Technology options and interoperability for Urban Vehicle Access Regulation (UVAR) Schemes

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## Glossary

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<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANPR</td>
<td>Automatic Number Plate Recognition</td>
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<tr>
<td>ASECAP</td>
<td>Association Européenne des Concessionnaires d'Autoroutes</td>
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<td>CEN</td>
<td>Comité Européen de Normalisation</td>
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<td>DSRC</td>
<td>Dedicated Short Range Communication</td>
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<td>EC</td>
<td>European Commission</td>
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<td>EETS</td>
<td>European Electronic Toll Service</td>
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<tr>
<td>EFC</td>
<td>Electronic Fee Collection</td>
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<tr>
<td>ETC</td>
<td>Electronic Toll Collection</td>
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<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
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<td>EU</td>
<td>European Union</td>
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<tr>
<td>GIS</td>
<td>Geographical Information System</td>
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<tr>
<td>GLONASS</td>
<td>Globalnaya Navigatsionnaya Sputnikovaya Sistema=RUS version of GPS</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>GSM</td>
<td>Global System for Mobile</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
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<tr>
<td>ISO</td>
<td>International Organisation for Standardization</td>
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<td>ITS</td>
<td>Intelligent Transport Systems</td>
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<tr>
<td>OBU</td>
<td>On-Board Unit</td>
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<tr>
<td>OCR</td>
<td>Optical Character Recognition</td>
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<tr>
<td>RFID</td>
<td>Radio Frequency Identification</td>
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<td>UVAR</td>
<td>Urban Vehicle Access Regulation</td>
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<tr>
<td>V2I</td>
<td>Vehicle to Infrastructure</td>
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<td>V2V</td>
<td>Vehicle to Vehicle</td>
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<tr>
<td>ZTL</td>
<td>Zona a Traffico Limitato (Limited Traffic Zone)</td>
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CHAPTER I – Introduction

This NBGD on 'Technology options and interoperability' is meant to provide an overview of technological options and their interoperability. This concerns both current options and such likely to be developed in the near future with reference to the implementation of UVAR schemes in Europe. Interoperability may have a technological as well as a geographical dimension. The technological interoperability of a specific option addresses the capability of the technological options to adapt to different scheme design and characteristics. For example, in terms of vehicle type detection, payment methods, period of operation, e.g. night or selected day time slot and enlargement of a UVAR area. The geographical interoperability deals with the capability of the technological options to operate at different scales (urban, regional, national, European). In general, the implementation of UVAR schemes is more concerned with the technological interoperability given the local scale of UVAR schemes. However, reaching geographical interoperability may reduce implementation costs and facilitate the movement across borders as well as contribute to completing the Single Market in the area of transport.

The range of technological options supporting UVAR implementation schemes has broadened considerably in recent years, for instance by the development of global positioning systems and mobile technologies. It is reasonable to expect that this trend will continue. Technological options unveil new opportunities in terms of easing operating characteristics, e.g. by the facilitation of methods of payment and the enlargement of geographical coverage.

However, despite the greater opportunities from technological development the selection of the most appropriate technology still relies on trading-off a considerable number of factors.

They range from the extent and types of roads to be covered, the types and numbers of road users to be charged or enforced and the augmented capability in terms of data collection to emergent privacy issues. The most sophisticated technological solutions can maximise compliance, guarantee thereby an acceptable stream of revenues to pay back investment where charges are applied and can be implemented with low costs of ownership and maintenance.

The main objective of this NBGD is therefore to review the relevant aspects involved in the selection of the technological solutions while supporting the different options with concrete examples on available options.
CHAPTER II – The challenges

As discussed in the NBGD on Vehicle Types, Exemptions and (Cross-border) Enforcement, the role of technology applications adopted in the implementation of the different types of UVAR schemes is strongly correlated with the type of UVAR schemes under examination.

The following table shows the relationship between the role of technologies and the UVAR functionalities.

<table>
<thead>
<tr>
<th>UVAR functionalities</th>
<th>Technologies</th>
<th></th>
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<th>Mobile Tech.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle detection, e.g. Low Emission Zones</td>
<td>Low Tech.</td>
<td>✔</td>
<td>✔</td>
<td></td>
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<tr>
<td>Charging, e.g. congestion charging</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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</tbody>
</table>

A low level of technology is used for the implementation of permit access schemes for a number of Low Emission Zones in which the low-technology identification of vehicles can correspond to stopping vehicles at the entrance of or within the regulated zone, checking a permit to enter or the vehicle emission sticker on the windscreen of vehicles or enforcing on parked cars. Low-technology solutions also involve urban redesign, as street space redesign and boulders positioning.

There are many factors that affect the enforcement technology decision which can include practical, financial, social or political reasons. Generally, low-technology solutions may be a more favourable choice for smaller schemes with fewer vehicles and high-technology options for larger more complex schemes with more vehicles as well as charging schemes.

At the same time high technology may be associated to toll rings or cordon-based schemes entailing some degree of automation through for example automatic number plate recognition (ANPR) or fully automatic electronic charging and vehicle identification techniques as, for example, LEZs in London and the Netherlands, over 200 ZTLs in Italy and many of the charging schemes.

Focusing on the UVAR scheme characterised by an important role of technology both addressing enforcement techniques and methods of payment, six types of technologies can be identified, four of which (the no. 1, 2, 4 and 6 in the list below) are relevant in urban areas:

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

**Overview of technological options**

1. **Video cameras or ANPR** (Automatic Number Plate Recognition) are widespread technologies utilizing fiber optic or broadband to convey information from roadside cameras to a hub site where information is processed. It does not require on-board units (OBUs) and costly roadside equipment. In terms of enforcement, a strong limit is the lack of harmonisation of vehicle license plates which can make the identification of the vehicle problematic (also in presence of adverse weather conditions). This technology requires foreign vehicles to be registered before approaching the scheme area due to national vehicle database issues. Data protection and legal issues may arise from the application of the technology depending on the Member State. For example in Germany the picture needs to capture who is driving, while in the Netherlands the driver may not be identified. It should also be considered that for ANPR manufacturing there are no CEN standards to date.
   - Example: Applications in cordon-based or area-based UVAR schemes: e.g. London, Milan, Stockholm.

2. **DSRC** (Dedicated Short-Range Communication) can be considered the most widely adopted technology in Europe, in particular as far as electronic payments are concerned in both urban areas and nationwide networks. The technology is based on radio communication between a mobile device inside the vehicle (OBU) and fixed roadside equipment. The OBU microwave technology (DSRC 5.8 Ghz) allows levying the tolls electronically as soon as the vehicle approaches the fixed roadside equipment without stopping it. It is important to stress that the technology benefits from standardization (CEN standard 15509), geographical interoperability (on some European motorways networks) and, to a minor extent, technical interoperability (some OBUs can also be used to pay for parking in certain environments). DSRC technologies use in general inexpensive OBUs (ranging from €5 to €10) but they require the installation of costly roadside equipment. In urban areas, the most appropriate technological version of DSRC applications is the one defined as multi-lane free flow (MLFF) in which vehicles do not need to slow down to pay the toll. The association of DSRC with ANPR technologies for enforcement has become a common standard. The technology is generally not perceived as raising privacy issues despite the fact that users must save personal data stored in the OBU.
   - Example: Applications in urban areas such as Singapore, Stockholm, Göteborg, Santiago del Chile, Melbourne, Florence and the Norwegian cities (e.g. Oslo, Trondheim)

3. **RFID** (Radio-frequency) represents a technological option with similar performance levels to DSRC. This technology uses generally ANPR technologies for enforcement as DSRC technologies. Compared to the DSRC technologies, its main advantage is the lower cost of OBUs (~€1). The main geographical area of application is the US, with no significant applications in Europe (except for the access point regulation in the Mersey Tunnels and Gateway Bridge in the UK). One of the reasons behind the slow deployment of the technology in Europe is the significant investment required to replace existing technologies.
   - Example: Applications on US motorways (e.g. North Carolina)

4. **GNSS** (Global Navigation Satellite System) technology requires the interplay of three components:
   1) A GNSS OBU module which is the infrastructure that allows users with a compatible device to determine their position, velocity and local time by processing signals from satellites in space
2) A GSM module securing GPRS data communication from the OBU to the back office and vice versa; and optionally

3) A microwave module (DSRC transceiver) to communicate with fixed and mobile enforcement points, e.g. control gantries provided with DSRC and/or ANPR technologies.

From an economic point of view, this option requires cheaper roadside equipment than DSRC/ANPR options but costs of the GNSS OBU module are higher than DSRC OBU units in the order of magnitude of a factor ten. However, in the long run, GNSS-based options may prove cost-effective: common standards for GNSS OBUs may reduce costs due to a possible integration with car manufacturers and the higher flexibility of the application (e.g. through maps updating) can change the UVAR’s conditions (position, time, period of day) at virtually no cost.

Furthermore, interoperability of GNSS-based systems has proven to be effective both geographically and with reference to existing DSRC applications.

Data privacy may be an issue because of the relevant amount of information collected with the possibility to create movement profiles.

Concerning the urban areas in Europe, there are promising signals from the potential use of the current improved performance in urban canyons of Galileo (the European GNSS). Several ongoing trials (e.g. in the Greater Copenhagen area) and in the past (Eindhoven) show promising results. On the other hand, in the London trials carried out between 2004 and 2007 the scale and density of tall buildings and the configuration of relatively narrow streets, particularly in the City of London, prevented the level of precision location of vehicles, Singapore is planning to shift the DSRC-based technology to the new Global Navigation Satellite System (GNSS)-based ERP system, which will be operational from 2020. The urban road operator interest in such a system, using also the first EGNOS services, lies in the possibility to distinguish areas where different rules/ pricing schemes are applied, i.e. to select roads in dense urban areas inside/ outside the UVAR area. Other interesting features are the real-time monitoring of vehicle itineraries and stops according to permits and the reliable positioning of urban regulated fleets.

- Example: From 1 January 2014, Slovakia’s Skytoll system added additional 1st, 2nd and 3rd class roads (urban roads) to the GNSS-based charged network, expanding the total chargeable road network for heavy goods vehicles.

- In the period from October 2010 to July 2011, the EGNOS2road (E2R) project assessed the added value/ economic benefits of EGNOS with respect to the GPS for the road sector, specifically for two applications: road tolling and tracking & tracing of professional fleets. EGNOS is operational and provides three services over Europe augmenting the GPS position in terms of enhanced accuracy and integrity information: EGNOS Open Service (EGNOS OS) and EGNOS Safety Of Life (EGNOS SoL) broadcasted via the satellites’ signal, and EGNOS Commercial Service (EGNOS CS) distributed to professional users through terrestrial networks via a server named EDAS. E2R key findings are that EGNOS OS generally enhances the position measured using GPS only in all extra-urban and urban environments. The two operators involved in E2R, SAT (Italian motorway) and RSM (Rome Mobility Agency) evaluated the added value of EGNOS with respect to GPS standalone, and concluded that the benefits rely on enabling a more robust and reliable positioning.

5. Tachograph-based technology is based on an OBU connected to the vehicle odometer. The technology does not raise privacy issues and limits the roadside equipment needed to border crossings apart of the use of ANPR technologies for enforcement. On the other hand, the OBU is expensive. Since the first national application in Switzerland (2001), a certain degree of partial interoperability has been reached in accordance with the CEN DSRC 5.8 GHz standards successfully
implemented in Austria. However, the technology is applied on heavy goods vehicles only and it is of limited relevance in urban areas.

- Example: Application on the Swiss road network

6. **Mobile communication** (GSM and smartphones) is a promising technological option, supported by a continuing technological development even if the current applications in urban areas are actually limited to the trial or pilot stages. In combination with ANPR, DSRC, RFID and GNSS technologies, the mobile communication technologies play an important role as far as payment mechanisms are concerned. For example, according to the C2S trial in Portugal, the OBU integrated with the smartphones through a mobile application pays the toll and the enforcement role is played by ANPR technologies. In general, mobile communication technologies allow the user to pay the toll being more interoperable (due to the smartphone technologies) and transparent (the user can see the tolls and charges in real time). Since recently, it is possible to pay the access fee to the UVAR Milan Area C via smartphone x.

Having said that, the technology is not mature yet and various issues still need to be addressed such as the rapid technological obsolescence of some standards. For example, current systems based on GSM solutions could become obsolete in the near futurexi. It is worthwhile to note that the EC Directive on the interoperability of electronic road toll systemsxii in the Community has indicated DSRC, GNSS and GSM/GPRS as the only suitable technologies. However, the Directive was not applicable to small, strictly local road toll systems and its implementation has mainly concerned the tolled interurban road network.

**Trading off the technological options' characteristics**

The following table focuses on the comparison between four relevant aspects (implications) for each technological option concerning their application in UVAR schemes, not including the comparison with low-technology options, e.g. manually enforced schemes, which are generally cheaper to run:

- Costs
- Privacy
- Interoperability
- Enforcement

<table>
<thead>
<tr>
<th>Technological option</th>
<th>Costs</th>
<th>Privacy</th>
<th>Interoperability</th>
<th>Enforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Number Plate Recognition (ANPR)</td>
<td>Generally low implementation costs: no expensive roadside equipment or OBUs. High back office expenditures may incur due to the need to keep the foreign vehicle registration databases updated.</td>
<td>Vehicle driver identification may be a problem depending on Member States legislation.</td>
<td>There are neither European standards on ANPR, nor is there standardization concerning license plates. However, the technology has proven to be interoperable with other solutions in electronic toll collection.</td>
<td>This is primarily a technology for enforcement. Widely applied in UVAR and non-urban enforcement methods.</td>
</tr>
<tr>
<td>Dedicated Short Range Communication</td>
<td>The technology needs an OBU which is generally cheap.</td>
<td>No major privacy issues are involved</td>
<td>The technology is subject to European standardization</td>
<td>This is primarily for data collection while...</td>
</tr>
<tr>
<td>Technological option</td>
<td>Costs</td>
<td>Privacy</td>
<td>Interoperability</td>
<td>Enforcement</td>
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<tr>
<td>(DSRC)</td>
<td>However, roadside equipment (gantries) for tolling and enforcement are costly in particular where a dense network of equipment is necessary.</td>
<td>given that the position of the vehicle is not monitored. Personal information may however be needed to fill in the OBU.</td>
<td>Notably CEN rules make the technology interoperable (e.g. for parking and tunnels).</td>
<td>DSRC technologies are also used for enforcement in the form of mobile enforcement units equipped with DSRC.</td>
</tr>
<tr>
<td>RFID (Radio-frequency)</td>
<td>The costs are similar to the DSRC technology except for the cheaper OBU.</td>
<td>No privacy issues raised.</td>
<td>In the US, where the technology is mainly implemented, geographical interoperability has been reached.</td>
<td>This is primarily for data collection while ANPR is still used for enforcement.</td>
</tr>
<tr>
<td>Global Positioning System (GPS)/Global Navigation Satellite Systems (GNSS)</td>
<td>Implementation costs and back office work for maintenance and map updates make the technological solution expensive since the OBU price is higher than in the DSRC solution.</td>
<td>Data protection may be an issue due to the significant required amount of information collected from the users.</td>
<td>The technology is interoperable as the examples of the German and Austrian GPS-based systems show.</td>
<td>Roadside equipment, e.g. gantries or cameras required for enforcement. Maybe operational problems with urban canyons and nearby routes.</td>
</tr>
<tr>
<td>Tachograph</td>
<td>Despite part of the maintenance cost being born by the user, the implementation costs are high (OBUs and roadside equipment).</td>
<td>No data protection and privacy issues.</td>
<td>Some interoperability with border countries has been realized.</td>
<td>Enforcement gantries are needed.</td>
</tr>
<tr>
<td>Mobile communication</td>
<td>The applications require lower investment in roadside systems while no OBUs are required.</td>
<td>Data protection may be an issue. Potentially, relevant personal information may be collected.</td>
<td>Interoperability of smart phone applications is high but technological obsolescence of standards may be an issue.</td>
<td>The enforcement in smart phone-based systems is similar to that of DSRC or GNSS-based systems. DSRC and ANPR technologies are needed.</td>
</tr>
</tbody>
</table>

The table shows that the final choice of technology for any scheme which aims to be cost-effective in the long term has to be made after trading off a certain number of factors.

In urban areas, Automatic Number Plate Recognition (ANPR) has been in service for many years. In everyday operation, it offers convenience of use and robustness, does not require OBUs and has proven to be interoperable. The cost to run such systems relative to other high-technology options is typically low and the technology is well understood by road operators.
Schemes combining Dedicated Short Range Communication (DSRC) with ANPR technologies for enforcement, particularly in motorways, e.g. TELEPASS, have been implemented in several tolling motorways as well as deployed on strategic routes in a certain number of European member states. However, in urban areas, the need of monitoring gantries and the corresponding lack of physical barriers makes the DSRC implementation not particularly widespread (apart from Singapore and Norwegian cities and some case in Italy, e.g. the Milan Area C.).

GPS/GNSS solutions in urban areas must face several barriers: Firstly, additional roadside equipment need to be installed to improve signals where they are weak (e.g. in urban canyons), augmenting investment costs. Furthermore, compared to the DSRC equipment, which have the advantage of being cheap to procure and easy to use, the OBUs required for GPS/GNSS-based schemes are expensive. Another important barrier is enforcement since in order to avoid additional investments for gantries, the risk of high non-compliance rates is high.

From the point of view of the cost-efficiency of the technological solutions, mobile communications systems from trials and research projects may be a promising option: flexibility to define and modify what and how is to be charged, no significant physical tolling roadside or infrastructure investment needed, no need for OBUs or costly enforcement infrastructure. However, uncertain accuracy in detecting vehicles in the urban context or in certain sections of the network and more importantly the inability to classify vehicles make their use in urban areas problematic, at least in the near future. Furthermore, a mobile method's disadvantage is that it requires a smart phone which discriminates against persons who do not use this appliances.

**Future technological options**

Other technological developments may in the future support the implementation of UVAR schemes even if a sufficient number of trials and pilots are not available to draw preliminary conclusions. Among them, it is worthwhile to mention the following:

- In-vehicle Intelligent Transport Systems (ITS) technology, for example within the Cooperative Vehicle Information Systems (CVIS) and Communications Access for Land Mobiles (CALM) areas. Connected Driving (or C-ITS) technologies, which allow vehicles to become connected to each other, and to the infrastructure and other parts of the transport network. These technologies can in the future provide technological functionalities favouring billing fines, vehicle identification and positioning.
- In-vehicle applications such as telematics for vehicle and driver management, eCall, usage-based insurance (UBI) and different types of Event Data Recorders (EDRs)
- Low cost combined GNSS/accelerometer devices to track movements even where satellite visibility may be poor;
- Mapping standards, map quality, highway section asset management and algorithms for determining when a vehicle has passed a “virtual tolling point” or similar “toid” (Topographic Identifier); and
- Cloud-based storage and processing which reduces operating costs and improves the speed of calculation of the distance driven, the toll due and the cleaning of erroneous data.
Chapter III - Available options

This chapter focuses on the illustration of examples of technological options implemented in European UVAR schemes. Despite the fact that technological options usually work in combination, the available options described in this chapter have been identified according to the prevailing operating technology in order to flag examples of technological solutions representative of specific types of technologies. Namely, two types of technological solutions have been identified:

- Automatic Number Plate Recognition (ANPR)-based technologies as used in London, Stockholm and Milan;
- Dedicated Short Range Communication (DSRC)-based technologies as used in Norwegian cities, e.g. Oslo.

The following boxes describe for each urban area the technological characteristics of the UVAR schemes while the final section focuses on lessons learned.

**ANPR-based technologies**

**London**

The London congestion charge entered into force on 17 February 2003. It was introduced by Transport for London (TfL) in February 2003, following an extensive public and stakeholder consultation and was extended westwards in February 2007. The charge was initially set at £5, then raised on 4 July 2005 to £8, £10 in 2011 and £11.5 at the time of drafting of this text. The daily charge must be paid by the registered keeper of a vehicle that enters, leaves or moves around within the congestion charge zone between 7 a.m. and 6 p.m.

As stressed by Transport for Londonxiv, there are no barriers or tollbooths. Instead, drivers are paying to register their Vehicle Registration Number (VRN) in a database. ANPR-based technologies read a vehicle’s number plate as it enters, leaves or drives...
within the charging zone and check it against the database of those who have paid the charge or those who do not have to pay (because they are exempt or registered for a 100 per cent discount). Once a VRN has been matched, the photographic images of the vehicle are automatically deleted from the database.

The daily charge can be paid before or on the day of travel, by telephone, text message, online and by post. Drivers have up to midnight on the day of travel to pay the £11.50 charge or £14.00 if they pay the next charging day after travelling in the zone.

The charge can also be paid via Congestion Charging Auto Pay which is an automated payment system that has a discounted daily charge rate of £10.50. Drivers need to register with TfL to pay via Auto Pay and it will automatically record the number of charging days a vehicle travels within the charging zone each month.

On 2004-2005 several technological trials were carried out by Transport for London in order to test other technological options based on a) GNSS/ GPS (satellite positioning) b) GSM (mobile phone) and c) DSRC (tag and beacon).

Vehicles were fitted with On Board Units (OBU) which communicated with GPS satellites, identifying the location of the vehicle. OBUs needed to be permanently installed with access to a power supply in a vehicle. The units should ideally be part of the vehicle build and retrofitting of units is likely to be problematic.

It was found that the scale and density of tall buildings and the configuration of relatively narrow streets, particularly in the City of London, prevented the level of precision location of vehicles.

Mobile telephone technology (GSM) is based on a network of cells which form the framework for communication. Generally, the denser the urban area, the smaller the cell sizes are. At that time, in London the cell sizes were not refined enough to facilitate identification of vehicles to the degree of precision that was required.

Dedicated Short Range Communication (DSRC) with tag (Transponder) & Beacon involve communication between roadside beacons and transponders placed in vehicle windscreens. Technology can be either microwave or infrared-based. Initial findings produced when DSRC was originally trialled during Stage 1 at two locations in Inner London produced encouraging results and it was decided to undertake further trials.

An area was chosen where the local borough council, Southwark, was consistent with the concept of Congestion Charging. Representatives of Transport for London attended a number of public meetings to inform major stakeholders such as community and neighborhood groups about the trials. The major critical aspect of public interest relating to the trials focused on the installation of roadside equipment in connection with the DSRC element of the trial. Due to the characteristics of the London roads, it was concluded that the installation of gantries would not be considered an option.

In conclusion, some of the technological options (mobile communication and the use of satellite positioning devices) were considered promising, also in the light of additional trials results, but not yet ready for their widespread implementation.

To the contrary, trials focused on the improvement of ANPR technologies notably by the replacement of analogue cameras with digital ones and by undertaking the image processing in roadside cabinets adjacent to the enforcement cameras which provided benefits in terms of enhanced image quality. There are considerable cost savings associated with the transfer of data by broadband rather than by fibre optic.
## Milan

In January 2012, the city of Milan implemented a congestion charging scheme in Italy, known as AREA C. The AREA C system was designed to replace the previous scheme (ECOPASS), implemented in 2008.

The ECOPASS scheme was a Low Emission Zone in which vehicles were charged to enter the area and the fee structure was based on the vehicles' emission standards. The underlying technological architecture relied on 43 Closed Circuit Television (CCTV) access points installed along an area of 8.2 km². As a vehicle passed under the access points, the car number plate was matched against information stored in the national motor register database to determine the vehicle category (emission standards) on the basis of which the charge was determined. Technical specification concerning interfaces with the national Ministry of Transportation database were defined and agreed upon.

However, the implementation of the system was undermined by several technical problems as the automatic number plate reading devices triggered the levying of thousands of erroneous fines. Technical problems and various reasons, e.g. to relieve congestion, led to replace the ECOPASS system with the Area C.

On June 2011, citizens' involvement through public consultation led to the new congestion charge Area C which started operating in Milan on 16 January 2012: the scheme is now in force every working day from 7:30am-7:30pm with no charge on weekends and public holidays but in the latest revision of the scheme a further free entrance slot has been implemented on Thursday evenings (the cameras stop working at 6pm instead of 7:30 pm in order to encourage weekday shopping activities).

New ICT platforms were set up and cars entering Area C are now detected by a system of 43 electronic gates (of which seven are reserved for public transport vehicles), equipped with ANPR (Automatic Number Plate Recognition) technologies.
Stockholm

The Stockholm congestion charge was introduced as a trial between 3 January 2006 and 31 July 2006. Through a referendum in September 2006, the residents of Stockholm voted for the reintroduction of the congestion charges in August 2007 and this has been operational since then.

The charging system consists of a cordon with 18 payment gates situated around the inner city with a time-differentiated toll being charged in each direction. On 1 January 2016, congestion taxes have been increased in the inner-city parts of Stockholm and congestion tax has been charged on an additional access point.

Originally the technological framework relied on a combination of RFID technologies and ANPR for enforcement. Wireless RFID technology was supplied by the Norwegian company Q-Free. The system worked by using a Q-Free on-board unit and roadside technology in combination with an operational system. Payments were made via a number of channels including direct debit triggered by the recognition of the on-board electronic tag. Q-Free cameras detected and record car number plate images using Automated Number Plate Recognition (ANPR) software to identify those vehicles without tags, and were also used to verify tag readings and provide evidence to support the enforcement of non-payers.

When the charges were reintroduced after the public consultation, the automatic camera identification ANPR system, originally intended only as a secondary means of vehicle identification, became the basic technology abolishing the use of transponders, due to their good performances.

Now vehicles are registered and identified automatically at control points through a photograph of their number plate. The flow of traffic is not affected as drivers do not have to stop or slow down. Payment is made in arrears; there is no need to pay at the roadside.
DSRC-based technologies

Oslo

The Oslo toll cordon is the largest urban toll scheme in Norway. It is in operation since 1990. It is a classic cordon pricing scheme with 19 toll stations installed around the centre of Oslo. Vehicles driving into the city centre are subject to a fee when passing the toll cordon. Every vehicle accessing the city centre necessarily has to pass a toll station.

The underlying technology is a combination of DSRC technologies and ANPR for enforcement. Since 2008, the charging system is fully automatic. It is based on On-Board Units (OBU), specifically AutoPass tags based on DSRC (provider Tecsidel) and Automatic Number Plate Recognition (ANPR) technology for vehicles not equipped with OBUs.

In 2007 the three Scandinavian countries of Sweden, Norway and Denmark initiated the AutoPASS-EasyGo cooperation, meaning that everyone with an electronic tag from one of the cooperating countries could use their own tag as a means of payment at the toll stations in all three countries. During 2013 this cooperation will be extended to include Austria for all vehicles over 3.5 tonnes. According to estimates, 50 % of Norwegian vehicles are equipped with the AutoPASS OBU.

In sum, the following DSRC-ANPR technology characteristics need to be underlined:

• DSRC system is based on the European CEN standard
• The open standard is owned and managed by the NPRA (Norwegian Public Roads Administration)
• Standardised hardware and software applies for all the Norwegian urban tolling projects
• Full national (and Nordic, i.e. Denmark, Sweden and Norway) interoperability allowing motorists to use the same OBU in all Norwegian and Nordic toll projects; and
• The AutoPASS system is owned by the NPRA comprising technical specifications, OBUs and all road side equipment.

In terms of cost effectiveness, approx. 220,000 vehicles pass the toll ring daily (the road with the most traffic having 46,000 daily). Approx. 40% of all drivers in the Oslo region pass the toll ring daily. The gross revenue in the last three years (data from 2014) has been more than EUR 80m annually. Operational expenditure is approx. 11% which is significantly less than the cost of administrating taxes. Thus, the toll ring system might be considered as an effective collection system xvii.

Lessons learned from the available options

In discussing the technology options available for the implementation of UVAR schemes, it emerges that the technological options should not be regarded as an “either-or” but as complementary options.

Among the factors affecting the most appropriate technological combination, it can also be considered urban topology.

In fact, urban topology matters: in Stockholm and Oslo, where the worst congestion problems (urban roads) can be located along a natural cordon around the city centre, the implementation of cordon charging UVAR schemes is viable. In urban areas with multiple access options such as in Milan or in London, the identification of a cordon is more difficult.

Cordon charging systems as in Norway or in Stockholm combine Dedicated Short Range Communication (DSRC) and ANPR technologies. When a vehicle passes a charging point, it is detected, identified by the on board unit and a charge may be deducted from the smart card. Vehicles detected without an on board unit or smart card are photographed for enforcement purposes and Automatic Number Plate Recognition (ANPR) technology is used to identify exempt vehicles or allow for enforcement.

However, the roadside equipment (gantries) that needs to be installed to read OBUs in DSRC solutions may be not compatible with the urban environment as it was demonstrated in the London trials xviii.

In dense cities such as Milan or London, using Automatic Number Plate Recognition (ANPR) technologies is an option. Drivers purchase a permit and their vehicle is then added to an electronic list; automatic cameras record vehicles crossing cordons (or entering certain areas) and check number plates against the list.

ANPR-based systems are also appropriate where passenger cars represent the largest segment of traffic and the number plate identification is reliable according to technological developments. This solution offers generally low capital and operational
expenditures. However, back office operation expenditures may grow when the operation has to deal with a great share of foreign vehicles.

An example of back office activities with an indicative cost estimation is provided in the following box with reference to the case of Rome Municipality ZTL.

The technological system operating in the Rome ZTL is a network of 42 electronic gates using ANPR for various schemes (daily or nightly schemes, different zones, ecc) of access control, permit management, exemptions, e.g. disabled people, and enforcement. The simplified architecture of functions underlying the enforcement process is depicted in the following diagram:

![Diagram of enforcement process](image)

Source: F.Nussio, “Mobility Agency of the City of Rome, Mobility Masterplan, ITS and LTZ in Rome”, 2015

The system checks the violating vehicles not in real-time, and the process needs to be completed with the fine notification to the vehicle owner within 6 months from the violation itself. Operating costs for the management of the enforcement system operations, e.g. violation and permit management, interface with the Rome municipality police database and with the public vehicle owner register, including technical maintenance can be estimated in about €4-5 million/year, not including labour costs for checking violations. Such expenditures could be compensated by revenues coming from issuing permits. Higher costs need to be considered in case of quasi real-time systems, where the timing for update and payments is tight (in Rome, from violation to the notification of payment, the time lag is about six months).
Furthermore, concerning the comparative cost assessment of DSRC and ANPR options, it should be considered that where DSRC and other methods are used, camera technology is still also needed to detect those that don’t pay or have OBUs. This gives another advantage to ANPR enforcement, as it only requires one technology to be used.
CHAPTER IV – Potential impacts of a common European approach on technology and interoperability

As mentioned in previous chapters, technological options in UVAR schemes depend on various factors, notably UVAR functionalities, as well as city size, traffic conditions, existing road infrastructures, urban architecture and, last but not least, available budget.

Depending on the objectives of the UVAR scheme (for instance to limit the access of certain vehicles to specific areas vs. to reduce congestion vs. to increase the overall air quality and liveability of the city etc.), technology options and their combination could also change.

When looking at a common European approach, interoperability more than technology itself is of the essence.

More interoperability could enable road users to easily obtain access to cities throughout the EU with a limited number of electronic devices in the vehicle. This is more evident in the case of UVAR schemes with similar objectives but it could also be useful where the objectives are different.

Assuming the common adoption of the “user pays” principle where charges are directly related to the costs that users impose on the infrastructure, interoperability is essential to offer road and infrastructure charging policy in a flexible way without creating obstacles to traffic flows in European cities.

According to the Directive 2004/52/EC and Decision 2009/750/EC, the European electronic Toll Service (EETS) has to ensure interoperability of tolling services on the entire European Union road network. With a single service provider, subscription contract and on-board unit, EETS is supposed to facilitate daily operations for road users, improve traffic flows and reduce congestion. TOLL2GO and EasyGo are two current examples in EU. The first is a joint service provided by the German Toll operator as well as by the Austrian ones. The second is a European partnership between Denmark, Norway, Sweden and Austria that enables the use of one and the same OBU at more than 50 toll stations in Denmark, Sweden, Norway and Austria, as well as many ferry services within Denmark and between Denmark/Sweden and Denmark/Germany. A similar service could help establish interoperability in European cities and enable road users to circulate throughout the European Union without having to be concerned by charging procedures changing from one city to another.

This does not require one single service provider but there should be interoperability between the different systems so that paying charges would be a seamless operation.

Interoperability could also increase security in the whole of Europe generating useful information for the relevant law enforcement authorities checking the data against a common database. In case of no matching data, the recording would automatically be deleted.

Interoperability could also play a key role for UVARs without a charging scheme. It should be a part of the EU Directive 2010/40/EU (ITS) and useful integrated services should be easily be offered and used (e.g. P&R, Rail, public transport system, parking, car sharing, e-biking, or any smart ticketing system) without having to be concerned with different procedures, applications and languages.
In the previous chapters it was demonstrated that ANPR is the most used technology in European UVARs also due to enforcement reasons, its easy-to-use approach and relatively lower costs. In addition, the performance and features of ANPR are continuously improving, enabling new fields of applications. In fact, the global ANPR system market is expected to grow at a compound annual growth rate (CAGR) of more than 12% in the next 4-5 years\textsuperscript{xix}.

However, the lack of licence plate standardisation and the challenges for Member State cooperation in setting up a European licence plate database make UVARs' case for achieving international interoperability weak, other than making interoperability of cross-border enforcement of penalties problematic.
CHAPTER V – Barriers and enablers to a common approach

Barriers at local and EU level

ANPR mistakes and license plate standardisation

- Demonstrations across Europe show that the technology needed for automatic number plate recognition (ANPR) is reliable and affordable. It has however an intrinsic rate of non-recognition in the real operational environment (up to 10%). Wrong enforcement especially during the launch of the system can create negative reactions. Non-detection and incorrect reads in ANPR systems can be strongly reduced by overlapping camera readings and supporting machine systems with human aid. Hence, the UVAR scheme needs to be supported by a well-tested operational scheme able to reduce such problems. Furthermore, as mentioned above, the lack of license plate standardisation at EU level diminishes the geographical interoperability of ANPR.

GPS/GNSS systems are not yet ready to operate on their own in full-scale UVAR systems.

- There are still several problems regarding technology that have to be solved before a GPS/GNSS system can be implemented in full-scale in UVAR schemes. GPS-based systems require a OBU installed in all cars crossing the UVAR and such installation activity is enormous and very costly. Also, much further work needs to be carried out concerning methodological, software, and technical issues.
- UVAR schemes in general and specifically zone charging schemes do not require continuous monitoring which is a main benefit of GNSS systems. The general problem with a GPS-based system is that it has to work the whole time the car is in a charged area. A cordon-based system is much less demanding because the technology only needs to work when a cordon is crossed which reduces enforcement to primarily checking vehicles crossing cordons.

Use of GPS/GNSS system for regulated fleet needs to be regulated by contract.

- For regulated fleets like coaches for touristic purposes, public transport or delivery vehicles, the adoption of GPS/GNSS/EGNOS solutions for monitoring and control purposes need an appropriate regulative framework. A penalty can be applied in case of non-compliance only in case a law establishing the application of a sanction is in force and the GPS/GNSS equipment is duly approved.

Equipment could not work properly

- Demonstrations in trials and pilot across Europe have experienced problems with OBUs regarding loss of battery power, poor quality of GPS reception and loss of signals notably when the system was set up. Recommendations are to undertake extensive testing of prototypes before implementing the final product and to check the quality of the GPS signal received when installing the equipment. For instance, loss of signals could be compensated by specific technical methods, like dead reckoning systems and real-time map matching, which are able to calculate the current position by using a previously determined – or a fixed – position and updating that position based upon known or estimated speeds over elapsed time.
and trajectory. Running a small-scale pilot that includes analyses of the log data is also necessary in most cases.

The multi-application functionalities to the on-board unit

- The new generation of OBU features long lifetime, compact site and very good performance at any speed. The user memory can be structured in several elements and be able to host most common harmonised specifications in tolling as well as for other applications such as parking, UVAR access, gas stations, logistic management etc.. This functionality enables interoperability. However, this cannot always be guaranteed because data structure in the memory has to be defined immediately after initialization. Afterwards, an update of the software or data of the on-board unit is subject to multiple requirements. Then the complexity of the system increases and consequently the sources of errors in all steps of the system development and operations process may frequently occur. Additional applications could also interfere with other vehicle features like battery consumption or with other DRSC/RFID/GPS systems operating in the same environment. Moreover, data privacy and caution for different application stakeholders sharing OBUs and/or data need to be considered.

Privacy issues

- Despite of the many potential benefits of Intelligent Transport Systems, the associated increase in vehicle/infrastructure electronics and communications raises security and privacy issues where ITS technologies must ensure the integrity, confidentiality and secure handling of data including personal and financial details ensuring the full protection of citizens’ rights. Concrete guidance on personal data protection and standards for specific aspects of ITS as in the case of UVAR scheme application, where path control and full-scale use of GNSS positioning systems could have wide application for specific fleets and vehicles should be taken into account.

Legal implications for GPS/GNSS/EGNOS position

- The attributions to the GNSS position shall be expressed as a “yes/no” values and not as a percentage in order to have a legal value when associating the detected vehicle to a specific position. In other words it would be necessary to define a threshold under which the positioning data are not validated and they have no legal value. Above the threshold, the data has legal validity as recognised by contract or law. Such a threshold is a sort of “tolerance” associated to the data and it is related to the accuracy of the measurement done by the instruments, typically derived from the testing during the type approval procedure. Currently the type approval process is based on Member States’ rules and procedures. Specifically for the use of EGNOS and Galileo features, the definition of European common guidelines to harmonise the establishment of Member States rules is recommendable, for ensuring interoperability, compatibility and continuity.

Enablers at local and EU level

ANPR systems work sufficiently well

- Due to the intrinsic rate of failure in vehicle recognition, there will probably always be a small share of vehicles that cannot be identified by the system. Implementation in London and Stockholm show that after the ANPR system was implemented, non-compliance diminished drastically. This shows that automatic systems such as ANPR are more efficient than systems focusing on manual control.
If the UVAR scheme's objectives call for several zones or time-differentiated fees, it is advised to use DSRC. Even in this case ANPR should be a necessary complement for enforcement purposes.

**OBUs can integrate ANPR systems**

- UVAR system can be designed to integrate more technologies. With cordon based ANPR, the photograph of the non-compliant car's license plate is processed by an OCR system. Where data reliability does not reach the required threshold, the photograph is manually controlled and checked against the central database. This process could be supported by a parallel OBU system where vehicles equipped with OBUs are automatically authorized removing photo reliability controls and by that decreasing the operator's workload. Control protocols should in any case be produced in order to detect incorrect use of the OBU or card and their association to the license plate.

**Use of GPS/EGNOS system to support regulated fleet**

- For specific fleets subject to regulation in urban areas like public transport, coaches for touristic purposes or delivery vehicles, a GPS-based system is mostly already used for monitoring purposes or quality control checks. However, due to the complex networks and driving environments, other than political or commercial barriers, a GPS-based system has some limitations like extra costs derived from the need of visual control and inspections requiring personnel effort in case of claims in order to verify data reliability.
- The possible enhancement of the present GPS-based system is EGNOS OS that generally improves GPS performances. This development is valid for all extra-urban and urban environments, for commercial GPS/EGNOS receivers and antennas with different enhancements and less valid in cases with dense and tall buildings/ foliage conditions and of standard antennas. Specific systems like EGNOS CS/EDAS can provide a higher confidence in the position calculation.
- Future adoption of the EGNOS system for regulated fleets could enhance present applications which are already based on GPS. It could be adopted in present/future operations where the use of satellite navigation technology is planned and in order to develop new applications supporting a more effective regulation of the traffic in urban and suburban areas and between urban and interurban roads (i.e. urban/extra-urban interoperability).

**Transition to low carbon economy**

- Transport is the backbone of the economy, essential for the functioning of the single market and the free movement of goods and people. The global transition towards a low-carbon economy has started, supported by the Paris Climate Agreement. Transport will need to play an important role in this transition. In this sense, the EC communication "A European Strategy for Low-Emission Mobility" states that the EC will propose and create enabling conditions for low-emission mobility, advocating fair and efficient pricing in transport. Cities account for 23% of transport CO2 emissions and many urban areas are in breach of air pollution limits. The strategy will depend on cities and local authorities and UVARs are an important part of a comprehensive approach towards sustainable urban mobility planning in which technology choices could support the set-up of flexible areas where applying different policies to more polluting vehicles.

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1 SWD(2016) 244 final.
VI Recommendations

Taking into consideration the complexity of EU urban areas and the impossibility of finding a “one size-fits-all” solution, the following recommendations provide indications on how trading-off the specific characteristics of UVAR technological solutions to pursue increased interoperability and effectiveness.

- When planning UVAR and its associated technology, number plate recognition (ANPR) technologies should be considered, as they have proven to be reliable and effective, are cheaper, and easier to implement since they do not require in-vehicle equipment, though they are probably more expensive to operate, in terms of back-office expenditures and operational costs. The technology has also proven to be interoperable with other solutions in electronic toll collection, e.g. in combination with DSRC technologies. ANPR also has the advantage of not requiring additional equipment in vehicles, and is also required as an enforcement method in addition for other technological enforcement methods. However, the lack of licence plate standardisation and the challenges for Member State cooperation in setting up a European licence plate database make UVARs’ case for achieving international interoperability weak.

- The choice of technology is also influenced by urban topology and UVAR objectives, e.g. charging. In Stockholm and Oslo, where the worst congestion problems (urban roads) can be located along a natural cordon around the city centre, the implementation of cordon charging UVAR schemes is viable. Cordon charging systems as in Norway or, originally, in Stockholm, combine Dedicated Short Range Communication (DSRC) and ANPR technologies. The set up of costly roadside equipment (gantries) in a few important points may be compatible with specific urban topology. In urban areas with multiple access options such as in Milan or in London, the identification of cordons is more difficult. DSRC technologies offer a high level of interoperability with parking and tunnels, as shown in the Nordic European countries.

- Global Positioning System (GPS)/GNSS solutions in urban areas, although promising in terms of interoperability, face several barriers: in particular, additional roadside equipment need to be installed to improve signals where they are weak (e.g. in urban canyons), driving investment costs up. In general, the appropriate combination of technologies must cope with the everyday problems, e.g. acceptability, privacy issues, legal problems, technical reliability, etc. Every combination should be evaluated ex-ante, through an experimental period where all the particularities of the scheme itself are tested with all the involved actors and stakeholders.
i NBGD n° 2 “Vehicle Types, Exemptions and (Cross-border) Enforcement of Successful Urban Vehicle Access Regulations (UVAR) Schemes across Europe”

ii An exhaustive introduction to the key categories, from the point of view of charging technologies, can be found in “Technology options for the European Electronic Toll Service”, European Parliament Study 2014

iii Technology options for the European Electronic Toll Service”, European Parliament Study 2014

iv A review of current development in GNSS applications in Europe is “GNSS Adoption in Road User Charging in Europe, Issue 1, European GNSS Agency, 2015”.


viii TREN/G4/41-2010- SI2.573856

ix Partial, or one way interoperability, happens when a system designed in one country can be used to pay charges electronically in a second country, but the unit in the second country cannot be used to pay charges in the first country.

x http://www.comune.milano.it/wps/portal/ist/it/servizi/mobilita/area_c/modalita_pagamento


xv Swedish Transport Administration, “On 1 January 2016, congestion taxes in Stockholm will be raised and congestion tax will be levied on Essingeleden”

xvi “Road Tolling in Norway – a brief introduction”, Norwegian Public Roads Administration, Astrid Fortun/Erik Furuseth, 2007


xix Automatic Number Plate Recognition System Market by Type (Mobile, Fixed, Portable), Application (Traffic Management, Law Enforcement, Toll Collection, Parking Areas), & Geography - Analysis & Forecast to 2020, December 2015

xx PRGrCSS (Pricing Road Use For Greater Responsibility, Efficiency And Sustainability In Cities Competitive and Sustainable Growth Programme), at an early stage to EGNOS2Road (2010) assessing the added value/ economic benefits of EGNOS with respect to the GPS for the road sector

xxi EC communication SWD(2016) 244 Final