of trying to apply requirements of the Eurovignette Directive in the context of an ETC scheme. The Eurovignette Directive indicates that Service Points need to be open and available 24/7/365 to enable users to pay for their vignette using traditional payment means. From the Commission’s perspective it was not intended that this requirement would be applied to ETC schemes. However, this interpretation was adopted and incorporated into the requirements for the LKW-Maut HGV system in Germany; the same was the case for the Ecotaxe scheme in France. The consequence of this was that there was a far higher CAPEX and OPEX cost for establishing and implementing the necessary number of service points. In the case of Ecotaxe, this increased level of cost had a substantial impact on the viability of the solution from a cost perspective. Given the current situation and the variety of interpretations, it appears that there would be significant benefit if the Commission could provide guidance on the interpretation and intention of the relevant Directives and their application to different types of tolling schemes.

Enforcement issue at the European level

In terms of enforcement, the responsibility of the Member State to demonstrate the equity of treatment of each user. The Member State has also to guarantee that the penalties are applied.

All the toll charger and toll operator we met claimed that even if the fraud case is confirmed and the violator is identified then the State Member enforcement authorities has no solution to recover the due toll and penalties as soon as the violator (member of another Member State or non-Member State) has left the country except if he is back one day and stopped by the mobile enforcement team.

Eucaris is an example of cooperation that allow access to other State Member databases (vehicle ID and driving licenses). Unfortunately, the toll violation was not included into the list of violation of the “cross border” directive due the fact that toll violation was considered as a dangerous violation. The direct impact is that the performance of the enforcement solution doesn’t require too high KPI because it will be impossible to send the fine and to recover it. The violators even if there are not so many know it.

Moreover, there is a general lack of cooperation between the Member States at this level. The alternative is bilateral agreement like Germany signed with Austria and Netherlands. Nevertheless, it’s time consuming to be settled. Some toll operators also mandate some private companies to process to the international fine collection.

Nevertheless, a harmonized solution for Europe could preserve the non-discrimination.

Support for prospective EETS Service Providers

A core part of the EETS business model is the presence of EETS Providers. As mentioned earlier in this study, there are a number of different challenges to prospective EETS providers entering the market. Principal amongst these is the need to contract with all Toll Chargers and the steps involved in achieving that. This is offset against a backdrop of uncertainty regarding the commercial viability of providing such a service.

The EC should consider the **arrangements needed to make it commercially viable to be an EETS Provider**. This could include remuneration agreements, common contractual terms for engaging with Toll Chargers and so on.

In addition to this, to support transparency and to **engender trust between the Toll Charger and the EETS Service Provider**, the EC may want to consider providing a certification body that confirms that the EETS provider is able to process and handle the data in the correct way and the necessary procedures in place to ensure the integrity of the charge data.

Incorporating existing systems in an interoperable environment

A major request from the existing stakeholders is that any evolution of the Directives has to be applied starting from a defined date. Moreover the existing toll schemes have to be taken into account. Under this approach, the strategy towards interoperability should be built step-by-step based on the existing schemes, and that there would be no requirement to retrofit a new or evolved Directive to those schemes already in operation, unless there is financial support from the EC or elsewhere to make the necessary amendments. There is an open question about how this entry to market is funded, and where the burden should fall.

Use of technical solution

Impact of specific national requirements:

A requirement that allows an enforcement authority to be able to check the status of a user at any point in time and anywhere leads to thick solution at least for the occasional or non-subscribers. Most operators suggest that they are able to consult an user account in real time means that the OBU is able to transfer its x,y position in real time to the central system. However there are technical considerations that will have an impact on the effectiveness of this approach, including:

- The availability of the mobile network anywhere on the tolled network
- The technical capacity of the mobile network to support hundreds of thousands of low volume data transfer, and;
- The data costs proposed by mobile network operator.

Due to these constraints, the toll operator may make the decision to adopt a thick client solution. The consequence of this is that the OBU must be able to embed the toll domain features and the sufficient memory and CPU to operate them. A major drawback is that if all toll operators request the same type of operations inside the OBU then an oversized OBU will be requested. Furthermore the toll charger is defining the OBU which does fit with its needs and not to fit with other toll domains. The message received from prospective ETS providers is that they would be hesitant to respond to tenders that propose an OBU that can serve multiple toll domains as the price of an OBU with the requisite CPU, memory etc. would likely be uncompetitive.

One example that illustrates the complexity of the current situation is the OBU that was defined and produced by Ecomouv’ to serve non-subscription users and the clients of the primary ETS provider. The OBU and proxy provided by Ecomouv’ was not able to operate in the Belgium toll domain due to the lower levels of CPU and memory, as well as having an embedded soldered sim card that belonged to a French mobile network operator. The result of this is that it would have been impossible for the French OBU to run on two separate GNSS toll domains.

Most of the time, the first priority of a new toll operator is to develop and produce the requested number of OBU for the start of operations locally. It means that there are risks that the new OBU will require an iterative development and evolution to fit the requirements of all the toll domain. Such an approach is complex, time consuming and not facing any economic reality.

It is recommended that to achieve the European interoperability, **EC should make arrangements that would enable EETS Providers to engage with new toll schemes as the scheme goes live.** This could either be based on technical requirements relating to the activation of the relevant toll applications when entering a particular toll domain, facilitating the exchange of certain agreed data between the EETS Provider and the Toll Charger, or some alternative approach.

EU Directive on EETS Provider

The general comment is that the European Directive for EETS provider is based on an attractive vision of Europe nevertheless it's not business oriented. Today more than ever before investing companies must have a business including a ROI that is beneficial in short term. The priority are as follow :

- Initiate:
  - Member States (or/and Toll Chargers) and the EC working together to define the specifications (general and detailed) of the functionalities, performances and services of a GNSS OBU, to be interoperable with existing toll schemes and also respond to the requirements of each Member State. They will become the reference base for all future toll schemes.
  - Take into account the EETS provider's point of view and the conclusion of the Regional EETS project and then finance a demonstration project of an OBU/Proxy (3 models minimum), that will be certified for the different toll domains and allow the EETS Provider to get accreditation for those new OBUs.
- Set up a body at a European-level that can facilitate the type approval for any toll domain. No matters what type of chosen technology, the interoperability between GNSS and DRSC toll domains requires a European independent entity that will be able to facilitate the introduction of new OBU on the market by being the unique entry contact point to get the type approval of a new OBU with all the European toll domains
- Define an European contractual framework to simplify the interface between a toll charger and an ETS provider
- Being subscribers to an EETS Provider could also generate a discount to final user because of the savings compared to a non-subscriber.

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Appendices

A Abbreviation

Glossary

Name	Definition
3G / 4G	Mobile telecommunication technology
ANPR	Automatic Number Plate Recognition
ASECAP	Association Européenne des Concessionnaires d'Autoroutes et d'ouvrages à Péage (European Association for tolled motorways, bridges and tunnels)
ASFA	Association des Sociétés Françaises d'Autoroutes et d'ouvrages à péage
BAG	Bundesamt für Güterverkehr (German Federal Office for Goods Transport)
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CAPEX	Capital Expenditure
DBFO	Design Build Finance Operate
DSRC	Dedicated short-range communications technology
EETS	European Electronic Toll Service
EETS Decision	Decision in Oct 2009 to approve the EETS Specification
EFC Directive	Directive 2004/52/EC2
ETC	Electronic Toll Collection
GDDKIA	Generalna Dyrekcja Dróg Krajowych i Autostrad (General Directorate for National Roads and Motorways)
GNSS	Global Navigation Satellite Systems technology
GPS	Global Positioning System
GSM	Global System for Mobile. Protocol for cellular networks
HGV	Heavy Gross Vehicle
ISM	Industrial Scientific and Medical
KPI	Key Performance Indicators
LGV	Light Gross Vehicle

Name	Definition
LKW Maut	LastKraftwagen Toll. Heavy Vehicle Toll (in Germany and Austria)
LSVA	Leistungsabhängige Schwerverkehrsabgabe (Swiss Heavy Vehicle Fee)
MDT	Multi-Dimensional Tool
MLFF	Multi-lane free flow technology
NDS	Národná diaľničná spoločnosť (Slovakian National Highway Company)
NFC	Near Field Communication
OBU	On Board Unit
OCR	Optical Character Recognition
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
RFID	Radio Frequency Identification
RSE	Road Side Equipment
SCUT	Sem Custos pars o Utentes (motorway with no cost for the users)
SLA	Service Level Agreement
TTFF	Time To First Fit
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VRM	Vehicle Registration Mark

B List of Interviews

Toll Charger / Toll Operator

Germany

BAG	Dr. Rainer Weck	Project leader EETS
	Doris Ludwig Schreiber	HGV-Toll Principle Administration
	Bärbel Semrau	Leader of IT-Operations for HGV Tolling
	Gerhard Hubbeling	Leader of Department HGV Tolling
	Antje Geese	Leader of Department HGV Tolling (Federal Ministry of Transport and digital infrastructure)
BVMI	Edith Buss	Regierungsdirektorin - Division Financial and Competition Policy, Trade and Industry, Toll Service and External Costs
Toll Collect Gmbh	Dr. Michael C. Blum Stephan Kösling, MBA	Head of Corporate Strategy & Business Development Head of Strategy and Business Development Department
	Stephan Kösling, MBA	Head of Strategy and Business Development

Austria

Asfinag Maut	Bernd Datler	CEO

France

ASFA	Jean Mesqui	General Director
	Valérie Dumerc	Legal Director
	Gwenaëlle Toulminet	Legal Department
	François Malbrunot	CEO of Logma
French Ministry of Ecology, Energy and Sustainable Development (DGTIM)	Olivier Quoy	Deputy Head of the pricing mission, DGITM/SAGS/MT

Italy

Autostrade per l’Italia	Giuseppe Langer	Director for IT & Systems

Slovakia

Skytoll	Jiri Kopecky	Business development manager
	Anton Bodis	PR and communications manager

NDS	Milan Rac	Director responsible for IT and tolling

Hungary

National Toll Payment Services	Varga Zoltán	CEO, Toll Service Zrt.

ETS Provider

Europe

AETIS	Eva Tzoneva	President

Germany

AGES MAUT GmBH	Rolf Herzog	CEO
AGES EETS GmbH	Thomas ALBER	Project Manager
Shell Deutschland	Eva Tzoneva	

France

Emetteur Vinci Autoroutes	Jérôme Lejeune	President

Italy

Telepass	Francesco Maria Cenci	Electronic interoperability manager

Czech Republic

Eurowag	Miroslav Vitasek	Project Manager responsible for introduction of EETS products

Technology Provider

Europe

3M	Rik R. Nuyttens	European Regulatory Affairs Manager
	Philippe Stubbe	Market Development Manager

Austria

EFKON	Max Staudinger	International Sales Manager – Major Projects

France

Sanef ITS	Philippe Juin	Industrial Director
	Cedric Besson	International Business Development Director
Vinci Concessions	Laurence Dhomme	Project Manager
	Laure Nalet	Operation & Systems Manager
Thales Communications & Security S.A.	Philippe Monier	Business Development Road, Director
	Denis Perret	Product Line Manager pour la Product Line « ITS Road ».

Turkey

Vendeka Defense Industry and Trade Inc.	Baki Kuran	Chairman and CEO

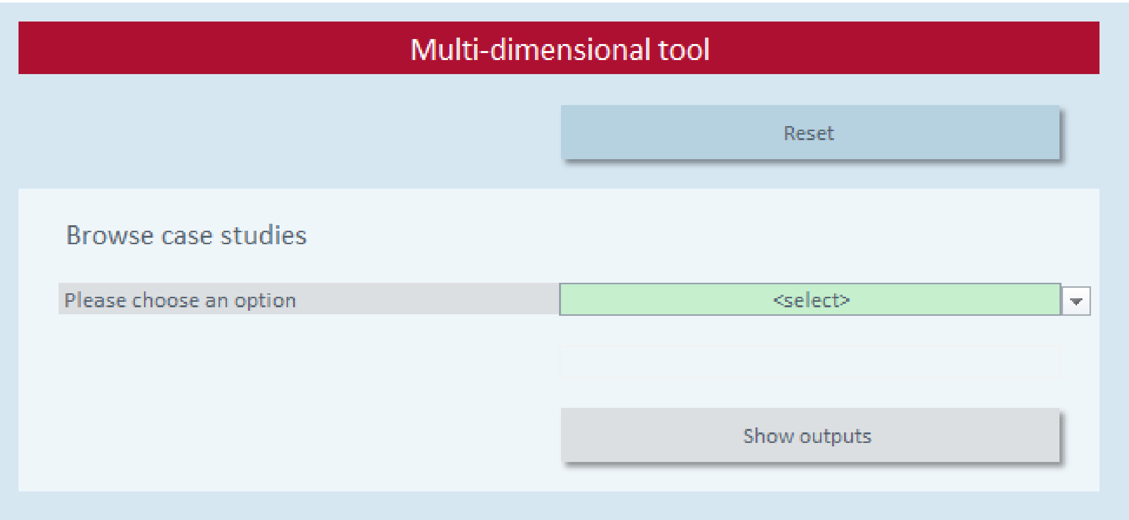
C Exploring the evidence base

A multi-dimensional tool has been prepared that enables the user to explore:

- Key information about different toll schemes around Europe
- Links to further reading
- Review key information and performance data about different tolling technologies
- Explore the case studies where the technologies have been deployed

The multi-dimensional tool takes the form of an excel spreadsheet which presents the user with the available evidence based on the users selections. It is available upon request from the European Commission.

Figure C.1: MDT user interface



The user should select an option from the drop down menu, and click on ‘Show outputs’. This will open a further worksheet that presents the requested information.

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