“*Anders Betalen voor Mobiliteit*”

An OBU component catalog

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Document information:

Title : An OBU component catalog
Customer : Ministerie van Verkeer en Waterstaat
Author(s) : E.J. Veenis en P.H. van Koningsbruggen
Version : 1.1
Date : 4th August 2006
File : An OBU component catalog v1.1.doc
Project : *Anders Betalen voor Mobiliteit*
Project number : MTD06001

Document change control:

Version	Date	Author	Comments	Review	Style
0.1	21-6-06	EVE	Initial version.	-	-
0.2	04-07-06	EVE	Updated version after first Workshop with Electronics manufacturer.		
1.0	14-07-06	EVE / PKO	First release for review by V&W, costs not yet included.	PKO	-
1.1	04-08-06	EVE	Added the cost estimations and processed the review comments of V&W, JWE and Admin.	JWE	Admin

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MANAGEMENT SUMMARY

The 'Kilometerprijs' (KMP) system comes with a so-called On-Board Unit (OBU) that is mounted in the vehicle. The OBU shall record the usage of the roads and initiate the payment of the fees associated with this usage.
The planning to have all vehicles in The Netherlands equipped with an OBU by the end of 2013 is rather strict. To relieve the task of issuing the OBU, and especially mounting the OBU in the vehicle, a monolithic, compact and easy-to-install OBU is foreseen. Such an OBU can be mounted in the vehicle by the vehicle owner / driver himself, no matter whether it is a passenger car, truck or motor bicycle, or whether it is a regular user or temporary user.

Depending on the overall KMP concept there is a variety of possibilities to shape this OBU. In order to come to a sound cost estimation (given the variety of possibilities) three archetypal OBU variants have been defined, representing an increasing capability to support the vehicle driver. These three variants are:
1. the *Secure Position Recorder* that collects position time series for upload to a central system;
2. the *Secure Tariff Monitor* is a secure position recorder with additional functionality to translate position time series into distance driven on a road type at a moment in time and the calculation of a tariff associated with this mobility;
3. the *Secure Mobile Payment Box* is a secure tariff monitor with additional functionality to pay directly for a driven trajectory.

On hardware level each of these variants share some common hardware functions. The main differences between the three variants are that:
- the *Secure Position Recorder* asks for sufficient wireless communication network bandwidth to submit the trails of position data, or for sufficient memory in the OBU to store these trails. Furthermore, because the trails of individuals are known by the Central System, additional privacy precautions are necessary;
- the *Secure Tariff Monitor* and the *Secure Mobile Payment Box* ask for a fault-tolerant procedure to update the tariff tables and the digital maps in the OBU.

The introduction of KMP between 2010 and 2013 requires an average 2.7 million OBUs per year. Such a large scale introduction of a new product in a relatively short time period should match with the technologies chosen. In this report two approaches are presented.

The first approach is to realize the OBU variants with key-modules; ready to use off-the-shelf building blocks that provide a set of dedicated functions. Another approach is to integrate most of the necessary digital functions which results in a decrease of the number of components and a shift from component costs (per OBU) to development and management costs (spread over all OBUs).

The cost estimates for 2.7 million OBUs per year (between 2010 and 2013) for both approaches are shown in the table below.

	OBU variant		
Approach	Secure position recorder	Secure tariff monitor	Secure mobile payment box
Key - modules	€**107,15**	€**125,7**	€**131,6**
Integration	€**85,8**	€**104,65**	€**119,7**

Table 1. Cost estimates.

The estimates apply to the so-called self-controlled production model. In this model the Ministerie van Verkeer en Waterstaat takes the lead in the production of the OBUs. As a consequence the Ministry is responsible for the realization and production process. If production is *outsourced* this means a risk margin; insurances and pre-financing double (as a rough estimate) the costs for the OBU compared to the costs associated with the self-controlled production model. The costs are expected to triple if production takes place on a *commercial basis*.

A risk analysis shows that major risks appear in the definition, design and development of the OBU. A definition of the system concept including how to handle temporary users, together with a solid security- and RAMS analysis are recognized as critical success factors. Smoothening the design and development process asks for a quick project start with prototyping in 2007.

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1. INTRODUCTION

1.1 Background

The Ministers of Transport (Dutch: Verkeer en Waterstaat) and Finance (Dutch: Financiën) have asked the 'Platform Anders Betalen voor Mobiliteit' to initiate a study for an electronic road charging system that contributes to the accessibility and is acceptable for the road users. The study [Het Kan!] showed that such an electronic road charging system can be realized within the limitations of European legislation, that privacy of road users can be guarantied and that such a system can meet the requested reliability and availability. It was further postulated that enforcement was possible with reasonable efforts.

The proposed solutions had different electronic road charging concepts, diverging in the influence they impose on the road user, requiring different (road)infrastructures and having their own approach when it comes to prevent fraudulent use. Each of the proposed variants also requires a specific deployment-, maintenance- and back office organization.

The outcome of the study [Het Kan!] also showed that additional research was necessary for a number of issues.

1.2 Goal

One of the issues is the more detailed set-up of an On-Board Unit (OBU) for the 'Kilometerprijs' (KMP) and the costs coming with such an OBU.
This report captures the results of the phase 2 study aiming at an estimation of the total costs for development, production and deployment of the On-Board Unit (OBU) for the 'Kilometerprijs' as specified in the draft Requirements Specification of the Ministry of Transport [Requirements]. To enable the process of decision making the report focuses on the relationship between OBU functionality and costs rather than on component costs per se.

1.3 Structure of this report

The structure of this document follows the approach that is described in the 'statement of work' [StatementOfWork]:

- Chapter 2, introduces the OBU in its environment and the stakeholders that have an impact on its functionality. The chapter ends with a short description of three OBU variants with different functionality and complexity whose product-costs are further analyzed.

- Chapter 3 presents a mapping of requirements onto OBU functions and the mapping of these functions onto possible technical solutions.
- A translation of the technical solutions into an architecture for three OBU variants is the subject of chapter 4.
- An estimation of the costs for each of the OBU variants is the subject of chapter 5.
- Chapter 6 focuses on the risks associated with the product life cycle of the three OBU variants.
- A possible migration path and deployment scenario are the subjects of chapter 7.
- Some remarks on the initial requirements and suggestions for additional requirements are the subject of chapter 8.

1.4 References

[Het Kan!]	Eindrapportage Techniek, Organisatie, Handhaving en Kosten van varianten van Anders Betalen voor Mobiliteit. Ministerie van Verkeer & Waterstaat 14 juni 2005
[StatementOfWork]	Memo Statement of work subject 2. Ministerie van Verkeer & Waterstaat 19 mei 2006
[Requirements]	Requirement Specification 'Anders Betalen voor Mobiliteit' Ministerie van Verkeer & Waterstaat Versie 0.2, 27 maart 2006

2. OBU VARIANTS

The line of approach in this document is that components will be integrated in a compact holder that is mounted on the vehicle's windscreen. The device is equipped with a supply wire and a connector for a connection to the vehicle's battery.

This approach results in a monolithic, compact OBU which can be used in any vehicle irrespective of its category (passenger car, truck, motor bicycle) and the frequency of usage (regular usage or incidental usage). For the regular user the OBU can be powered via a direct connection with one of the vehicle's power supply wires.

The main argument for such an easy to install OBU comes from the plan to equip all vehicles in The Netherlands (about eight million vehicles) with an OBU in a period of two to three years. This requires a simple installation procedure that can be conducted by the vehicle owner himself.

2.1 The OBU in its environment

The figure below presents the OBU in its environment.

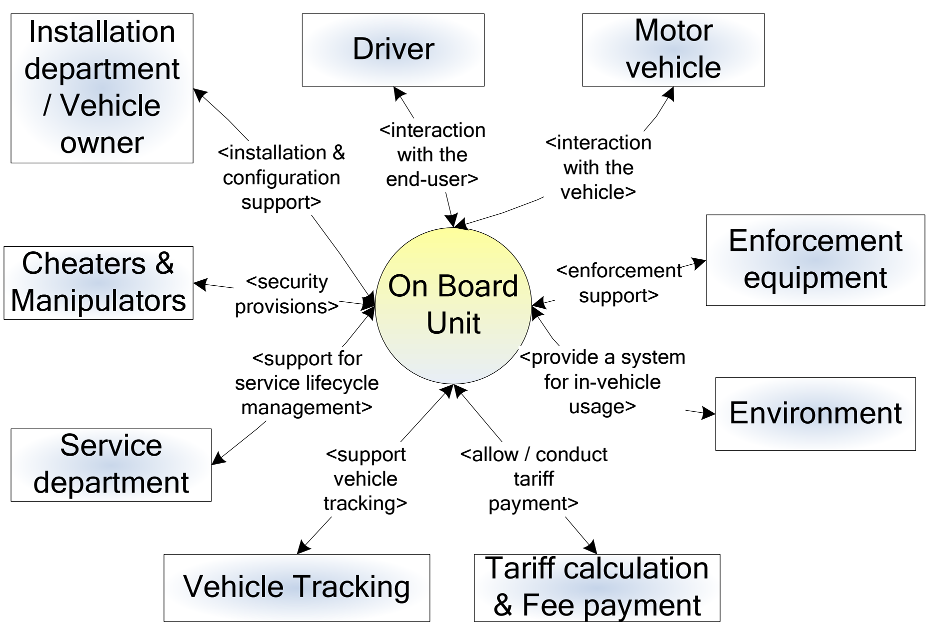

Figure 1. Interaction diagram.

The rectangular boxes identify 'stakeholders' (roles) that interact (in the broadest sense) with the OBU. The arrows indicate the functionality that is requested from the OBU in order to cope with the interaction with the stakeholders. The interaction types (the texts between <> in Figure 1) refer to function groups that are used in chapter 3 to derive technical solutions.

The following stakeholders are identified:

- the **vehicle driver** is the end-user of the OBU. Interaction between the vehicle driver and an OBU is realized through a Man Machine Interface which might consist of a single signaling LED up to a complete menu driven computer interface with display and a keypad;

- the **motor vehicle** in which the OBU is mounted. The vehicle shall not only provide a stable mounting basis but also supply the energy necessary for the OBU to function. The vehicle can also be a source of vehicle data like odometer et cetera;

- **enforcement equipment** is the apparatus that (remotely) collects data from the OBU with the aim of preventing and / or detecting fraud. The OBU might include provisions to allow a remote enforcement terminal to identify the vehicle's OBU and / or to collect status information;

- the **environment** represents the influence that the vehicle environment (amongst others the temperature and automotive requirements) has on the OBU housing and electronics;

- the Central System is modeled as a pair:
  - the **fee calculation** sub-system that is - as its name suggests - responsible for the calculation of fees on the basis of location / time information from vehicles. Needless to say that this system is only present in a system concept that allocates fee calculations to the central system(s);

  - **fee payment** represents the functionality associated with the payment for mobility.

- the **service department** is the organization that is responsible for the life cycle management of the OBU. Associated responsibilities are - depending on the system concept chosen - the distribution of new OBU software, maps, tariff tables and the like;

- **cheaters & manipulators** represent all activities that prevent an OBU from operating normally with the focus on paying less or even not paying at all. The (system and the) OBU in combination with the enforcement procedure shall limit the chance of unnoticed fraudulent use to an accepted level.

- the **installation department / vehicle owner** represents the legal body or person that installs OBUs in vehicles. Another task of the installation department / vehicle owner is the configuration (including personalization) of the OBUs. A task that should be accommodated by the OBU.

2.2 OBU variants

The design, production and operational costs are determined for three OBU variants. These variants differ in the functionality and features they provide to their end-users and the central systems (the KMP concept), thereby representing three OBU-archetypes in a much broader spectrum of possibilities. The variants that are the subject of this study are defined below.

2.2.1 Thin OBU – secure position recorder

The thin OBU is a position recorder that collects position time series for upload to a central system.

The central system has the task to attach a tariff to the position time series, that is: translate subsets of the position time series into the trajectories driven, select the tariff table that corresponds with the vehicle type and the time the trajectories were driven, calculate the associated fee per trajectory and finally sum up the total fee to be paid. The central system in this solution has the role of a service provider taking care of the actual declaration and payment.

2.2.2 Chubby OBU – secure tariff monitor

The chubby OBU is an expanded version of its thin nephew. Its additional features include the translation of position time series into distance driven on a road type at a moment in time and the calculation of a tariff associated with this mobility. This makes the chubby OBU a tariff monitor.
Other features allow the chubby OBU to present tariff information to the vehicle driver and to upload the mobility costs to a central system (for later payment).

The central system has the task to initiate and process the actual payments given the uploaded mobility costs. Other tasks include the distribution of road maps, tariff tables and software updates. In this variant the central system has the role of declaration counter, receiving the declarations and initiating and processing the payments.

An advantage of the chubby variant is that the central system has no knowledge about the route that was driven, thus preserving the privacy of its users. This however comes at the cost of adding map matching functionality and the functionality to store road maps and tariff tables into the OBU.

2.2.3 Thick OBU – secure mobile payment box

The thick OBU is the successor of its chubby nephew. It contains the functionality to pay for a driven trajectory. This additional functionality makes the thick OBU a mobile payment box.

The central system has the task to verify (and receive) the payments made by the OBU. Other tasks include again the distribution of road maps, tariff tables and software updates. In this variant the central system has the role of an electronic clearing house.

3. OBU FUNCTIONALITY

This chapter focuses on the function groups that were identified in paragraph 2.1. The function groups are matched against the requirements, decomposed into sub functions and finally mapped onto possible technical solutions.
The functional decomposition process is structured as follows:

- [xxx] - function groups are expressed in terms of the requirements coming from [Requirements];
- <<u>underlined</u>> - main functions are decomposed into sub-functions;
- <*italic*> - sub functions (underlined font) are mapped onto possible technical solutions (in italic);
- <***bold***> - technical solutions that are candidates for the cost estimation are chosen (in bold font), including the reason for their selection.

3.1 Vehicle tracking

The system shall be able to determine the distance driven in the Netherlands [1][1] at a certain time [2] at certain locations [3] on all roads [5].

The vehicle tracking function can be allocated to the OBU. Tracking in the OBU is however possible at several levels of detail as shown in the decision tree below. A minimum system only collects vehicle positions for immediate upload to a central system for time stamping and further processing. More advanced OBU implementations use the positions for map matching and even fee calculations.

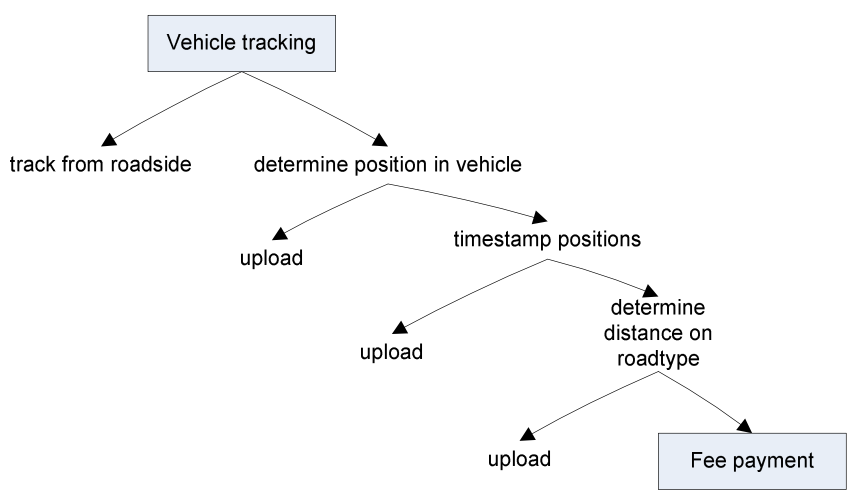

Figure 2. Vehicle tracking decision tree.

[1] References to the requirements are shown as numbers between [].

1. track the vehicle from the roadside
   The tracking of vehicles from the roadside requires an "ultra thin" OBU but also requires a huge investment for roadside equipment, in the form of a dense, fine-graded network of DSRC gantries. The solution is not recognized as a serious option for KMP and therefore not further described in this document.

OR

2. determine the current position in the vehicle
   - ***(A-)GPS*[2] (or GNSS)** (Assisted-) global positioning system is chosen as the basis of each of the OBU variants because it is a proven technology with sufficient position accuracy;

   - *DGPS* (differential GPS using local radio stations);
   - *EGNOS* (trusted GPS);
   - *Loran C* (the father of GPS);
   - *GSM / UMTS* (based on cell recognition. Might be used if the requirement to differentiate tariffs depending on road types is relaxed).

   i. immediate upload vehicle ID and location changes to a central system allows a fee calculator to timestamp the data and to calculate a fee for the driven trajectory.
      - ***removable medium like a chip card;***
      - ***DSRC;***
      - ***GPRS;***
      - *Z-WAVE* (a wireless RF-based communications technology);
      - *WLAN*;
      - *WMAX*;
      - *UMTS*;
      - *combinations* of the above (depending on the usage and origin of the data communication).

      A removable medium is expected to fulfill the data exchange needs for OBU variants with minimal functionality like the position recorder.
      OBU variants that are likely to be more user friendly shall implement a wireless communication channel with a central system that is based on DSRC (only when driving with a speed near to standing still) or GPRS.
      New technologies are also feasible in 2012 at a cost and level of integration which are comparable with today's technologies.

OR

   ii. timestamp location in the vehicle

[2] **Assisted GPS**, or **A-GPS**, is a technology that uses an assistance server to cut down the time needed to determine a location using GPS. It is useful in urban areas, when the user is located in "urban canyons", under heavy tree cover, or even indoors.

- ***internal clock in the OBU*** synchronized to a reference clock (that is located somewhere outside the vehicle);
- ***time is a sub-function of the positioning system*** which is used to synchronize (set) an internal clock in the OBU.

  Both solutions for time stamping are recognized as necessary for each of the OBU variants in order to prevent fraud due to GPS spoofing (if the system clock and the GPS time differ too much something is wrong, see paragraph 3.8).

  a. upload vehicle ID and time stamped locations to a central system (see above for candidate solutions);

  OR

  b. determine the distance driven on road type in the vehicle
     - ***map matching*** (various levels of detail like areas, sections, projection to nearest road etc. depending on OBU variant)
     - dead reckoning by means of an ***accelerometer***, *gyro* and or *odometer* (connection to the vehicle's odometer).

     A combination of the above is chosen for the OBU variants to improve availability / reliability and minimize the chance of fraud.

     1. upload vehicle ID and distance driven on road type at a certain time to a central system (see above for candidate solutions);

     OR

     2. calculate the fee (see paragraph 3.2.1).

3.2 Fee payment

The fee depends on the distance driven in the Netherlands [1] at a certain time [2] at certain locations [3] depending on the vehicle characteristics [4] on all roads [5].

Fee payment is modeled as a two step function:

1. calculation of the fee;
2. debiting of a bank account;

as shown in the decision tree below.

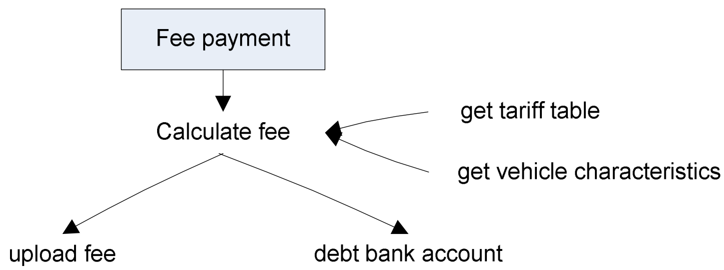

Figure 3. Fee payment decision tree.

3.2.1 Sub-function: fee calculation

Calculate the fee for the distance driven on road type at time with the vehicle with vehicle characteristics and for a given tariff table

- fee calculations require some amount of ***memory and processing capacity***;

- the vehicle characteristics are part of the fee calculations:
  - ***static*** (set once during installation of the OBU in the vehicle);
  - *dynamic* (read from the vehicle via a vehicle interface);
  - *combination* of the above.

  Fee calculations are expected to be based on static vehicle characteristics because the dynamic variant requires interaction with the vehicle's electronics which is hard to access (legal issues), is based on proprietary designs and is non-standard (implementations vary from vehicle brand and model).

- a tariff table is necessary to calculate the fee. The tariff table might be:
  - ***semi static*** (installed once and updated during maintenance);
  - ***discontinuous download*** (e.g. while parking in a parking lot, at a fuel station);
  - ***continuous download*** (via radio broadcast or GPRS);
  - ***manual update*** (using an external memory device like a memory stick, chip card etc…).

  The procedure for updating the tariff table also applies to the distribution of new program versions and road map updates. It seems logical to use an already existing data communication channel (for position, fee or payment data uploads) with the central systems for the implementation of the download function. Each of the above solutions is therefore a candidate to be found in an OBU product.

  The fee calculation is followed by:

  a. the uploading of the calculated fee to a central system for (later) payment by the vehicle owner;

OR

b. an (electronic) payment performed by the OBU that debts the bank account of the vehicle owner with the fee.

3.2.2 Sub-function: debt bank account

Payment of the fees due can be done by decreasing a pre-paid budget, direct payment of the fee coming with the recent vehicle trip, or post-payment of a bill containing the fees of the trips over the last period. The pre-payment and post-payment options can stick with the sub-function 'fee calculation' (see previous sub-paragraph). The direct payment option needs an additional sub-function: debt bank account.

Direct fee payment is defined as an electronic payment action that is initiated from the vehicle via the OBU. The payment shall be reliable [12] [13] and shall be performed in such a way that it minimizes the discomfort of the vehicle driver [14], and is safe and easy to use [16].

The direct, electronic payment from a vehicle requires:

- an electronic purse or chip-based debit card
  - a ***SIM*** that corresponds with the person who is willing to pay the mobility fee;

- a placeholder for the electronic purse / chip-based debit card
  - an ***ISO7816 interface*** to allow the insertion of a chip card including the SIM;

- a (wireless) two - way data communications channel to implement the payment flow between the chip card in the OBU and a central system:
  - ***DSRC*** (payment while not driving);
  - *W-MAX* (payment while not driving);
  - *blue tooth;*
  - *WIFI;*
  - ***GPRS*** (payment while driving);
  - *others.*

  The proposed solution is (again) based on proven technology. The solution in 2012 is expected to provide at least the current functionality against comparable costs.

3.3 A system for in-vehicle usage

An OBU shall be fraud resistant [23] safe and easy to use [16], shall protect its users from discomfort [14] and shall be able to present the cost for driving to the driver of the vehicle [15]. The OBU shall meet the applicable legislation as well as the European directive on the interoperability of electronic road toll systems [11].

These requirements limit the mounting location (of at least the component(s) that interact with the vehicle driver) to a location in the field of vision of the driver. The limited cost requirement [17] further suggests a cost optimized "all in one" OBU design that is applicable for all sorts of vehicles, including motor bicycles.

The functionalities to be provided by the cabinet in combination with the mounting location are:

- act as a placeholder for the OBU electronics;

- being tamper proof:
  - ***attempts to access*** the OBU electronics shall be recognized by the electronics (and clear any stored data);

    The housing together with the electronics inside shall be constructed in such a way that an attempt to open the house destroys the electronics and clears the contents of the fraud sensitive memory areas.

    The requirements to facilitate occasional road users [9] and foreign number plates [10] have a strong relation with the required security provisions [23]. E.g. detection of the removal of the OBU from its mounting location that is followed by the clearing of its internal data would increase the level of tamper resistance. This mechanism would, on the other hand, prevent quick (de-)installation of the OBU in the vehicle of an occasional user.
    The temporary use of an OBU should be solved as part of the system concept and is not further addressed in this study.

- meeting the legislation that applies to in-car electronics (including electronics developed for retrofitting);

- getting its energy from the vehicle's battery:
  - ***connection to the vehicle's battery;***
  - *own battery* (requires replacement functionality);
  - *solar powered* (uncertain in the Netherlands).

- providing a housing for the electronics, including antenna(e) and sensors (imposes a limitation to the possible mounting locations);

- allowing (easy) installation (including retrofit) and maintenance.

3.4 Enforcement support

The OBU shall include functionality to support enforcement [18] [23].

Depending on the KMP concept chosen, the OBU shall support enforcement by providing combinations of the functions that are described below - preferably using already existing interface(s):

- identify the vehicle:
  - ***license plate recognition*** with a direct connection to the central system;

- determine if an OBU is present in the vehicle:
  - ***cyclic automatic keep alive message*** (Here I'm now!);
  - ***requested keep alive message*** (Saw your license plate. Make yourself known.);
  - trying to ***establish a connection*** with the OBU to collect data (Who are you?).

- determine if the OBU functions correctly (note: status changes reflecting the functioning of the OBU shall also be reported to the user):
  - ***read OBU data*** via a ***wireless communications*** link (using an already existing communications interface).

- determine if the OBU corresponds with that vehicle:
  - ***cross check*** if identification read from OBU corresponds with the number on the license plate (check could be performed by ***central system*** or by a ***remote enforcement terminal***).

Each of the above enforcement implementations is worth considering. A final selection of enforcement techniques should be done on system concept level.

3.5 Interaction with the vehicle

Up to date information from the vehicle - like speed, trailer present or not, et cetera, requires an interface with (parts of) the vehicle electronics ("the electronics under the hood") [4].

The interface with the vehicle highly depends on the make and model. Although a ***CAN bus*** is frequently used to exchange data in a vehicle,

the message formats and timing are proprietary and therefore vary from one car manufacturer and model to another.
A connection to the vehicle electronics is therefore not recommended.

3.6 Interaction with the end-user

The interaction with the vehicle driver by means of some form of Human Machine Interface covers (HMI) requirements like:

- showing the actual costs for driving [15];
- signaling the vehicle driver in case an error occurs, and as a side effect, the adequate road pricing is no longer guaranteed [12] and [13].

Technical solutions for the HMI range from a simple ***signaling LED / buzzer***, via a ***small LCD***, ***display with keypad*** up to an ***open interface*** to existing in-vehicle media centers (also known as the "in-vehicle telematics platforms") or nomadic devices like mobile phones, PDAs and navigation devices.

3.7 Installation and configuration

Installation is the process of mounting the OBU in the vehicle in such a way that:

- its user interface is in the field of vision of the vehicle driver [15];
- its antennae have good reception / transmission quality [12][13][18];
- the OBU is installed with reasonable effort [17].

The functionality associated to installation is allocated to the technical solutions for the housing and mounting location which are described in paragraph 3.3.

Configuration is necessary to either:

- establish the link between an OBU and the vehicle in which it is mounted;
- provide a mechanism to link an OBU to its user.

Both types of configuration are a crucial element in the tolling system (which is expected to be addressed in the overall system concept).
The configuration procedure(s) and the associated OBU functionality shall not violate any (inter)national privacy regulations [24]. The solutions chosen shall also be fraud resistant [23].

➧ The privacy issue shall be an integral part of the ***system concept*** in combination with the ***organizational aspects*** of installation and configuration.

- The security provisions to prevent and detect fraud are the subject of the next paragraph.

3.8 Security provisions

Security provisions refer to the OBU functionality to:

- prevent fraudulent usage of the system [23];
- allow the system to recover from fraudulent usage [23];
- comply with national and international privacy regulations [24].

The level of security is highly related to the system concept. It can be expected that the given application domain requires precautions at several levels:

- secure the data communication between the OBU and a central system**:**
  - ***secure Application Module (SAM);***
  - ***secure Identification Module (SIM);***
  - *integration of SAM / SIM;*
  - *SAM and SIM integrated in the processor* in combination with hardware security precautions (e.g. *scrambling of the ASIC building blocks*).

    The cost scenarios assume the presence of separate SAM and SIM components. Integration of the SAM and SIM is possible on a technological level, however, it might be more difficult to realize on an organization level.

- secure logging of vehicle positions:
  - *see* the technical solutions above in combination with a ***tamper protected memory area*** (that is: the memory area is cleared if the housing is opened / damaged).

- sanity check of logged positions:
  - *see* the technical solutions above, this is the time used to cover some sanity checks of the positioning data received.

- fraud resistant product by means of:
  - ***tamper proof housing***;
  - ***tamper proof hardware*** (loss of data if the housing is opened).

    A combination of the above to reach the highest possible level of fraud resistance.

- detection of fraudulent usage of the system:

- ***monitoring of the battery voltage*** (to be able to detect removal of the OBU power connection);
- ***monitoring of vehicle movement***;
- *connection to the vehicle motor management* (to determine vehicle speed);
- *a combination of the above.*

The connection to the vehicle electronics was already discussed in paragraph 3.5.

3.9 Service life cycle management

Life cycle management is defined as: the OBU functionality that is necessary to keep existing OBU systems up to date if the overall system's concept changes through time [6], [20] and [21]

The flexibility in its design and the support of different implementation scenarios are reflected by the OBU's possibility to:

- ***store a new tariff table;***
- ***store a new roadmap;***
- ***allow software updates;***
- ***provide sufficient spare processor capacity*** (to allow new tariff algorithms to be realized);
- ***provide sufficient spare memory capacity*** (to allow new tariff algorithms to be realized);
- ***interface with vehicle electronics*** (to gain access to vehicle dynamics for future / advanced fee calculations based on a variety of vehicle / engine parameters);
- ***provide an open platform interface*** (to allow the OBU to integrate with existing in-car systems).

  The conclusion is that flexibility and support of future implementation scenarios are not allocated to one single component but are an integral part of the OBU design.

4. ARCHITECTURE

Defining the system architecture(s) is the process of selecting useful combinations of technical solutions that best match with the functional requirements and organizational aspects of KMP. The process is driven by the three different OBU variants as defined in chapter two, the technical solutions derived in chapter three together with the results of a consultation of the parties that are defining the system concept (taskforce 1).

4.1 Reference architecture

Each of the three OBU variants is realized with a selection of components that belong to the reference architecture that is shown below.

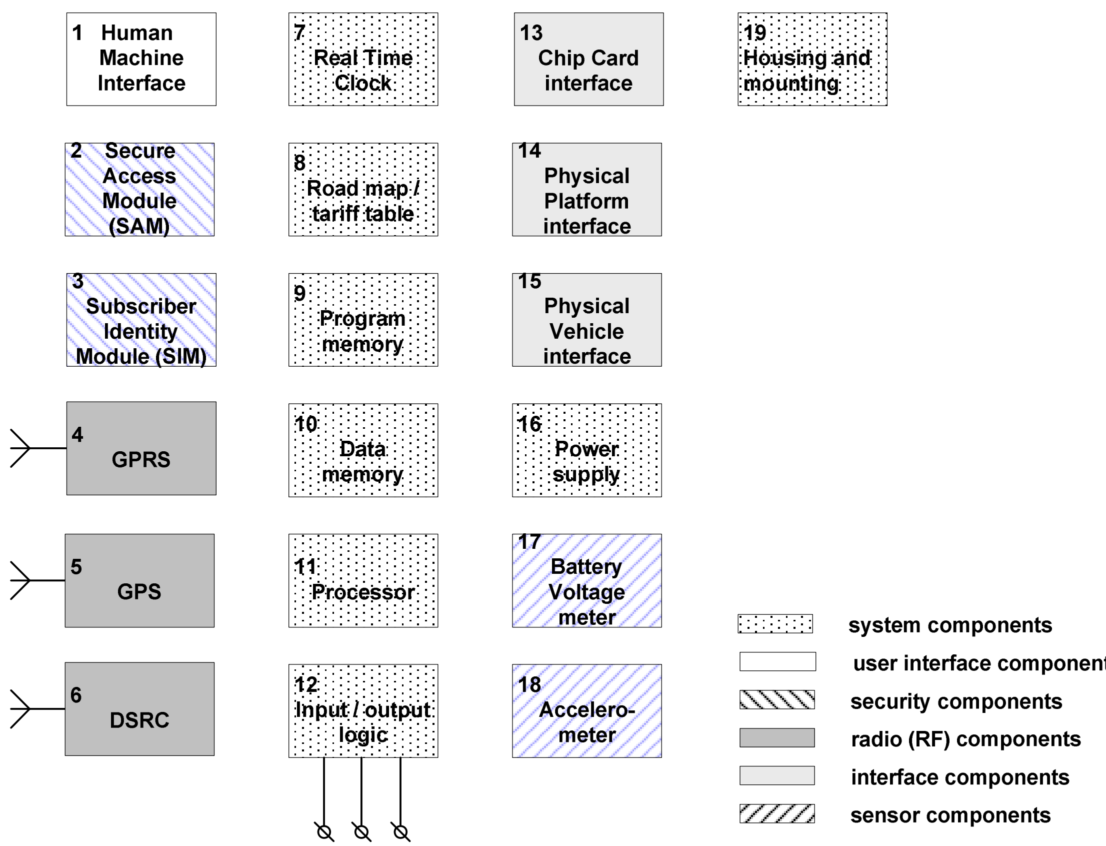

Figure 4. Reference architecture block diagram.

The mapping between the components in **Figure 4** and the functions from chapter 3 is shown in the table at the next page.

ID	Component	Implements function(s)	Remarks
1	Human machine interface	Interaction with the end-user / Installation and configuration	Ranging from a single LED / buzzer combination up to a display and keypad
2	Secure Application Module (SAM)	Security provisions	These functions are candidates for integration. In large quantities integration in the processor is also possible
3	Secure Identification Module (SIM)	Security provisions	
4	GPRS (General Packet Radio Service)	Vehicle tracking Fee payment	Determine in which GSM - cell a vehicle is located. Proving a mechanism of sending data via the GSM - network
5	GPS (Global Positioning System)	Vehicle tracking	
6	DSRC (Dedicated Short Range Communication)	Fee payment / Enforcement support	
7	Real Time Clock	Security provisions	
8	Road map and Tariff Table (memory)	Service life cycle management / Vehicle tracking	Size depends on the required functionality
9	Program memory	A system for in-vehicle usage	
10	Data memory	A system for in-vehicle usage	
11	Processor	A system for in-vehicle usage / Installation and configuration	Performance should match required functionality. The processor is also able include the functionality of a SIM and / or SAM
12	Input and output logic	Security provisions	Connects the processor to sensors / status signals from the vehicle
13	Chip Card interface	Security provisions Fee payment	Slot allowing the insertion of a secure / removable device (e.g. 'mobility chip card') for: • the identification of a user; • the secure transfer of mobility data to the removable medium; • the interfacing with an electronic purse or chip-based debit card as issued and owned by the banks.
14	Platform / Device interface	Security provisions	Allowing existing in-vehicle electronic devices and/or nomadic devices to connect to the OBU, providing a means to 'nicely' interact with the vehicle driver via display(s) and input devices
15	Physical vehicle interface	Interaction with the vehicle	Allowing the OBU to gain access to vehicle data
16	Power supply	A system for in-vehicle usage	Including some limited backup power support
17	Battery voltage meter	Security provisions	Detect removal of the power supply
18	Accelerometer	Security provisions	Detect loss / failure of the positioning component while moving
19	Housing and mounting	A system for in-vehicle usage	

Table 2. Component - function map.

4.2 The secure position recorder

The position recorder is a kind of in-vehicle black box that tracks vehicle positions and securely stores them for later upload to a central system.
The central system timestamps and translates the vehicle positions into a trajectory driven at a time, which is in turn enriched with tariff information that corresponds with the given vehicle class.
The result is a mobility fee to be paid by the vehicle owner.

4.2.1 Building blocks

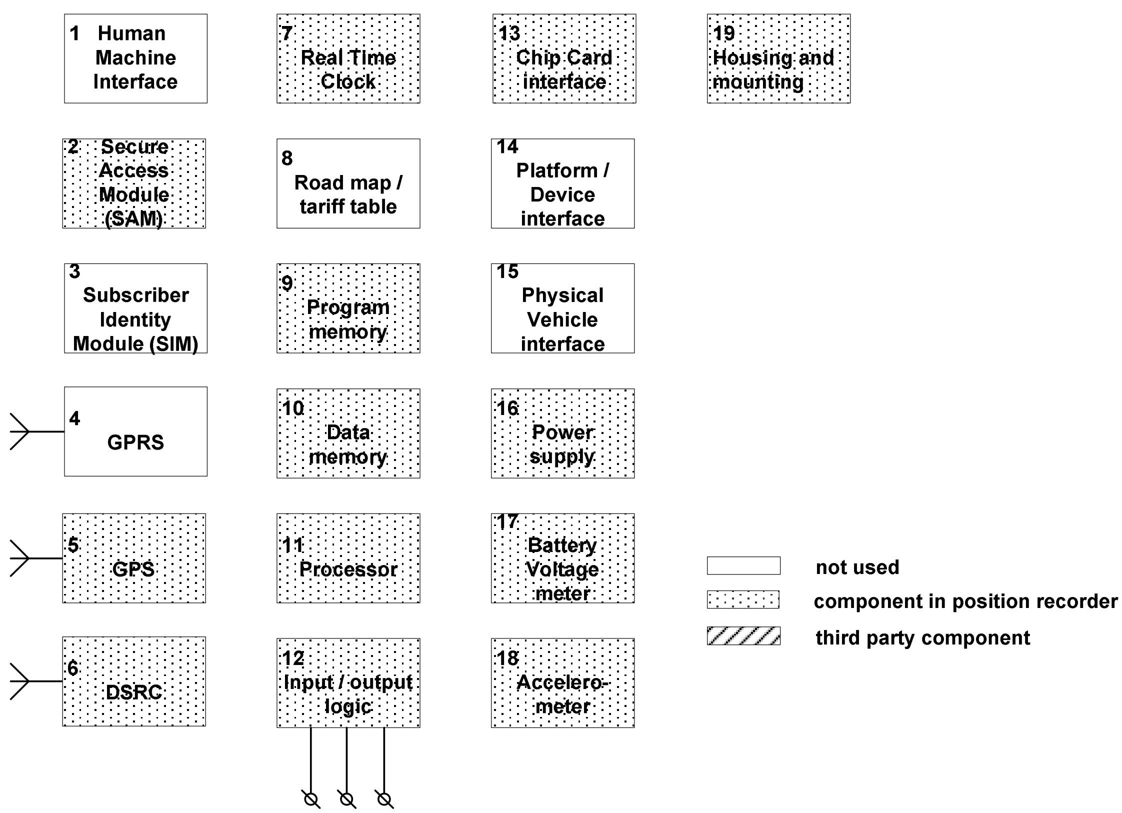

Figure 5. Secure Position Recorder component diagram.

4.2.2 Component list

The component list coming with the secure positioning recorder is depicted in Table 3.
Alternatives for the selected components are discussed in paragraph 4.5.

Function	**Technical solution** (x) = number of building blocks	**Remarks**
Vehicle tracking	GPS (5) processor (11) memory (9, 10) SAM (2) ***Alternative: GSM/GPRS (3 & 4)***	(2) for secure storage of positions
Sub-function: fee calculation	-	done by central system
Sub-function: debt bank account	Chip card interface (13) ***Alternative: GPRS (3 & 4)***	(13) for the transfer of the tracked positions to a central system (that calculates the fee)
A system for in-vehicle usage	Housing and mounting in the vehicle (19)	
Enforcement support	DSRC (6) ***Alternative: GPRS (3 & 4)***	At fixed locations and / or via mobile systems
Interaction with the vehicle	Power supply (16)	Connected to the vehicle's battery
Interaction with the end-user	Output logic (12)	status LED controlled via processor
Installation and configuration	Secure memory (10) SAM (2)	to store the relation between OBU and the vehicle
Security provisions	Accelerometer (18) and battery voltage meter (17) Real time clock (7) Secure memory (10) SAM (2) Security provisions in housing and mounting (19) Input logic (12) ***Alternative: Physical vehicle interface (15)***	(18, 17) to be able to detect GPS spoofing while driving (7) to be able to compare GPS time and system time (12) to be able to detect if the OBU is removed from its mounting location ***(15) as an alternative for 17 and 18***
Service life cycle management	Chip card interface (13) DSRC (6) ***Alternative: GPRS (3 & 4)***	downloading of software updates (e.g. at a filling station / during maintenance)

Table 3. Secure Position Recorder component list.

4.3 The secure tariff monitor

By adding:

- additional ***memory*** to store a road map and a tariff table, and
- additional ***processing power*** for map handling and map matching;
- and a ***small display***

to the secure position recorder, the OBU gains the capability to match the vehicle movements with a road map and to attach a fee to the driven trajectories using a tariff table together with the vehicle characteristics that are maintained by the OBU (stored once during initialization). The calculated fees can be presented to the vehicle driver and stored in secure memory for later upload to a central system. In this way the secure tariff monitor emerges.

4.3.1 Building blocks

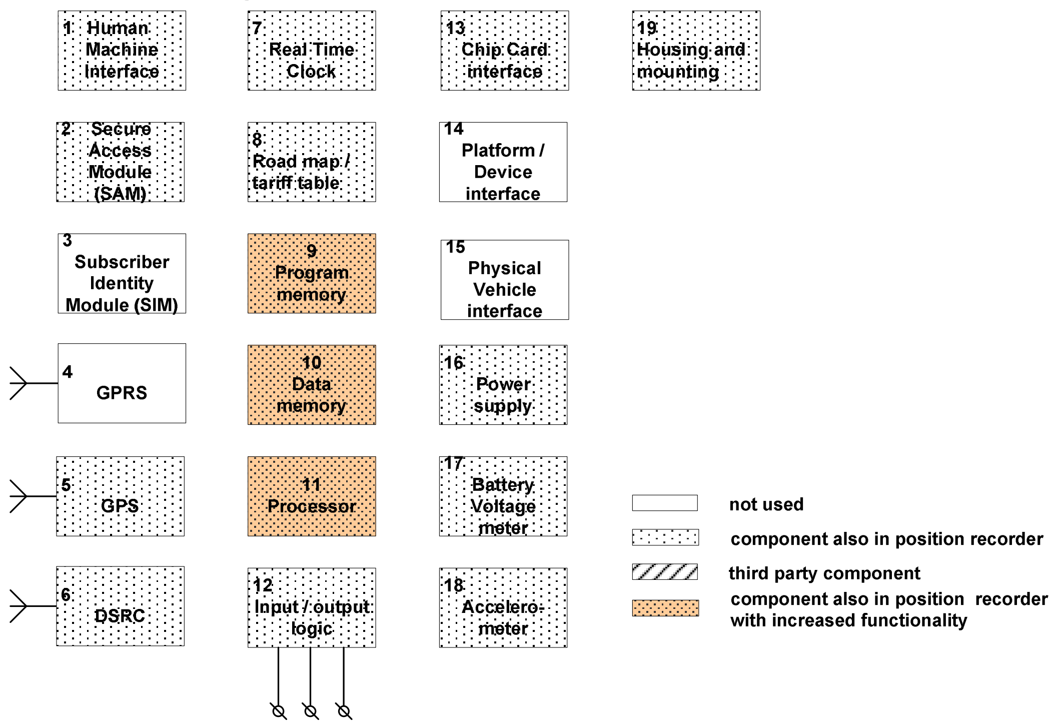

Figure 6. Secure Tariff Monitor component diagram.

The technical differences between the trip recorder and the mobility monitor are small, since DSRC (e.g. at a gas station, at the entrance of the motorway or of a city) can be used for updating the tariff table and fee uploads, where the removable medium (chip card) can be used for the same actions the road map downloads (updating the road map).

By adding a GPRS data link to the core functionality a more continuous link to the central system for uploads and downloads becomes available, provided that the capacity of the cellular network is sufficient (see also paragraph 4.5).

4.3.2 Component list

Function	**Technical solution**	**Remarks**
Vehicle tracking	GPS (5) processor (11) memory (9, 10) SAM (2) Chip card interface (13) ***Alternative: GSM/GPRS (3 & 4***	(2) for secure storage of fees
Sub-function: fee calculation	processor (11) map matching / tariff table (8)	calculate a fee for a given series of positions
Sub-function: debt bank account	Chip card interface (13) ***Alternative: GPRS (3 & 4)***	(13) for the transfer of the fees to be paid to a central system
A system for in-vehicle usage	Housing and mounting in the vehicle (19)	
Enforcement support	DSRC (6) ***Alternative: GPRS (3 & 4)***	At fixed locations and via mobile systems
Interaction with the vehicle	Power supply (16)	Connected to the vehicle's battery
Interaction with the end-user	Human Machine Interface (1) ***Alternative: Platform / Device interface (14)***	Small display to present status and tariff information to the vehicle driver ***(14) for connection to an existing in-vehicle or nomadic device***
Installation and configuration	Secure memory (10) SAM (2) Road map / tariff table (8)	(10) to store the relation between OBU and the vehicle (8) to store initial versions of the road map and a tariff table
Security provisions	Accelerometer (18) and battery voltage meter (17) Real time clock (7) Secure memory (10) SAM (2) Security provisions in housing and mounting (19) Input logic (12) ***Alternative: Physical vehicle interface (15)***	(17 & 18) to be able to detect GPS spoofing while driving (7) to be able to compare GPS time and system time (12) to be able to detect if the OBU is removed from its mounting location ***(15) as an alternative for 17 and 18***
Service life cycle management	Chip card interface (13) DSRC (6) ***Alternative: GPRS (3 & 4)***	downloading of software updates and updates of the road map and the tariff table (e.g. at a filling station or during vehicle maintenance)

Table 4. Secure Tariff Monitor component list.

4.4 The secure mobile payment box

The mobile payment box is the logical successor of the tariff monitor. In addition to the functions found in the tariff monitor it contains the functionality to pay for the calculated fees.
The chip card interface is no longer used for the transfer of collected data but allows insertion of an electronic purse (or chip card) to be used in the process of (securely) debiting the bank account of the cardholder with the amount of the fees driven. The OBU should be classified a payment box for personal use, so not all requirements coming with a public payment box are valid for the OBU. Furthermore the OBU will function as a mobile extension of the actual payment box function which is allocated to the central system.
Due to the need to have a (more) continuous bi-directional data link between the OBU and central system the choice was made to replace DSRC in the component diagram by GPRS. The choice has also been made to use a dedicated OBU display and keypad for the user interface in order to keep up the self-reliance of the OBU. Alternatives are described in paragraph 4.5.

4.4.1 Building blocks

The building blocks to create a minimum mobile payment box are shown below. Alternative solutions are listed in paragraph 4.5.

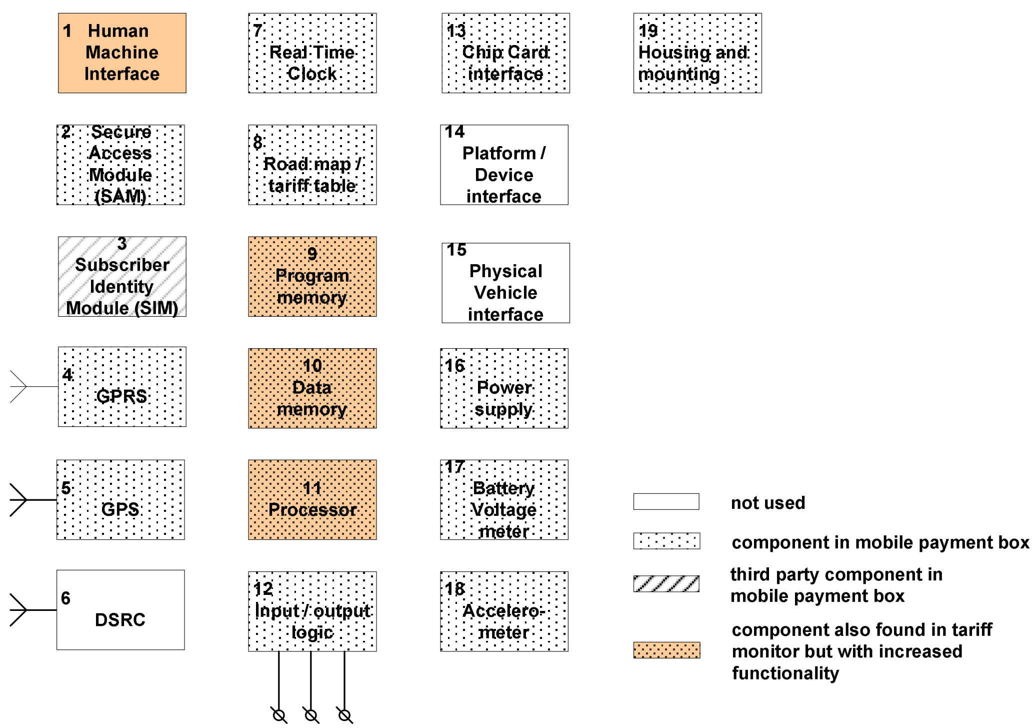

Figure 7. Secure Mobile Payment box component diagram.

4.4.2 Component list

Function	Technical solution	Remarks
Vehicle tracking	GPS (5) processor (11) memory (9, 10) SAM (2) Chip card interface (13)	(2) for secure storage of fees
Sub-function: fee calculation	processor (11) map matching / tariff table (8)	calculate a fee for a given series of positions
Sub-function: debt bank account	Chip card interface (13) GPRS (3 & 4) ***Alternative: DSRC (6)***	(13) allow the usage of an electronic purse or chip-based debit card
A system for in-vehicle usage	Housing and mounting in the vehicle (19)	
Enforcement support	GPRS (3 & 4) ***DSRC (6)***	Interrogation of vehicles in a specific (part of the) cell ***(6) At fixed locations and via mobile systems***
Interaction with the vehicle	Power supply (16)	Connected to the vehicle's battery
Interaction with the end-user	Human Machine Interface (1) ***Platform / Device interface (14)***	(1) Dedicated display (about 20 characters and keypad (0..9) to interact with the vehicle driver ***(14) for connection to an existing in-vehicle or nomadic device***
Installation and configuration	Secure memory (10) SAM (2) Road map / tariff table (8)	(10) to store the relation between OBU and the vehicle (8) to store initial versions of the road map and a tariff table
Security provisions	Accelerometer (18) and battery voltage meter (17) Real time clock (7) Secure memory (10) SAM (2) Security provisions in housing and mounting (19) Input logic (12) ***Physical vehicle interface (15)***	(17 & 18) to be able to detect GPS spoofing while driving (7) to be able to compare GPS time and system time (12) to be able to detect if the OBU is removed from its mounting location ***(15) as an alternative for 17 and 18***
Service life cycle management	GPRS (3 & 4) ***DSRC (6)***	downloading of software updates and updates of the road map and the tariff table. Also used for payment transactions ***(6) non-continuous variant for downloading, updating and payment transaction***

Table 5. Secure Mobile Payment box component list.

4.5 Alternatives for the selected components

Alternative solutions are depicted in italic bold font in Table 3, Table 4 and Table 5. The alternatives and their impact are the subject of the rest of this paragraph.

4.5.1 GPRS versus DSRC

For quite some of the proposed functionality GPRS and DSRC are counterparts.

GPRS allows continuous bi-directional access to a central system, thus allowing various appealing features to be integrated in the OBU. Examples are automatic uploads of mobility data, the automatic downloading of software, tariff table and road map updates. Another possibility is the direct payment of the fees.
GPRS is based on commercially available cellular networks, and is therefore ready to use.

The GPRS function comes with a relatively expensive component (see chapter 5) and additional (fixed) costs for subscription to a telecom operator and (variable) costs for data transfers. Although it can be foreseen that special tariffs apply for an application like KMP, the remaining costs will still be considerable.

GPRS is not restricted to one telecom operator. In The Netherlands five telecom operators are operational, bringing the issue forward how to handle subscriptions.
Although GPRS is ready to be used, it is unknown whether or not the available network capacity is sufficient for KMP[3].

DSRC allows on-the-spot bi-directional access to a roadside system, thus allowing various appealing features to be integrated in the OBU (provided that the vehicle's speed is adjusted to the transaction time needed). Examples are automatic uploads of mobility data, the automatic downloading of software, tariff table, and the remote and direct payment of the fees.
DSRC uses beacons which should be installed above and along the Dutch road network. When setting up such a network DSRC can be combined with WiFi hotspots (which is of course also a possibility in case GPRS is used).

[3] Think, for example, of a situation where GPRS is used for enforcement on a motorway like the A4 where about 2300 - 2400 motor vehicles per hour per lane can pass. Think also of a situation where OBUs submit the fees they need to pay for or even conduct the payment transactions once they have finished their trip. This will lead to quite a volume of data transfers during the rush hours.

DSRC is a well proven solution in situations with large volumes of vehicles passing the beacons / gantries.
DSRC is rather cheap at the OBU side (not an expensive component, no subscription fee, no communication costs). However, DSRC comes with substantial cost to set up a sufficiently fine-graded network of beacons to cover the relevant part of the Dutch road network; a DSRC network which can be controlled by the KMP service provider itself, which gives extra flexibility in extending the network.

The choice between GPRS and DSRC on the OBU-level will depend on the whole KMP system concept.

4.5.2 SIM / SAM versus dedicated, secure processor

An alternative worth mentioning is the replacement of the SIM and SAM by a processor with integrated crypto functionality (kind of turbo chip card). Although the integration seems only feasible for large production quantities it minimizes the component count and increases the robustness and fraud resistance of the solution.

4.5.3 GSM versus GPS-based vehicle tracking

The role of GPS in vehicle tracking can be replaced by GSM. In a GSM solution the GSM network cells that are entered by the moving vehicle are recorded. Tariffs are attached to each cell, or a combination of cells, thus allowing a central system to calculate a fee for mobility. A disadvantage of this solution is that the position accuracy is limited to the size of an average GSM network cell.
Given the rather strict positioning requirements (accuracy of the arterial roads within cities), the GSM option is not further analyzed in this report, although the solution makes elegant use of an already existing infrastructure.

4.5.4 A direct interface to the vehicle electronics versus fully autonomous operation

The level of protection against fraud is increased if the OBU's tracking function has access to vehicle status information (via a vehicle interface). A disadvantage of connecting the OBU to the vehicle (e.g. via a CAN-bus) is the lack of standardization of in-car equipment, thus requiring specific solutions for each brand and model / type of vehicle. This is why the vehicle interface is left out of the cost calculations.

5. COST ESTIMATES

This chapter presents an estimation of the costs that are associated with the development, (production) engineering, manufacturing and testing of each of the three OBU variants. The cost estimations are given for two different technologies; one using key modules and another with digital functions integrated into an Application Specific Integrated Circuit (ASIC).

Two different, dedicated companies were consulted to validate the costs of the key modules solution. Another specialized company was consulted to collect and validate the possibilities for integration of OBU functionality and the associated costs. The result of this latter consultation was that most of the digital functions could be integrated in one ASIC. The (non-component) remaining costs of the estimations are based on experiences gained in past projects in combination with consultation of manufacturing companies.

5.1 Assumptions

The following assumptions apply:

- all estimates are in Euros per 1 - 08 - 2006;
- the costs for key modules are based on quantities of 10,000 at present. Projections for larger quantities were made as far as possible;
- the costs for ASIC production are based on quantities of 2.7 million pieces per year for the first three years. After October 2012 it was expected that 800,000 pieces per year are required;
- each OBU variant requires dedicated design and engineering effort. A modular solution (e.g. a version with assembly options) that allows the production of either one of the three variants is feasible but is not part of the estimations;
- the costs for distribution, marketing, installation and keeping OBUs on stock are left out the estimations;
- the cost estimates highly depend on the production model. The cost estimates presented in this document apply to the *self-controlled production* model. In this model the Ministerie van Verkeer en Waterstaat is responsible for the production of the OBUs and associated risks.
  If *production is outsourced* a risk margin, insurances and prefinancing double (as a rough estimate) the costs for the OBU compared to the costs associated with the self-controlled production model.
  The costs are expected to triple if the production takes place on a *commercial basis*.

5.2 Key - module approach

5.2.1 Bill of material

	OBU Variant		
Component	Secure position recorder	Secure Tariff Monitor	Secure Mobile Payment Box
Human Machine interface	0,60	3,65	6,00
SAM	6,00	6,00	6,00
GPS	20,75	20,75	20,75
DSRC	20,75	20,75	0,00
GPRS	0,00	0,00	20,75
RTC	0,75	0,75	0,75
Memory - SRAM	1,10	1,10	1,10
Memory - Flash (road maps and tables)	0,00	12,20	12,20
Processor and program memory	6,45	6,45	6,45
IO	1,25	1,25	1,25
Chip card interface	4,00	4,00	4,00
Power supply (voltage regulation, external)	2,65	2,65	2,65
Sensor – accelerometer	3,35	3,35	3,35
Sensor – voltage meter	0,65	0,65	0,65
Housing, PCB and cable	6,00	6,00	6,00
Sub-total	**74,3**	**89,55**	**91,9**

Table 6. The key - module component catalog.

Remarks:

1. GPS, DSRC and GPRS are RF components each consisting of an analog, digital and antenna part. Because of their commonalities the prices of these key-modules are assumed to be equal;
2. because of the limited functionality a single processor platform (including SRAM memory) is selected for all three variants. Flash memory for map and table storage can be added as a separate flash card;
3. today new technologies emerge, allowing manufacturers to combine communications functions with processor kernels. Relatively low-cost circuits come on the market that integrate GPRS and processing functions with enough program space to allow customers to load their own applications. These are promising developments that could further lower the costs of an OBU.

5.2.2 Manufacturing costs

Component	**OBU variant**		
	Secure position recorder	Secure Tariff Monitor	Secure Mobile Payment Box
Licenses	0,00	1,00	1,50
Certification and qualification	0,10	0,15	0,20
Design	0,75	1,00	2,00
Assembly & Test	18,00	20,00	22,00
Packaging	4,00	4,00	4,00
Miscellaneous	10,00	10,00	10,00
Sub-total	**32,85**	**36,15**	**39,7**

Table 7. Overview of manufacturing costs.

Remarks:

1. license cost include the fees for the use of road maps and a reservation for the use of GPRS (secure mobile payment box only);
2. the costs for certification & qualification, design and assembly and test are assumed to slightly grow (per OBU) with the complexity of the product.

5.2.3 Total costs

	OBU variant		
	Secure position recorder	Secure Tariff Monitor	Secure Mobile Payment Box
Bill of material	**74,3**	**89,55**	**91,9**
Manufacturing	**32,85**	**36,15**	**39,7**
Total	**107,15**	**125,7**	**131,6**

Table 8. Estimated total costs key module approach for the self-controlled production model.

5.3 Integrated approach

5.3.1 Bill of material

Component	OBU variants		
	Secure position recorder	Secure Tariff Monitor	Secure Mobile Payment Box
ASIC	6,00	6,00	6,00
Human Machine interface	0,60	3,65	6,00
SAM	6,00	6,00	6,00
Non-integrated part GPS	11,60	11,60	11,60
Non-integrated part DSRC	11,60	11,60	0,00
GPRS	0,00	0,00	20,75
Non-integrated Memory - Flash (road maps and tables)	0,00	12,50	12,50
Chip card interface	4,00	4,00	4,00
Power supply (voltage regulation, external)	2,65	2,65	2,65
Sensor – accelerometer	3,35	3,35	3,35
Sensor – voltage meter	0,65	0,65	0,65
Housing, PCB and cable	6,00	6,00	6,00
Sub-total	**52,45**	**68**	**79,5**

Table 9. The integrated approach catalog.

Remarks:
1. The ASIC integrates the processor platform including static- and program memory and the digital parts of the GPS and DSRC components.
2. The digital part of GPRS is not available as an Industrial Property (IP) core and is therefore left out of the ASIC.
3. The non-integrated parts of GPS and DSRC are the analog and antenna parts.

5.3.2 Manufacturing costs

Component	**OBU variant**		
	Secure position recorder	Secure Tariff Monitor	Secure Mobile Payment Box
Licenses	0,25	1,25	1,75
ASIC design	0,25	0,25	0,25
Certification and qualification	0,10	0,15	0,20
Design	0,75	1,00	2,00
Assembly & Test	18,00	20,00	22,00
Packaging	4,00	4,00	4,00
Miscellaneous	10,00	10,00	10,00
Sub-total	**33,35**	**36,65**	**40,2**

Table 10. Overview of manufacturing costs.

Remarks:

1. The license costs of IP-cores are assumed to be €0.25, or 2 million for the total series.
2. ASIC design, including mask making adds €0.25 per OBU to the total design costs (compared to the key-module approach).

5.3.3 Total costs

	OBU variant		
	Secure position recorder	Secure Tariff Monitor	Secure Mobile Payment Box
Bill of material	**52,45**	**68**	**79,5**
Manufacturing	**33,35**	**36,65**	**40,2**
Total	**85,8**	**104,65**	**119,7**

Table 11. Estimated total costs integrated approach for the self-controlled production model.

5.4 Catalog usage example

The usage of the catalog is illustrated by the following example that compares the cost of the secure position recorder with the slim OBU defined by mm-Lab.
The slim OBU is in essence a secure position recorder with additional GPRS communication facilities and a simple display and keyboard. The table below gives an impression of the effect of adding building blocks to the secure position recorder to create its slim counterpart.

5.4.1 Key module approach

	OBU Variant	
Component	Secure position recorder	Slim OBU
Human Machine interface	0,60	6,00
SAM	6,00	6,00
GPS	20,75	20,75
DSRC	20,75	20,75
GPRS	0,00	20,75
RTC	0,75	0,75
Memory - SRAM	1,10	1,10
Processor and program memory	6,45	6,45
IO	1,25	1,25
Chip card interface	4,00	4,00
Power supply (voltage regulation, external)	2,65	2,65
Sensor – accelerometer	3,35	3,35
Sensor – voltage meter	0,65	0,65
Housing, PCB and cable	6,00	6,00
Manufacturing	**32,85**	**32,85**
Total	**107,15**	**133,3**

Table 12. Key module approach: secure position recorder versus slim OBU.

5.4.2 Integrated approach

Component	**OBU variants**	
	Secure position recorder	Slim OBU
ASIC	6,00	6,00
Human Machine interface	0,60	6,00
SAM	6,00	6,00
Non-integrated part GPS	11,60	11,60
Non-integrated part DSRC	11,60	11,60
GPRS	0,00	20,75
Chip card interface	4,00	4,00
Power supply (voltage regulation, external)	2,65	2,65
Sensor – accelerometer	3,35	3,35
Sensor – voltage meter	0,65	0,65
Housing, PCB and cable	6,00	6,00
Manufacturing	**33,35**	**33,35**
Total	**85,8**	**111,95**

Table 13. Integrated approach: secure position recorder versus slim OBU.

6. RISK ANALYSIS

The risk analysis follows the different phases in the life of an OBU, namely:

- ***Concept***
  During this phase the KMP system concept is defined. The whole KMP project is politically sensitive. Quite some of the technically oriented risks can turn out to be a political risk. For example, an OBU that does not work correctly might not be trusted by the public, finally resulting in a rejection of KMP.
  Therefore a thorough security and RAMS (reliability, availability, maintainability and safety) analysis shall be an integrated part of the concept phase.

- ***Requirements & Specification***
  During this stage the complete, precise and unambiguous specifications for the OBU as part of the overall KMP system are developed and published. For the OBU, essential elements additional to the functional specifications are:
  - quality of the components (needed for the selection of the IP cores and the design of the ASIC/SIP);
  - required yield on level of ASIC/SIP;
  - required yield on level of the PCB.

- ***Design & Development***
  This life cycle stage considers the:
  - components:
    - final selection of the IP cores;
    - design and development of integrated ASIC and/or SIP;
    - design and development of the interfaces of the IP cores to the outer world;
    - design and development of the test suite needed to verify the quality of the manufactured ASIC / SIP.
  - PCB:
    - design and development of the PCB;
    - design and development of the test suite needed to verify the quality of the manufactured PCB.

- ***Manufacturing***
  During this stage the designed OBU is manufactured, consisting of the following processes:
  - manufacturing of the ASCI/SIP;
  - manufacturing of the PCB;
  - assembling the OBUs.

The OBU shall be manufactured in a secure environment. This environment should be certified by the KMP service provider, since he is responsible and therefore liable for the OBU.

- ***Issuing***
  In this stage the OBUs are brought from the manufacturers into the vehicles. Besides distribution aspects, it is important to specify:
  - how to activate and/or update the configuration of the OBU matching the characteristics of that specific vehicle and vehicle owner;
  - how to mount the OBU in the vehicle;
  - how to register the OBU by the Central System.

- ***Operations***
  During this stage the OBU and the counterpart of the OBU in the Central System have become operational and constitute an enabler for the KMP.

- ***Management and updating of the OBU***
  This part of the OBU life cycle is about ensuring and maintaining operational conditions.

- ***End of life***
  This is the last part of the OBU life cycle. The OBU is removed from a vehicle and brought to the service provider for recycling.

- ***Certification***
  In all phases except ‘issuing’ and ‘operations’ either the environment where the activities take place or the product from a phase needs to be certified.

6.1 Risks in the sequential life cycle steps

6.1.1 Concept

Risk 01	Not enough time to define a system concept that meets the required level of security and fulfills the RAMS figures.
Measure 01	Withstand political pressure to do things in a rush and reserve enough time to analyze and perform additional research.

Risk 02	The KMP initiative is bypassed by other initiatives of providers of navigation systems, insurance companies, and others. The KMP-OBU then becomes 'another device in our cars' which might undermine the acceptance of the KMP initiative.
Measure 02	Do not delay. Start the next phase. Include other parties in the project beforehand.

6.1.2 Requirements & Specifications

Risk 03	Non-complete and/or ambiguous requirements.
Measure 03	Finalize set of requirements for the OBU not before having them tested in a serious pilot with this OBU.

Risk 04	Non-stable requirements.
Measure 04	Perform a pilot. Stabilize and freeze the requirements for the OBU after the pilot.

Risk 05	Non-complete and or ambiguous specifications.
Measure 05	Perform a pilot. Use the OBU as used in the pilot to define the specifications.

6.1.3 Design & Development

Risk 06	Fault in the design of the ASIC / SIP.
Measure 06	Verify the design of the ASIC / SIP using a test suite that is based on the specifications.

Risk 07	Fault in the design of the PCB.
Measure 07	Verify the design of the PCB using a test suite that is based on the specifications.

Risk 08	Fault in one of the test suites.
Measure 08	Before testing the design of the OBU, verify the test suites by virtually testing the specified ASCI / SIP and the PCB.

6.1.4 Manufacturing

Risk 09	Yield in ASIC / SIP is not secluded from the ‘misfits’.
Measure 09	Use the test suite to seclude the yield.

Risk 10	Yield in PCB is not secluded from the ‘misfits’.
Measure 10	Use the test suite to seclude the yield.

6.1.5 Issuing

Risk 11	Obsolescence of components.
Measure 11	Major criterion in the IP core selection is the expected lifetime of the component.

Risk 12	Components out of stock.
Measure 12	Build a buffer of components in order to overcome a period that the components are out of stock.

Risk 13	Incorrect personalization.
Measure 13	Personalization shall be done by the issuer before handing over the OBU to the vehicle owner.

Risk 14	Incorrect match between OBU and Vehicle.
Measure 14	Keep the vehicle characteristics to be stored in the OBU as limited as possible (e.g. number plate number only) and have them stored in the OBU by the issuer as far as possible.

Risk 15	Non-official OBUs circulate.
Measure 15	Manufacture and issue the OBU in a secure environment, so the authenticity of the OBU, its personalization and its match with the vehicle can be verified during the enforcement transactions.

6.1.6 Operations

Risk 16	Fault in the operations cannot be traced back to its origin.
Measure 16	Make fault tracing part of the design of the OBU, the design of the manufacturing process and the design of the issuing procedures.

Risk 17	OBU integrity is violated.
Measure 17	Design and implement the OBU and its components based on certain well-defined boundary conditions, and check in runtime constantly whether the boundary conditions for the OBU and its components still are true.

Risk 18	OBU operates in a non-authorized manner.
Measure 18	Define the mandatory, optional and forbidden behavior of the OBU in the Design & Development phase. Check the behavior in runtime.

Risk 19	OBU operates outside specifications.
Measure 19	Define the necessary performance, accuracy and correctness of the OBU, its components and its functioning in the Design & Development phase. Check in runtime (in combination with the Central System and as an integral part of the system concept as well!) the performance, accuracy and correctness as far as possible.

Risk 20	Security of the OBU and its functioning is threatened, respectively violated.
Measure 20	Define the necessary level of security of the OBU and its functioning in the Design & Development phase. Check in runtime (in combination with the Central System) the security as far as possible.

Risk 21	Continuity and consistency of the OBU and its functioning is threatened, respectively violated.
Measure 21	Define the necessary levels of continuity and consistency of the OBU and its functioning in the Design & Development phase. Check in runtime (in combination with the Central System) the continuity and consistency as far as possible.

Risks that depend on the characteristics of the distinguished OBU variants are described below.

Risk 22a	*All variants*: hitch in the accuracy of the positioning.
Measure 22a	Add functionality to the software in the OBU to verify the correctness and reliability of the GPS signal.

Risk 22b	*Secure tariff monitor and mobile payment box variants*: out-of-date digital map is used for map matching.
Measure 22b	Accept an intermediate time interval between starting the distribution of a new map and the date of commencement of this map.

Risk 22c	*Secure tariff monitor and mobile payment box variants*: out-of-date tariff table.
Measure 22c	Accept an intermediate time interval between starting the distribution of a new tariff table and the date of commencement of this table.

Risk 22d	*Secure position recorder*: in case GPRS is used, the GPRS capacity is not sufficient to submit the trails of positioning data.
Measure 22d	• Include a backup possibility to submit the trails of positioning data (e.g. chip card + wireless interface). • Measure already incorporated in the selection of components in paragraph 4.2. • Incorporate additional memory in the OBU to store additional positioning data.

6.1.7 Management and updating of the OBUs

Risk 23	Fault in the updating of the OBU, resulting in one or more of the operational risks identified in the previous paragraph.
Measure 23	Incorporate the management and updating procedures in the design of the OBU, its components and its functioning.

6.1.8 End-of-Life

Risk 24	Non-official OBUs circulate (instead of recycling an OBU, the OBU is retrofitted into another vehicle).
Measure 24	Manufacture and issue the OBU in a secure environment, so the authenticity of the OBU, its personalization and its match with the vehicle can be verified during the enforcement transactions.

6.1.9 Certification

Risk 25	Incorrect OBUs are coming on the market.
Measure 25	Certify the ASIC / SIP, the OBU as a whole and the OBU ready for issuing before factually issuing them.

7. ORGANIZATIONAL ASPECTS

7.1 Migration path

The migration path is defined as the steps that are necessary in the process of developing and producing OBUs for all vehicles in the Netherlands. This process is expected to require three years or more.

The risk analysis in chapter 6 shows that it is hard to expect that the KMP is introduced at once. Several aspects of the system are to be developed and practical experience is required before serial production of OBUs can start.

Following this route one can think of the following migration steps:

1. define a concept;
2. start a prototyping phase. Install OBUs based on key modules in up to 100 vehicles. Aim for a flexible solution that allows for changes. Objective if the prototyping is to come to a proof of concept for the OBU (and thereby complete, unambiguous and stable requirements);
3. design and develop the OBU;
4. manufacture a first set of OBUs;
5. pilot phase in which the first set of OBUs will be tested thoroughly (and where necessary improved) in a range of different vehicles and with a range of different end-users;
6. start the manufacturing of the full set of OBUs;
7. start issuing the OBUs once there is a buffer of OBUs of about two to three months;
8. once the OBUs are issued start the operational phase of the KMP.

The migration steps are incorporated in a draft planning in Figure 8. As can be seen from this figure, the overall planning for the OBUs alone is rather strict, leaving ample room in the planning for unexpected events and issues.

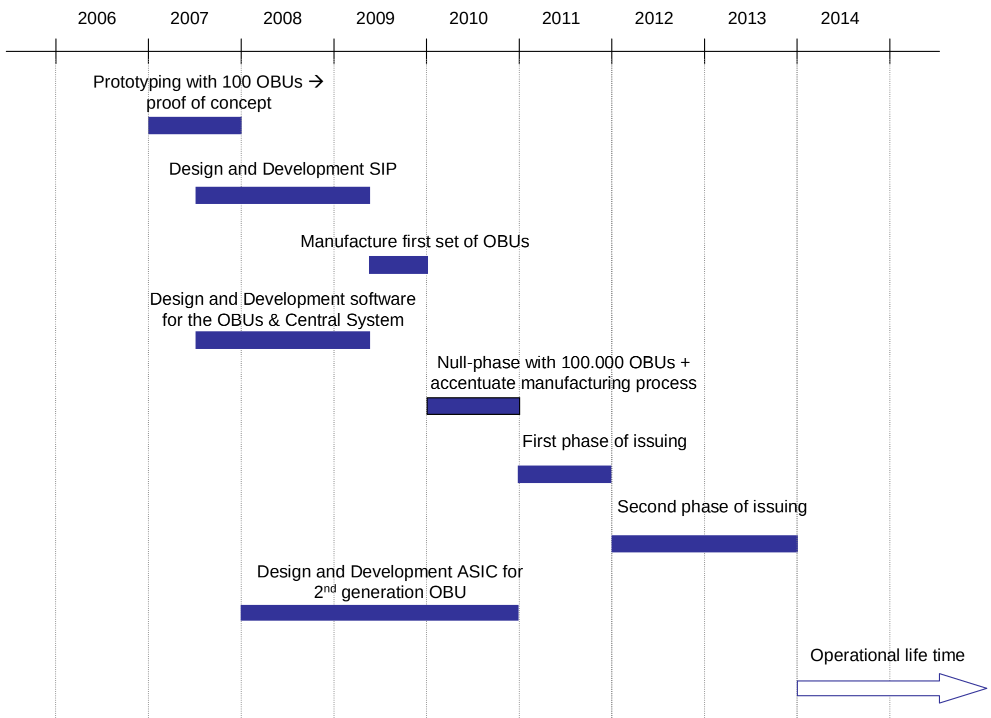

Figure 8. Draft planning of the OBU design & development, manufacturing and issuing

7.2 Deployment strategy

The deployment strategy should match the migration path. The strategy should address the effort to set up the back office infrastructure, to install OBUs in the vehicles and to organize an enforcement apparatus.

The draft planning as depicted in Figure 8 has been the main argument to start this cost analysis with the assumption that the OBU should be a monolithic, compact and easy to install device. Such a strict planning can only be realized when the vehicle owner can install the OBU himself in a manner quite similar to the issuing and installation of digital TV decoders nowadays.

For the longer term it can be foreseen that a KMP - OBU becomes one of the key-components within an integrated in-vehicle telematics platform. With such an approach, key KMP - OBU functionality is combined into a single module. This module is used by automotive OEMs for integration in their in-vehicle telematics platforms.

The components to realize such an OBU key module for a mobile payment box are shown below.

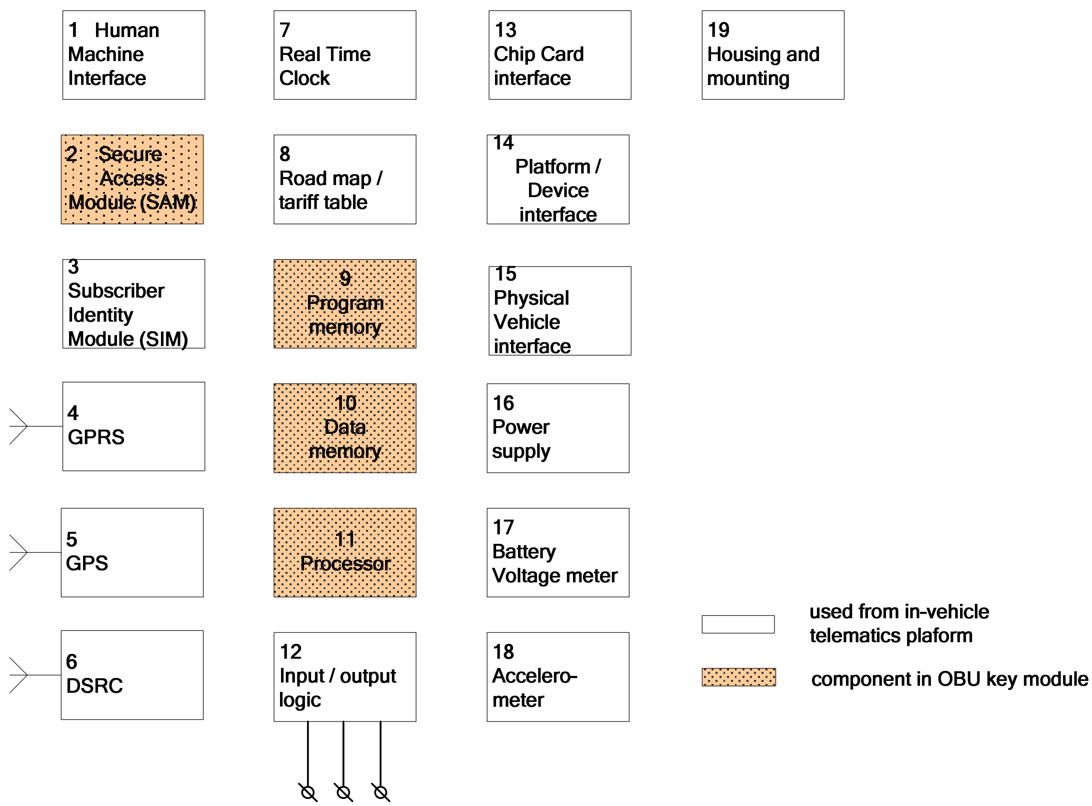

Figure 9. A mobile payment box created with an OBU module and in-vehicle telematics functionality.

8. REQUIREMENTS REVIEW

The requirements review is split in two parts:

1. part one presents some review comments on the 24 initial requirements;
2. the second part introduces some additional requirements.

8.1 Some comments on the initial requirements

- there are no objective criteria to determine if requirements [6], [12], [13], [14], [15], [16], [20], [21], [23] and [24] are met in a given solution;

- requirements [9] and [10]: both requirements concerning temporary usage are likely to have a strong impact on the technical and organizational aspects of KMP. It might be an idea to leave room (or give a hint in the rationale section of the requirements specification) for non - technical solutions as well (think of vignettes etc);

- requirement [11]: does this mean that the system should also be fully operational in other countries?

- requirement [12] and [13]: there is not necessarily a coupling between reliability and correct and adequate road user pricing! It is suggested to split these requirements into separate requirements including a qualification;

- requirement [14]: protection against discomfort is not likely to be a function of an OBU. Reformulate in something like; An OBU shall not distract a vehicle driver from his primary driving task.

- requirement [15]: an OBU can be visible but not provide any useful information. Reformulate in something like; Information provided by an OBU shall be presented to the vehicle driver (in such a way that requirement 14 is met).

- requirement [16]: suggestion; Split this requirement into requirements concerning operational aspects and safety (see also requirement 14). Add a new system function requirement that addresses social acceptance of the solution.

- requirement [18]: suggestion; add an estimation of the system revenue that replaces the unqualified 5%.

8.2 Suggestions for additional requirements

- Formulate a main system requirement (the mission / its goal) in terms like, for instance:

  'KMNP shall be a socially accepted replacement for the Dutch 'motorrijtuigen belasting' (road tax) by charging motor vehicles for individual trips'

  and

  'The KMP system shall reward its users if other transportation modalities are used than transportation by car'.

  All other requirements are a subordinate of this main requirement.

- Add a requirement that specifies the lifetime of the system.
- Add a requirement that specifies that a Reliability, Availability, Maintainability and Safety (RAMS) analysis for the entire system is required and that the system design shall comply with the results of this RAMS analysis.
- Add a requirement that specifies the RAMS budgets including their allocation to the different subsystems.
- Add a requirement that requests for an integral risk analysis that covers all aspects of the system.