

Notitie

To
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Subject
Technology options for road pricing

Earth, Life & Social Sciences

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1 Introduction

Many countries face the negative effects of road transport such as congestion, air pollution and accidents. In Europe congestion costs are close to 100 billion Euro (European Commission, 2014). One potentially effective measure to reduce these negative effects of road transport is road pricing. Another motive for introducing road pricing is generating revenue (which can compensate for tax reductions due to the renewal of the vehicles fleet). Road pricing are policies that impose direct charges on road use (Jones and Hervik, 1992).

In Europe several different types of road pricing policies are implemented. Examples include the London congestion charging scheme (LCCS), the Stockholm congestion charge (SCC) and the various national truck tolling schemes in European countries. The most implemented type of road pricing is charging heavy goods vehicles. Despite several plans and initiatives (such as the plan for nationwide kilometre charging in the Netherlands), road pricing has not been implemented for passenger transport on a large scale and on all roads.

The implementation of road pricing requires sufficient public and political support and can be a cumbersome process. Technology is one of the key factors that has an impact on this support and the implementation of road pricing. The technology deployed influences the user acceptance of the scheme. Technologies can differ in their user friendliness, cost and additional services.

Rapid technological developments could enable the introduction of road pricing policies for passenger transport. Recently many pilots and projects applied new connected and cooperative technologies, which are considered the first steps towards automated driving. These ITS developments could potentially offer new technologies and faster deployment of these technologies. The Commission is also currently reviewing its EETS legislation (European Electronic Toll Service system) which defines the rules for EU-wide compatibility of charging technology which presents an opportunity for new technologies or communication standards to be set at EU level. Interoperability is very important here.

Transport & Environment's mission is to promote, at EU and global level, a transport policy based on the principles of sustainable development. Road pricing is one of the measures that could contribute to this mission. Therefore Transport & Environment has asked TNO to investigate the technology options to facilitate the implementation of road pricing.

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Objective

The objective of this study is to give an overview of different types of road pricing and associated technologies, to assess the technologies and link them to developments in the field of ITS, and to deduce from that the policy options regarding technologies to facilitate road pricing policy implementation.

2 Overview of types of road pricing

This chapter gives an overview of different types of road pricing. This overview was made using scientific literature.

Road pricing includes a range of specific policy measures. For specific types of road pricing there are commonly used terms. In this section options are presented and common road pricing measures are explained.

2.1 Scope

In this report road pricing is defined as policies that impose direct charges on road use (Jones and Hervik, 1992). Financial measures related to vehicle ownership, registration or parking (e.g. vehicle ownership and registration charges, circulation taxes and parking charges) are not considered road pricing measures and neither are fuel taxes as they have an indirect effect (through usage of space for parking and fuel consumption) on road usage. Also types of pricing that do not require technology (e.g. vignettes using stickers or toll using cash payments) are not included. More information and references on financial measures other than road pricing can be found in Santos et al. (2010). Also out of scope in this research is pricing of individual roads, bridges and tunnels. The study focusses on nationwide kilometre charging. Finally, this study focusses on types of road pricing that are an option for passenger cars on a large scale in the not too far future. For example road pricing that incorporates slot management, revenue management or "Über" characteristics, are not taken into account.

2.2 Road pricing characteristics

Table 1 presents an overview of road pricing characteristics. This illustrates that the design options for road pricing measures are plentiful. The specific combinations of characteristics of measures can have an impact on the technology choices. In this report the focus lies on the technical aspect of charging, regardless of the policy objectives. The technology options discussed in this report are therefore relevant for all target groups and motives and objectives. Within the type of incentives a distinction is made between charging and rewarding. As road pricing measures based on rewarding (where road users receive a financial reward for not driving) are only implemented in Netherlands and its implementation in practice is not common worldwide, incentives in this report henceforth refer to charging, although it is expected that the technology options presented in this report can be used for rewarding measures as well.

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Table 1: Overview of road pricing characteristics (Vonk Noordegraaf, 2015).

Characteristic	Examples for each characteristic
Target group	Pricing for: <ul style="list-style-type: none"> • all motorized traffic • only trucks / heavy goods vehicles • only passenger cars
Motives and objectives	Pricing: <ul style="list-style-type: none"> • to influence the behavioural choices of travellers • to generate (or redistribute) revenues • to increase the fairness of transport policies (e.g. the principle of the user pays or the polluter pays) • to decrease the negative effects of traffic (e.g. congestion, emissions, accidents)
Geographical scope	Pricing implemented: <ul style="list-style-type: none"> • nationwide • regionally • in (part of) a city • on a road segment • on a tunnel/bridge
Incentives	<ul style="list-style-type: none"> • Charging undesired road use choices (prices) • Rewarding desired road use choices (subsidies)
Payment (amount)	Based on: <ul style="list-style-type: none"> • number of passages • distance travelled (kilometres) • number of visits to the area Fixed or differentiation of the charge/reward depending on the time of day (e.g. peak vs off-peak hours), place (e.g. predetermined distinction between more and less congested areas), actual traffic flow/ level of congestion, energy-use, emissions, noise, road safety and driving style

2.3 Typology of road pricing measures

To structure the discussion on the technology options Figure 1 presents a typology of charging in areas.

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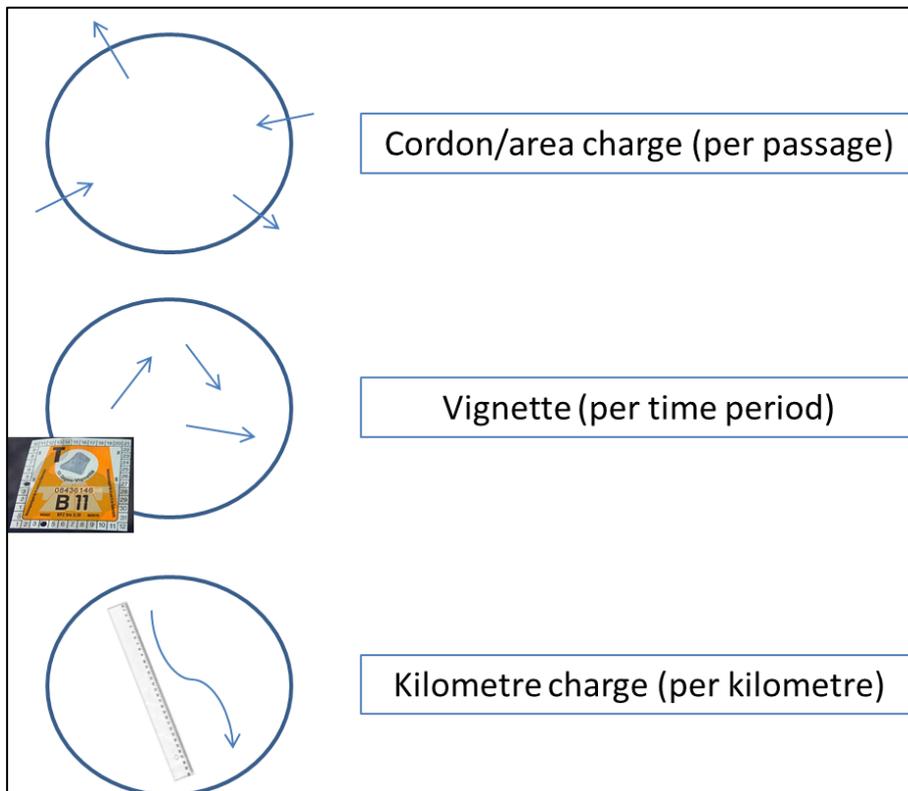


Figure 1 Typology of road pricing measures for areas (networks).

The geographical coverage of the road pricing measures can range from a limited area such as a road network (e.g. a Central Business District, city centre, city or larger urban area) to an extensive road network (e.g. a province, region, country or several countries). Delimited road segments (e.g. several kilometres of highway) are outside the scope. To determine the amount of road usage in a certain geographical area, three different methods are distinguished:

- Per kilometre (distance based)
- Per time period (e.g. per day, workweek, month, year)
- Per passage

Note that in theory it is possible to charge per trip (regardless of the length of the trip or to time spend). However, as it is complex to define a trip (due to the fact that often trips are combined or paused for activities in between) and to the authors' knowledge no examples of this type of road pricing measure have been implemented or are considered in practice, this price foundation is not taken into account.

Different types of price differentiation are possible. Differentiation based on time can range from flat charges (one price that is valid at all times) to variable charges (e.g. distinguish between the period where the price is charged and periods free of charge) and to completely dynamic charges, where prices vary in small time steps and can be calculated based on the actual level of congestion. In addition to time based level of differentiation, there are also other types of price differentiation that can be included in a road pricing measure. Examples are by static vehicle characteristics (e.g. emissions – 'cleaner' vehicles pay less, gross vehicle mass, safety class), non-static road usage characteristics (e.g. number of passengers,

actual weight, number of axles on the ground) and location (e.g. higher price in congested places).

2.4 Well-known types of road pricing

For specific types of road pricing there are commonly used terms. For the most well-known types of road pricing a brief description is included below.

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Road pricing terms, measures and cases

A frequently used synonym for road pricing in the literature is 'road user charging', a well-established term in the field of transport economics (Ison and Rye, 2003). In addition, there are terms that refer to a specific configuration of a road pricing measure. Perhaps the oldest specific road pricing measure is road tolling, where road users pay a fee for the use of a road segment of a selection of road. For example "the majority of intercity highways in France, Italy and Spain" (De Palma and Lindsey, 2000:14) are tolled. Other well-known terms indicating specific measures are cordon charging and area charging. "Cordon Charging involves charging drivers crossing a cordon to enter a specific area – usually the city's central business district (CBD)." (Ieromonachou et al., 2007:19). Examples of cordon charging cases are so-called toll-rings in Norway and the proposed cordon charging scheme in Durham, United Kingdom (Ieromonachou et al., 2006). "Area charging applies to vehicles for accessing and travelling within a specified area." (Ieromonachou et al., 2007:19). Examples of cases where this measure is implemented are the case of 'Electronic Road Pricing (ERP)' in Singapore and the case of the "Congestion Charging scheme" in London, the first named after the technology used and the latter after the aim of reducing congestion. Also the case of Ecopass in Milan, 'the zonal scheme designed to reduce pollution' (Anas and Lindsey, 2010:71), was named after one of the main objectives. Another specific and well-known road pricing measure is kilometre charging, implying "the payment of a certain charge for each kilometre by the vehicle user." (Ubbels et al., 2002:256). Examples of kilometre charging cases are the proposed truck tolling schemes in the United Kingdom, Sweden and Germany or the Netherlands where kilometre charging was considered but not implemented. In the Netherlands kilometre charging was differentiated to time, place and vehicle characteristics, referred to by Li and Hensher (2012) as daily bottleneck charging.

Another example of a specific type of road pricing measure are the congestion-level dependent charges such as the High Occupancy Toll lanes (an extension of the earlier implemented HOT lanes). The majority of examples of this type of road pricing are found in the United States. Last, there is the category of measures based on rewarding. Examples are the measure 'Credit Based Pricing', combining pricing and rewarding incentives (Kockelman and Kalmanje, 2005) and the cases of the implemented Peak Hour Avoidance (or simple Peak Avoidance) measures in the Netherlands.

Taken from (Vonk Noordegraaf, 2015)

2.5 Truck tolling systems

From all types of road pricing, in Europe truck-tolling systems are by far the most implemented types. In the last 15 years many European countries have been building national, free-flow, distance-based, truck tolling systems. The next table shows some properties of a selection of the most well-known truck tolling systems. As can be seen in the table, for truck tolling different types of technology are used. These technologies can potentially be used for charging of passenger cars as well.

Table 2 Overview over different technology options for truck tolling

Country	Introduction	Trucks	Technology	Operator	Road network	Tariff based on
Switzerland	2001	>3.5 tons	Odometer+ GPS, DSRC	LSVA (Mobatime)	All roads	Distance, GVW (gross vehicle weight), emission
Austria	2004	>3.5 tons	DSRC	Asfinag (Go-Maut)	Motorways, highways	Distance, emission, axles
Germany	2005	>12 tons	GPS, telco DSRC	Toll Collect	Motorways, federal trunk roads	Distance, emission, axles
Czech Rep.	2007	>3.5 tons	DSRC	Myto CZ	Motorways, highways, 1st class roads	Distance, road class, day of week, emission, axles
Slovakia	2010	>3.5 tons	GPS, telco DSRC	SkyToll (Myto)	Highways, expressways, 1st- 3rd class roads	Distance, road class, GVW, emission, axles
Poland	2011	>3.5 tons	DSRC	ViaToll	Motorways, expressways, national roads	Distance, road class, GVW, emission
Belgium	2016	>3.5 tons	GPS, telco DSRC	Satellite	Motorways, highways and a selection of local and regional roads in the Brussels district	Distance, road class, GVW, emission
Hungary	2013	>3.5 tons	GPS	National Toll Payment Services PLC (NÚSZ Zrt.)	Public road network (motorways, highways, main routes)	Distance, road type, category of motor vehicle (J2, J3, J4), environmental classification

All systems were built and tailored specifically for the requirements of the respective countries. Therefore the interoperability is very limited. Only between Germany and Austria a joint service (TOLL2GO) is in effect, which enables users to use the German system in Austria (but not vice versa) (See for more details on interoperability section 4.2).

From the table can be deduced that there are roughly two major technologies to determine the position of the truck and thus the distance travelled: GPS and DSRC.

3 Overview of road pricing technologies

This chapter contains an overview of possible technologies that are needed to realize and facilitate road pricing.

Despite the wide range of possible road pricing measures, all measures have a basic functional architecture in common. Figure 2 illustrates different subsystems included in the functional architecture. Road use measurement; data communication; and enforcement and inspection are related to road use. Road use measurement and data communication are part of the primary system. Enforcement and inspection are supporting this primary system and as this report focusses on the primary system, specific technology choices for enforcement and

inspection are outside the scope of this report. The subsystems registration (database), billing and information are related to charging. As these subsystems are of administrative nature and involve no fundamental technical architecture choices, the charging process is also outside the scope of this report.

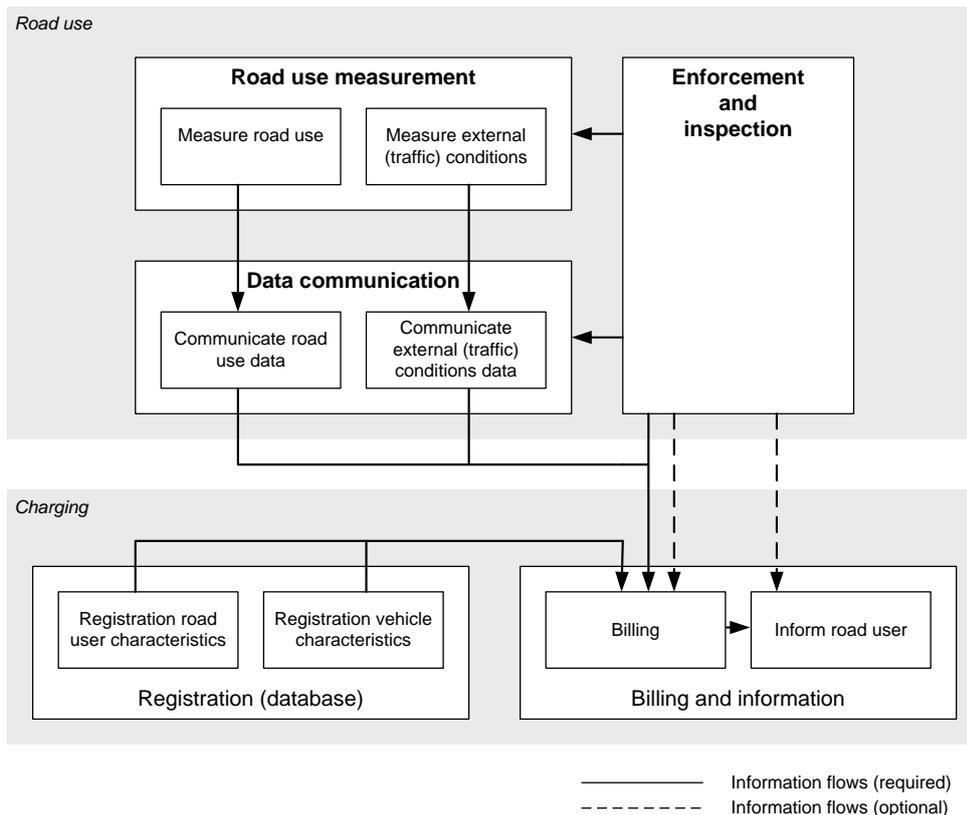


Figure 2 Functional architecture for road pricing schemes, taken from (Vonk Noordegraaf et. al, 2009).

The primary subsystems of any road pricing system are *road use measurement* and *data communication*.

3.1 Road use measurement

Road Use Measurement is concerned with the localization of the vehicle.

Depending on the type of road pricing scheme, this subsystem typically performs one or more of the following tasks:

- detect that the vehicle is passing a cordon;
- detect that the vehicle is driving inside a certain area;
- detect that the vehicle is driving on a certain road segment;
- determine the distance that a vehicle has driven on a certain road, road segment, or area.

In almost any scheme also the time or time period in which such a localization or distance measurement was performed will be stored. Sometimes this is relevant for the applied charge, but almost always this is relevant for traceability reasons.

A wide range of technologies are available for Road Use Measurement. The optimal choice depends on the task it has to perform, the type and amount of

roads in scope and the number and type of vehicles subject to the charge. The technologies can roughly be divided in two groups: those that require road-side equipment and those that are completely in-car.

Localization technologies that require road-side equipment

- ANPR (Automatic Number Plate Recognition).
- RFID (Radio Frequency Identification)
- DSRC (Dedicated Short Range Communication).

ANPR is the most elementary form of localization, as no technology needs to be put in or on the car (all vehicles are required to have a number plate). However an ANPR system requires a camera (in the human-visible, infrared or ultraviolet), together with software that can perform the automatic recognition of those license plates. ANPR is used in Stockholm to detect cordon crossings and in London to detect movements inside the charged area. In more sophisticated systems that involve OBUs, ANPR cameras are often used for enforcement purposes.

RFID systems consist of RFID tags in the vehicles and a RFID reader on the roadside. The reader detects and obtains the ID of the tag just like an ANPR camera detects and recognizes the number of the license plate. In the United States RFID systems are used to pass toll booths without the need to stop. The Netherlands is currently investigating the possibility to equip all license plates with an RFID tag to ease the detection and recognition process of number plates (the tag then transmits a unique identifier that enables to retrieve vehicle information from the RDW vehicle database). The implementation respects privacy in the sense that only authorized readers will receive the unique identifier and can identify the vehicle.

DSRC systems consist of an OBU in the vehicle and a transponder on the road-side and provides one-way or two-way communication. In Europe, DSRC is a standardised communication protocol in the 5.8 GHz microwave band for automotive use. The European directive on the interoperability of EETS in the EU prescribe DSRC as the technology for OBU-roadside communication. DSRC should not be confused with IEEE 802.11p, which is the prescribed data exchange standard for ITS applications in Europe (this standard uses the 5.9 GHz band).

In-car localization technologies

The only actual used and feasible localization technology that does not require road-side equipment is GNSS (Global Navigation Satellite System). The most well-known and mostly used system is the Global Positioning System (GPS, American). Other GNSS systems are Galileo (European, not yet ready – when this will be rolled out it will further increase the accuracy of GNSS applications), GLONASS (Russian) and Beidou (China). Europe has also constructed the GPS augmenting system EGNOS (European Geostationary Navigation Overlay Service).

In principle it is also possible to create a positioning system based on the signals from cellular towers. However it is not expected to be a serious competitor of GNSS systems.

Devices in which GNSS technology are integrated are:

- OBUs dedicated to tolling
- OEM systems (fixed navigation system, eCall)
- Nomadic devices (smartphones)

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OBUs are devices that are installed in the vehicles (after-market devices). It depends on the type of OBU whether the OBU is installed professionally or is self-installable and whether they are built in the dashboard of the vehicle, fixed on the dashboard or placed in a cradle on the dashboard or windshield (referred to as OBU). OEM systems are integrated into the vehicle during the manufacturing process (referred to as in-car system). Smartphones are not fixed into the vehicle. The OBU can perform several functions, including collecting and refining the movement data, enriching the movement data, charging, and aggregation and billing. A *thin* OBU only collects and refines the movement data; the other functions are included in a back office functionality. If the refinement of the collected data is an extra step covered by the OBU, the device is referred to as *slim* OBU. A *smart* OBU covers three steps: collect and refine; enrich and charge; and aggregate. The last option is a *thick* OBU, in which all process steps occur in the device in the vehicle (Ministry of Transport, Public Works and Water Management, 2008). Furthermore, the OBUs can, for example, be utilized with audible warnings and a display.

3.2 Data communication

For most road use measurement systems that involve road-side equipment no additional data communication technology is required in the car. The communication with the roadside combines the localization and the communication, as the road-side equipment will transmit the data that is required for the billing system to the back-office by own means.

In-car localization technologies use cellular communication to transmit the relevant data to the back office:

- 2G (e.g. GSM, GPRS)
- 3G (e.g. UMTS)
- 4G

4 Quick scan assessment of road pricing technologies

When implementing road pricing, the basic choice between having roadside or in-vehicle systems directly determines the magnitude of the cost components, the support of additional services, the scalability of the overall system, and the flexibility. This comes forward in the assessment.

For the quick scan assessment we focus on kilometre charging and not on cordon/area charging and vignette, because we focus on implementation of road charging on a large (national, European) scale.

In section 4.1 the criteria for the assessment are given. There are two aspects that are not used as criteria for the assessment but that are handled in separate sections: interoperability (section 4.2) and privacy (section 4.3). Interoperability and privacy are both very dependent on how road pricing is shaped, and this is not per se a technical question.

The actual assessment is described in section 4.4.

More information about and technology related lessons learned from the introduction of road pricing in Belgium is given at the end of this chapter in a separate text box. This illustrates a number of aspects included in the assessment.

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4.1 Criteria

The criteria for assessment are as follows:

- **Project management:** how much effort is needed to implement road pricing with this technology? The implementation of road pricing is a large project in terms of time, means (financial budget and project team) and deliverables. The time period required from the initial idea until final implementation generally takes years. A large project team is required. Often many deliverables are defined making the implementation of road pricing a complex project. Each technology differs in the amount of project management that is needed to implement road pricing.
- **Costs:** what are the technology costs involved? Each technology has its own characteristics when it comes to the cost structure (e.g. roadside versus in-car equipment). This is influenced by for example the maturity of the technology and the competitiveness of service providers.
- **User acceptance:** this criterion has two components: privacy protection and effort for the user to obtain and use the system. If privacy is not well protected it will result in a lower user acceptance. In addition, user acceptance is higher if the user can obtain and use the system easily.
- **Links with ITS developments:** in the field of ITS, many developments are taking place such as connected and cooperative technologies and automation. Connected and cooperative technologies are a predecessor for automation. Vehicles with connected systems can communicate with other systems for example about their positions. Vehicles with cooperative systems exchange information between the infrastructure and the vehicle (I2V) or between vehicles (V2V). ITS systems concern a wide range of systems from systems that give information, to systems that give specific advice, to driving support systems to full automation. Road pricing technologies that have overlap with other ITS technologies that contain GPS and telecommunication (such as in-car dynamic speed advice and road works warning) can benefit from that.
- **Enforcement:** how difficult is it to enforce the road charging? For example an ANPR system is easier to enforce than a smartphone application. Enforcement for all technologies is carried out with ANPR. For all technologies, there are different ways to do the enforcement in a more strict or loose manner. It greatly depends on the amount of effort the government wants to put into it. Enforcement is mainly done using roadside equipment, which consists of ANPR cameras (for vehicle identification) and possibly, depending on the tolling method, also DSRC beacons, laser systems and other measurement devices. These technologies are used to determine the vehicle class, weight and/or number of axles. For each detected vehicle the road-side enforcement system checks whether that vehicle is correctly registered, whether the data is consistent with the back office data, whether the user is not blacklisted for any reason, and in case of in-car technology whether that technology is active and functioning correctly. The OBUs of in-car positioning systems can also have their own enforcement checks, such as the consistency of the GNSS signals, occurrence of position jumps, consistency with acceleration sensors, etc. In order to discourage system fraud, a combination of stationary enforcement stations, flexible (moveable) enforcement stations and human enforcement officers should be used, in addition to sufficiently high fines for fraudulent users. For smartphones enforcement is more difficult than mentioned above (although it works in principle the same) because of the 'appstore' concept and the fact that people need to have their smartphone with them and the app on.

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4.2 Technical interoperability

Achieving a high level interoperability between road pricing systems in different countries has shown to be very challenging.

Achieving interoperability starts with having an incentive for countries and service providers to arrange for some level of interoperability. In this section we focus on the technical interoperability as this is seen as the first step towards completely integrated systems and we leave the administrative and service related aspects (e.g. one bill or one website with all information for road usage in multiple countries that have implemented road pricing) outside the scope of this report.

The European Commission has implemented regulation, the European Electronic Toll Service (EETS), for interoperability. The EETS standard allows for different technology options to be used. At the moment different technology options for truck tolling are used (see Table 2) resulting in the use of different types of in-vehicle equipment (e.g. an OBU with GPS or a DSRC device). Hence, currently trucks driving through several European countries where road pricing is implemented need to be equipped with various in-car devices. However, within three years EETS has to be available for vehicles above 3.5 tonnes and/or allowed to carry more than nine passengers (including the driver), and within five years for all other categories of vehicles (European Commission, 2015).

Whether a technology option of one road pricing system (A) can be used for another road pricing system (B) and vice versa depends on a number of issues. Firstly, it depends on the functionality of the technology option. For example, if road pricing system A uses DSRC technology, which is only capable of determining vehicles' positions on the locations where road side equipment is installed, it cannot be used for a road pricing system that uses OBUs with GNSS (and has only a limited amount of DSRC gantries on the roadside). However, road pricing systems based on an OBU with GNSS often use DSRC as supportive technology to distinguish for example road usage on a highway from road usage on a secondary road located parallel and very close to the highway (where GPS is not accurate enough to distinguish between those two roads). Another reason why OBUs with GNSS often also have DSRC is for enforcement. Hence, the technology options with most advanced technical functionality (e.g. detailed positioning and elaborate communication) are generally technically suitable to be used for road pricing systems that use less advanced technology options but not vice versa. Note that this example describes the technical interoperability which enables trucks to use the German system in Austria (but not vice versa).

Even if road pricing systems are technically suitable for interoperability, each road pricing system has its own scheme design and tariffs. For example, if a service provider that is active in country A wants to be able to determine the road usage in country B as well, this service providers needs to implement additional software on the technical device or in the back office to determine the road usage in country B according to the specification of the road pricing system in country B. Hence, arranging technical interoperability also requires additional effort from the service provider.

This brings us to another, related, challenge. The experiences with truck tolling have demonstrated that often a business case for a service provider to provide his service to other countries than his "home country" is lacking. Currently, the in-car equipment is provided to the road user free of charge and the cost of the equipment is paid by the government implementing the road pricing system. Every

road user for which the road pricing system applies receives the in-car equipment. Hence, once all vehicles in country A are equipped by the service provider in country A, a service provider of country B has no incentive to charge a road user in country A as he does not get a compensation of country A for a new device. Furthermore, currently countries only compensate the service provider that has implemented the service in this country (say country A) for charging (a monopoly position). Hence, a service provider of another country (e.g. country B) does not get any compensation for charging road usage in country A.

There is one exception where there is a business case of cooperation. If country A has implemented road pricing and country B is implementing road pricing and country A has a technology that can be used in country B as well, country B can save money by making a deal with country A for those road users that drive in both country A and B. If for those road users country B can use the in-car devices of country A, compensation of country A for the additional usage of the technology can be cheaper than equipping the road user with a new device.

4.3 Privacy

Ensuring privacy protection of the personal information of road users is an important technology related aspect of the implementation of road pricing. The safeguards implemented to ensure privacy as well as the perception of road users and other stakeholders of privacy, can have a large effect on the acceptance of road pricing. The road pricing system should be designed such that privacy is adequately protected. However, there are different views on which level of privacy protection is adequate. Overall, there are three main aspects that determine how difficult it is to protect privacy. First, it depends on the amount and type of personal data and data on vehicle usage that is measured. For example, real-time route information is much more privacy sensitive than the information about entrance and exit of a cordon. Second, it depends on who has access to the data. Third, it depends on how long the data is being stored. Overall it holds that the less information is collected, the less people have access to the information and the shorter the information exists, the easier it is to protect privacy. For each aspect various safeguards (such as freedom of choice on which level of detail data is shared and whether users can view and correct data) can be implemented to protect the privacy. It must be noted that not only the amount of personal data and the safeguards to protect these, but also other aspects, such as trust in the implementing agency, have an impact on the perception of privacy.

The technology options included in the assessment (see section 4.4) differ in the amount and type of vehicle data that is collected. ANPR collects information on the number plate of the vehicle. As this is directly linked to the personal data of a road user this is generally considered privacy sensitive information. It depends on the amount of road side locations whether only isolated points or routes can be determined (the latter is considered more privacy sensitive). The same holds for DSRC and RFID with the exception that it is technically feasible to design an anonymous system. For OBUs and smartphones holds that they collect detailed information about the vehicles movements on charged roads and, depending on the setting, also on uncharged roads. Note that it is always possible to anonymize vehicle data in the charging process (after determining the price) but that even from anonymized data, if in large quantities and detailed enough and without further privacy safeguards, personal data can be derived. Another aspect that affects the level of privacy protection is where positioning data is processed. This is illustrated in Figure 3. All positioning data can be processed in the OBU (a thick OBU; e.g. resulting in the communication of the total price), a combination of

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processing in the OBU and back office (e.g. resulting in the communication of the total amount of kilometres driven), or completely in the back office (e.g. resulting in the communication of the detailed positioning data). Generally the less positioning data is communicated to the back office the easier it is to protect privacy. As explained before, opinions on an adequate level of privacy protection differ and for each technology option a range of safeguards to protect privacy can be implemented.

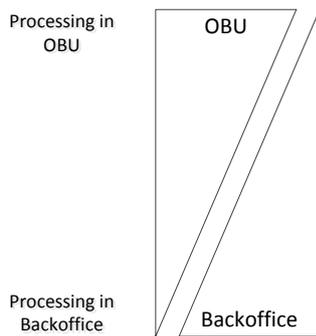


Figure 3 Processing in the OBU or in the back office.

4.4 Assessment

The different technologies are scored on the criteria as described above, in a qualitative way using expert judgement. The possible scores are ++, +, 0, -, --.

In Table 3, the results of the quick scan assessment can be found. Below the table further explanation per technology can be found.

Table 3: Quick scan assessment of road pricing technologies

	Project management	Costs	User acceptance	Link with ITS development*	Enforcement
ANPR	-	--	0	0	+
RFID	-	-	+	0	+
DSRC	--	-/--	0	0	+
OBU with GNSS + telco	--	-/--	--	+	+
Smartphone	+	+	-	++	--
In-car GNSS	0	0	-	++	+

* For this criterion, no negative scores are given, since links with ITS development either do not exist (0) or are there (+ or ++).

It is important to note that the scores cannot be added so that an overall ranking can be made. Not all criteria might be equally important, and there might be other criteria or reasons for a specific case.

Technologies for which road-side equipment is needed (ANPR, RFID, DSRC), become increasingly expensive as the size of the chargeable road network increases. Therefore these technologies are not feasible when the goal is to have a kilometre charging system that functions on all roads (including roads in cities and all secondary roads). On the other hand, when using technologies that do the

positioning in-car (DSRC, OBU, smartphone, in-car GNSS), it is required that all vehicles are equipped.

ANPR

The main strength of an ANPR system is that all vehicles are already equipped with a license plate. From the user point-of-view this is an advantage, as he does not have to worry about installing any equipment in his car that continuously tracks his whereabouts. It depends on the density of the cameras whether continuously tracking whereabouts is possible. However the disadvantage is that ANPR cameras are relatively expensive, they cannot be easily used for other applications than road pricing, that they do not have a high recognition rate among license plates from all different countries, and they can even do wrong identifications. Another disadvantage of ANPR is that it is not possible to anonymize the license plate.

RFID

The RFID technology in this assessment is defined as an identification chip in the license plate that can be read at full speed by an RFID reader above the road. The advantage compared to ANPR is that RFID readers are far less expensive than ANPR cameras. Of course there still need to be RFID readers installed on all chargeable roads. License plates with integrated RFID chips are still in the test phase. A possible advantage from the user perspective is that privacy can be better protected compared to ANPR. In addition, this technology also allows for the reduction of license plate fraud. Of course a road pricing system based on RFID license plates requires governmental laws to oblige each vehicle to have a chipped license plate. RFID technology for road pricing, comparable to the DSRC technology, is not common in Europe.

DSRC

DSRC technology, just like ANPR and RFID, requires road side equipment on all chargeable roads. Furthermore each car needs to be equipped with a DSRC device. As both roadside and in-car equipment are used this option requires considerable project management effort. The costs of this technology option depend on the type and amount of roads in scope and the number and type of vehicles subject to the charge. When a limited road network (few roads, not including local and regional roads) is charged this option is less costly than a technology option based on in-car only technology. Since the car has to be equipped, DSRC is probably more intrusive for the user than the previous two technology options. Also road side equipment is required, making expansions of an already implemented pricing system more costly than when using technology options that do not require road side equipment. The advantage of DSRC on the other hand, is that it only does localization on chargeable roads and that it could be anonymised for users who prefer it, by using an anonymous (prepaid) account. Although DSRC is intended to be interoperable by the EETS directive, exact implementations may differ between countries.

GNSS OBU

A system which uses a GNSS OBU with telecommunication means is far more flexible than the previous three systems, as no roadside equipment is needed for the positioning function. This means that modifying or extending the chargeable road network can be done with a software update (in either the back office or in the OBU), rather than moving or installing additional roadside equipment. The disadvantage of a GNSS based system is that the GNSS OBU is far more costly than a pure DSRC OBU, and more effort is needed to install the device in the

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vehicle. Similar to the DSRC option the costs depend on the type and amount of roads in scope and the number and type of vehicles subject to the charge. When an extensive road network (many roads, including local and regional roads) is charged this option is expected to be less costly than a technology option using in-car and roadside technology. The costs of a GNSS OBU are estimated to be between €50 and €200. The costs depend on whether the OBU has a display or not, whether it needs external antennas, whether it is built-in or not, whether it includes licensing or not, the amount of OBUs manufactured, etc. On the market a wide range of OBUs are available, some of which are 'thick', and some of which are 'thin'. This 'thick' and 'thin' refers to the amount of processing that is performed in the OBU or in the back office (proxy). A thin OBU does most of the processing in the back office, while a thick OBU does most of the processing itself. 'Thin' and 'thick' OBUs differ in their technical functionalities (e.g. CPU, memory, link to additional sensors, software on the OBU, software on the back office etc.). As different countries have different ways of computing the chargeable amount, the OBU must know how to adapt the processing when arriving in another country. Another disadvantage is that OBUs may need to be fixed installed in the vehicle, which can be a burden to the user. However self-installable OBUs are also used, although cars with metalized windscreens may not be suitable for this (the windscreen blocks the GNSS signals). The OBU tracks every movement, so privacy needs to be protected well (see also section 4.3).

Smartphone

The advantage of using smartphones for road pricing is that a large majority of road users already has smartphones and these devices have a lot of functionality (positioning, communication, acceleration sensors, apps to be installed). They could be well suited for road pricing systems. However a large disadvantage is enforcement. How can the enforcement bodies make sure that a user always brings his smartphone along for all trips and has the 'road pricing' app running and how can be proven that a defaulting user is deliberately not using the app. Furthermore the app can more easily be hacked than the GNSS OBU described before, as a GNSS OBU can be more easily secured against hostile intrusion in contrast to a smartphone where users can install their own apps next to the road pricing app. Having a non-secure and non-reliable technology will easily undermine the user support for a road pricing system and therefore these aspects need to be dealt with when a road pricing systems based on smartphones is considered. To the author's knowledge there is not yet an adequate solution for the enforcement of smartphones.

In-car GNSS

In-car GNSS is defined as a system in which the GNSS and telecommunication functionality is already integrated in the vehicle by the vehicle manufacturers (OEM companies), including an open interface for service providers to make use of these functionalities in order to implement road pricing services for the authorities. Currently several OEM companies equip new cars with connected car functionality. This implies that vehicles have access to the internet using cellular communication to transmit data from the vehicle to the OEM, a service provider or road authority or with other cars or with roadside equipment. This communication technology can also be used for providing data and information in the vehicle. If the communication includes a certain level of cooperation or negotiations between vehicles, between vehicles and the infrastructure and/or a back office (or traffic control centre), this is generally referred to as cooperative systems (abbreviated as C-ITS) (TrafficQuest, 2014). In addition to communication, many new vehicles are also equipped with positioning technology (via GPS). However currently they

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are not obliged to let other parties make use of them. If OEM companies were to be obliged to have GNSS and telecommunication functionality with an open interface in all cars they produce, all kind of ITS and road pricing services can be implemented. The costs of technology for localization and communication are then lower compared to the before mentioned GNSS OBU, however other cost components (e.g. display, software, communication costs itself – charged by the telecom provider) are unknown. An example of an ITS service is eCall, in which the vehicle automatically transmits its location to the emergency services after a crash. If it were to be used for road pricing, it is important that this in-car GNSS system is standardised in such a way that road pricing service providers can actually implement the variety of road pricing functionalities based on this in-car GNSS system. Most likely most of the processing would then be done in the back-office. For eCall, there are no regulations that prevent added services, neither is there an obligation to be open for other services. Data collected by eCall can only be used for eCall services. Only in case of an incident data (at least position) is communicated. It is not clear yet how open the underlying technologies of eCall are to be used by other services.

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Implementation of road pricing in Belgium

Belgium is implementing a kilometre-based tolling system for Heavy Goods Vehicles (HGV) with a maximum permissible weight of more than 3.5 tonnes. The technology option chosen is an OBU with GNSS. In 2011 an agreement was made on having a road pricing system for HGVs, implementation started in 2014 and the charge will come into effect on April 1st 2016. This timeline demonstrates that even though there is already experience in Europe with this technology (see table 2), it requires several years of preparation.

The implementation of the road pricing system is according to plan and has not (yet) faced any significant technology-related challenges. It must be noted that the roll-out of the On Board Units and the first part of operating the system are generally considered the most challenging. For example, it took quite some time and effort before the German toll systems was operating smoothly. The steps taken in the preparation process so far are drafting the architecture, a market consultation, the selection and layout of the specifications, the procurement and negotiation and awarding the contract to the service provider.

The Belgium government has chosen to use as much as possible functional requirements. The set of starting points, preconditions and requirements are defined at the strategic, tactical and operational level, together comprising the architecture. The requirements were realistic and supported the mutual expectations of the parties involved. Technology is advanced enough to allow for various types differentiations in the charge. Offering parties had to show that their system fitted the requirements. The technology choice was a starting point, the architecture prescribes the use of a GNSS-based system. The GNSS OBU is self-installable. The charging system allows for differentiated charging. The charge includes weight, emissions class, and road type.

One party had the integral responsibility from beginning to end (design, build, finance, maintain, operate – DBFMO) and this made for a limited number of interfaces between different parties and their responsibilities.

An important lesson learned in the project was to use functional requirements in de tender. This way, maximum use could be made of the knowledge of market parties and the state of the art technology.

Based on (Van Huis, 2015) and Viapass (2015)

5 Opportunities and threats

There are many developments and influences that can pose an opportunity or threat to the large scale implementation of road pricing. In this section several technology-related opportunities and threats are discussed.

One of the developments in de field of ITS is the entry of new parties to the mobility market. Examples of new parties in the field of mobility are insurance companies offering Pay As You Drive or Pay How You Drive services, fleet owners offering feedback to drivers on their driving style and service providers offering multimodal travel information services. Hence, in designing a road pricing scheme, the potential role of other parties than the government and the toll service provider could be considered to improve the overall business model. On the other hand, the design and implementation of road pricing is already complex and involving more parties can increase its complexity.

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Traditionally new services for road users were introduced by the automotive companies (OEMs). OEMs are still an important player and they want to install certain systems in the car. For example they are introducing connected cars with built-in positioning and communication technologies. It is a trend that more and more OEMs install in-car GNSS system for multipurpose use, such as safety systems (eCall), navigation and automation. Road pricing could piggyback on this development.

With the rapid deployment of smartphones and retrofit OBUs (self-installable), there are alternatives for the built-in OBUs. The major advantage of the use of smartphones is that its use is already widespread in contrast to retrofit OBUs which are distributed whenever a specific service requires a technology platform in-car. The increased usage of smartphones increases the potential of this technology option relative to its alternatives that are less widespread. However, a large issue with using smartphones is enforcement. To the authors' knowledge there is not yet an adequate solution for this. This makes using smartphones for road pricing at the moment not an option.

The introduction of ITS services fits with broader developments in society. In many infrastructural domains, consumers receive detailed feedback on their behaviour and the consequences of choices (this is sometimes labelled as "the quantified self"). These insights enable consumers to learn from their own behaviour and can motivate consumers to make different choices. For example, energy companies offer devices that give feedback about energy use. Road pricing could also give consumers more insight in their own behaviour.

On the other hand, acceptance of road pricing is generally lower when more detailed data is involved and the amount of data collected is large (see section 4.3 on privacy). With some of the technologies it is possible to create a road pricing system on a European wide scale. It is expected that from the perspective of user acceptance, this might face resistance. Also when the system would not be European, but a framework that national governments could use, resistance from users can be expected.

The developments in ITS have also changed the view of consumers towards services. For example the field of travel information apps has become much more mature. The quality of the service of travel information apps has increased over the past years, increasing consumers' expectations. The most commonly used travel information apps are provided by professional companies who are constantly updating the quality of the service and expanding the functionalities in the apps. For example, travel information apps often also provide information on the speed limits, traffic controls, traffic jams and incidents. In addition, most of these services offered to consumers are free of charge. This might have two implications for the introduction of road pricing. First, if the implementation of road pricing is based on a technology using an OBU, road users might expect more functionalities than road pricing (e.g. travel information services and navigation). Second, road users will not accept an obligation to pay for the cost of an OBU, as road pricing is in principle a legally obliged tax or retribution measure.

ITS also enables location specific services. For example traffic management is increasingly taking into account the local traffic conditions and context (e.g. dynamic peak hour lanes). In fact, the traditional traffic management focus on congestion is widening to include multiple objectives (e.g. optimizing both traffic

flow and air quality). Every city and region has its own objectives and priorities (e.g. congestion reduction, reduction of environmental pollution etc.). Following this trend towards more location specific design of policy instruments, it is considered a benefit if the road pricing technology can support different charging schemes for specific locations, i.e. every country can charge in a different way and change this if necessary.

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6 Discussion and recommendations

Many European countries have to deal with the negative effects of road transport such as congestion, air pollution and accidents. Road pricing is an effective measure to deal with these impacts and can also be used to raise revenues. Currently there are a number of existing road pricing mechanisms in place in Europa: area charges (e.g. London), road charging for trucks (e.g. the LKW Maut in Germany and Austria), and pricing on delimited road segments (e.g. bridges, tunnels). At the moment there are in Europe no nation-wide road pricing schemes for passenger cars (leaving aside vignettes such as in Austria). However, a number of countries are discussing this policy option. There are several different technology options for such a nation-wide road pricing system. It depends on the objectives and design of the road pricing system which technology is most suitable. The most important design choice for a nation-wide charging system is the choice for using roadside-only technology, in-car technology or a combination.

The discussion in this section focusses on a specific road pricing measure: nation-wide road pricing for passenger cars on a detailed network (not just motorways, but also secondary roads and roads in cities) for all road users. When considering such a nation-wide road pricing system, using roadside-only technologies (ANPR, RFID, DSRC) is likely to be too expensive due to the relatively high investment costs. We therefore consider GNSS to be more suitable for such a nation-wide passenger car road pricing system. GNSS technology can be retrofitted in the vehicle using an OBU or could be fitted in the car as standard by the OEMs. It is expected that the technology costs for GNSS are higher in the first case compared to the latter where it will be part of the manufacturing process.

In fact, new cars already have to be fitted with "*in-vehicle receivers that are compatible with satellite navigation*" from 2018 as part of the recently agreed eCall legislation. However, whilst GNSS will become standard, it is not clear whether the current legislation would enable the use of eCall technology for road pricing purposes. At the same time the market development of ITS applications, vehicle connectivity and vehicle automation would require the fitment of many of the key components of a GNSS OBU (receiver, telecommunication, processor, DSRC communication).

Recent studies indicate that in-line fitting of these technologies in "one box" would cost around €100 per vehicle (European Parliament, 2014). Note that the absolute technology cost are high when a large vehicle fleet has to be equipped (e.g. for Germany 48 million vehicles have to be equipped resulting in costs of several billion euros). Even if a cost benefit analysis demonstrated a societal surplus, high technology costs can be an implementation factor that negatively affects public and political support.

GNSS OBUs are generally able to support DSRC (e.g. for enforcement), but mostly not the other way round (see for example the Germany-Austria example). Hence, the wider scale use, or even mandatory fitment of GNSS OBUs would not make legacy systems based on DSRC obsolete. Since many countries already

have road pricing for trucks, road pricing for passenger cars could use this basic infrastructure, especially if it is GNSS-based.

In theory, the business case for road pricing using GNSS could further improve if ITS applications can 'piggyback' on the equipment. From a technology point of view open interface contributes to this and can decrease costs and help creating multi-service platforms. However, for a tax instrument privacy and security are very important and combining other services with road pricing might not be considered feasible from this point of view. Hence, whether the business case improved in practice (by creating synergy between road pricing and ITS applications), needs further investigation.

What could the European Union do to facilitate nation-wide road pricing for all road users on a detailed road network?

Since different countries have different goals we assume that each government will want to introduce its own scheme. In that case, the chosen road pricing system has to be dynamic, robust and flexible.

The Commission is currently assessing whether the revision of the European Electronic Tolling Service (EETS) legislation might provide the opportunity to better integrate different types of ITS equipment (e.g. eCall, tracking & tracing devices, OBUs for road pricing) currently installed in trucks. All these devices use (or will in the future use) satellite positioning, mobile communications, dedicated short-range communications (DSRC), alone or in combinations. Integrating them in one single device could bring considerable economies of scale, but also allow cross-feeding of data to increase the functionality of each individual application, and create the potential for new value added services, in particular for hauliers.

We recommend that the EU extends this assessment to passenger cars, and:

- Considers mandating standardised GNSS and telecommunication technology for all new cars;
- Assesses the creation and possible mandatory fitment of a 'one box' platform that can be used for eCall, road pricing and other ITS applications, while also considering privacy and security.

The Commission should ensure that this technology:

- Is open to third parties to enable and accelerate ITS and vehicle automation trends, to the extent that it guarantees the essential safety and user acceptance requirements;
- Ensures an adequate level of privacy protection, i.e. that tracking and tracing of vehicles would need to be subject either to the approval of the vehicle owner or part of a democratic decision at the appropriate governmental level in the case of road pricing.

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7 References

European Commission (2014). Clean transport, Urban transport. Urban mobility. Mobility and Transport 30/09/2014 ed.

European Commission (2015). Technical rules on electronic tolling, http://ec.europa.eu/transport/modes/road/road_charging/technical_rules_en.htm
Last accessed: August 25, 2015

European Parliament (2014). Technology options for the European electronic toll service – study. European Parliament's Committee on Transport and Tourism, 2014.

Jones, P., Hervik, A. (1992). Restraining car traffic in European cities: An emerging role for road pricing. *Transportation Research Part A* 26, 133-145.

TrafficQuest (2014). Coöperatieve systemen & Automatisch rijden. State-of-the-Art achtergronddocument http://www.trafficquest.nl/images/stories/documents/State_of_the_Art/3.3_coperatieve_systemen_automatisch_rijden_sota_achtergrond_rapport_v2.0.pdf
Last accessed: August 25, 2015

Van Huis, J. (2015). Personal communication on the Belgium kilometre-based tolling system. July 24, 2015

Viapass (2015). <http://www.viapass.be> Last accessed: August 25, 2015

Vonk Noordegraaf, D.M., et. Al (2009). Technology options for distance-based road user charging schemes. D.M. Vonk Noordegraaf, B.M.R. Heijligers, O.A.W.T. van de Riet, G.P. van Wee, TRB, 2009.

Vonk Noordegraaf, D.M. (2015). The implementation of road pricing measures. T2015/forthcoming, TRAIL Thesis series, the Netherlands.