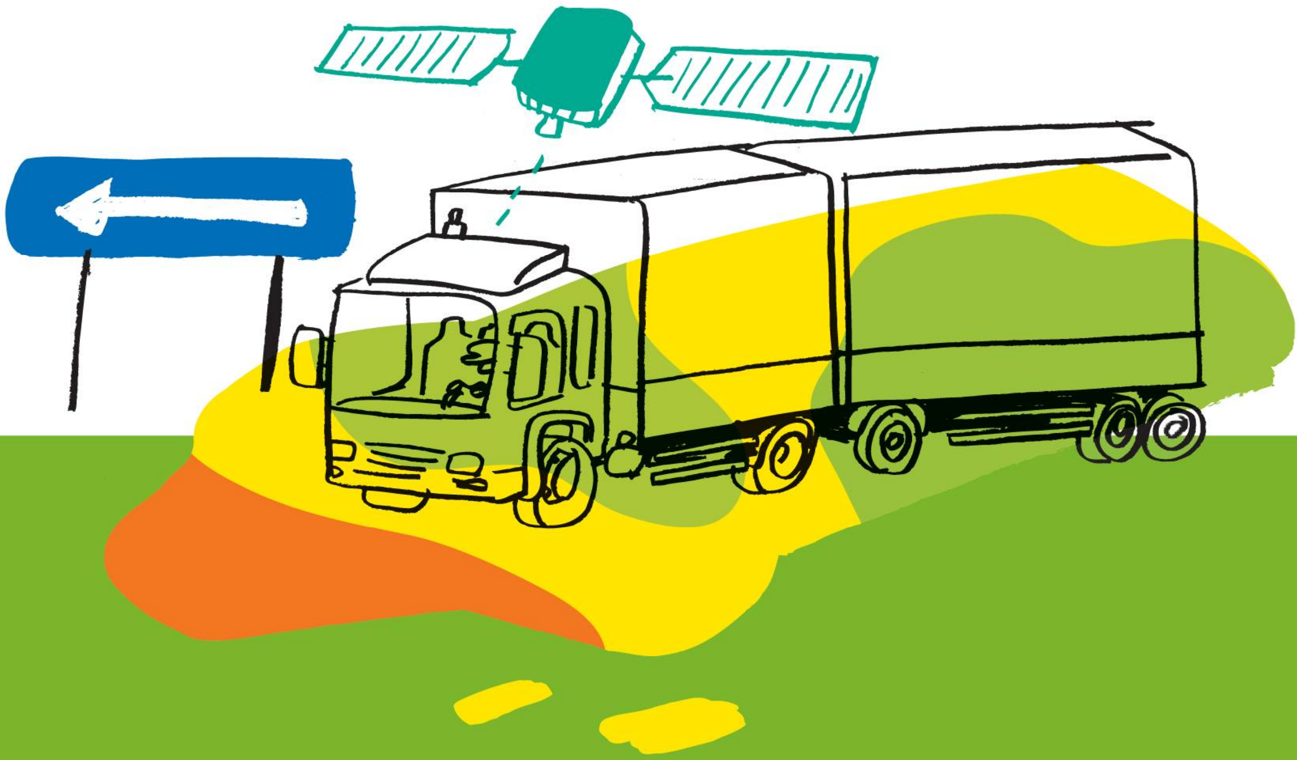

A kilometre tax for heavy goods vehicles in Sweden – A conceptual systems design.

Part 2: Proposals for systems design

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arena

ARENA REPORT 2008:3

2008-02-29

The ARENA project

ARENA is a national project that aims to build competence for a future introduction of a road user charging system for Heavy Goods Vehicles (HGVs) in Sweden. The project has been developed in accordance with EU Directives and the Swedish public authority plans to introduce a kilometre tax for HGVs. ARENA started in 2006 and is financed by the Swedish Road Administration and the Swedish Governmental Agency for Innovation Systems. NetPort.Karlshamn is the project coordinator.

The approach of ARENA is to take a wide view and not only focus on technology. Innovation potential, consequences and possibilities related to an implementation of road user charging is also important as well as respecting that different stakeholders have different needs and requirements. This requires interaction between relevant stakeholders at an early stage. The role of the ARENA project includes the following elements:

- acting as broker both between groups of stakeholders who normally do not meet and between competitors within the same group
- develop and support knowledge both within the project but also as a coordinator between other projects

A concept for a kilometre tax system in Sweden is developed with a functional approach, which does not prescribe any technical solutions. The concept is generic rather than specific, in the sense that it should be possible to implement the result in several ways. Hence, we are trying to define the system independently from its final technical design. The motivation for this is that the time horizon for realisation is far ahead, maybe 3-6 years, and we can expect considerably changes in technical preconditions over this period. The concept includes a number of characteristics that differs from existing systems, which will reduce cost, promote innovative solutions and enable European interoperability.

The work of ARENA will continue in ARENA 2.0, where the concept will be further developed in close cooperation with the industry and relevant authorities and administrations. A full-scale demonstration will be developed for the ITS World Congress in Stockholm 2009.

Swedish Road Administration

The Swedish Road Administration (SRA) is the national authority assigned the overall responsibility for the entire road transport system in Sweden. SRAs task is to co-operate with others to develop an efficient road transport network in the direction stipulated by the Swedish Government and Parliament. SRA has been commissioned to create a safe, environmentally sound and gender-equal road transport system that contributed to regional development and offers individuals and the business community easy accessibility and high transport quality.

VINNOVA

VINNOVA (Swedish Governmental Agency for Innovation Systems) is a State authority that aims to promote growth and prosperity throughout Sweden. VINNOVAs particular area of responsibility comprises innovations linked to research and development. The tasks are to fund the needs-driven research required by a competitive business and industrial sector, and to strengthen the networks that are such a necessary part of this work.

Preface

This report has been developed within the ARENA project[1]. It presents an approach to a systems design for the foreseen Swedish kilometre tax for heavy goods vehicles, providing a platform for a continued analysis within the project concerning feasibility and viability, security etc.

The report has been developed by Ulrik Janusson[2], Thomas Sjöström and Jonas Sundberg at SWECO VBB, and is based on and represents the authors own judgements. It has been thoroughly discussed with various stakeholders inside and outside the project, but does not represent a formal common standing for the project partners of ARENA.

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[1] *www.arena-ruc.se*
[2] Earlier family name Karlsson

Table of contents

Introduction

The objective of the ARENA project is to develop a possible solution for a Swedish kilometre tax system for heavy goods vehicles. The development will follow several stages, where the first step is to develop a conceptual systems design.

We have decided to use the term *conceptual* in order to underline that the solution shall be generic rather than specific, in the sense that it should be possible to implement the result in several ways. Hence, we are trying to define the system independently from its final technical design. The motivation for this is that the time horizon for realisation is far ahead, 4-6 years, and we can expect considerably changes in technical preconditions over this period.

The structure of the Conceptual design

The Conceptual design is divided into two documents with annexes:

Part 1: Requirements and preconditions

Part 2: Proposal for systems design (this document)

Special comment to this document

This report includes an example of a technical implementation. It shall be understood that this is made in order to illustrate the concept, and not in order to present a proposed technical solution.

Main functions

DFD 0 – Main functions in the kilometre tax system

The global function ”charge kilometre tax” is composed of four Main Functions:

1. Establish User Contract
2. Register Track Data
3. Charge Payment
4. Compliance Control

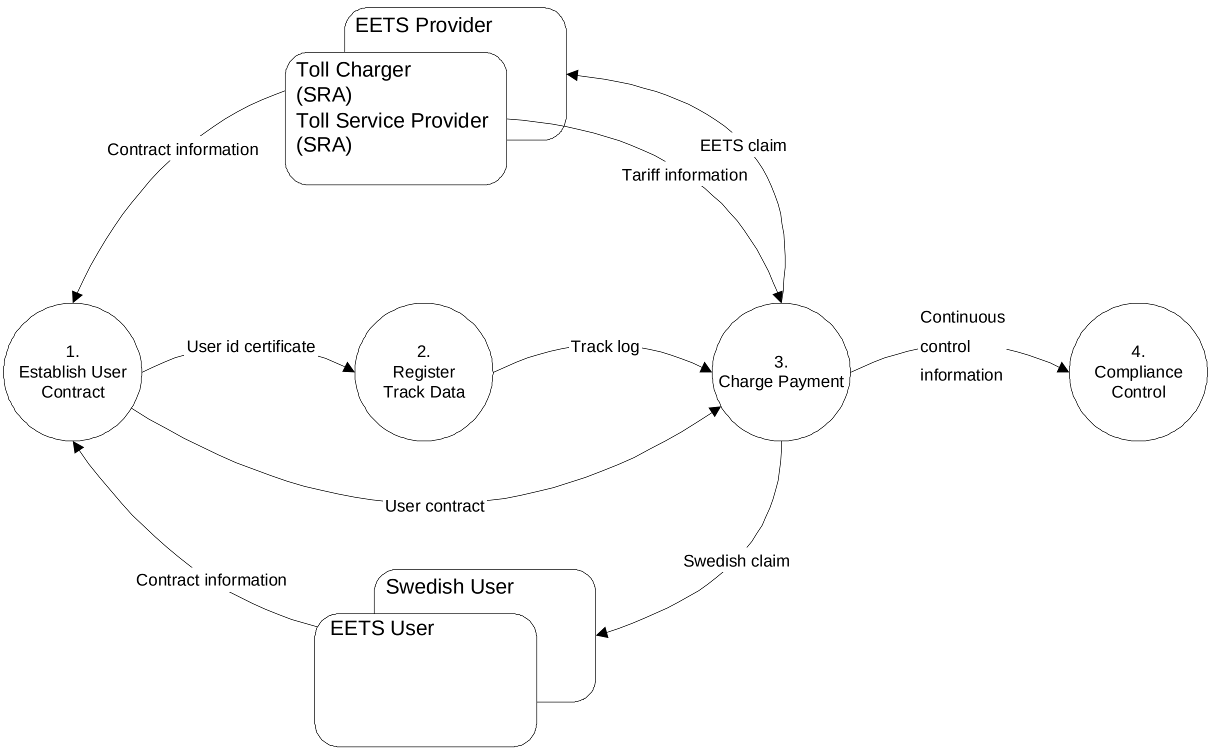

Figure 1 DFD 0: Main functions and data flows in the kilometre tax system

Explanations to the diagram

A contract is established (Function 1) between the user (representing a particular vehicle) and a service provider, which may be Swedish (within Sweden only) or European (EETS, in all Europe including Sweden). The European EETS Provider provides OBU´s to associated EETS Users, and a Toll Service Provider (e.g. SRA) provides the same service towards Swedish users. The contract includes vehicle characteristics and other user information that are taken into account in the tax calculation and debiting process. The contract establishment includes issuing a security module which is installed in the OBU (User id certificate).

The decision whether a vehicle that have performed Track Data Registration (Function 2) is liable to pay tax is taken in the Charge Payment function (Function 3), based on the track log and user contract information. Charge Payment also takes into account possible discounts or additions, based on vehicle characteristics, earlier registrations and performed payments. The Toll Charger (e.g. SRA) will provide information on applicable tariffs, and the kilometre tax is calculated and decided upon on the basis of track logs signed by the OBU.

The debit is made by invoicing Swedish users, or the associated EETS Provider for further claims towards the EETS User concerned. The information flows and processes for invoicing and payments are however outside the scope of this document. The Control System (Function 4) is provided with reported declaration sequence numbers per vehicle, which are unique for each transaction.

The compliance control consists of a series of functions. There is a real-time control of the OBU function, as well as control of reported data and that the positioning unit is providing correct information. The compliance control is also looking at the function that calculates the tax due, and is using also other sources of information (e.g. vehicle trip-meter) for control purposes.

Functions

Function	**Content**
1. Establish User Contract	See DFD 1 – Establish User Contract
2. Register Track Data	Successive positions (track data) of a vehicle are registered in the OBU in real time
3. Charge Payment	Decision on liability to pay tax is taken, the tax is calculated and debited
4. Compliance Control	Control of trip declarations made and the OBU function in real time. Control of calculations and payments in non-real time. Management of exceptions and fraud.

Information flows

Information flow	**Content**
EETS Contract Information	The information required to establish a contract between an EETS Provider and a user (vehicle owner). Among others, vehicle characteristics (environmental class, number of axis and max laden weight), owner and registration id, payment information
SRA Contract Information	The information required to establish a contract between SRA and a user (vehicle owner). Among others, vehicle characteristics (environmental class, number of axis and max laden weight), owner and registration id, payment information
User Id. Certificate	A unique secure vehicle identifier and a certificate to sign data
User Contract	The contract between the user and his service provider (SRA or EETS)

Track Log	The travel path for a specific vehicle together with required control information (e.g. dynamic vehicle information[3]). See also DFD 2.
Tariff Information	The tariff class and length for all road links in the kilometre tax system, and the tax associated to each tariff class
Continuous Control Information	Data provided for each tax decision to ensure that no gaps appear in the transaction records and declarations
Swedish claim	Claims for kilometre tax towards a vehicle owner with a Swedish Contract
EETS claim	Claims for kilometre tax towards a vehicle with an EETS Contract. Claim is sent to the EETS Provider associated with the user

[3] E.g. use of trailers

Detailed Functional Descriptions

DFD 1 – Establish User Contract

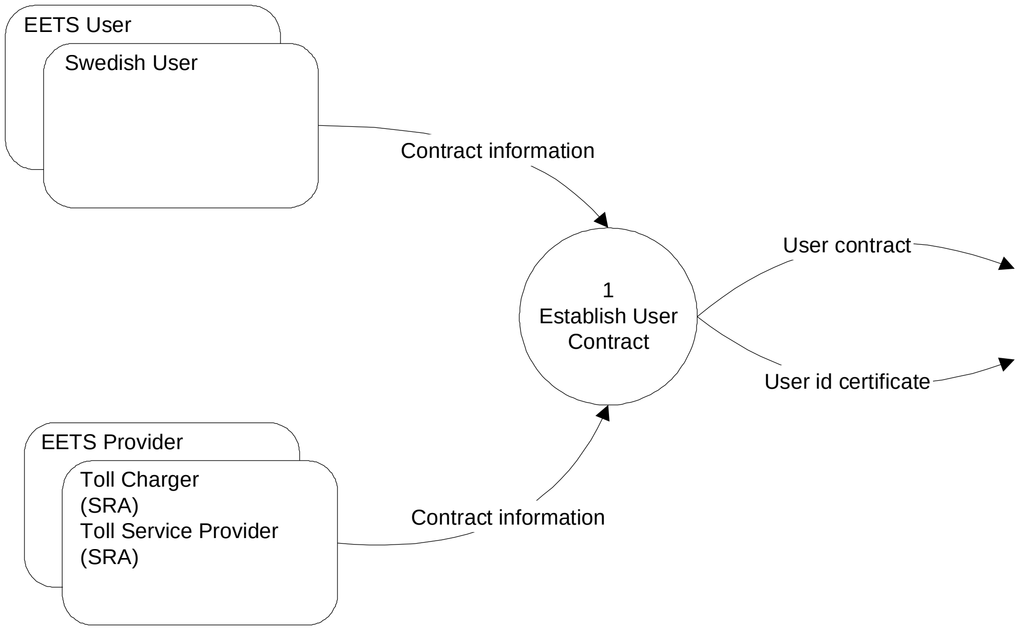

Figure 2 DFD 1: Establish User Contract

Explanations to the diagram

A user only transporting goods domestic in Sweden enters into an agreement (Establish User Contract, Function 1) with a Swedish toll service provider (e.g. SRA). A user transporting goods in also other European countries enters into an agreement with an EETS Provider. Hence also Swedish users driving outside Sweden will prefer to enter an agreement with an EETS Provider in order to avoid multiple contracts and multiple OBU´s. The EETS Provider manages payment transactions and agreements with road user charge systems nationally and internationally in accordance with an interoperability contract[4]. This means that a user needs only one contract and one OBU for all the road user charges systems he encounters. Within this function, the user will provide information on vehicle characteristics of importance for the tax calculation to the Toll Service / EETS Provider whom in return provides a payment means, e.g. an OBU[5] and necessary certificates for security and integrity protection. Contract information is used to provide background information for tax calculation.

Functions

Function	Content
1. Establish User Contract	A contract is established between an user and an issuer of payment means for road user charges (OBU). An identity-reference is created and exchanged between user and issuer. Those procedures that are required by the concerned EETS / Toll Service Provider to accept a user as a client are registered in the agreement.

[4] The design of an interoperability contract is part of e.g. the CESARE project. This will not be discussed further in this report.
[5] The payment means can be reduced to a unique and secure method for validating track data

Information Flows

Information flow	Content
Contract Information	See DFD 0 – Main functions in the kilometre tax system
User Contract	See DFD 0 – Main functions in the kilometre tax system
User id certificate	A unique and secure vehicle identifier and a certificate to sign OBU data

DFD 2 – Register Track Data

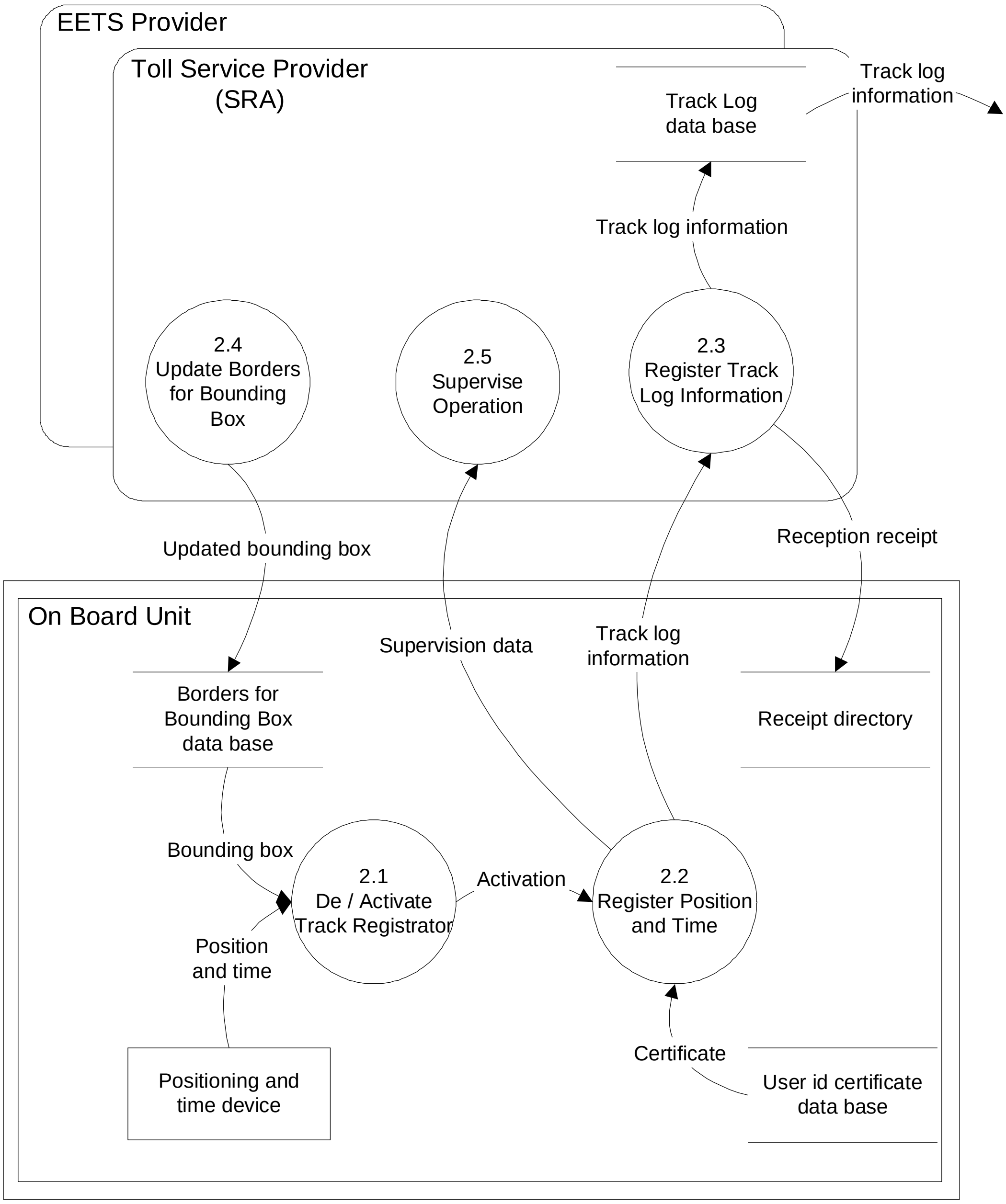

Figure 3 DFD 2: Register Track Data

Explanations to the diagram

When the vehicle cross a geographical border (defined through function 2.4), the OBU will activate or de-activate the track registration (function 2.1) due to the known borders of the area where the kilometre tax is liable. Output from the positioning- and time device inside the OBU are registered in batches as position- and time statements, numbered and signed by the User Id certificate and stored in the secure area of the OBU (function 2.2). Track log is communicated in accordance with the systems requirements to the Toll Service Provider whom communicates back a receipt where reception of the Track log is acknowledged (function 2.3). This receipt may later be used as the users proof of track log declaration in a control situation. When the OBU enters into active registration mode is it reasonable to expect a verification of the interface between the Toll Service / EETS Provider and the OBU e.g. to verify that the Toll Service Provider accepts reports from the OBU in that specific area. In combination with this “handshake” also some kind of supervision of the OBU function can be initiated and e.g. operational instructions downloaded to the OBU (function 2.5). This interface shall not be mixed with the control parts of the system which perform verification “from the outside” while this function is internal inside the system. This interface will be proprietary in the sense that it is most likely an interface between two system parts being supplied by the same entity.

Functions and data stores

Function/data store	**Content**
2.1 De-/ Activate Track Registration	A function that trigger or terminate the OBU´s logging of position and time when the vehicle cross the border to the area included in the kilometre tax. The precision needs not to be very high as long as more logging is done than required. This is first of all a protection against unnecessary communication costs from transport in areas (e.g. abroad) where no tax is due.
2.2 Register Position and Time	Each position and time record is added to the present batch of records for the coming report to the central system. Each batch is given an unique sequence number. This is carried out inside the secure component of the OBU and in a way that ensure that all data have to be reported in order to fulfil the requirements from the control systems
2.3 Register Track Log information	The signed track logs that have been uploaded from an OBU are registered and stored in a central system server, and a receipt of reception is communicated to the sending OBU. Following this, the EETS/Toll Service Provider resumes the responsibility for the further steps in the payment process
2.4 Update Borders of Bounding Box	Function updating (by download to the OBU´s) information on the borders of the area for which the kilometre tax is effective (in the format of polygons)
2.5 Supervise Operation	An internal support function verifying the functionality and validity of the interface between the OBU and the EETS / Toll Service provider system
Border for Bounding Box database	Database containing updated information on the borders of the area for which the kilometre tax is effective (in the format of polygons)
Track Log data base	Central system database for track log registration and directory
Receipt directory	Receipts for uploaded track logs are stored in an OBU registry as proof of declarations in case of control situation
User id certificate database	A data store with the unique and secure vehicle identifier and a certificate to sign OBU data

Information flows

Information flow	Content
Activation	Instruction changing track logging mode (on/off)
Position and time	Longitude, latitude (or other position indicator[6]), date and time
Track log	One record with a) A list of longitudes and latitudes (or other position indicators) with corresponding date and time b) changes in dynamic vehicle data (e.g. presence of trailer) c) the vehicle identity d) a sequence number increasing with 1 for each record, preventing gaps in information e) a flag indicating occurrence of too many un-reported position and time records f) a signature to ensure the message integrity
Reception receipt	A signed receipt from the CS on the successful reception of an uploaded track log (including its identifier)
Supervision data	Information ensuring and controlling the correct functioning and the validity of the interface between the OBU and the Toll Service / EETS Providers road side system.
Certificate	A unique and secure vehicle identifier and a certificate to sign OBU data
Bounding Box	The borders of the geographical area where the OBU is in active registration mode
Updated Bounding Box	Changes in the border definition

[6] Different position indicators can be mixed; co-ordinates, DSRC installations, GSM positioning support etc.

DFD 3 – Charge Payment

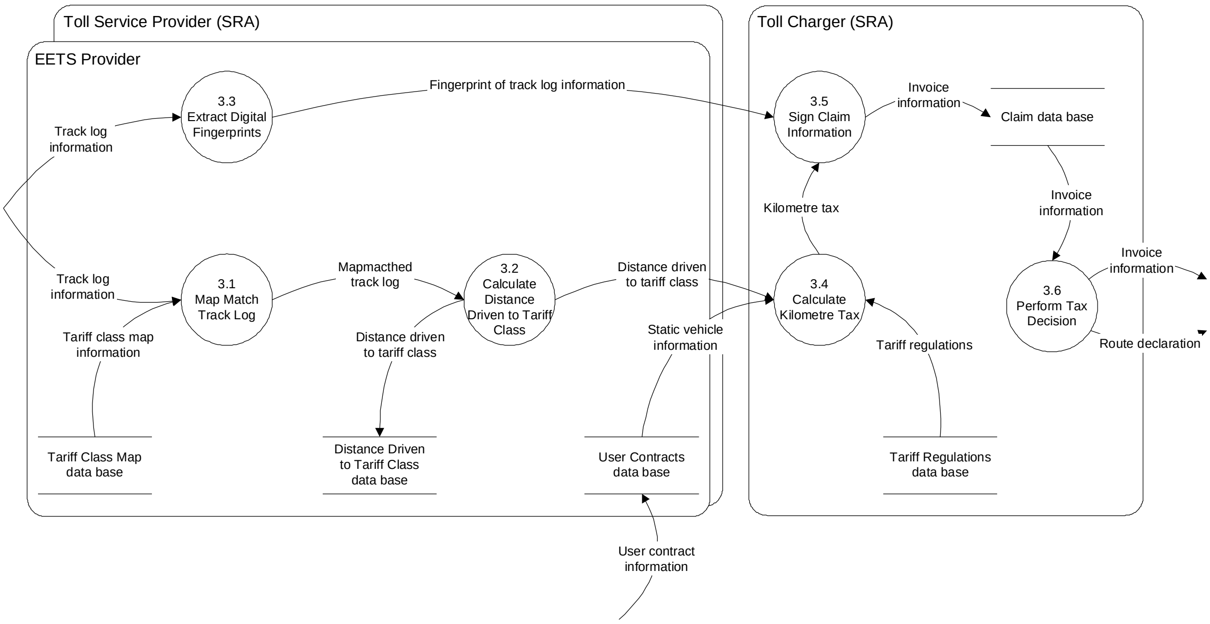

Figure 4 DFD 3: Function Charge Payment. Sub-functions 3.1-3 are managed by the EETS/Toll Service Provider, while 3.4-6 are managed by the Toll Charger

Explanation to the diagram

The Track Log which have been sent from the OBU to its associated EETS / Toll Service provider is transformed through map matching into a verified travel path (sequence of road segments as defined in the "price list" (tariff class map data base). Total driven distance per tariff class[7] is calculated (function 3.2) and stored in a database for control purposes. The kilometre tax is calculated by the Toll Charger[8] (function 3.4) from the applicable tariffs, dynamic vehicle data retrieved from the Track Log (e.g. presence of trailer) and relevant vehicle characteristics from the contract (e.g. environmental class).

The function *Extract Digital Fingerprints* (function 3.3) process the original track logs ("raw data") and extracts the set of fingerprints related to the track logs forwarded for tax decision. This set of fingerprints links the kilometre tax with the original track log, and can be used for control and verification purposes. The finger print process can establish a singular relation between the tax decision and the underlying information, without any need to reveal the track log in clear print to the Toll Charger. This is above all a measure to protect the privacy of the user.

The fingerprints and the resulting kilometre tax are merged and digitally signed (function 3.5) by the Toll Charger. The signature means that the Toll Charger will certify the correctness of the data, and the combined information can be brought forward for a formal tax decision (function 3.6) and the user debiting process. The tax decision and invoice will include a table with the track log sequence numbers included in the claim, for user verification.

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[7] All road segments are classified in tariff classes (e.g. high, low, or zero fee applies)
[8] This is a presumed legal requirement for Sweden

Functions and data stores

Function/data store	Content
3.1 Map Match Track Log	Consecutive positions are map matched against a digital road map (e.g. NVDB[9]) and the journey converted into a series of road segment.
3.2 Calculate Distance Driven to Tariff Class	Each road segment is assigned a tariff class according to the principles of VTU[10]. The total distance travelled on each tariff class road is calculated. Observe that the reported journey may include road segments that are exempt from tax.
3.3 Extract Digital Fingerprints	The digitally signed fingerprints of the Track Log are extracted from the Track logs
3.4 Calculate Kilometre Tax	Each tariff class corresponds to a price per kilometre, which multiplied to the length of the road segment and with vehicle specific parameters gives the kilometre tax for the road segment. A specific set of regulations handles anomalies and particularities like procedures to apply when the journey involves only one road segment.
3.5 Sign Claim Information	The digitally signed fingerprint of the Track Log is combined with the calculated kilometre tax and digitally signed. The result is a set of information including as well the resulting tax as a reference to the “raw data”.
3.6 Perform Tax Decision	The formal tas decision is performed and a claim is invoiced. In the case of a Swedish user the claim will directed towards the vehicle owner. In case of a EETS user the claim will be directed towards the EETS provider.
Tariff Class Map data base	A digital road map (e.g. according to NVDB) where each road segment is defined and assigned a tariff class.
Distance Driven to Tariff Class data base	A data store to be used for control and verification purpose. It includes the resulting distribution of distance driven per tariff class road and the track log sequence numbers included.
User Contracts data base	The OBU issuer (EETS or Toll Service Provider) database with static vehicle characteristics
Tariff Regulations data base	The regulations applied for tax calculations and tax decisions
Claim data base	Data base with the compiled datasets used for tax decisions

Information flows

Information flow	Content
Tariff class map information	Each road segment in NVDB is associated with a specific tariff class

[9] NVDB, the national Swedish road data base, shall be regarded as an example of a suitable platform
[10] The National Road Tax Investigation, SOU 2004:63

User contract information	User information and vehicle characteristics required for the appropriate tax calculation and claim forwarding
Map matched Track Log	The travel path expressed as a series of road segments
Distance driven to tariff class	Driven distance per tariff class and the included sequence of track log data
Tariff regulations	The rules required to calculate the tax from trip information. Examples are price per km. for the different tariff classes, time differentiation rules, minimum and maximum limits, environmental class parameters etc.
Kilometre tax	The resulting kilometre tax
Fingerprint of track log	The digitally signed fingerprint of the track log. The fingerprint ensures a reference back to the raw data for control purposes
Invoice information	A digitally signed combination of the fingerprint of the Track Log combined and the calculated kilometre tax. A set of information including as well the resulting tax as a reference to the "raw data".
Route declaration	The sequence numbers of the track logs associated with the claim / invoice. Allows the user to verify the reporting chain.
Static vehicle information	Fixed information of relevance for tax calculation, e.g. environmental class
Track log	See DFD 2

Distribution of functionality between Toll Charger, Toll Service Provider (SRA) and EETS provider

The distribution of functionality between actors is trivial in those cases where the user is associated with the Swedish Toll Service Provider since as well the role of Toll Charger as the role of Toll Service Provider may be maintained by SRA and its contractors. Here the user will not clearly distinguish the distribution of responsibility and functionality[11].

A more interesting situation appears with EETS users[11]. They will have a particular contractual relation which also includes the EETS providers payment obligation. The whole process of track data registration (through track registration, Function 2) is clearly the responsibility of the EETS provider.

Remains the Charge Payment process. Here as much responsibility as possible must reside with the EETS Provider, except for the formal tax decisions. There are many reasons to this:

- The EETS Provider has the best possibilities to follow up the users through their contractual relation
- The EETS Provider will be able to apply its own methods and knowledge to interpret/transform the track log to a travel path

[11] If the Swedish TSP is an entity outside SRA, the situation will be quite similar to the EETS case

- It allows for each EETS Provider to apply also its own methods for communication between the OBU and the Central System
- The Toll Charger will have a well defined counter-part when it comes to the definition and application of performance criterions, quality levels etc.
- The formal tax decision, including tax calculation, has to be made by a Swedish authority (The Toll Charger)

For this reason, it is reasonable to give the responsibility for Functions 3.1-3.3 to the EETS Provider, and the remaining functions to the Toll Charger.

It should be noted that that this distribution of responsibilities between the Toll Service Provider and the Toll Charger may also be subject to discussion in the Swedish case.

DFD 4 – Compliance control

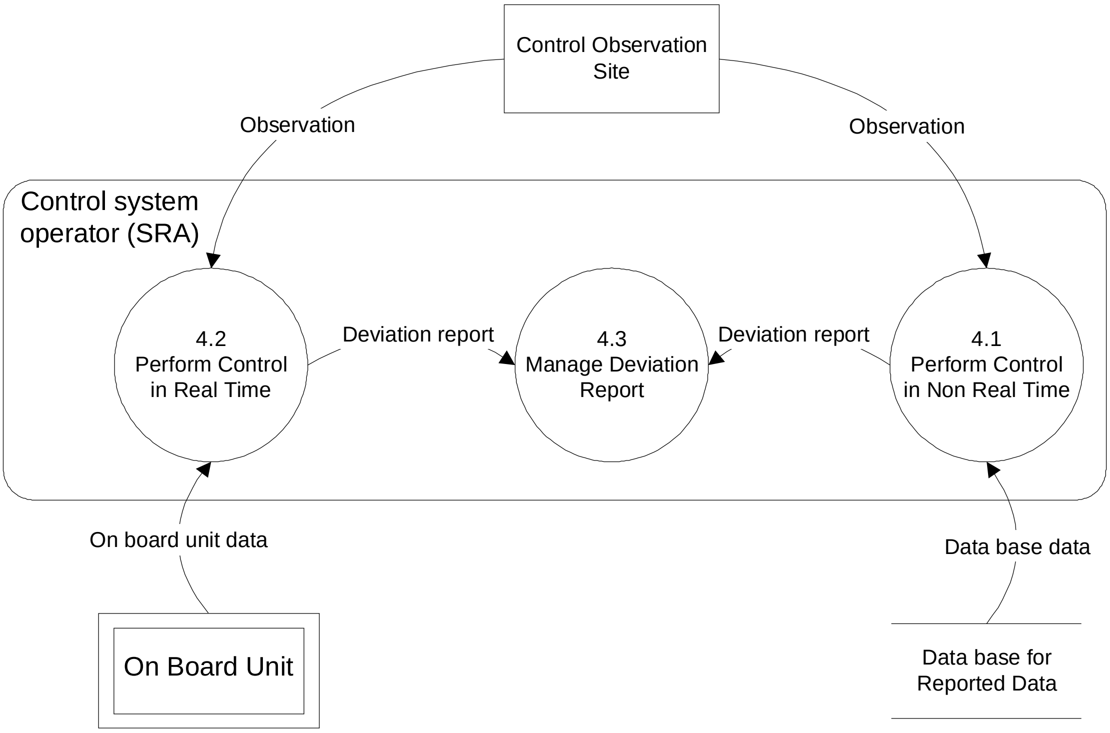

Figure 5 DFD 4: The Compliance Control Process

Explanation to the diagrams

The *Compliance Control Function* includes the various control mechanisms that will be associated with the kilometre tax. Control is made off-line on verified payments (4.1) as well as against the OBU in real time[12] (4.2). An important characteristic of the compliance control is that different control methods supplement each other. The functions and methods that are presented here shall be regarded as examples of different types of control rather than final or detailed proposals. It is also obvious that the opportunity for control is different for domestic and foreign vehicles. Data that is registered through the annual vehicle inspection (e.g. trip meter data) can not be expected to be accessible for foreign vehicles.

[12] This is an optional functionality, although required for e.g. NORITS interoperability

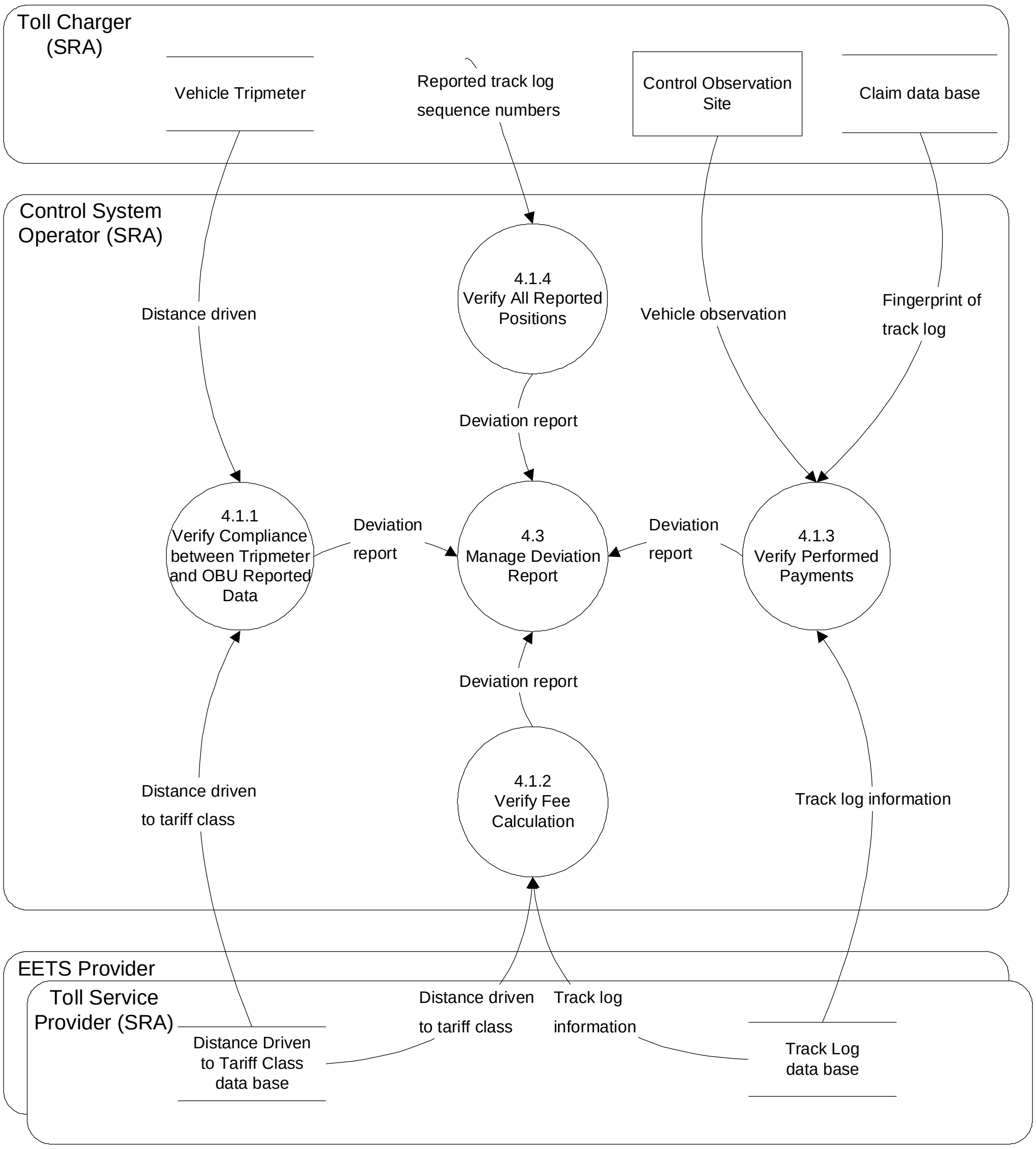

Figure 6 DFD 4.1: The Non real time compliance control

Control functions may share information with other systems, as the digital tachograph or the vehicle trip meter in order to detect deviations. The tachograph and the trip meter store information on distance driven which can be verified against the distance reported through the kilometre tax system. This process is carried out in the function *Verify compliance between trip meter data and reported OBU data* (function 4.1.1) and can be carried out with the annual inspection or between specific time periods[13].

The proof that the use of a certain road segment has been properly declared is stored in the *distance driven to tariff class* database with the Toll Service Provider, and that receipt can be compared with

[13] The tripmeter is an example of a parallel system recording travelled distance. Also the tachograph and other possible systems can be used for this kind of control. Depending on the period studied, possibly also foreign vehicles and vehicles in international traffic can be subject to control.

the track log data (function 4.1.2 *Verify fee calculation*) reported by the OBU. This control can be used to verify the correctness of the map matching and also the proper information management by the Toll Service Provider. Any discrepancy will generate exception handling. The OBU provides all registered track logs with a sequence number (function 2.2). Through function 4.1.4 *Verify all reported positions* the completeness of the reported information is checked (there shall be no missing sequence numbers) which ensures that all trips have been reported. The use of sequence numbers allows the user to cross-check reported trips against charged tax, as the sequence numbers are included in each tax claim.

An important control method is to match observations (either from video registration or DSRC communication with OBU) against verified payments. This is carried out in function 4.1.3 *Verify performed payments* where the Toll Charger collects / requests the track log data that include a specific observation (vehicle + time + place) and necessary keys to decode and verify the associated *fingerprints of track log* that the Toll Charger received together with the associated declaration (Distance driven to tariff class + static and dynamic vehicle information). Registration of all vehicles entering and leaving the country provides a list of all foreign vehicles that are expected to perform payments for a certain time period. Vehicles that have remained inside the country should be able to report an undisturbed track log without missing segments. Also pictures from random checks at "speed camera sites" are used to verify compliance with the kilometre tax. Compliance is controlled in two steps: First step means controlling that a valid declaration from the vehicle concerned exists, second step means verifying the full content of the declaration. Not all observations will be subject to control of the second step. Deviations of either kind (absence of declaration or faulty declaration) will bring the vehicle to black-listing.

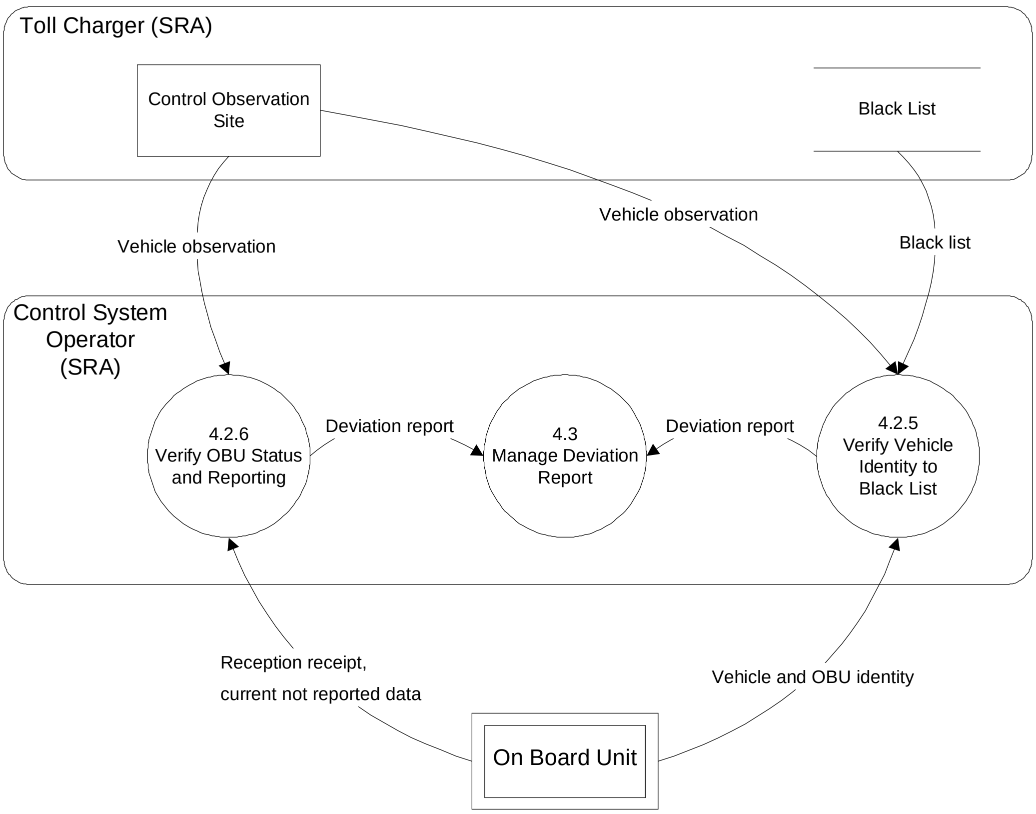

Figure 7 DFD 4.2: The real time compliance control

The system uses two kinds of black lists:

a) One including **the identity of OBU**´s that do not perform reporting as requested, and for this reason have been black listed by the Toll Charger, and also e.g. OBU´s that have been reported stolen or where the user has not fulfilled his obligations towards the associated issuer (EETS / Toll Service Provider). In the latter case, all obligations of the Toll Service Provider cease. This black list is available at DSRC based Control Observation site and will trigger video registration when a black listed OBU is passing the control station. All vehicles in this group are also brought into the next type of black list.

b) A black list including **the vehicle**s (registration numbers) that have been recorded for an exception, e.g. in case of a post-payment control or recorded absence of declaration from a foreign vehicle. Also cases where efforts to establish a DSRC contact has failed and video registration has been made belong to this group. It should be possible to stop vehicles belonging to this black list for road side control, at borders, at combined control of driving time etc. , in order to issue fines.

Control against black lists is made at passage of Control Observation Sites (function 4.2.5 *Verify Vehicle Identity to Black list*) and in connection with road side control.

An important possible control method is the real-time control *Verify OBU status and reporting* (function 4.2.6). When OBU´s pass a Control Observation Site, control is made on the presence and functionality of the OBU through DSRC. The OBU provide proof that it is not tampered with through response to a status request, and provides also its latest *Reception receipt* (DFD 2) and the current batch of not reported track log. This control is carried out in real time by DSRC and the control system can immediately verify whether correct recording is ongoing. This kind of control can also be made by mobile units, e.g. by use of hand held DSRC readers.

Functions

Function	**Content**
4.1 Perform Control in Non Real Time	See DFD 4.1
4.2 Perform Control in Real Time	See DFD 4.2
4.1.1 Verify Compliance between Tripmeter Data and OBU Reported Data	Reported OBU data is compared with trip distance recordings from other systems, e.g. the vehicle tachograph or the vehicle trip meter.
4.1.2 Verify Fee Calculation	Control of the correct application of map matching and distribution to tariff classes to the track log.
4.1.3 Verify Performed Payments	Verification of payments against background information. Requires access to original track log.
4.1.4 Verify all Reported Positions	Verification that all Track Log sequence numbers have been reported (no numbers missing)
4.2.5 Verify Vehicle Identity to Black List	Real time control of OBU identity versus the OBU Black List. Is performed at Control Observation Sites
4.2.6 Verify OBU Status and Reporting	The function controls in real time that there is an OBU installed in the vehicle and that it functions properly. The OBU response information include a reference to the last reception receipt and information from the

	secure core on the latest recorded but not reported track log.
4.3 Manage Deviation Report	Detected deviations are brought forward for exception handling and possibly enforcement.

Data stores and external objects

Data store / External object	Content
Data base for Reported Data	Generic. See detailed data bases below
Vehicle trip meter	Example of supplementary trip recording
Distance driven to tariff class data base	A data store to be used for control and verification purpose. It includes the resulting distribution of distance driven per tariff class road and the track log sequence numbers included.
Track log database	Central system database for track log registration and directory
Control Observation Site (Station)	Road Side installation equipped with DSRC and video registration capacity. Register and control passage of all HGV in real time.
Black List	Data base comprising identity of all OBU´s which have been considered as non-valid. Available at all Control Observation Sites. Data base comprising identities (license plata data) of vehicles that has been concluded as non-compliant
Claim data base	Data base with the compiled datasets used for tax decisions

Information flows

Information flow	Content
On board unit data	Generic. See detailed information flows.
Observation	Generic. See detailed information flows.
Data base data	Generic. See detailed information flows.
Distance driven	Record of distance driven during a certain time period from other source than track log (e.g. vehicle trip meter)
Distance driven to tariff class	Driven distance per tariff class and the included sequence numbers of track log data
Track log	See DFD 2
Reception receipt	A signed receipt from the CS on the successful reception of an uploaded track log (including its identifier)
Current not reported data	Track log that has not been uploaded from the OBU (current batch)
Vehicle observation	A Control Site recording of the presence of a certain vehicle at a certain place at a certain time

Route declaration	The sequence numbers of the track logs associated with the claim / invoice. Allows the user to verify the reporting chain.
OBU identity	A unique identifier of the OBU (and hence the vehicle)
OBU status request	A cryptographic challenge in a challenge/response sequence
Deviation Report	A negative result from a control function. Trigger exception handling procedures.
Black list	Generic. Either list of OBU id´s that are not valid or list of vehicles (registration numbers) that shall be enforced
Vehicle identity	Vehicle registration number (license plate)

An example of technical implementation

Taking into account the vast road network that will be included in the kilometre tax for Heavy Goods Vehicles in Sweden, a realistic implementation must be based on the use of in-vehicle On Board Units for collection and communication of trip data, corresponding road side and central systems and control measures applied to validate that trip information has been properly declared and/or that the OBU is active. To be able to design the data flows between the OBU, the road side installations and the central systems is it necessary to make assumptions on the OBU functionality, capacity, security measures etc.

The on-board unit

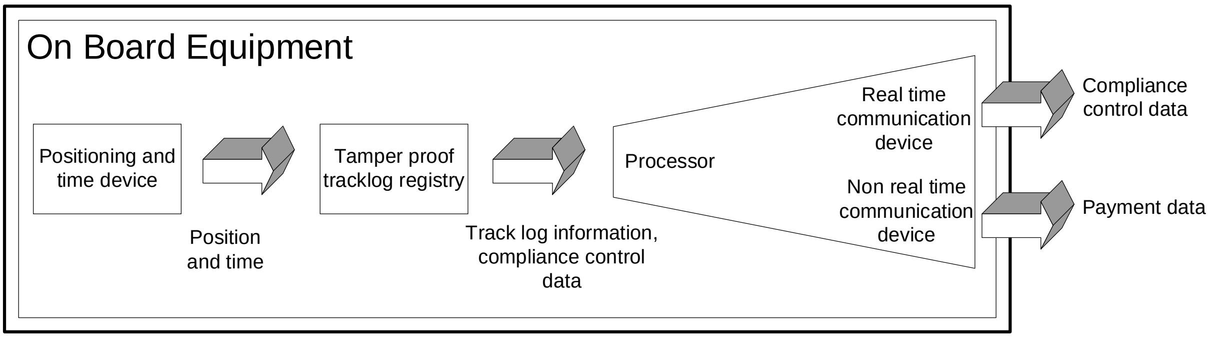

Figure 8 OBU Architecture

Positioning- and time device

Current time and position are continuously provided by sensors. The level of precision required is not yet fully clarified. Several techniques can be envisaged; GNSS systems as GPS is already available and Galileo is coming. We can also foresee combinations of GNSS and CN or even CN only. Also signals from road side installations, like DSRC, can be used to enter position and time data.

An important feature of the Swedish concept is that it does not prescribe a particular solution for sensors, suppliers may decide on any combination of technologies, as long as the precision and density is good enough to provide a good representation of the actual travel path as it is used to restore the travel path for tax calculation (see DFD 2).

The Secure Track Log Recorder

The most important feature of this component is that it is tamper proof. Hence it can be considered as a trusted device by as well the User and the Toll Service Provider as the Toll Charger.

The secure Track Log Recorder is the kernel of the OBU in the Swedish concept. It could be a smart card (IC-card) which stores and generates the Track log from the position and time records that is coming from the Positioning- and time device.

The Secure Track Log Recorder store a batch of records, until reporting criteria is met, attach a sequence number to the batch to enable verification of all information being reported, and finally signs the batch and sequence number to guarantee its validity and to prevent later manipulation. The process is designed to prevent any efforts to generate valid data packages at later moments, e.g. in the event of a control situation.

The key control functions will require that the control response include or can point at information that has been signed by the Secure Track Log Recorder.

Processor

A processor ensuring that the secure Track log is reported (uploaded) either on command or according to a pre-defined periodicity, and providing a response to a control request. No particular requirements on security or trustworthiness are needed.

Communication units

The OBU is equipped with two communication units. The communication unit that is used for control purposes has to be able to communicate in real time due to the requirement of a real time control function. The communication distance may be short, and this may even be regarded as an advantage since it then also can be used to position the vehicle.

As this will mean that the responding device most likely is a road side installation, we can expect that the amount of transferable data must be limited. As we have an additional requirement on interoperability with existing DSRC-systems, is it easy to envisage DSRC as the communication solution selected for the real time communication. Communication on this link is always initiated by the road side installations.

The non-real time communication is mainly used to report (upload) Track Log data. The periodicity in the reporting will depend on geographical position, driving pattern and access to network. A probable selection of technique is Cellular Network of type 2,5 G or better.

The Toll Service (EETS) Providers central system

The Toll Service Provider receives signed Track log from the OBU. The Track Log is map-matched and converted into a series of pre-defined road segments according to “tax-NVDB”[14]. This information is then compiled into a ”declaration” consisting of driven distance per tariff class and other information of relevance for the tax calculation (e.g. dynamic vehicle characteristics).

In the case of an EETS User, we assume that the EETS Provider is responsible for the (communication) interface to the associated OBU´s. The EETS Provider is also responsible for converting the Track Log and compiling it with other information to the declaration required for the tax decision. This means that the Toll Service Provider will have access to a certified map matching algorithm and the underlying network database (tax-NVDB).

Since the Toll Service (or EETS) Provider also generates a digital fingerprint of the Track Log that forms the basis of the declaration, the Travel Log in clear print does not have to be included in the declaration. This will make it possible for the Toll Charger, when needed (e.g. in compliance control), to verify the track log that formed the basis for a specific declaration.

[14] E.g. a version of the national road database (NVDB) where the road network is defined as a set of road segments (links), and each segment has specific properties like length and tariff class

The Toll Chargers central system

The Toll Charger calculate the kilometre tax using the declaration received (distance driven per tariff class and static and dynamic vehicle characteristics) and applying the various rules that are defined for the tax calculation (possible reductions for first and last segment, maximum levels etc.) and combine this information with the fingerprint of the Track Log to a digitally signed unique set of information which is used for the tax decision.

The communication of the tax decision, and the regulations applied for the tax decision may follow the principles applied for the Stockholm Congestion Tax.

The Control System

We expect the control system to use parallel and supplementary methods:

a) The OBU is equipped with a real-time communication unit (e.g. DSRC) to enable identification and response to control requests at Control Sites, border crossings etc. Exceptions will trigger video registration of license plates, and an off-line request to provide proof of a performed Track Log registration or reference to a provided declaration.

b) In case of off-line control, the Toll Service Provider will be requested to display the specific Track log corresponding to a certain declaration or a specific observation of the vehicle at the road network. Exceptions (failure to prove declaration) will trigger a contact with the vehicle owner / Toll Service Provider. As the User through his OBU (IC-card) can provide a reception receipt on submitted Track Logs, the position of the vehicle owner versus the Toll Service (EETS) Provider can be secured.

c) Spot checks through registration by video, manual observation, hand held DSRC or other methods, will be pursued as in b)

d) Verification of declared trips against other registrations, e.g. the vehicle trip meter, requested tax deductions for fuel costs etc.

e) Registration of all vehicles entering and leaving the country, hence it will be known which (foreign) vehicles that are expected to provide route declarations before leaving the country.

A Control Site is normally a gantry equipped with DSRC transcievers, equipment for vehicle classification (video or laser scanning) and video registration units. This is quite similar to the gantries used for the Congestion Tax in Stockholm[15]. This kind of sites will be seen on the primary road network and at border crossings (with or without DSRC).

The secondary road network will be equipped with video-registration units only (possibly shared with the speed camera infrastructure).

An important feature of the control system, that is outside the technical system, is the possibility to audit business processes of transport service providers in order to ensure that they have a sound implementation of kilometre tax procedures in their business systems. Companies without such sound procedures, will face increased control from e.g. tax authorities.

[15] Probably only front plate pictures are required in combination with some method for classification of vehicles

Threat analysis

Below are presented a number of possible attacks that an intentional cheater could use to try to avoid payment of the kilometre tax. For each attack we also present our counter measures. We assume that a cheater has manipulated the system and has full control over *all* functions *except* those housed in the tamper-proof hardware component.

No OBE

Threat

When analysing all sophisticated loopholes that may exist it is important to not forget the simplest cheat of them all – to remove or unplug (or simply not install) the on board equipment that was to be used for registration and reporting of travel data.

Counter measure

The solution presented in this document relies on spot checks where the vehicle in real time must be able to prove that its data has been reported correctly, which in turn requires an on-board equipment. This is done at Control Observation Sites which are established on the road network, and also through mobile units. It should be possible to stop vehicles on the spot to settle the matter directly with the driver if an OBE is not present. Simply registering the license plate number is not fully enough since many national vehicle registries around Europe have very poor quality and offers limited access.

Manipulation of the positioning- and time device

Threat

Our solution does not secure the positioning- and time device itself. Therefore it is possible to break the connection between this device and the secure track log registry either to completely stop or to alter the dataflow with the help of some kind of cheating equipment. The result is that erroneous (made-up) or no track logs are registered.

Counter measure

The OBE must in a control situation in real time (in practice probably the duration of a DSRC-session) be able to produce the most recent track log reception receipt and a fingerprint of the not yet reported track log currently in the secure track log registry (this action will also force a transferable packet to be compiled so that the fingerprint will not change later on). The transaction sequence numbers on the track log receipt and on the unsent track log must be consecutive. The transaction sequence numbers are written and stamped by the secure track log registry and thus trustworthy. The positions and times in the unreported track log must of course be in accordance with the time and place where control was carried out. This data can not be extracted directly from the fingerprint but can either be a part of the control communication or be retrieved later on from the toll service provider.

Manipulation of the communication devices

Threat

The real time and non real time communication devices in the OBE are used for control communications and track log reporting respectively. All data sent over these links will be signed by the secure track log registry and can therefore not be manipulated without destroying the signature.

Another possibility to fraud is simply to prevent all communication. For the real-time communication device this is the same as when no OBE is present (see section “No OBE”). However the case of prevented communication over the non-real-time communication device, i.e. stopped track log reporting, takes a bit more care in the counter measures.

For a correct answer to the challenge in a control situation a track log reporting reception receipt is needed and also the following, not yet reported track log with transaction sequence numbers. A cheater could see to it that he/she gets one receipt and then never report again, making all the data pile up in the OBE. This way no fee would be billed to the account of the cheater, in addition the available memory in the OBE would eventually overflow and data would have to be thrown away.

Counter measure

When data collected in a control situation is compared with data reported in the usual way it will be easy to spot if the two differ in some way. However, this is not an operation that can be carried out in real time. Firstly, data needs to be retrieved from the toll service provider, an operation that includes a certain delay, and secondly, there has to be something reported that can be compared with. If cheating is confirmed after the control situation is ended the retrieval of usage fee and penalty fee can be initiated. But this is a slow and cumbersome procedure. An alternative counter measure would be a simple black listing of the OBE.

But this does not satisfy our requirement of being able to perform compliance control in real time. On top of this the problem of memory overflow needs to be addressed. Therefore a parameter is included in the track log (stamped by the secure track log registry) indicating whether an overflow has occurred. The driver and OBU will hence soon be alerted on the malfunction, and subject to enforcement in case of continued failure to report.

We can also expect that there is a “handshake” procedure between the OBU and the Toll Service Provider which will signal to the driver at the beginning of each session whether there is any problem with the non-real time communication. The OBU will simply not enter into “operational” mode if it cannot report track logs.

Selective reporting

Threat

Another problem could be if data was not fed into the secure track log registry until a control was performed. When there is no compliance control, data can be thrown away without ever having entered the registry.

Counter measure

The track log registry has a short delay in its input procedure, just long enough to make it impossible during one DSRC-session to feed all the data needed into the track log registry to produce a satisfactory control response.

Threat

The user might be aware of certain areas where spot checks are never performed. Assuming a “no logging” button has been installed on the OBE, this would be a good time to press it, as it will not be detected.

Counter measure

There is no area where it is guaranteed that spot checks will *never* occur, but there are several where it is exceedingly unlikely. It is not possible to just raise the penalty fee to match the low probability of detection since the levels would soon be completely unreasonable. Instead deterrence could be achieved with a combined threat of penalty fees and black listing. If detected it is also possible to for example block that haulier from receiving any public contracts.

The problem can be minimised with permanent control stations. Even though their existence would be known in advance to any cheater they still force the OBEs to produce a reasonable track log for their route to and from that control station.

Data not reported on time

Threat

There will be a limit to how old the track logs can be before they are reported. This limit can be exceeded through deliberate manipulation or through driving in areas where there is no communication coverage.

Counter measure

It is still the responsibility of the vehicle owner that track log data is reported. The user interface should be designed in such a way that it is clear if any data is running the risk of expiring. In that case the driver must use some alternative reporting procedure.

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Published papers produced within the project

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