Innovative Enforcement Systems for Road Tolls
Preface
This report is part of the ARENA project, a Swedish knowledge platform on road user charging. The report highlights how toll chargers and supervising authorities can enforce compliance with autonomous road toll system in an efficient and privacy protecting manner. Other aspects than road toll compliance and enforcement functions are exceptional in this report and for a comprehensive coverage of road charging, generic publications are recommended.

The report is written from a Swedish perspective, but include an international outlook and aim at generic knowledge. Specific prerequisites for distance-based tolling in Sweden are the size of the country, the size of the population and the size of the vehicle fleet, leaving us with an extensive road network, sparse population and relatively few vehicles. Motorways and expressways counts for a relatively small share of the total road network, while secondary roads often are of good standard, in practice offering almost the same average speed as motorways, especially for trucks. This calls for extensive coverage of the road network if tolling is to be efficient, otherwise the leakage of traffic to non-taxed roads would be significant.
# Table of contents

1 Background .......................................................................................................................... 5  
1.1 The role of the control system in tolling .......................................................................... 5  
1.2 Multiple principles on enforcement systems .................................................................... 6  
1.3 Key concepts for enforcement system ............................................................................ 7  
1.4 Focus on autonomous systems ....................................................................................... 8  
1.5 Legal frameworks in Europe and in Sweden .................................................................... 8  

2 International outlooks ........................................................................................................... 10  
2.1 Switzerland ...................................................................................................................... 10  
2.2 Germany .......................................................................................................................... 13  
2.3 Slovakia ............................................................................................................................ 17  
2.4 France ............................................................................................................................... 19  
2.5 Lessons learned from the four countries studied ............................................................. 21  

3 Other techniques and approaches ......................................................................................... 26  
3.1 EUCARIS and EPC ........................................................................................................... 26  
3.2 Telecom Data and other location-based services ............................................................. 26  
3.3 Trusted Recorder ............................................................................................................. 27  
3.4 E-call ................................................................................................................................. 29  

4 Swedish conditions and opportunities ................................................................................ 30  
4.1 Extensive road network but few vehicles ........................................................................ 30  
4.2 Passenger cars ................................................................................................................. 31  
4.3 Institutional design ......................................................................................................... 32  
4.4 Tariff design .................................................................................................................... 33  
4.5 National borders ............................................................................................................. 35  
4.6 Borders to other tariff zones within the country .............................................................. 36  
4.7 Nordic cooperation ......................................................................................................... 37  
4.8 Notification obligation .................................................................................................... 38  
4.9 Occasional visitors ......................................................................................................... 38  
4.10 Privacy ......................................................................................................................... 39  

5 Conclusions and recommendations ...................................................................................... 40
1 Background

1.1 The role of the control system in tolling

A road toll system consists of several connected subsystems that must function both separately and in collaboration with each other. A distinction between four main subsystems can be made: payment-, measuring-, enforcement- and sanction systems. This is a functional classification, and the four subsystems do not correspond to physically separate entities. For example, an on-board equipment (OBE) contains equipment that handles functions related to several of the subsystems.

The payment system provides the road user one or more methods to pay the tax or charge issued. It might, for example, be linked to credit cards, direct debit, cash advance account or payment over the counter in stores. In turn, the measuring system consists of equipment and processes that together measure, calculates and reports road usage during a period of time. Payment system and measuring system can be designed largely independent of each other.

The enforcement system, which is the focus of this report, consists of the equipment and processes that together create the likelihood to disclose system failure, or if a user tries to circumvent any part of the measuring system for their own benefit. This is in turn associated with the sanction measures available to discourage any such circumvention. For a rational individual the incentive to evade paying is estimated by aggregating the probability of detection with the net profit of evading. It is therefore by the combination of the enforcement- and the sanction systems the incentives for end users to evade or not is created, while the linkage between the measuring system and the control system is largely a matter of information technology.

\[\text{Figure 1. A schematic illustration of the four sub-systems that are linked in a tolling system. The arrows indicate how interwoven sub-systems are with each other. This report focuses on the enforcement system, but touches, where necessary, the payment-, measuring- and sanctions systems.}\]
There is at least one significant dependence between the payment system and the enforcement- and the sanction systems, namely the requirement of notification. A user charge system based on requirement for the operator to notify a claim on the user differs from a system based on requirement for the road user to report their usage. Requirement of notification creates incentive for the user to complicate the notification process; since a notification failure means fee waiver. This is particularly important for vehicles registered in countries where Sweden has weak support for exchange of traffic registry information.

The four sub-systems thus all influence each other, and especially important is the linkage between the enforcement system and the tariff design in the measuring system, which can be said to mirror each other. To fully understand the implications of changing one detail in one of the subsystems, a careful analysis of the consequences for all the others is needed, and to do so may require pooling.

In the tolling industry the most generally observed linkage is the one between the measuring system and the enforcement system, where the former requires the latter, while the latter allows the former. If, for example, a tariff is applied that calculates the toll as a fixed, and for all vehicles equal, charge per kilometer, valid for all roads at all time, an enforcement system that ensures that the travelled distance for each vehicle is measured and reported is sufficient. However, if the charge is different for different types of roads, at different times of the day and depending on vehicle weight, a much more advanced enforcement system is required to ensure that the reported road usage matches the actual. The interrelation is further complicated since both the probability of being detected and the penalties that may harm an evader, might differ depending on which tariff component is being compromised.

1.2 Multiple principles on enforcement systems

In principle, an enforcement system has to be able to handle at least the same level of detailed information as the system it is set to monitor. The more detailed and complex tariff structure, the more detailed and complex the compliance- and enforcement mechanisms have to be. This principle is known in information theory of Ashby's Law of Requisite Variety, and is central when approaching the area in an engineer's manner.

However, public administration and especially the handling of taxes, rests on further principles than just information theory. Although, a more complex tariff structure generally is more difficult to monitor than a simple, the authorities does not demand a hundred per cent control of all aspects of the system. Each authority must balance costs against benefits and do in many cases accept a certain degree of discrepancy when assessing what is disproportionately costly to measure and to correct.

In addition to such a principle, which can be described as business-like balance between the costs of enforcement functions and the revenue it generates, the authorities involved have to consider other important principles such as equality, transparency and the right to amends. Therefore, those who want to design a practically working and introducible enforcement system for road tolls, in addition to purely information technology and business-like attributes also have to consider the constitutional, legal, financial and operational aspects.
1.3 Key concepts for enforcement system

An enforcement system operates by comparing the data from the measuring system with independent observations from three sources: from the roadside, from inside the vehicle or from the operator’s central data system.

From the roadside, an observer - which can be a human or an automated control station register a vehicle’s identity, position and characteristics relevant for what tariff to be used, such as the number of axles.

From inside the vehicle, an independent observer consist of one or more sensors in addition to those that are used by the measuring system, where differences between the two types of sensors is an indication that something is not right. It may include an accelerometer that indicates vehicle movement, whilst a GPS receiver indicates stagnant.

In the central system, the plausibility of observations can be assessed and observations from other sources compared. I.e checks that the route driven is contiguous and without loop holes, comparisons between the reported road usage and the cost of fuel entered in financial statements, or the odometer measuring at the yearly car inspection, can be carried out.

Figure 2. The three sources for independent observations; the roadside observer, the observer within the vehicle (OBE) and the observer in the toll operator central data system.

The toll systems in operation today often use several different kinds of enforcement functions in combination. In addition to the applications that are running in current systems, the standardisation bodies ISO and CEN along with industry, is developing a new technology for independent observation from inside the vehicle, which with applied cryptography makes it possible to reduce the possibility of creating false route data and to compare the reported data with independent observations at the road side, without reveal further details about route or location. The latter does not increase the
enforcement quality, but may help to maintain a high degree of supervision without increasing the degree of privacy intrusion.

1.4 **Focus on autonomous systems**

Since several years Sweden use congestion tax and will soon use infrastructure charges on bridges. Since these forms of tolling are known and relatively simple in its design, it is not that difficult to design a suitable enforcement system. This report tackles the issue at a higher level than what is required today, and analyses the needs based on the assumption of a tariff scheme differentiated by distance, time of day, type of road and vehicle type. Therefore, what is proposed here is technically more advanced and more costly to implement than what is necessary for the toll systems available today or planned for in Sweden.

This higher ambition also makes international comparison relevant; primarily those that apply some form of autonomous system, i.e. solutions based on on-board equipment in each vehicle that measure and report road usage without the support from dedicated equipment by the roadside, often with the aid of satellite positioning technology. The techniques and methods to enforce the basic roadside-based systems are not covered here, since they are regarded not to add essential knowledge from a Swedish perspective.

1.5 **Legal frameworks in Europe and in Sweden**

Extensive work has been done on a European level to describe and sometimes harmonize systems, rules and processes of tolling systems, at first through the EFC directive (2004 /52) and later by Decision 2009/750, which marked the entry into force and started the clock when the decided actions would be introduced. In October 2012, the directive would have been introduced for trucks, and at the same time in 2014 for passenger cars. It is thus clear that the Directive has not met its first deadline and that the second is unlikely to be met. Parts of the sometimes sharp criticism aimed at the Directive and the Decision has proved correct, where the main objections can be summarized in two points;

1) There is no room for a reasonable business model for the prospective service providers. The Decision contains a long list of mandatory requirements that drive costs, but hardly any reasonable opportunity for revenue.

2) The EU Commission has given priority to get the decision through and therefore avoided the difficult trade-offs, which would have required substantial compromises. This might be most visible in the fact that coordination of requirements on enforcement systems is excluded in both the Directive and the Decision.

Based on the deep co-dependence between the enforcement system and the measuring system the second paragraph mentioned above is particularly severe. Even if all toll systems in Europe would apply exactly the same measuring system, interoperability will not be achieved if the view on compliance and enforcement is fundamentally different.

The legal foundation for what tariffs a EU country can apply, and thus how the measuring system can be designed, consists of the so-called Eurovignette Directive (which actually consists of three directives: 1999/62/EC, later modified by 2006/38/EC and 2011/76/EU). The Eurovignette Directive aims
to reduce the differences in tariff structures across countries and to introduce a minimum level of differentiation between different types of road use and vehicle standards.

Although most of the directive text is generically written, rather as recommendations and principles, there are some distinct requirements:

- Road toll is a fee charged in relation to the distance travelled and the type of vehicle, while vignettes charges are based on what time the infrastructure is used and the emission class of the vehicle.
- Road toll and vignette charge should not be applied simultaneously for the same road, except for bridges, tunnels, mountain passes and congestion.
- All road charges, tolls and vignettes, must be applied in a non-discriminatory manner, meaning they must not give advantage to vehicles from their own country or other selected user groups. It is therefore not allowed to give substantial discounts.
- No road charging system, whether it is tolls or vignettes, may introduce mandatory inspections by the member state EU-borders.
- A road charge, on average, must not substantially exceed the costs that can be directly linked to build, manage and develop the infrastructure for which the fee is charged.
- In addition to the direct costs of infrastructure a fee may be added to cover the external costs of air- and noise pollution. The Directive requires such pricing to be guided by the principle of efficient pricing, that is, to be close to the societal marginal cost. There are also fixed limitations for such an externality charge; 16 cents/km for air pollution and 1,1/km for noise are the maximum values.

The Swedish Government in 2011 appointed a governmental investigation, the 2011 Road Toll Investigation, inter alia, to interpret and draw conclusions from these European regulations, and to clarify the legal prerequisites of tolling in Sweden. The investigation presented its reports in 2012\(^1\) and 2013\(^2\) and provides the most updated and comprehensive picture available of the legal situation for road charging in Sweden. Its contribution is welcome since earlier investigations, preparatory work and reports, in many cases has been incomplete and partly contradictory. But not even after this massive effort, there is a clear picture of how an enforcement system could be designed in a way that is both legally acceptable and cost-efficient to implement and operate. This report will later return to where the suggestions from the Road Toll Investigation would need to be adjusted to create adequate conditions for a well functioning enforcement system, as part of a Swedish road toll system.

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\(^{1}\) Delbetänkande av 2011 års vägtullsutredning, SOU 2012:60, Stockholm, 2012
\(^{2}\) Slutbetänkande av 2011 års vägtullsutredning, SOU 2013:3, Stockholm, 2013
2 International outlooks

This section describes in detail how three existing and one planned autonomous tolling system works with focus on enforcement. For each system the overall characteristics, the institutional arrangements, possible legal considerations that can be instructive and specifically how the enforcement function is solved, how the desired degree of supervision is achieve and, where appropriate, how privacy issues is handled, is being described.

2.1 Switzerland

The Swiss system went live in 2001 and was thus the first of its kind in Europe and the world. It is sometimes not regarded as an autonomous toll system because of its simple tariff that does not require any advanced information about vehicle routing. A fixed fee per kilometre, based on total weight, is charged for all heavy vehicles (above 3.5 tonnes) on all roads in the country at any time of day. The only differentiations made are based on the presence of trailer and the Euro emission class.

2.1.1 Institutional Arrangements

The Swiss system is regulated in a law that passed referendum in both cantons and at the national level. This need for public support has probably contributed to the law and the system’s relatively simple design. The system is different from most other European solutions since it is entirely operated by the government, with the Customs Authority, a part of the Ministry of Treasury, as the single road toll authority.

2.1.2 Measuring system

For vehicles registered in Switzerland the measuring system consists of an on-board unit connected to the vehicle’s tachograph for odometer data. The distance travelled is accumulated in the on-board unit and manually reported by the haulier, who exports a monthly report and uploads it to the toll charging authority. Even if the equipment is mandatory the reporting procedure is based on a principle of self-declaration. If the heavy vehicle is driven abroad, that part of the trip should not be charged. Therefore, at each border crossing there is a gantry with antennas for microwave communication (DSRC), which sends a signal to the on-board unit that it is leaving the country and have to stop measure. Similarly, it activates the on-board unit when the vehicle returns to Switzerland.

Temporary visitors in the country are not required to have an on-board unit and for them the odometer is used as primary measuring system. When a foreign vehicle is entering Switzerland, the driver must stop and declare mileage in a self-service kiosk at the customs office. The procedure is the same when leaving the country, and the difference between the two readings is the basis for charging.

If all on-board units worked without any problems and if no haulier had any interest in evading toll, the described equipment would be sufficient, but for the Swiss toll charging authority to trust the

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3 Dedicated Short-Range Communication, microwave communication designed for Intelligent Transport Systems (ITS)
declarations there is an enforcement system in operation, carefully suited to the measuring system, with components as observer in the vehicle, by the roadside and in the central toll data system.

### 2.1.3 Observer in vehicle

The primary information of distance driven is collected from the tachograph by the measuring system. To verify that the input source is not manipulated or completely turned off, two other sensors are used. The on-board unit has an accelerometer that senses engine vibration and vehicle movements, and a GPS-receiver that senses vehicle movement. None of these sensors collect data for measuring or reporting purposes. Only if the subsystems provide dissimilar indications, an irregularity indication is written to the charge report that the on-board unit generates. In a similar way, the GPS receiver together with a map of the Swiss borders is used to verify that the DSRC signals received at entry and exit from the country are correct. While it is relatively easy to shield off or disrupt a GPS receiver it is very difficult to generate fake GPS information in a way that both give a lower calculated charge and is synchronized with the other sensors observations. Overall, these three sensors make it very difficult to create false data streams without creating anomalies in-between them.

If a haulier intentionally or accidentally completely disconnects a sensor or the power supply, the on-board unit (which has an internal rechargeable battery) will alert the driver that it needs examination, while it logs the type of error that occurred. Since users are bound to contact customer support when such an alarm occurs, this kind of behaviour, aimed at gaining advantage, will not last very long.

### 2.1.4 Roadside observer

The Swiss system only uses one dynamic attribute in its tariff, namely if a trailer is connected or not. Because it is more expensive to drive with a trailer than without, and the driver set this attribute it leave a potential opening for evasion. The solution used is not at all based on the authority's activities, but the social control in the industry. A row of LEDs is fitted in the on-board unit, facing the windshield and indicating the on-board unit set up at the occasion. That way, drivers from competing carriers can see if a truck is driving with improper setting. Also the police and customs authorities, which are responsible for supervision, can see this, but in practice it is proved that industry colleagues mainly carry out the control.

In ten locations, Customs has mounted automatic control stations with cameras and other equipment. They are primarily designed to handle the trucks and buses that are occasional visitors and therefore lack the otherwise mandatory equipment on board. By taking pictures of vehicles at these locations Customs can make a reasonable assessment of the declared distance when leaving the country. However, this system is not accurate enough to provide an exact observation with the same precision as the measuring system.

More thorough manual checks are done at customs clearance stations. The driver knows that the customs officers sometimes control the self-declared reading. If the driver then reported a high mileage on entry or too low on exit, legal action are taken on site, which may include fines, substantial delay of the trip and more thorough checks at later trips. Through the combination of reasonably high risk of detection and strong negative consequences, few of these occasional visitors try to circumvent the system.
The customs authorities also have access to a car with measuring equipment that can be used to test on-board units while driving, but it is not used much and does not significantly contribute to the control system's overall efficiency.

Switzerland's specific situation in Europe - within EFTA and Schengen, but outside the EU - is worth noticing. This means that they can use border inspections, something EU countries only can apply at third country border. Therefore, the Swiss solution is not entirely applicable to Sweden or other EU-countries.

2.1.5 Observer in central system

The third and final link in the enforcement chain is assessments in the central data system. The plausibility of what is reported is tested through follow-up on alarm reports from any of the sensors in the on-board unit, and trough comparing data from other public systems. By collecting bookkeeping data on fuel costs and total sales from hauliers, a rough estimate can decide what hauliers to select for audit. Since the charge legally is a tax, a search warrant is not needed to follow up on suspected evasion. Instead, a regular tax audit is used, which in practice means a reverse burden of proof compared to criminal cases - the haulier must be able to present their business in a manner in which costs, revenues and reported road toll are convincingly linked.

As far as the authorities know, irregularities mostly consist of unsettled payments of debited road charge. This starts a recovery process that after some nine months ends up with immobilisation and dismounting of number plates. In most cases, the company concerned is already bankrupt by then.

2.1.6 Privacy

Privacy is not a big issue in the Swiss system. Only freight traffic is affected, and even more important the system does not collect any position data at all. Only the total distance per vehicle per month for commercial traffic is collected, which hardly can be regarded as sensitive personal data.

2.1.7 Costs

A department with forty people operate the system, manage customer service, follow up on anomalies and run other operations. A moderate estimate indicates that ten of them work with enforcement. Add to this the extra customs officers at border crossings needed to control the road toll. These costs are difficult to estimate because the officers take care of all customs obligations, and the additional cost of the road toll is not reported separately.

It is the on-board units that are the biggest cost driver in the system. Switzerland is a small market and applies a system with a unique design, whose costs they cannot share with any other country. Approximately 50,000 trucks in the country and another 20,000 foreign trucks are using on-board units. The volume is large enough to require establishment of a comprehensive and quality-controlled industrial process, while the numbers are too small to achieve economy of scale. The last time on board equipment was replaced, the cost per unit was approximately € 350, but the supplier believes that it is reasonable to reduce this to less than a third if the manufactured volumes were larger.

The total cost of the system is in the order of 4-8 % of revenue, but it’s not only because of low costs but also due to the relatively high tariffs.
2.2 Germany

Germany introduced its existing road tolls, LKW Maut, in 2005, making it the first autonomous tolling system. It uses satellite positioning as its prime sensor to measure road usage, in this case trucks on the Autobahn. Today, the system's coverage has expanded to 14,000 kilometres of motorway and just over 1100 kilometres federal trunk roads. Euro emission class and number of axles affect the tariff, but type of road, region or time does not.

2.2.1 Institutional Arrangements

Germany was a part of the Eurovignette collaboration, but stopped charging such a fee in 2003 in preparation for the introduction of the new system. Technical and organizational problems led to a year and a half of delays, which meant a huge loss of tax revenue for the state. Since the total revenue from the kilometer tax is over four billion EUR - several times more than what the old vignette collected - the state has more than compensated for the loss, if compared to what would have happened if they stayed with the Eurovignette.

Charge is only collected from vehicles with a maximum weight exceeding 12 tonnes. Initially hauliers had to choose considerably lighter vehicles to avoid the charge, which would require more trips and thus was not profitable, but soon after the tariffs was published, trucks with a maximum weight of 11.99 tons was introduced in Germany, making them charge-free, but still carry the same volume but not the weight as a full size truck.

The image below is from the truck manufacturer MAN's advertisement for one of their models. Note the text marked with a red box.

![Image from www.mantruckandbus.com](https://www.mantruckandbus.com)

*Figure 3. Screenshot from www.mantruckandbus.com, where the attribute "toll free" of a 11.99-tonne truck is highlighted*
The German government chose, perhaps for enterprise policy reasons, to procure an innovative and thus previously untested solution from a consortium of mainly German companies – the Toll Collect consortium was formed by Daimler and Deutsche Telekom together with the French company Co-firoute. The idea that the government through a huge investment will stimulate national enterprises to develop a future export success has been present in several countries when considering introduction of innovative autonomous road toll systems, but the success of the strategy has so far not materialized.

The German solution is in practice a public-private partnership, where the strictly regulated venture Toll Collect, runs the measuring- and payment systems on their own, while they work closely with the Federal Agency for Freight Transport (BAG) in matters relating to enforcement. The authorities manage the enforcement system almost entirely by themselves. In parallel Satellic, a company owned by Deutsche Telekom, focus on export ventures and other commercialization of the technology solution.

The on-board units used are supplied from two different companies working with the same specification, meaning that a certain degree of competition within the system exists, but Toll Collect is the only provider to end users (Toll Service Provider) and the technical specification is not openly available.

2.2.2 Measuring system

The German measuring system consists of a vehicle-mounted GPS receiver, whose signals are interpreted in the on-board unit and compared with a pre-set list of cross sections of the road network, which can be described as virtual gantries. Once the on-board unit detects that it is passing through such a virtual gantry, a tolling event is registered. At the end of the journey all toll events are compiled, priced and reported via a data link in the cell-phone network. An early legal requirement that the driver at all times should be able to see the accumulated debt on a screen in the cab caused part of the measuring system to be built into the on-board unit. The central system of the toll operator also receive data on what road segments the vehicle has passed, but this is part of the enforcement system and is not used for charge calculation.

Occasional users have the option to pre-declare their route on the web or in a self-service kiosk before the journey, instead of mounting an on-board unit. Although less than 10 % of all revenues collected comes this way, the method is used by half of all vehicles, and especially trucks that only run occasionally in Germany and hauliers who have to weak liquidity to put up the money for an on-board unit.

2.2.3 Observer in vehicle

The German on-board unit, just as the Swiss, has several built-in security features that will enable detection of any attempt to manipulate it. However, in the German case the observer in the vehicle plays a much smaller role of the overall control system than in Switzerland, where it is vital.

2.2.4 Roadside observer

The most important enforcement function is based on roadside observations. At an average of every 50 kilometers of toll road a control gantry is mounted above the road, with the equipment to communicate with the on-board units and to measure, classify and take pictures of vehicles passing. Out of 300 such gantries about half of them have a rest area downstream, where BAG control staff can
halt trucks that have been identified as suspected for road toll irregularities by the gantry. The gantry alert the enforcement staff if;

- No signal can be received from any device on board the vehicle and the system can not connect a manually declared trip to the automatically recognised number plate of the vehicle
- The vehicle's on-board unit indicates fewer axles than the vehicle's exterior profile and dimensions indicate
- The vehicle is identified as suspect from earlier occasions or has an unpaid debt from an earlier violation
- The on-board unit indicates that it is not functioning as it should, or may have been manipulated

Although BAG have 278 enforcement vehicle equipped, and staff enough to keep them running around the clock, only a minority of control gantries are staffed at any given time. When a gantry is unmanned, it may still be active and then send suspicious abnormalities to the operator's central systems for manual tracking and registration.

The control vehicles that are not waiting downstream of a control gantry drive around the road network and reads the on-board units from trucks on the fly. It is also part of their mission to check the drivers’ hours of service, thus the tolling system does not have to carry the entire cost of BAG enforcement.

In addition to fixed and mobile controls, BAG also have equipment to set up 30 temporary control stations, giving the advantage that more vehicles can be checked than by the mobile units, while it is more difficult for drivers to know in advance where controls are sited and adapt to this.

The BAG officers working on the roads have earned a very good ability to glance at a truck and determine its maximum laden weight and its Euro class. But since there are vehicles that are nominally registered with 11.99 tonnes maximum weight and their appearance is almost identical to the corresponding twelve-tonnes vehicle, twenty stations capable of weight-in-motion have been installed.

Altogether BAG is determined to reach a level of supervision where a truck, on average, will be checked every tenth trip on the tolled road network. The technology that is used to read the control data from the on-board device is based on infrared light, unlike what is done in other countries. At the time when the German system was introduced, there was no standard available, while today a complete European standard based on DSRC technology is set.

For foreign hauliers enforcement almost exclusively rely on roadside observations and physical inspections. Germany has agreements with Austria and Switzerland for mutual exchange of vehicle registration data, but for most other countries, it is only when the truck is on site that BAG can execute sanction.

Anyone stopped for driving without having paid becomes liable to pay the outstanding road toll, not only to the current distance, but also for all previously observed and recorded violations in the system. The amount must be paid on the spot, otherwise the BAG seize the number plate and immobilise the vehicle. In addition to the unpaid road toll a penalty is added, but of legal reasons BAG may
not claim the driver on the spot. Instead they require a 1000 EUR deposit from drivers of vehicles registered in countries where it is hard to claim the debt afterwards.

The penalties for evasion can be severe. At the first infringement the driver is fined with 100 EUR and the haulier with 200 EUR. The amounts are doubled at the second infraction and then rise until the haulier is fined with a maximum of 50 000 EUR at the fifth occasion.

**2.2.5 Observer in central system**

If the unmanned gantries report discrepancies to the central system on several occasions, involving the same vehicle or the same trucking company, BAG may choose to start an investigation. If it is a German company, the authority has far-reaching opportunities to make a toll audit, and review customer invoices, purchase of fuel and other documents that can be used to estimate their traffic on the tolled network.

The personnel working with central system enforcement means that the hauliers are very creative when it comes to finding new ways to avoid paying. They must constantly learn new methods to identify suspected fraud. Their conclusion is that it is not possible to foresee all types of evasion or to build a fully secure system from beginning, improvements to the system has to be added as you go.

**2.2.6 Costs**

The total cost to run the German system is estimated at about 700 million EUR, of which 550 million are derived from Toll Collect and the rest from BAG and other agencies. There is no official data on the enforcement costs, but with some 600 people working on supervision, in Toll Collect and BAG combined, it might be a two-digit number of millions of EUR.

Altogether the compliance and enforcement activities achieve their goals and as a share of total traffic, very few try to avoid paying. The operator’s estimate is that some sort of attempt to cheat the toll is done during about 0.5% of the remunerated trips, and that includes incorrect setting of number of registered axles and similar manner to avoid a part of the charge. The number of successful evaders is considered as negligible, and there is reason to believe this, given how densely the roadside controls are and the high penalties. If, however, trucks down to 3,5 tonnes would be included the situation might be different, as it would mean many more vehicles, more small trucking- and other companies and many more trips that only occurs along one or a few stretches of the toll road network.

**2.2.7 Privacy**

Germany has the strictest laws in Europe, maybe in the world, to protect privacy. Although the German toll system is limited to a part of the road network and only apply to the heavy commercial traffic, the privacy aspects was important for the system design and the procurement. In order to protect the driver from being unnecessarily monitored some information is aggregated in the on-board unit, and only the first and last sections of road travelled is stored with exact time stamp. Thus the authority cannot use the system to see exactly how fast drivers run at different times or were they took a break.

In addition, the information is protected by both hardware controls and encryption to prevent unauthorized intrusion to access it, and as soon as the information is no longer needed for tolling purposes it is erased from the system.
While privacy of the tolling system is strictly monitored, the haulage companies own usage of satellite-based systems for management of vehicle fleets (Fleet Management System) has become so common there are few truck drivers who are not already monitored in detail by their employer.

2.3 Slovakia

Since 2010 Slovakia use a system of distance-based tolls for commercial vehicles exceeding 3.5 tonnes. The toll is charged for more than 600 km of motorways and 1 800 km of expressway. Today, 215 000 vehicles are equipped with on-board units, of which 65 000 are registered in Slovakia.

2.3.1 Institutional Arrangements

Slovakia has chosen a solution that is close to the German, where a private company has been contracted to design, build and run practically the whole road toll operation. There are various authorities responsible for motorways, expressways and local roads and to outsource this much of government activities is one way to simplify administration and make the users face a single supplier in all road toll matters.

Due to legal reasons, the enforcement process could not be outsourced. The system operator, SkyToll, manages the enforcement system and provides equipment, control gantries and vehicles. Each enforcement vehicle is staffed with one person from SkyToll and one from the police, both of them with expertise and mandate necessary to perform compliance control.

2.3.2 Measuring system

The system uses an autonomous on-board unit whose primary sensor is a GPS receiver. The hauliers must purchase and install a simple on-board unit. This device compares the position of the vehicle with a set of pre-programmed virtual gantries and report to the central system, where the pricing occurs. Transit traffic has had the possibility to prepay for their route without having to install any on-board unit. This opportunity was discontinued as of October 2013.
Users can choose whether to pay in advance or afterwards and reporting intervals are adapted to payment model. For those who pay in advance the road usage is reported every hour and for those who pay afterwards the road usage is reported at the end of each trip. The division between the two methods is about 50/50.

Euro class and number of axles differentiate the tariff, which in practice is close to differentiation by vehicles with/without trailer attached. No differentiation is made based on time, region, road category or congestion.

### 2.3.3 Observer in central system

As in the German tolling system, some controls are built as observations in central system, even though the emphasis is on the roadside control. A small team of the operator is involved in the enforcement process, but mainly to follow-up on observations from the roadside and only to a lesser degree to actively look for suspicious behaviour in the data received. The most important control here is to ensure that the route is reasonable and continuous.

Another important task for the observer in the central system is to assess when and where on the road network they suspect behaviour is located and to guide the portable and mobile enforcement units there.

The single best enforcement activity is a deterrent. When TV news shows a truck driver who gets stopped and fined an instant impact is measured.

### 2.3.4 Roadside observer

Just as in the German system the toll road network is equipped with control gantries where the vehicles on-board units are checked, the last recorded transactions are read and matched with expected values. In total there are 46 control stations along the road network, of which six are fixed and 40 mobile. Pictures of suspected trucks are taken; license plates are automatically read and the vehicles measured for classification by laser. After finalised investigation, cases are sent to the central system for finishing and possible claims.

For vehicles not registered in Slovakia and thus difficult to reach for debt recovery a "black list " is used, which is available in the roadside equipment and the mobile control stations. Mobile inspections are implemented either by putting up a portable control gantry at the roadside and to have blue-light vehicle downstream of the gantry, or by passing trucks and read their on-board units on the fly or at rest areas or fuel stations. The latter method is efficient when it comes to gathering enough evidence and to hand out sanction on the spot, but it demand a lot of resources and only a small portion of all the traffic can be supervised this way.

SkyToll has 80 employees working in the enforcement process, and add to that about 200 police officers, wholly or partially involved in the task. A total of 30 control vehicles are in operation on the road network.

Penalty fees are high, up to 1 600 EUR but lower if paid on the spot. The driver of the vehicle is liable to pay part of the penalty and the haulier the rest. If a vehicle is stopped, earlier recorded offenses, with a history of 24 months, will be prosecuted simultaneously.
The most common error is that the on-board unit is installed incorrectly, for example by placing it on the dashboard instead of attaching it to the windscreen. Among the more conscious methods to evade, it is common to either state fewer axes or simply drive without on-board unit.

2.3.5 Observer in vehicle
Since the measuring system is dependent on an accurate GPS signal the enforcement system is dependent on detecting if the GPS signal is missing or manipulated. If the on-board unit detects that the vehicle is moving but the GPS signal is not consistent with the motion, a red warning light alerts the user. The driver immediately has to contact customer service at that point. No connection exists between the on-board unit and the tachograph or other data source in the vehicle. Except for power supply, the on-board unit is completely autonomous, even in relation to other vehicle equipment.

2.3.6 Costs
The operator does not want to share their detailed cost for the enforcement function, but is of the opinion that the sanction fees and surcharges collected covers more than the cost of the enforcement process and make a rough estimate that 15 % of operating costs derives from the enforcement process.

In total more than 200 000 EUR are collected as sanction fees and surcharges, compared with the 150 million EUR that the road toll adds to the treasury annually. With an estimated fraud level of 0.6-0.9 % of the trips the state loses about one million EUR per year in lost revenue due to evasion.

2.3.7 Privacy
In Slovakia privacy never was significantly debated before the launch of the toll system. The operator put great emphasis on safety aspects in their description of the system, but the focus is rather on protecting the financial transactions than personal data.

2.4 France
France would have become the latest in a series of European countries to deploy a distance based toll system, but after a series of delays and problems, the government has now suspended the project indefinitely. Since the system is not yet in operation there are several aspects of the system where it is not possible to get full and final knowledge.

2.4.1 Institutional Arrangements
The new French toll system is designed to complete an extensive network of semi-state owned and private tolled motorways that has been around since several decades. The existing toll roads are mostly traditional, with toll booth and gates where users have to stop and pay manually or choose dedicated transponder lanes. Although transponder usage is extensive, it is usually not "multi-lane free-flow" installations.

Today's toll roads are exclusively motorways, and they often run parallel to state-owned trunk roads, Route National, with less capacity, and so far have been free of charge. To cut costs, many hauliers chose trunk roads, with increased wear, congestion, noise and emissions inside the small towns and villages as a result. Therefore, the state has decided to charge a kilometer tax for heavy traffic, carefully adapted to the existing charges, with a vision to bring the heavy traffic to the roads that are best
suited for them. The toll covers 10 000 km of national roads and 5000 km county and local roads, the latter primarily to prevent displaced traffic to end up on even smaller roads.

The French system is based on a market-oriented principle that ARENA early advocated, and that the EU directive on interoperability partially formalized, meaning that the state requires the transport industry to report and pay for their road usage and private service providers offer solutions that make it practical and financial viable to meet the requirements. A consortium (consisting of Autostrade per l’Italia, SFR, SNCF, Steria and Thales) has been contracted to form an operator called EcoMouve. EcoMouve acts as the central toll charger and in turn contract the toll service providers that the road users sign contracts with. Additionally, EcoMouve themselves offer a basic service for those unable or unwilling to sign a contract with any of the commercial operators.

![Image](image.png)

Figure 5. The planned French Exotaxe was based on a market-oriented principle with several toll service providers for the road user to choose from.

A key part of the solution is the mandatory certification of the equipment used by service providers. The parties involved must be able to trust the data supplied. This means that the party issuing the certification, the notified body, in this case COFRAC (Comité Français d’Accréditation) also becomes a key actor. In addition, at least five agencies with the authority to carry out inspections of road usage charge (customs, the fiscal authority, the authority for ground transportation, the police and the gendarmerie). This institutional arrangement is more complex than any country tried in the past and it is possible that this complexity contributed to delays in the project.

The French system would offer very generous discounts for regions that are considered disadvantaged. For instance in Brittany the road toll is reduced by 50%, which may seem surprising given the Eurovignette Directive writing about heavy discounts to be in conflict with the requirement of non-discrimination.

2.4.2 Measuring system

The French solution leaves an element of system design for each toll service provider, but all must adapted to the EcoMouve interface and reporting requirements. When a vehicle enters an area where there is a road section covered by the new toll system, the vehicle must start reporting which of the total 4100 toll points that it passes. Moreover, they themselves must store a detailed route description to present in case of an audit. Within five minutes after a toll point has been passed, it has to be reported to the operator.
Manual registration will not be offered, thus everybody need to obtain an on-board unit from any of the service providers or from EcoMouve.

2.4.3 Observer in vehicle

Only equipment from the toll service provider is fitted into the vehicle. There are hardly any central requirements. Supervision functions built into the service providers’ equipment are to protect their own interests or to fulfil the service level requirements of the toll charger.

2.4.4 Roadside observer

The toll charger provides equipment and vehicles for roadside supervision, while all authorities that already have power to monitor vehicles and transport companies also have the right and in some case the obligation to enforce the new toll.

Since all vehicles must report the detailed route to EcoMouve it is enough to make an observation of the vehicle to verify that the trip is correctly reported. The number of axles, which as in many other systems is manually set on the on-board unit, has to be verified by the supervisor.

The penalty for driving without paying is about 700 EUR and at least in the early versions of the legislation there was room to gradually raise the penalty for repeated offends.

2.4.5 Observer in central system

The customs authority can carry out audits of the transport companies in retrospect. Here, they have far-reaching authority and the burden of proof fall, like a tax audit, on the road user.

For vehicles not registered in the country, the owner or the driver must present registration documents to support the weight and Euro emission class to be applied.

2.4.6 Costs

EcoMouve are not able or are not willing to make any estimate of the cost of the control system yet.

2.4.7 Privacy

Already in the early stages authorities worked with the French data inspection board to ensure that the system would be acceptable from a privacy standpoint. The system only covers heavy traffic and those who drive a lot in France are already accustomed to use transponder to pay tolls, which probably contributed to the complete lack of debate about privacy.

2.5 Lessons learned from the four countries studied

2.5.1 Economies of scale

A pattern can be perceived among the investigated schemes are the number of vehicles affected. In countries with few trucks in traffic, such as Switzerland or Slovakia, the numbers of on-board units produced become a problem. To produce 100 000 units of advanced equipment is challenging enough to put up an industrial process with careful quality control. At the same time the numbers are too few to offer economies of scale for the manufacturer. Therefore, on-board units may be disproportionately expensive for a small country with unique functional requirements, making it impossible to use exactly the same device already in use in another country.
France is served by up to a million trucks that will be taxable in the new system, which is a challenge when it comes to distributing and installing equipment but also an advantage in terms of economies of scale in production and adaptation of road toll equipment. Now France has chosen a model where all on-board devices will not be delivered from the same provider, which could diminish economies of scale. However, it is quite possible that several toll service providers procure their hardware from the same manufacturer, and thus still reach economies of manufacturing. It is also likely that toll service providers will find synergies with other parts of their business. For example, a company that today offers debit card for fuel, insurance for the transportation industry or fleet management system, has good potential to become a provider of toll services and take advantage of the customer relations and customer service processes already in place. A market shared between multiple service providers could, because of this, reach higher economies of scale and synergies than a market managed by one toll operator.

2.5.2 The most important observer

Switzerland emphasise inspections of the on-board unit, the central system and the country's borders. This fits a system with the same charge everywhere and on all roads. Since most of the traffic is domestic it seldom or never cross the border between the tolled and a non-tolled area. With a simple tariff the enforcement system could be simple as well. Also driving on private roads or terminal areas are subject to the same charge per kilometer, which eliminates the need for a detailed map with entry- and exit points at the border of the toll area.

Germany, Slovakia and France only charge part of their road network. This means that even domestic trucks regularly cross borders between a tolled area and a toll free area. The measuring system must be able to correctly detect when this happens. It also means that those who want to evade charging have an incentive to try to get the measuring system to perceive driving on a toll road as driving outside of the tolled area. Thus, the enforcement system must have its own source of information (from the vehicle, the roadside or a third party) that can indicate if there is misconduct in the road usage declaration.

All three countries have chosen to primarily rely on their own observations from the roadside, simply by investing in a network of fixed, portable and mobile enforcement stations. The density of enforcement stations have to be enough to even cover local traffic, that otherwise might run without being checked or detected.

Because these three countries only charge part of the road network, mainly motorways with long distances between exits, relatively few checkpoints per kilometers of road is required. To achieve the same enforcement effect in a more densely meshed network of roads, require more checkpoints, not only in absolute terms but also in terms of number of stations per kilometer of road.

2.5.3 Institutional arrangements

The countries studied have chosen different ways to procure and run the toll operations. In Switzerland, suppliers deliver equipment and knowledge to the authority, which then runs the operations. This requires the authority to acquire and retain skills, but they are not depending on suppliers and they can make strategic decisions without being hindered by contractual issues or mismatched incentives between providers and principal.
In Germany and Slovakia anything that is not direct authority exercise, have been outsourced to a private operator. (This model is also common in systems for truck tolls that primarily use transponder technology). It makes it easier to get started if the authority does not have expertise or the resources to run the business themselves and it takes advantage of market forces and price pressure during procurement. However, once the contract has been awarded the authority is victim of a monopoly situation and all changes are negotiated from a much weaker position.

The French model seems attractive from an economic theoretical perspective. Only the minimal portion of the operations is procured and becomes a regulated monopoly (EcoMouve, which is operator in the role of the Toll Charger). For those parts of the business that could be exposed to competition, freedom of establishment is offered and service providers from other business sectors are encouraged to enter the business. The aim is to achieve competition in the market instead of competition of the market.

Security and interoperability in the supposed dynamic market solution are safeguarded through a rigorous program of certification and a small number of well-chosen mandatory standards and specifications. Theoretical attractiveness, however, is no guarantee of feasibility, and the overall complexity of the solution may have been a contributing factor to the extensive delays that are at hand.

The German system also saw significant delays, although the state selected a turnkey solution from the apparently large and assured consortium. The market-oriented model is obviously not the only solution that can cause difficulties in implementation.

**2.5.4 The State measure or the user declares?**

There is a principal difference of who is responsible to measure and report and thus who carries the burden of proof, even though none of the countries studies explicitly makes this distinction. When the state or its proxy issues equipment and read the data it is in practice the state that measures road usage, and if the equipment suddenly stops working, it is difficult to blame the user, as long as they fulfil their duty to report when the on-board unit indicates an error. When a user reports their planned route in a Web service, it is an active declaration, and if the driver is caught on a different route, it is obvious that the user is responsible for the misconduct.

To locate the burden of proof, and thus affect incentives, it is vital for the enforcement system whether the responsibility to measure and report lies on the issuing authority or if it is a declaration duty of the user. It is particularly important if you want to apply something similar to the French system of free establishment of a toll service provider.

The French system is clearly built around the declaration duty, while the other three systems are based on the idea that the authority or the toll charger is performing the measuring (Web services excluded), with users strictly obliged to use the prescribed equipment.

When the state is responsible to measure road usage, it needs the authority to demand the road users to contribute to measuring according to the specifications prescribed by the authorities. In an autonomous system it is not possible for the authority to measure without the road users assistance, since important parts of the system are physically located in the vehicle. If an error in the process or the equipment would occur it would be the responsibility of the authority, and the same goes for the burden of proof.
With this model, the legislator may choose to criminalize the lack of equipment or attempt to manipulate it, and thereby partially overcome the need to prove that road usage is not reported or paid correctly. This method is used in the old French law (which governs the traditional tolled motorways with tollbooths and gates) where evaders are punished for passing the red light at the toll station and not to have used the road without paying.

### 2.5.5 User adjustment to the rules

All systems show user behaviour adjustments on the legal side of law violation but with consequences that can affect the overall outcome. This is not unique for road tolls, but can be seen in almost all types of taxation. In the Netherlands during the 18th and 19th century real estate was taxed based on the width of the facade facing the street, which gave rise to the characteristic narrow houses in Amsterdam and old Dutch towns. Similarly, Germany has seen increased use of trucks with a maximum gross weight of 11.99 tons, but which in practice is a full-sized rigid trucks. In a similar way fees affect routing through Europe and the routes hauliers choose to optimize their operations are not always those that the authority wanted from the beginning.

These types of adjustments can be difficult to predict in its size and for all user groups, and it may have some impact on the choice of institutional arrangements. Since such a major change, as the introduction of a kilometer tax instead of a time based vignette, can be expected to lead to unforeseen adjustments, organizations that measure, monitor and collect the charge have to have both the incentive and mandate to continuously monitor and adapt to user response. In a procurement of a turnkey solution at a fixed price, it is difficult to build in incentives and mandates for adjustments, without losing the price squeezing bargaining power from the procurement phase. This dilemma, where fierce price pressure during the procurement partially conflict with the encouragement of adaptation and innovation is not unique but has been experienced in many industries since the law on public procurement went into effect.

### 2.5.6 Both the probability and the sanction matters

A rational immoral actor weighs the probability of getting caught with the severity of the sanction. Getting caught does not matter much if the only thing that happens is that you have to pay the original debt. The research attempted to measure which of the two factors have the greatest impact, usually come to the conclusion that there is some distortion towards the probability to get caught at the expense of penalty size. This means; based on a calculated expectation value, an average criminal act somewhat irrational, by becoming a little more influenced by how likely it is to get caught, compared to how high the penalty is.

Another recurrent finding from this research is that the more emotionally related crime, the less the penalty weight in relation to the likelihood. But to evade road toll is not a crime of passion or something performed under the influence of peer pressure, alcohol or testosterone. Rather, it is reasonable to believe that a rational calculation of expected profit is a good prediction for people’s behaviour, and then the expected sanction matter much. In the studied countries sanctions for evading is relatively high and in some cases also immediate, in that they are claimed on the spot.

Another regular feature is the sanctions that increase with each offense, which is a way to threaten with a high penalty for anyone considering systematic irregularities, but still be able to limit sanction
to a reasonable and proportionate level for those who have committed an irregularity more by carelessness than direct intent.

### 2.5.7 Market segmentation

Although non-discrimination is a core requirement in the EU legislation this does not mean that a toll system operator must use exactly the same process for managing all user groups in a toll system. The vehicles that only drive within a toll area have different needs and can be handled differently than those who frequently cross the border between tolled and toll free roads. Similarly, simpler processes and equipment can be used for domestic vehicles, compared to vehicles registered abroad, and vehicles passing through occasionally can be handled differently than those who are regularly visiting.

Firstly, these various groups can be equipped with different measuring systems to gathering the primary charging data. And as the requirements of the measuring system can be different, also the enforcement system requirements will be different for different user groups. This is most obvious in how Switzerland handles temporary foreign vehicles by reading their odometer on entry and exit instead of force them to install an on-board unit. Also the process when a vehicle is stopped for roadside inspection differs between foreign and domestic vehicles in several countries, since it is difficult to afterwards claim payment from hauliers from other countries. To physically stop vehicles on the road is an additional sanction, since it causes delays and inconvenience for both the driver and the receiver waiting for the goods to be delivered.

All four cases studies describes the observer in the central system as highly efficient for domestic users but with little or no value for foreign vehicles. Through tax audits, where the expected toll payments are calculated from other data sources, such as fuel consumption or customer orders, the authority can get an opinion on which the main evaders are without having to prove each individual irregularity.

### 2.5.8 Difference controlling hauliers and controlling service providers

In France, there is an important difference compared to the other countries, namely the need to identify errors and irregularities from both the hauliers’ side and from the toll service providers’ side. The two groups have different incentives and different possibilities to circumvent the system and needs to be approached in different ways. It is essential in a system like the French to make clear to which extent a toll service provider is responsible for the possible irregularities of its customers.

There are no equivalent requirements in Switzerland, where the authority itself is operator, or in Germany and Slovakia where there is only one operator, making the enforcement function simpler, without considerations of equal treatment between different service providers.
3 Other techniques and approaches

So far, this report has focused on existing technologies and autonomous systems for heavy vehicles. It is by all means the type of system that is most likely to introduce short-term and where the monitoring concept is the most critical. This section summarizes some other techniques and methods of control of road toll that is not used in the four cases studied.

3.1 EUCARIS and EPC

There are several methods to recover debts from hauliers registered in other countries. The on-going EU project EUCARIS seeks to increase opportunities for countries to look into each other's vehicle registry. The map on the right shows which countries that are active or interested to start participating in the collaboration. Although the project developed successfully and it is technically feasible that a large number of vehicles on the roads of Europe can be identified with owner and address, EUCARIS is explicitly designed to support the Prüm council decision and thus restricted to law enforcement concerning vehicle registration – not tolls. As EUCARIS evolve and become more commonly used, it is possible that its scope is broadened, but today there is no evidence that this will be the case.

In addition to EUCARIS, whose value for toll purposes is yet not fulfilled, there is already a British company; EPC Ltd with local branches throughout Europe and by this can claim debts in most countries. They state that they can collect debts even if it would require a lawsuit. Their services are expensive, making them unsuitable for recovery of small debts. To send a reminder is not enough to create a strong incentive to pay as long as you do not possesses a collection mechanism. EPC can only offer this in countries that recognise their claim as legitimate and even then to a high cost per transaction. None of the systems described here relies on the services of this type.

3.2 Telecom Data and other location-based services

Today's autonomous toll systems mainly use the American GPS-service and the digital tachograph (only in Switzerland) as input sources. Siemens offers an on-board device that combines GPS signals with the Russian GLONASS satellites, but the effect is limited to a better measuring system, not a parallel enforcement systems. Meanwhile there are many other sources of positioning services. When a modern mobile phone shows where it is located on a map, for example, Google Maps, not only GPS signals contribute to its positioning. The phone measure signal strength from surrounding mobile phone towers and Wi-Fi network, which then is compared with mobile phone operators own
observations from known locations, allowing the position to be determined quicker and with better accuracy than GPS can offer.

These other sources could be used as an independent observation in an enforcement system. One way to use such data would be that an on-board unit verifies the measured satellite positioning data with other sources and alert when they do not match. Using data from secondary sources this way strengthens the observer in the vehicle by giving it access to more sensors and thus get more points of reference to compare.

Another idea would be to use data from mobile phone operators on what phones that are within the reach of what base stations and when. By mounting a fixed SIM card the on-board unit can make itself known to the base stations in the cellular network that the vehicle passes. With the assistance of telecom operators it would be possible to recreate a rough idea of any vehicle route. Such a recreated route can then be tested against the reported road use and deviations detected. This scenario, however, involves several issues. Firstly, it makes an authority dependant on private companies systems - telecom network equipment is not built to track cars, but to enable communication. Even if the legislation could force telecom operators into this type of assistance, it would end up in a difficult situation, in which one of the central processes of the tax authorities lays in the hands of companies, not authorities. Secondly, such a system would expose itself to criticism on matters related to privacy, since its design can bring to mind the extensive United States government monitoring programs that recently have been uncovered.

### 3.3 Trusted Recorder

In 2009 two Dutch researchers, de Jonge and Jacobs, published an article in the journal “Formal aspects of security and trust”, entitled “Privacy-Friendly Electronic Traffic Pricing via Commits”, where they present the basics of a model how a toll charger can verify if a toll is correctly paid without requiring the user to give up their privacy by sharing their entire itinerary. The big advantage of this model is that it allows for a kilometer tax with differentiated tariffs without requiring the toll operator to have full access to the underlying route in order to perform verification. By applying cryptographic methods the Gordian knot that ties together the measuring system with the enforcement system is solved.

Yet there are no practical implementation of the de Jonges and Jacobs solution, but a further development based on the same basic principles have been developed by the standardization bodies CEN and ISO, called Trusted Recorder. The standard for the most part finished but not yet formally adopted.

![Figure 7. Trusted Recorder and its relation to standards, threats and requirements.](image-url)
An implementation of the Trusted Recorder offers two unique advantages over the non-cryptographic solutions that apply today. Firstly, each registration is immediate cryptographically frozen in a way that it cannot be changed afterwards without leaving a trace. This excludes all variants of evading based on creation of a false trip report afterwards, based on identified roadside observation locations. This feature will therefore still require an independent observer at the roadside, but it does enable the toll operator to maintain the same level of supervision with a smaller number of checkpoints, by ensuring that the route declaration is not fictional, which seems particularly interesting in toll systems with extensive tolled road network in relation the tolled traffic.

The other important feature allows the toll operator to apply an independent roadside observer as a method without demanding a complete route description from the vehicle. Through this privacy is protected, which is of primary importance in a situation where private vehicles are taxed.

Trusted Recorder is a broad standard with many options that can be applied in various combinations. It does not compel, but enables the toll operator to ensure the driver full control over all the information on its itinerary. In such a configuration only a summary report is sent to the toll operator by the measuring system, including the total amount to pay and a cryptographic receipt, from which it is impossible to deduce any information about the route. If the supervision authority made an observation of the vehicle in a known location at a known time, it may request an excerpt from the vehicle just for that time. The vehicle owner submits a report from its on-board device that shows where the vehicle was driving at the time, along with the associated cryptographic receipts. By verifying the cryptographic information in the receipt, the authority can ensure the released location is part of the route that the toll charge was calculated from. In this way no new personal information about where the vehicle has been is revealed – the roadside observation is already known by the authority.

Because Trusted Recorder is a new technology, without adopted standard or reference installations, it comes with not only a higher cost than other solutions, but also a greater risk – and risk has been shown to be of key importance in countries considering the introduction of new types of road tolls. Here are three examples from Germany, the Netherlands and Sweden where high risk and emerging technologies has led to high costs:

- The introduction of the German LKW Maut meant, as described above, design and deployment of a completely new type of technology. The system was delayed for one and a half years with massive loss of tax revenue as a result.
- The Netherlands launched several attempts to replace its entire tax system for vehicles and roads to an extensive toll system for all vehicles, including private cars, but failed. Although costs for the state has been limited, potential suppliers have invested heavily in the early stages of procurements that later on have been dismissed.
- Prior to the introduction of congestion charges in Stockholm in 2006 the political debate was very intense and there was a wide perception that the issue could determine both the municipal- and the general election. The high political risk was delegated through a rigorous procurement with high penalties for the supplier that constructed the system, which in turn led to high costs to build redundancy into the system.\(^4\)

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\(^4\) See Transport Policy #18/2011, “Revisiting the cost of the Stockholm congestion charging system” for details.
With these cases in recent memory, it’s easy to see that the first implementation of Trusted Recorder should not be done as part of a full-scale national implementation of new toll roads. If the technology should stand a chance to contribute to a future system, it is wise to first conduct several increasingly extensive demonstration projects. Since this is a technology involving both measuring- and enforcement systems, several vendors ought to participate in such a project, so that not only each function can be demonstrated, but also overall interoperability.

3.4 E-call

The European Commission has long aimed for cars and light trucks to be equipped with functionality that can detect if a serious accident occurs and then automatically call emergency and report the vehicle position. A first directive was adopted in 2007 when the industry was encouraged to voluntarily introduce the service, but the Commission thought the progress was too slow and in September 2013 they took the decisions on the compulsory introduction as of October 2015. (Also the Council and the Parliament must confirm the decision before it is binding). This means that the European car fleet will gradually be equipped with a mandatory system with the capacity to calculate the location and report the information to authorities, which is at least superficially similar to the demands that can be set on an enforcement system of road tolls.

However, it is unlikely that e-call can be used as a significant part of a future Swedish toll system. Firstly, it will take a long time before the technology is available in a large proportion of the vehicle fleet, as it is only mandatory in new cars. Secondly, and perhaps most important, e-call means a specific functional specification that vehicle manufacturers must comply with. It means no general platform or any open interface that an authority may request access to afterwards. Nor are there any requirement for the verifiability of the data authenticity or privacy for e-call. Therefore, it is not reasonable to expect any material help from the introduction of e-call when it comes to road tolls.

4 Swedish conditions and opportunities

4.1 Extensive road network but few vehicles

In Sweden, the distances are long and the population scattered. Consequently there is a lot of road per capita and per vehicle. The total network consists of 400,000 km, half the road network is publicly funded and half is private.

Most European road tolls only charge the main roads, roughly equivalent European motorways, trunk roads and primary county roads in Sweden. A toll system that charges this part of the road network could be enforced using a system that mainly relies on roadside observations. An enforcement gantry every 50 km would require about 500 gantries in total. It’s a setup that would cost about two billion Swedish Krona (SEK) to establish - costly but at the same level as other countries have invested. With such a dense network of independent observations at the roadside a fairly simple on-board unit would be enough.

A toll system to cover all of the Swedish road network, or the entire publicly funded network, cannot within reasonable cost be supervised by a dense network of checkpoints. A sparse network of checkpoints is not an option either, because it would only capture long-distance traffic, but be open for evasion among those who only drive locally between checkpoints.

In this way a Swedish system for kilometer tax for heavy vehicles has more to learn from Switzerland than from the other countries studied. In this situation, it is more beneficial to accept a higher unit cost for reliable on-board devices, than to establish a dense network of roadside enforcement stations.

The table below illustrates the options available for systems with few respectively many vehicles and few respectively many road sections. Sweden and Switzerland represent the lower right corner. In Switzerland the desired level of supervision is achieved through a combination of using the same tariff on all roads, odometers and physical inspection at its borders. In Sweden, we can apply the first two options, but within Schengen we cannot apply the same border controls as Switzerland.

<table>
<thead>
<tr>
<th>Vehicles / Road sections</th>
<th>Few road sections</th>
<th>Many road sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many vehicles</td>
<td>DSRC or ANPR</td>
<td>Need for a new solution</td>
</tr>
<tr>
<td>Few vehicles</td>
<td>Optional</td>
<td>Secure on-board unit</td>
</tr>
</tbody>
</table>

Table 1. Relation between number of vehicles, number of road sections and suitable technical solutions for enforcement.

In addition to border controls there are other ways to verify odometer data. For a vehicle that solely runs in an area charged with the same tariff at all times, the measuring systems only need to capture total distance, as the odometer or tachograph that already exists in most heavy vehicles can handle excellent. A digital tachograph already has part of an enforcement system built in, in form of additional sensors that indicates if the user tries to manipulate it. Additionally, the Police and the Transport Agency performs enforcement on hours of service, which, with minor modifications, could serve as the roadside and central system check for the toll system as well.
In the upper left corner is the Slovak, German and French systems with large numbers of vehicles and fewer road segments. Here it is reasonable to set up enforcement gantries with radio equipment (DSRC), cameras and automatic number plate reader (ANPR) whose observations can be compared to the reported data.

4.2 Passenger cars

A system that tolls passenger cars would, for several reasons, end up in a completely different position than one for heavy traffic, of which at least four have a bearing on the enforcement system. Firstly a car system will end up in the upper right box in the table above, where there are no references to lean on. It would therefore, just as in the truck case, become unreasonably expensive to establish a dense network of independent checkpoints. Therefore, it will require a new type of on-board units that need to be less expensive and easier to install, to be able to introduce rapidly across the car fleet.

Because these devices will be needed in millions, rather than hundreds of thousand, it is reasonable to expect significant economies of scale in design and manufacturing of technology, but still a good technical solution for cars is several innovations beyond today’s solutions.

Secondly the authorities encounter significantly larger number of charged objects in a passenger car system than in a truck system, which reasonably increase the aggregated creativity of those inclined to avoid charging. When someone finds a way to circumvent the system, it does not take long for such knowledge to spread. There will be a significant market for fake on-board units and other products that can help to evade charging or detection. Therefore, a toll system for passenger cars must have a much more robust enforcement system, possible to update without the need for physical on-board units to be withdrawn or replaced.

Thirdly, issues on privacy will have much greater importance in a car system, which is highlighted in other ARENA reports. Privacy aspects makes a measuring system that reports detailed route data for all users more or less impossible, and if the measuring system is not to report detailed route data, the enforcement can not be based on such data being reported. That leaves only two types of system: those that only stores the accumulated data and thus can only be verified by a tamper-proof black box, and those based on Trusted Recorder.

A fourth and final important aspect of a car road toll enforcement system has to do with risk and uncertainty in the practical implementation. Today, there is no international precursor in distance-based road-tolls for cars. This means that all estimates of cost, time, user acceptance, risk of fraud and other important issues becomes guesswork and perhaps also wishes. To handle such uncertainty without the risk of high costs, require a series of incremental development and demonstration projects, where suppliers together with government agencies are allowed to experiment with equipment under realistic circumstances, but without the extreme contractual requirements and penalties which are almost always a part of a full-scale procurement.

For innovation an environment in which it is allowed to fail and try again is needed and major procurement of turnkey systems creates the opposite of such an environment. Here is a clear role for the road authorities as well as for research and innovation authorities to initiate and fund incremental and focused projects where the market can be allowed to experiment and share experiences.
4.3 Institutional design

The international analysis above indicates several possible institutional arrangements for setting up a road toll system for truck traffic. Distance-based road tolls for passenger cars have not yet been successfully introduced and because of this we lack comparison. However, the 2011 Swedish governmental Road Toll Investigation and the existing and planned systems in Sweden can provide some guidance.

4.3.1 Measuring or declare

In the above analysis of four European road toll systems for heavy vehicles, a distinction between when the authorities measure and when the user declares its road usage is made. This distinction can also be applied to the toll station based systems used for congestion charges in Stockholm and Gothenburg. They have the ability to detect, record and identify passing vehicles and the responsibility lies with the charging authority. All owners of vehicles are required to do is to keep the license plate clean and visible. Should the system fail to register or identify a passing vehicle there is no obligation for the vehicle owner to report the passage. If a vehicle owner pay anyway, the amount will be refunded if there is no passage recorded.

This procedure differs from the traditional process of the Norwegian road charge systems, where a manual payment is received and kept, even if the roadside equipment registers no passage. The payment is in itself a declaration of a passage that the system did not identify. (In the Norwegian systems it was not allowed to drive in the free flow lane without a transponder, as the photo identification was considered an enforcement process for potential evaders).

The old Swedish kilometer tax for diesel vehicles was also based on the principle of measuring by the authorities, but through a mandatory, trusted on-board unit, like the current tachograph system recording drivers' hours of service. The equipment is specified in detail by the legislature and the user cannot comply with any other equipment or in any other way. The lack of equipment is thus a violation in itself. The consequence of this model is very limited opportunities for the industry to develop functionality of the equipment, as it is based on a detailed specification governed by European legislation and is very difficult to change.

In an autonomous system, as a future Swedish kilometer tax could reasonably be, where the measuring mainly takes place in equipment in the vehicles, there are many reasons to design the system around a general road usage declaration duty rather than around specific mandatory equipment.

Firstly, with a declaration duty it is to expect active assistance from the driver when it comes to fitting the equipment correctly, supervising uninterrupted power supply and register the correct tariff, making the design of the system a lot easier. If the road user knows of its responsibility to report correct data and that the probability of detection otherwise is large, such a participation can be expected. But if the user knows that any failure or interruption in the operation of the equipment means lower taxes, little help to keep the equipment in working condition could be expected. Putting the burden of proof with the vehicle owner, as the duty of declaration does, makes the compliance process a lot easier.

Secondly, a declaration duty makes it easier to design a system that is rigorous in terms of both legislation and information technology and comprehensible to users. The system can be designed in a
largely technology-neutral manner, easier allowing public debate and making legislation more robust, allowing technological development instead of making it obsolete as new technologies appear on the market.

Thirdly, a declaration duty is easier to combine with a market-based model, as the one France chosen and as the EFC directive stipulates with the mandated European Electronic Toll Service (EETS), which permits and encourages multiple parallel toll service providers performing the measuring and reporting services. In such an environment, it simplifies to set clear performance requirements than to prescribe an exact technical solution.

### 4.3.2 Taxation

In Sweden, the congestion charge is a tax while the infrastructure charges are not. Tradition and jurisprudence behind this is well described in the Road Tolling Investigation. The basic principle, that charging for roads that are already built and paid for by taxes must be a tax, leads to the conclusion that a toll for all or most Swedish roads would be a tax, just as the congestion charge.

When it comes to taxes, it is normally the taxpayers' responsibility to declare their income, consumption, turnover or other taxed object. If the authority so chooses, it may require the taxpayer to show a sufficient basis for the amount declared. This also suggests a design of a distance-based road toll as a tax with a clear declaration duty for the road user.

As shown in the countries examined, the ability to use tax audit to verify the reasonableness of the amounts paid, is another benefit with taxes. When the tax payer carries the burden of proof, the authority does not have to prove beyond reasonable doubt that a vehicle has driven at a certain place at a certain time without paying for it, but rather just make it plausible that the total mileage reported does not match for example, the amount of fuel spent or the amount of shipments been carried for customers.

### 4.4 Tariff design

The more complicated tariff a toll system applies the greater requirements are placed on both the measuring- and the enforcement system. Even if a technology provider demonstrates very high accuracy measuring and reporting a specific tariff characteristic, it is not certain that the authority will be confident that the information has not been tampered on its way. Each variable characteristic that affects the tariff must be seen as a potential source of evasion. Here are some examples:

- If the tariff is higher for trucks with trailer this is an incentive to state “without trailer” even if the trip is in fact with trailer.
- If the tariff differs depending on time of day this is an incentive to manipulate the time stamp to get less peak traffic registered.
- If the tariff differs in different regions of the county this is an incentive to manipulate positioning to different locations than the actual.

To be absolutely sure that the trip report is not tampered, the authority must have an independent observation of the vehicle including any trailer and a reliable indication of where and when the observation was made, to compare with what has been reported.
This means that all tariff characteristics that may vary en route puts very stiff demands on the enforcement system. It is much easier to vary kilometer tariff by characteristics that are firmly attached to the vehicle. The vehicle’s emissions class, maximum laden weight and the possibility to attach a trailer can be found in the traffic registry and thus not within the hauliers power to influence (level 2 in the table below).

If a tariff is created with this in mind the kilometer tax only differs based on in-vehicle characteristics. Each vehicle will then have the same cost per kilometer at all times and in all regions. The system design allows for both measuring- and enforcement systems to be kept simple and cost efficient. In such a system, it is sufficient to protect the on-board unit (the observer in the vehicle) and a sparse network of independent observations at borders and at selected locations in the road network.

As soon as a single tariff characteristic can be varied by the driver (through configuration or manipulation), the need for a much denser network of independent checkpoints to detect evasion arise, which in the case of the Swedish road network quickly would be unacceptably costly. Within an autonomous toll system there are no intermediate positions. As soon as variable tariff characteristics are introduced a big step in cost of installing a functioning enforcement system is taken (level 3 in the table below).

However, there are at least two ways to handle this cost threshold. The first involves using the Swiss method to let drivers check each other by on-board units that visibly indicates their current configuration. Different combinations of LEDs could be established to clearly indicate if the tariff set is for heavy trailer, night or certain regions in the country. If this type of social control within the industry would be sufficiently is difficult to guess without real experience. This method also requires the authority to have great influence over on-board units’ design. This method does not allow on-board units already installed for toll schemes in other countries to be used.

Another practically feasible method to gradually even out the huge cost threshold and enable further precision in a simple tariff with a fixed charge per kilometer for different classes of vehicles, is to add roadside toll stations that handle the tariff variables that go beyond the autonomous measuring system. These stations are thus not checkpoints to verify the measuring of the autonomous system, but downright toll stations that with DSRC/ANPR identification creates its own charging record (level 2 B in the table below).

By placing such toll stations at selected roadside locations the autonomous system’s good qualities for long trips can be combined with the precision, verifiability and low cost per vehicle for the roadside based system. The method is based on a base level charge per kilometer managed autonomously and a dynamic parameter such as location, time, congestion, trailer or number of axles using external observations at a limited number of locations. The system may then increase the precision, one toll station at a time in places where it is particularly important, without having to go all the way to a dense network of monitoring stations.

This method can however, only add variables from a fixed location to the tariff, and cannot modify the kilometer tariff. It is thus possible to set the tariff X cent per kilometer as a base, and then add Y cent to pass a certain point during peak hours or with trailer. However, the method cannot be used to vary the basic tariff so that it is X cent per kilometer in the off-peak traffic, Y cent in peak traffic and Z cent with trailers.
The table below summarizes these tariffs characteristics into four levels:

- Level 1 is a common flat rate per km
- Level 2 adds vehicle characteristics as a basis for differentiation
- Level 2.b adds roadside toll stations
- Level 3 does not use roadside toll stations but instead allows fully variable tariffs.

<table>
<thead>
<tr>
<th>Tariff principle</th>
<th>Impact on road users</th>
<th>System impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Unified flat km-tax</td>
<td>Same km-rate for all vehicles everywhere at all time</td>
<td>Simplest possible system. An odometer or digital tachograph for measuring and a dense network of monitoring stations.</td>
</tr>
<tr>
<td>2. Vehicle flat km-tax</td>
<td>Different km-rate for different vehicles, but each vehicle always get the same charge. Differentiation could be based on emission class or maximum laden weight.</td>
<td>As #1 but with extended storage of vehicle characteristics in the traffic registry, also for foreign and not yet identified vehicles.</td>
</tr>
<tr>
<td>2B. Vehicle flat km-tax + position based surcharges.</td>
<td>As #2 but with surcharges on specific locations such as cities, bridges or tunnels, differentiated e.g. on: vehicle characteristics, location, time, congestion level, speed, weight, number of rolling axles, connected trailer.</td>
<td>Toll operator and roadside equipment measure the surcharges; no extra enforcement needed. Toll stations need ANPR and maybe DSRC. Cost of toll stations depend on tariff differentiations. The most complex tariff scheme if existing OBU should be used.</td>
</tr>
<tr>
<td>3. Vehicle differentiated km-tax</td>
<td>As #2 but each vehicle applies various km-tariffs under different circumstances. The tariff may e.g. be varied by: • Any vehicle characteristics • Region, town, countryside • Type of road • Timespan • Speed • Number of axles • Trailer • Driving pattern • Type of cargo • Loaded or empty running</td>
<td>Characteristics set by driver, therefore risks they are not correct. Extensive enforcement needed. Some tariff parameters are hard to monitor and a dense network of roadside observations are needed. In some cases social control within the trucking industry might be used, by demanding external indication lights showing OBU settings.</td>
</tr>
</tbody>
</table>

Table 2. Four principles for tariff design for distance based road charge systems.

### 4.5 National borders

For several reasons national borders play a large role monitoring both international traffic and the part of the domestic vehicles that regularly runs abroad. Firstly it matters because the EU has not yet established any cross-border jurisdiction for inspection and enforcement of road charges, and thus
offer limited ability to recover debts abroad. Secondly there is a need to verify that a vehicle left the country and thus is not required to pay for the distances driven while abroad.

As previously described, the Swiss system uses traditional border controls where odometer data is read manually, which is not a legally available option between Sweden and other Schengen countries. However it is quite possible to measure size, weight and vehicle configuration, take pictures and otherwise analyse the cross border traffic, as long as it is done without interfering with the free traffic flow and without discrimination. By establishing checkpoints at all borders, about 30 in Sweden, the authorities may have good view on which heavy vehicles that arrives, leaves or passes through the country. That information can then be combined with other sources to reconcile self-reported distances and amount.

If for example, a haulier claims that three quarters of the 10,000 kilometers reported from the odometer derives from trips in other countries, but the vehicle only been abroad a tenth of the billing period, the authority can reasonably and without having access to the detailed route data draw the conclusion that the haulier tries to deduct too much for traffic abroad.

In practical terms, the enforcement process can also facilitate this type of observing checkpoints. If the checkpoints are placed at a distance from the border, the police can collect data and stop the vehicle that is about to leave the country with a non-paid debt. That way, the police or another supervising authority, limit their actions and only intervene when the system indicates a vehicle with a debt big enough and with sufficient evidence worth the effort.

A system like this does not even have to identify the owner’s name and address. It is enough that each observation of a vehicle can be tied together with other observations of the same vehicle. A system that efficiently can create something descriptive like a vehicle fingerprint, by carefully and remotely measure and photograph it, can effectively handle evaders even if they have no on-board unit or if registered in a country without agreement on exchange of ownership information. When the vehicle is stopped, the driver can be presented with a decision on taxation and the evidence on which the decision is based, and the vehicle can be held as collateral or get the licence plates removed until the tax debt is paid.

To build this kind of network of monitoring stations around the borders with existing technologies is possible in the order of 100-150 million Swedish Krona. The system could also be of great benefit to trace dangerous cargo, stolen vehicles and to control drivers hours of service.

### 4.6 Borders to other tariff zones within the country

If a distance-based tolling scheme where the rate varies with the type of road or region is introduced, a choice of tariff category 3 in the table above is done. This means lots of challenges for the enforcement system. However, there are several reasons to prefer to apply this kind of differentiation in Sweden. The two most frequently mentioned requirements are seemingly different but puts similar demands on measuring- and enforcement systems:

- Particular attention should be paid to areas with large distances between cities and factories, and therefore it may be reasonable to charge a lower charge in rural areas and in the northern regions than in other areas.
Only about half of the road network is publicly funded and if a toll should follow the cost to establish and maintain the roads, it is reasonable that the roads that are privately paid for, such as the many forest roads, should not be charged as high as public roads.

In both cases, the measuring system has to tabulate total distance in at least two columns: full-price kilometers and low-price kilometers. This means that the measuring system must be able to define the two categories and that the enforcement system must make it likely for evaders that puts full-price kilometers in the discount column to get caught.

To establish monitoring stations, as at the national borders, at each entry or exit from private roads would not be a viable option, since that part of the network consists of many small roads, rather than a few large ones. The costs for being able to separately report different usage would be excessive.

A pragmatic way to get past the problem and avoid having to build the entire tolling system for what is called the tariff principle 3 in the table above would be to offer a standard deduction for private road usage. Although half the road is private it represents the least used parts of the road network. A simple operation would be to measure the total distance travelled and then deduct a minor percentage, under the assumption that one can reasonably expect that each haulier drive partly on their own driveway, on forest roads or cooperatively managed road.

The vehicle owners who believe they have a right to a larger deduction than the template would then be quite few, and it may be worthwhile for all parties to take the cost of a more advanced on-board unit with more built-in protection against manipulation and a more detailed examination of independent information. It is also conceivable that the authority is content with a summed distance reports from all who use the standard deduction, but require detailed itineraries from those who claim a larger deduction for travel on private roads.

### 4.7 Nordic cooperation

ARENA has initiated plans to coordinate new distance based charging systems in the Nordic countries. Such cooperation could significantly reduce the risks and costs of implementation while being easier to implement than the European attempts we have seen through the years. EU directives and decisions have consistently avoided the most difficult questions, concerning national sovereignty and taxation laws. But to get to true interoperability, including enforcement, which is necessary to achieve the benefits, the difficult issues also have to be solved.

What is crucial in this type of international agreements is to limit the total amount of variables available in a system. If the states limit their future design options, providers can begin to develop technologies and methodologies that support the options which states prioritized. With a known maximum complexity, suppliers compete to find the most efficient solution that covers all the possible options. But if states retain the right to add additional requirements this quickly reduces providers’ willingness to invest in a new technology that may prove insufficient as soon as a new requirement has been added.

If the market is enticed to invest in developing and testing innovative enforcement concept the states in return must offer a known and predetermined set of options in the solutions that the system can support. It means that the government must commit itself in a way that can be difficult to accept for a tax authority or a state, but the rewards are probably large, and if several countries
agree on a common specification it will send a clear signal to the market that this is an area worth spending research and development resources. Should the authorities decide to go ahead with the Nordic cooperation, it is important to include the harmonization of the maximum complexity of the specifications for the compliance and enforcement system.

4.8 Notification obligation

The 2011 Road Toll Investigation argue that the state can not reasonably be expected to announce any charges to debtors abroad, taking into account the costs it would entail. In contrast, however, it recognizes that when a road user does not pay, a reminder must be announced without any additional charge. In practice, the implication for the debtor is the same. A visiting road user who knows of the requirement to pay tolls can safely choose to "wait and see if they get a hold of me." If the authority does not succeed to notify the debtor, the trip is for free. If the reminder reaches the debtor, there will be no surcharge. For a rational, profit-maximizing road user, there is no reason to pay on own initiative, since there is always the chance of escaping and the cost of trying is zero.

By this simple reason, it is a reasonable principle that it should always be less expensive for the road user to pay the toll on its own initiative, complete, accurate and timely. In this matter it is important that the conclusions from the Road Toll Investigation will not be the final words. If a road user has the choice to voluntarily pay a known tariff, or ignore to pay but then take the risk of paying a higher tariff if revealed, the decision will depend on three things: the difference in tariffs, the perceived probability of being revealed and the internal discount rate (that is how reluctant the road user is to make a payment now rather than later). By putting the difference in tariffs high enough, an authority persuade the majority of road users to choose to pay voluntarily, even though the detection risk is low. (This logic is described in detail with examples and simulations in the fifth chapter of the doctoral dissertation Implementing Road Pricing: Standards Institutions, Costs, and Public Acceptance, KTH, Hamilton, 2012).

The model described, where the probability is weighed against the cost, is also applicable in a scenario where the authority has a notification requirement, if accepted that the first time a vehicle is stopped en route is the announcement in the form of a physical notification, and after that it can be expected that the road user is reached by the message and therefore can also be debited surcharges. Such a procedure would obviously be more expensive and delaying payment, because it is only at a second intervention that penalty get the full effect of the road user's incentives.

4.9 Occasional visitors

For all road toll systems occasional visitors are important to manage. For hauliers from other countries who often drive in the country, there may be a reason to equip them with on-board units albeit it comes with some cost for the toll operator and both cost and loss of time for the visitor. For occasional visitors it is not reasonable to require them to adapt to the national system unless it is fast and the cost to do so is negligible. Nor does the toll operator want to waste too much of resources on them.

In Germany, as described above, the ability to pre-book trips in a web interface is offered. Since most of those using this opportunity are occasional visitors, it would be wasteful to install costly equipment in their vehicles. In the German system, it is easy to check the trips booked via the web, as they
entered a precise route and checkpoints along the road continuously compare the advance booking to the observed traffic.

In Sweden, occasional visitors become a difficult challenge from an enforcement perspective. If chosen not to use a dense network of roadside equipment as part of the enforcement system, it becomes more difficult to verify advance booking – they neither have an observer in the vehicle (no onboard unit) or a third-party observer, as they do not declare in Sweden.

There are at least two possible solutions to this problem. Firstly, it is possible to restrict advance bookings to the ones that can be monitored. Suppose there are checkpoints at all national borders and a sparse network of checkpoints in between. Trips along the shortest route between two border crossings, transit traffic that is, can then easily be identified, and therefore offered advance booking. If a haulier pays for a pre-booking from the port of Stockholm to the port of Trelleborg on a specific date, you can make a plausibility assessment if the time between the first and second observation is what it takes to drive the fastest road, or if there is reason to suspect the haulier to practice cabotage instead.

It is much harder to handle a haulier that enter Sweden at the Öresund Bridge to do errands in the province of Scania, and then turn back the same way three days later. Without a dense network of roadside observations, it is impossible to reconcile if the stated distance in the country is correct. A pragmatic way to handle it would be to charge for the longest distance the vehicle can reasonably cover during the time period, but then there is a risk this will conflict with the Eurovignette directive, banning to have both time-based and distance-based tariffs simultaneously. Without a detailed negotiation with the EU Commission, it is difficult to determine if this is a possible way to handle occasional visitors. The French tariff design, which now has been approved by the Commission, may indicate that there is more leeway than the wording of the Directive suggests.

4.10 Privacy

Privacy is directly linked to the compliance and enforcement concept chosen. The requirements for details in the measuring system is often decided by the enforcement process, this is where the privacy level is defined.

ARENA’s report on privacy in toll systems describes privacy threats in detail and several measures are proposed. In conjunction with the provisions described some of the conclusions are magnified. It is clear that privacy, above all, is a big issue when tolls are introduced on passenger cars, but also the commercial road users have a right to a private sphere. It is also clear that the technical solutions, such as protected on-board units and Trusted Recorder has a role to play, and for that type of solutions to evolve, early and thorough experiment- and demonstration projects are required.
5 Conclusions and recommendations

To be able to get a larger portion of funding for roads and road traffic management to direct taxes and charges a comprehensive approach that includes the state to ensure that users are paying the correct amount is needed.

In the area of heavy freight traffic there are plenty of references and suppliers that built and operate systems similar to what we could possibly want in Sweden. Our special situation with extremely large road network relative to the number of vehicles is a specific requirement, and superficial similarities do not show that a workable solution is already at hand. As for distance-based toll for cars there are basically no successful examples to learn from. More extensive experiments and demonstration is needed in order to move forward.

Based on the observations made in this paper the author leaves the following recommendations to the authorities involved in issues of tolling, as a future method to bring in tax from and influencing behaviour in the transport sector in Sweden:

• Start with the Road Toll Investigation, which has made a solid overview of the current status and management of congestion charges and infrastructure charges, but be open to new principles that need to be applied for a general road charging system. Avoid notification obligation.

• Be aware of the differentiation of the tariff which are really necessary and which are possible to refrain. If possible, avoid all dynamic differentiations, since they are driving cost and complexity in the enforcement concept.

• Let the road user declare its usage instead of having the toll operator to measure. This saves costs, increases freedom for authorities and users to continuously develop technical solutions and it puts the burden of proof where it belongs - with the user.

• Push the possibility to handle occasional visitors with advance bookings with defined distances and time windows, to make it easy and inexpensive to manage those who do not drive very often in the toll scheme.

• Continue a Nordic co-operation with the ambition to solve the difficult issues that the EU has not succeeded to solve in the directives and decisions that affect interoperability between tolling systems. Focus on the maximum complexity of the tariff structure needed and begin to develop a common enforcement concept.

• Start small-scale procurement of experiments and demonstrations of Trusted Recorder both for heavy vehicles and passenger cars. This is a promising but unproven technology that will constitute one of the main strategic choices. If the technology is unproven, it will be unacceptable for implementation, and for good reasons, given the huge losses road toll project with unproven technologies caused earlier.

• When the pilot project is defined, allow the projects relating to passenger cars to be more open than those related to the heavy vehicles, and encourage innovation and experimentation, not only with already established companies in the industry. Maximise innovation potential now to reduce uncertainty and risk in later phases.
• Search for collaborations with i.e. the police, customs and traffic authorities to identify different authorities that would benefit from the establishment of checkpoints that can perform border control of heavy traffic. The functionality of such checkpoints is general and the cost could reasonably be shared between multiple agencies and applications.
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