Total Costs for the Development, Production and Deployment of the OBU

Final Report

Management Summary

Within the project "Cost Monitor" the Ministry of Transport, Public Works and Water Management tasked mm-lab with the provision of cost information on the development and production of different variants of Onboard Units (OBUs) for the envisaged Road Pricing System. Additionally, it was agreed that mm-lab should present – based on the overall requirements and mm-lab's experience – comments and ideas on the integration of the OBU into the context of the overall system solution, dealt with in the scope of the complementing assignments (1; 3-7).

The alternative system approaches (centralised versus decentralised charging) motivated the analysis of a thin client called "slim" OBU compared to a thick client called "smart" OBU prepared for basic (Value) Added Services – eventually to be enhanced with integrated (Value) Added Services (thick client called "rich" OBU). The different cost elements and the overall costs for each considered OBU variant are presented in table A (for more details see chapter 5.2 and 5.3):

	OBU Version		
Functional units	Slim	Smart	Rich
Cellular communication	22,00 €	22,00 €	22,00 €
Positioning	10,00 €	10,00 €	10,00 €
Enforcement	17,00 €	17,00 €	17,00 €
Human Machine Interface	4,00 €	11,00 €	22,00 €
Processing	15,00 €	27,00 €	47,00 €
Security	5,00 €	3,00 €	3,00 €
Power supply	9,50 €	9,50 €	12,50 €
Miscellaneous	18,00 €	24,00 €	24,00 €
Interfaces	0,00 €	0,00 €	4,00 €
BOM	100,50 €	123,50 €	161,50 €
incl. Manufacturing and Shipment	121,00 €	147,00 €	191,00 €
Externals	12,00 €	12,00 €	12,00 €
SW licenses	4,00 €	4,00 €	6,00 €
Total	137,00 €	163,00 €	209,00 €

Table A: Costs of OBU variants

The main findings of the comparison including all requirements on the different OBU variants can be highlighted in two statements:

Potential Cost Savings

Executing the payment decision at the backend system will save some cost in the OBU due to a smaller memory size, less processing power and a simpler Human Machine Interface (HMI). With such a slim OBU a cost reduction of 17% compared to the smart OBU is achievable. The overall reduction of 17% consists of a reduction of 5% due to the changed approach (thick client -> thin client) and a reduction of 12% due to the cancellation of any capability to support basic added services inside the OBU. The consequences of these savings must not be neglected:

- higher volume of data to be transferred to the Central Server,
- no capabilities for basic value added services inside the slim OBU,
- higher processing effort for charging in the Central Server,
- high risk of a public debate on the loss of privacy due to the system immanent transmission of complete tracks ,
- reduced or even missing flexibility concerning European interoperability and future applications.

Additional savings may be achieved by addressing the main cost drivers of the OBU. These are the GSM and the DSRC communication interfaces. Major cost improvements could be achieved by removing one of these interfaces.

Removing GSM, which is the main cost driver, would require additional communication via DSRC increasing investment and operational cost on the DSRC infrastructure. A much denser DSRC network would be required compared to a pure DSRC enforcement function. Real free flow tolling would become impossible due to throughput constraints of the DSRC data communication while driving with typical speed.

Leaving out the DSRC interface would result in a much more complicated enforcement system and would increase dramatically the cost for enforcement (mobile or CCTV based) as the London congestion scheme or the occasional user scheme in German Toll Collect system have indicated.

<u>OBU Installation</u>

The installation of any type of OBU is an expensive and time critical factor. Millions of working hours have to be spent in a very short time frame (see chapter 5.6). It is arguable whether the installation of 8 million OBUs can be performed without any phasing of introduction. The costs are generated connecting the OBU to the vehicle for power supply, odometer or Controller Area Network (CAN) access and external antennas. Technological solutions to reduce the effort are feasible with a certain risk on the introduction time frame of a road pricing system. Regulations e.g. to enable CAN access in all new vehicles (comparable to the emission control measurement via the mandatory standardised OBD interface of all new vehicles) and a corresponding standardisation would also facilitate the installation and would reduce cost.

The 2 main cost drivers for the installation are the mounting of external antennas and the car interface (ignition, CAN and/or odometer). The reasons promoting external antennas are EU regulations for radiation of wireless connection and technical constraints for certain cars, i.e. coated windscreens, restricted view of orbit and therefore the number and constellation of satellites seen when mounted inside.

Driven by the necessary focusing on OBU equipment the findings of this report should be seen as a significant but not exhaustive contribution to the assessment of the Total Cost of Ownership of the “In Vehicle Part” of the Road Pricing System.

Factors such as the necessary adaptation to numerous brands and types of vehicles and the resulting installation effort may define major cost impacts in the same order of magnitude as the equipment costs.

Despite the cost advantage (in vehicle) for the “slim” OBU considerations on political and public interest like

- interoperability in the European Union (EU) context (see chapter 10.1 and EU directive 2004/52/EC [3])
- privacy constraints (see chapter 10.1 and EU directive 95/46/EC [4])
- introduction of eCall in 2009 according to the rollout plan of the EC (see chapter 10.1 and Fact Sheet 49 [15])
- additional services generating revenues/benefits particularly for the citizens of the Netherlands, the operator of the Road Pricing System and commercial users (see chapter 10.2)
- future developments like Galileo (see chapter 10.1) or the replacement of odometer interface (see chapters 3, 5.3.2)

may favour the decision for a “thick client” approach.

History

Edition	Date	Change note	Responsible
01P01	19.06.2006	Draft report created	Author: Claus Hirdes Approval: Lothar Krank
01P02	05.07.2007	Draft report updated with feedback from the 2nd interactive meeting	Author: Claus Hirdes Approval: Lothar Krank
01	17.07.2006	Draft report released as version 01	Author: Claus Hirdes Approval: Lothar Krank
02P01	17.07.2006	Draft report updated for the delivery of the final version	Author: Claus Hirdes Approval: Lothar Krank
02	04.08.2006	Final report released as version 02	Author: Michael Koch Approval: Lothar Krank

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Tables and Figures

1 Introduction

mm-lab has been awarded to contribute to the Cost Monitor Project initiated by the Ministry for Transport, Public Works and Water Management of the Netherlands (further on shortly named Ministry). This project is dedicated to estimate the costs of an overall road pricing system and to prepare a presentation to the Parliament of The Netherlands. Parallel to a second company, mm-lab was charged with a cost analysis for an Onboard Unit (OBU) used to implement the vehicle part of this road pricing system ('kilometerprijs' (KMP)). Mm-lab provides a long term experience in tolling systems gained from the involvement of a world leading telecommunications supplier in the German toll system over years as well as from the development of mm-lab's own OBU, which is already implemented and available. This OBU is part of mm-lab's Telematics solution that is able to support tolling and Value Added Services (VAS) in parallel. As a consequence, mm-lab is not only able to provide cost information on a single item like the OBU, but always checks the OBU functionality against the overall system requirements and possible future evolution to improve the benefits generated by the investment.

Considering the task mm-lab is awarded we are clearly committed to the scope of work agreed with the Ministry. The summary report of the mm-lab evaluation for the assignment 2 reflects these agreements. It is organized according to the work packages as presented in the Project Management Plan (PMP) [5].

Chapter 2 shortly describes the scope of this report, its development in consequence to the interactive meetings and assumptions taken.

Chapter 3 lists the basic system characteristics with a proposal for the hardware related architecture of the OBU. This is based on the mapping of requirements to the needed main hardware components and modules.

Chapter 4 provides the functional counterpart to the hardware architecture. Based on the introduced definition of the road pricing system functions the requirements are mapped to these system functions with the resulting OBU architectures further evaluated. As a part of the evaluated scenarios the occasional user schemes and their impact to the overall architecture is shortly documented.

Chapter 5 provides the evaluation results of the cost analysis based on the system architecture summarized by the chapters 3 and 4.

As part of the rollout of a road pricing system the deployment of the OBU as well as the system test of the OBU are time consuming steps, which are manageable under specific preconditions that are highlighted in chapter 5.7.

The results of the risk assessment are documented and summarized in the attached spreadsheet [9]. The chapter 7 only highlights the main identified risks mapped to the work packages as described in the PMP [5].

Answers to the questionnaires linked to the requirements [6] are provided in chapter 8 together with the requested comments on the requirements.

The questionnaire raised as a result of the 1st interactive meeting is treated in chapter 9.

2 Scope

In order to qualify and weight the results described in the following chapters it is necessary to clarify the scope of work expected by the Ministry as well as the „evolution“ of this scope during the last few weeks. Therefore mm-lab opens this report with a description of scope as it was agreed with the Ministry, it highlights the changes done during elaboration and it points out the consequences of these changes on the results of the report.

2.1 Initial scope

The scope of assignment 2 (“Total cost for the development, production and deployment of the OBU”) was defined by the Ministry in document [1]. This document explains the work to be done according to the following two approaches

1. The first approach describes the life cycle of an Onboard Unit (OBU) from planning and development towards installation and operation.
2. The second approach comprises the system and cost relevant items from the basic concept towards the examination of costs and an annotation of specific OBU requirements.

The initial scope of work requires

- a project plan, which has already been delivered to the Ministry,
- the definition of basic OBU characteristics and focus areas considering three OBU variants with different complexity,
- the elaboration of an OBU concept and a corresponding high-level design considering different functional requirements and describing different functional characteristics (”slim” vs. ”smart” or “rich” OBU; definition see chapter 3). OBUs for special user categories (e.g. motor cycles, lorries, occasional users) have to be added,
- the estimation of overall costs comprising the costs for development, production, testing, certification and deployment of the OBU, and additionally considering cost estimates for different production volumes,
- the indication of deployment scenarios considering the fact that over 8 million vehicles have to be equipped with OBUs,
- a risk analysis to identify and prioritise the major risks for development, production, costs, introduction and operation of the OBU,
- comments on the requirements specification as given in [6].

2.2 Reduced scope to avoid overlapping with assignment 1

During the interactive meetings – particularly the 2nd meeting – the Ministry has adapted the scope in order to avoid extensive overlapping between assignment 1 [13], being responsible for the overall road pricing system and assignment 2 responsible for the OBU. As a consequence parts mainly dedicated to the overall system functionality were removed from assignment 2.

Examples are:

- Test of OBUs in different types or brands of vehicles and OBU system tests
- Logistics for OBUs
- OBU Management

Since an “intelligent” OBU is one of the key elements of a future road pricing system, mm-lab is convinced that these parts are important for an overall cost estimation. Mm-lab will at least refer on them where appropriate. It is an important task to clarify the boundaries between the assignments in such a way that no gaps occur in the overall architecture. Mm-lab clearly states that a crucial part of functionality closely related to the OBU (OBU configuration, maintenance, management) has to be performed in the central part of the system. In case of a thin client this even comprises the detection of a charging event, which defines whether a vehicle used a specific road.

2.3 Reduced effort for occasional user schemes

It has been expressed by the Ministry during the 2nd interactive meeting, that the effort spent for occasional user schemes should be reduced. Mm-lab therefore provides some indication on occasional user schemes but will not provide detailed cost estimates. We expect, that this will be done by assignment 1 [13]. Nevertheless mm-lab would like to indicate, that – based on former experiences – there is a certain risk that considerations on occasional user schemes dominate the system design on the overall road pricing system.

2.4 Final scope

mm-lab will finally provide information on the development and production phase of an OBU. Additionally we add information concerning the test of the OBU itself and the necessary effort to deploy the OBU, e.g. necessary effort for the installation of an OBU.

The OBU itself will be examined in three variants, each supporting the road pricing system:

- a “rich” OBU supporting additional services (thick client + services),
- a “smart” OBU (thick client) and
- a “slim” OBU (thin client).

The rationale for these variants is given in chapter 3.

Each of the different OBU variants will fulfil the complete set of requirements. Only such a process will result in comparable cost estimations and the identification of the main cost drivers per variant. Changes of the weighting of requirements are considered to be valid for all OBU variants.

Based on the identified cost drivers more cost-effective alternatives may be analysed. The consequences of these modifications have to be checked against all existing requirements and may result in an agreed change process for the requirements.

We strongly recommend to avoid changing the weight of a particular requirement before finishing the process described above. Such changes may result in cost improvements, which are marginal compared to their impact on the requirements, the overall system and the resulting overall costs.

3 Proposed basic system characteristics

The basic system characteristics as given below and the cost estimates as given in chapter 5 are based on the following assumptions:

- All requirements as documented in [6] have to be fulfilled by the proposed system.
- All requirements as documented in [6] have the same weight.

Looking at some of the requirements as documented in [6] the following hardware building blocks for the Onboard Unit (OBU) are identified as mandatory:

Requirement	Hardware component	Comment
1	CAN interface or Odometer interface or 3 dimensional accelerator	The mentioned hardware building blocks are different options to fulfil the requirement. The 3 dimensional accelerator is the only option, which requires no interface to the vehicle with the drawback is the current development status and the reduction of the precision and reliability
3	GNSS receiver; Gyro and Odometer or 3 dimensional accelerator	There is no Road Side Equipment (RSE) available to evaluate the position of the vehicle, therefore a Global Navigation Satellite System (GNSS) receiver with a Dead Reckoning (DR) function is needed; drawback for the 3 dimensional accelerator see above
4	HMI	The driver has to provide the information of a change of the vehicle characteristics, e.g. the type of trailer that has been connected which can only be realized by an appropriate Human Machine Interface (HMI)
7	GSM/GPRS or DSRC	Both implementations are in operation (Germany, Austria)
11	DSRC	Dedicated Short Range Communication (DSRC) is mainly used as enforcement interface
	GSM/GPRS GNSS receiver	The directive 2004/52/EC recommended that new electronic toll systems brought into service should use these technologies (see directive 2004/52/EC, article 2, paragraph 3)
15	Display	Dependent on where the unit will be mounted inside the car, a “visible feedback” for the current tariff might not be the optimal solution. This will lead eventually to a remote display or “acoustic feedback”.
1 – 4, 11, 15	CPU Memory	The wide range of data to be collected and registered needs a Central Processing Unit (CPU) to connected the various interfaces and enough memory for the applications and the data to be collected
24	SAM	The Security Application Module (SAM) provides the secure memory for the storage of encryption keys, charging records or for the encryption process itself

Table 1: Requirements and resulting hardware components

On base of the above given hardware components the following basic architecture can be extracted.

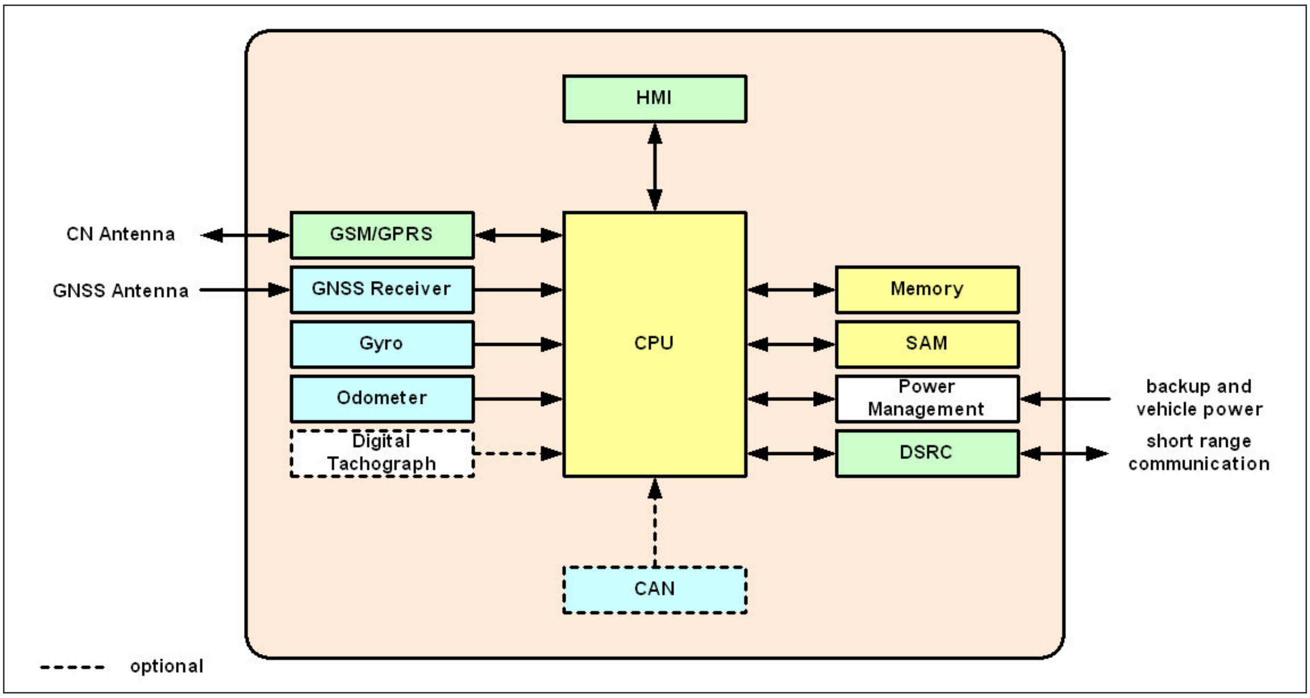

Figure 2: OBU hardware architecture on base of the requirements

With minor differences, this architecture is identical to the architecture proposed in [7]. Removing any of the above-mentioned components will lead to the violation of one or more of the requirements as documented in [6]. For more details on this please read chapter 4.

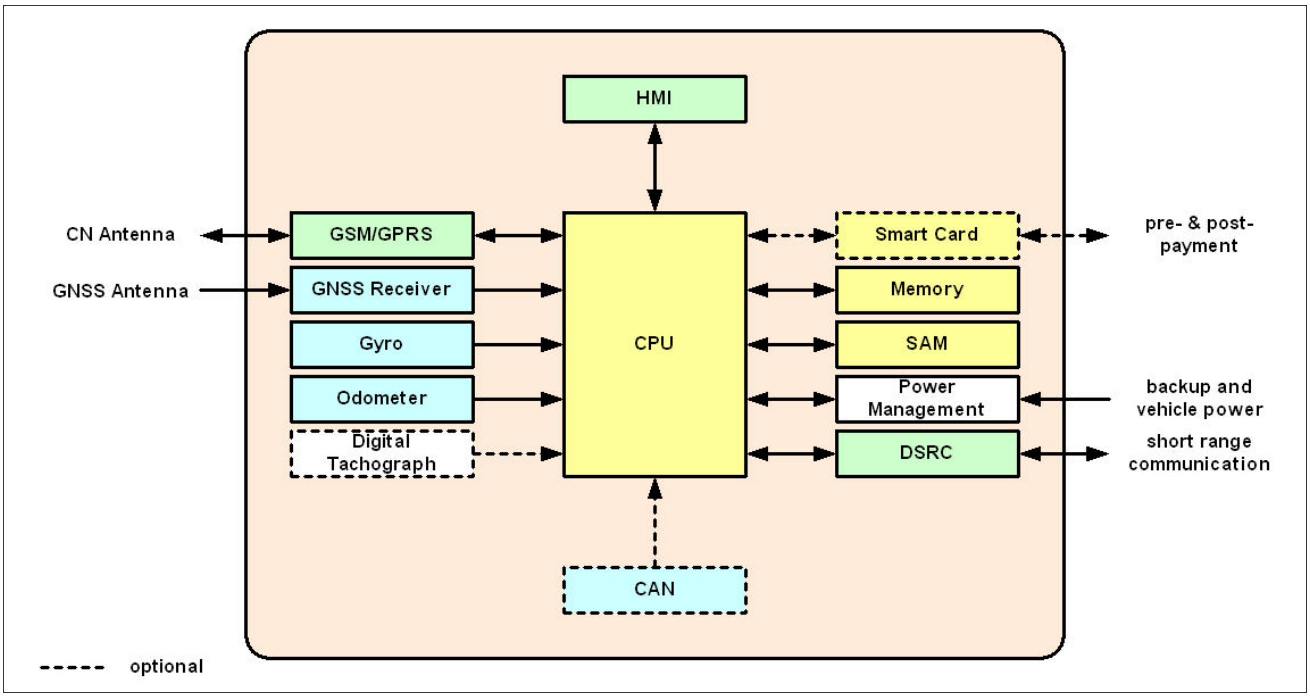

Figure 3: OBU hardware architecture on base of the 1st interactive meeting

The major difference between the OBU (hardware) architectures evaluated is therefore driven by the location of the corresponding system function. The following different approaches were evaluated:

- "rich" client: an OBU, which contains a sophisticated road pricing application that comprises positioning, localization, communication management, HMI management, charging management, security, enforcement and system management enriched with Value Added Services (VAS)
- "smart" client: an OBU, which contains the above described road pricing application and the possibility for basic VAS
- "slim" client: an OBU, which covers only the data collection, communication management, basic HMI management, basic security and enforcement.

Some examples for VAS are

- Floating Car Data to support traffic management
- Asset Tracking
- Dangerous Goods Tracking
- e-Call

To fulfil the above listed requirements both, thick ("rich" and "smart") and thin ("slim") clients, need to provide the hardware described above. Only changes of the requirements may result in simpler OBUs.

For the treatment of the occasional road users and road users with foreign number plates several alternatives are described and assessed in the following chapter.

4 High-level system design description

4.1 Requirement analysis

Although it is part of the assignment 1 [13] to define the system architecture for the requested road pricing system, it is recommended to have a look to the different road pricing system functions and their mapping to the requirements as documented in [6].

Road pricing system function	Comment
Billing Management	Creation of invoices and observation of payments receipt.
Charging Management	Collection of charging records created on base of single charge events and the corresponding tariff; provides the input for the Billing Management.
Communication Management	Long- and short-distance communication of the Onboard Unit (OBU) with the Central Server (CS) via GSM/GPRS and the enforcement authority via 5.8 GHz Dedicated Short Range Communication (DSRC) .
Enforcement	Depending on the occasional user scheme information has to be provided by the CS to the enforcement authorities.
Fraud Detection	Treatment of all relevant electronically recordable events.
HMI	The Human Machine Interface (HMI) provides the user with information concerning the vehicle characteristics, which may be defined by the user himself (e.g. type of trailer attached) or information that is generated by the system (actual road price) and most important the OBU status (indication of malfunctions).
Performance & Statistics	Evaluation functionality using different events and performance records to support the Toll Operator in the decision process for the optimisation of the road pricing system.
Positioning	Evaluate the precise position on base of Global Navigation Satellite System (GNSS) and Dead Reckoning (DR) with a granted level of integrity
Localization	Identification of the actual location (highway, zone, etc.); 'map-matching'.
Geographical Database	For the 'map matching' (detection of charging events on geographical data) the road network has to be (partially) described by geographical objects (segments, zones, etc.) that are stored and managed using a database.
Security Management	Authorization, authentication, access control and encryption/decryption procedures. Management of the security key infrastructure.
System Management	Management of the OBUs (configuration control, software release distribution).
Tariff Management	Set-up and maintenance of the tariff database.
Tariff Database	Complexity of tariff definition (distance, time, location, vehicle characteristics) requires a database.
Trouble Ticketing	Handling of user complaints.
User Management	Management of all user specific data like address, bank account for post paid service; Users are normal users and occasional users.
User Database	Number of users to be managed requires a database.
Online-Help	Management of helpful information for the user.

Table 4: Road pricing functions of a generic GNSS based road pricing system

The following table provides the mapping of these functions to the requirements. It still does not specify the location of the respective road pricing function, but it shows the impact on the requirements, in case the function would be changed or dropped and it also shows the impact on the system functions, in case a requirement is changed or dropped.

Road Pricing System Function	Reqirement																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Billing Management								X	X	X								X						
Charging Management	X	X	X												X							X		
Communication Management											X		X							X				
Enforcement									X	X		X												
Fraud Detection													X										X	
HMI				X										X	X	X								
Performance & Statistics																		X						
Positioning			X								X	X												
Localization			X									X												
Security Management													X	X									X	X
System Management																			X	X	X	X		
Tariff Management	X	X		X	X	X													X		X			
Tariff Database						X																		
Trouble Ticketing								X						X										
User Management							X	X	X	X										X		X		X
User Database							X	X														X		X
Online-Help																X								

Table 5: Mapping of road pricing functions to the requirements

The Table 6 shows, that the distribution of system functions to OBU and CS is identical for both approaches. The difference in the distribution of functions appears only between these two and the thin client. The number of system functions located on different positions is limited. The charging management, localization, security management, tariff database and the online help are located (partly) on different entities.

Road Pricing System Function	"Rich" OBU with VAS		"Smart" OBU w/o VAS		"Slim" OBU	
	OBU	CS	OBU	CS	OBU	CS
Billing Management		X		X		X
Charging Management	X		X			X
Communication Management	X		X		X	
Enforcement	X	X	X	X	X	X
Fraud Detection	X		X		X	
HMI	X		X		X	
Performance & Statistics		X		X		X
Positioning	X		X		X	
Localization	X		X			X
Security Management	X	X	X	X		X
System Management		X		X		X
Tariff Management		X		X		X
Tariff Database	X	X	X	X		X
Trouble Ticketing		X		X		X
User Management		X		X		X
User Database		X		X		X
Online-Help	X	X	X	X		X

Table 6: Operational location of the road pricing function for the different options

4.2 OBU system architecture as proposed by mm-lab

The basic architecture of the mm-lab proposed interoperable road pricing system is build on the concept of an OBU that comprises the main road pricing functions as listed in Table 6.

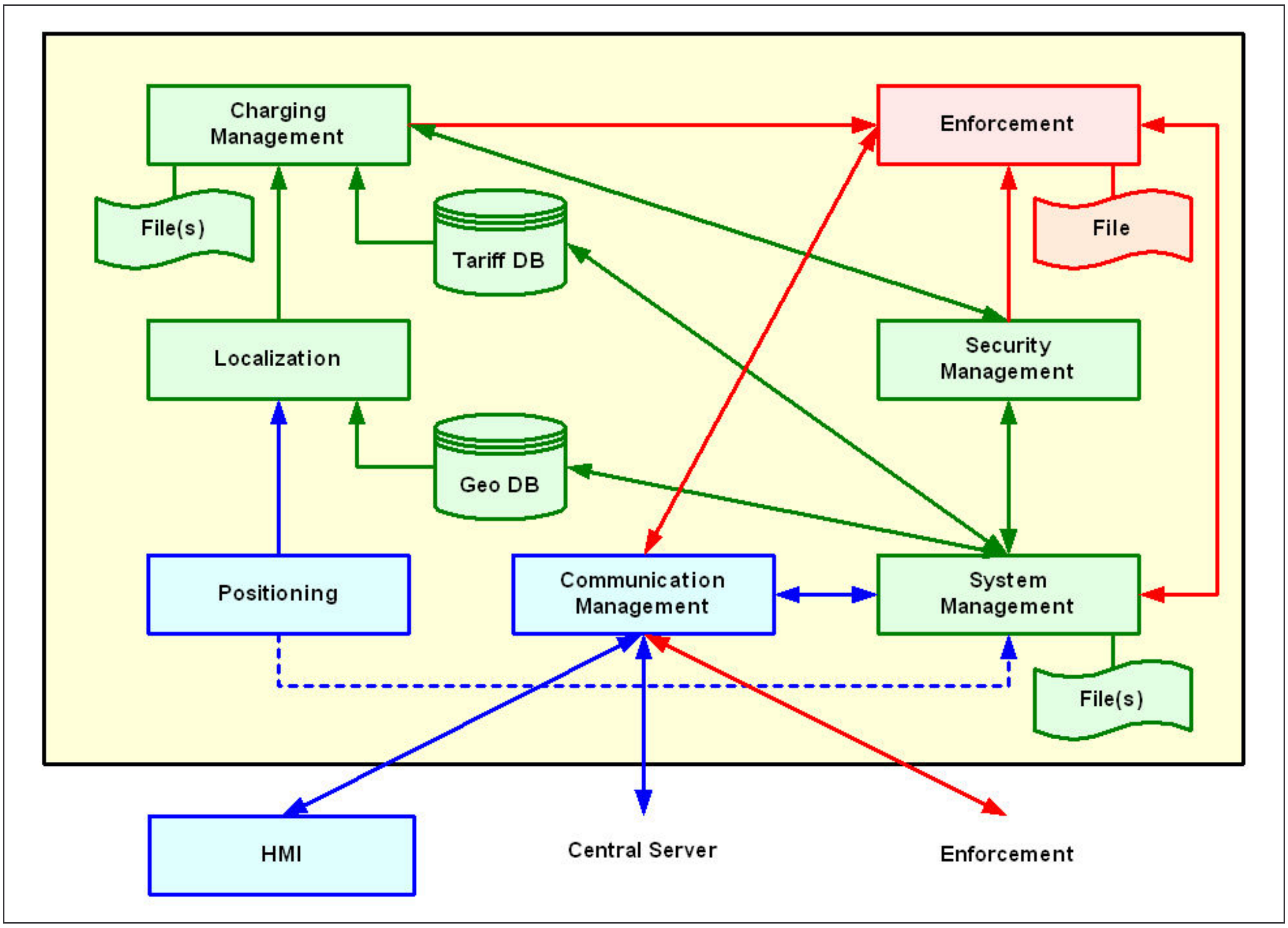

Figure 7: OBU system architecture as proposed by mm-lab

The purpose of each system function is given below, focusing on the OBU aspects.

- **Communication Management**: It enables the GSM/GPRS communication with the CS and the DSRC based communication with fixed and mobile enforcement units. Further on it serves the System Management to request driver input and to display the actual status and charging information via the HMI.
- **Positioning**: It evaluates the precise position on base of the information provided by the GNSS receiver and the DR module. The position is provided to the Localization for the detection of charging events and to the System Management to enhance the status information.
- **HMI**: The HMI provides the driver with information that is generated by the Charging Management system (actual tolling fee) and the OBU status

observed by the System Management. It serves as interface for the driver to specify adaptable vehicle parameters (e.g. trailer added, number of axles).

- **System Management**: The OBU part of the System Management is the central function that observes the correct working of all dependent road pricing functions. It is in charge of the status monitoring and is managing the update/upgrade of the software when requested. It provides the status relevant information to the Enforcement function and to the CS.
- **Security Management**: It serves all road pricing functions like System Management, Communication Management and Enforcement with the provision of encryption and decryption procedures. It is the only function that has access to the Security Application Module (SAM) where the security keys are stored. Any security violation will be immediately reported to the CS and stored in the respective log-file for Enforcement. Severe security violations or detected cases of fraud should in addition result in the destruction of the security keys.
- **Localization**: It is responsible for the generation of charging events based on the geographical data stored in the geographical object database (Geo-DB). For the definition of geographical objects mm-lab strongly recommends the preliminary standard PrENV ISO 17575 [12]. In case of a thin client approach the database is not available inside the slim OBU. As the localization only provides charging events, the definition of overlapping geographical objects is possible (e.g. a zone for congestion charging in Amsterdam within the zone representing the Netherlands).
- **Charging Management**: It generates charging records on base of charging events (provided by the Localization supporting the position dependencies and a calendar function supporting the time dependencies of the charging tariffs), the vehicle parameter and the driven distance. The tariff to be applied is retrieved from the vehicle specific tariff database (Tariff-DB), which is defined according to the second tariff model as shown in Figure 7. The events with all dependent information will be stored in the charging files for a limited timeframe (as long as the user has the right to object against the invoices received from the Toll Operator). The charging records will only contain the absolutely needed information to fulfil the EU-directive 95/46/EC. To reduce the communication frequency and costs between the OBU and the CS, the generated charging records are collected for a predefined timeframe before they are transmitted.
- **Enforcement**: It generates the required information for the enforcement units using the status information provided by the System Management, the charging information provided by the Charging Management and the security status and keys provided by the Security Management.

4.3 Proposals for the occasional user scheme

For the proposed occasional user schemes two preconditions have been defined:

- The solution shall be connected to the central server and the enforcement in a way, that there are no differences between the normal and the occasional users;
- There shall be only one type of occasional user.

The latter precondition nevertheless requires a detailed look at the various possible occasional user types (see Figure 8: Occasional user classification).

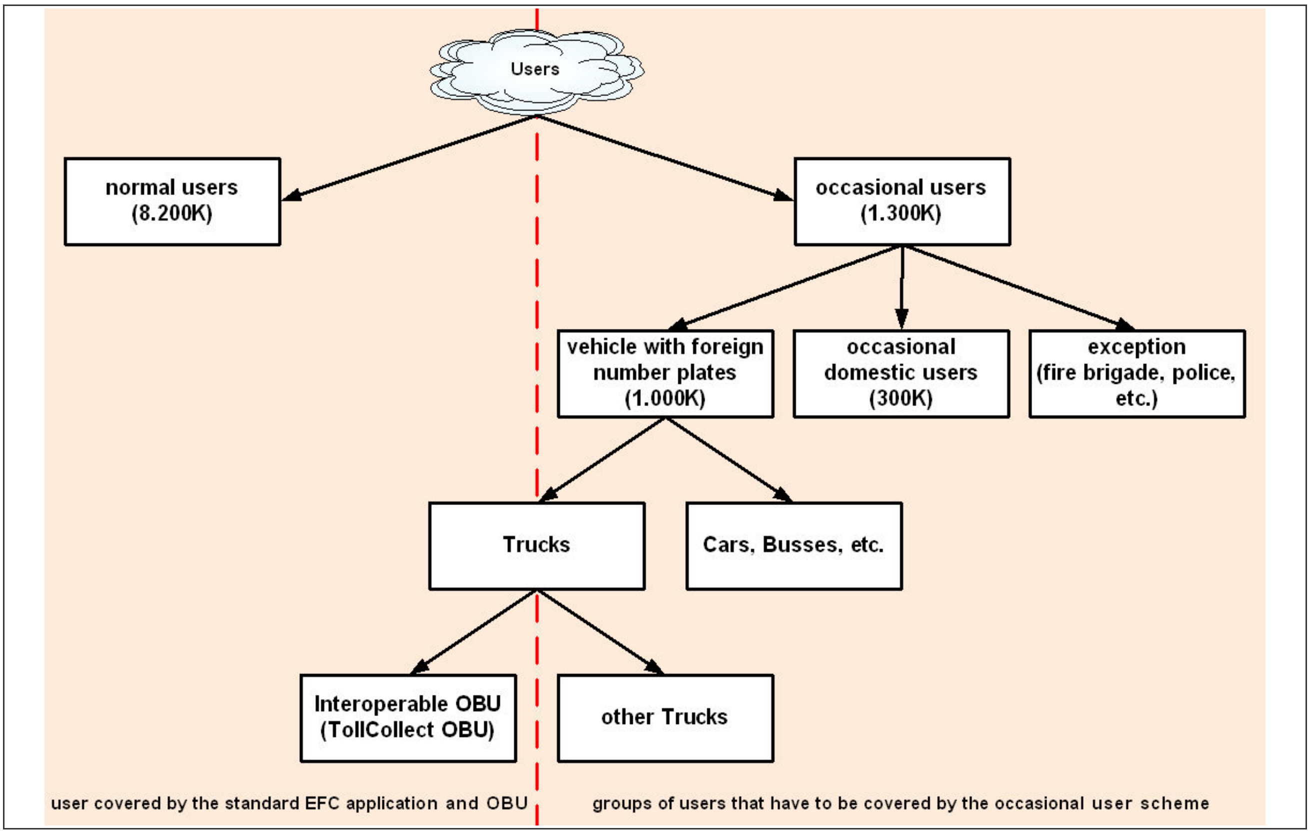

Figure 8: Occasional user classification (first approach)

In any case it is required to provide a clear definition under which circumstances a user is to be treated as occasional user. The definition might depend on the chosen occasional user scheme.

This classification – or better grouping – of the occasional users can also be done on the base of following subtypes:

- In the x-axis the type of vehicle can be distinguished (e.g. trucks and other vehicles)
- On the y-axis the nationality can be distinguished (e.g. Netherlands and foreign countries)

- Finally on the z-axis the type of customer can be depicted (e.g. freight transport, tourist, 'veteran car' driver, special vehicles (fire brigade, police, emergency vehicle, etc)).

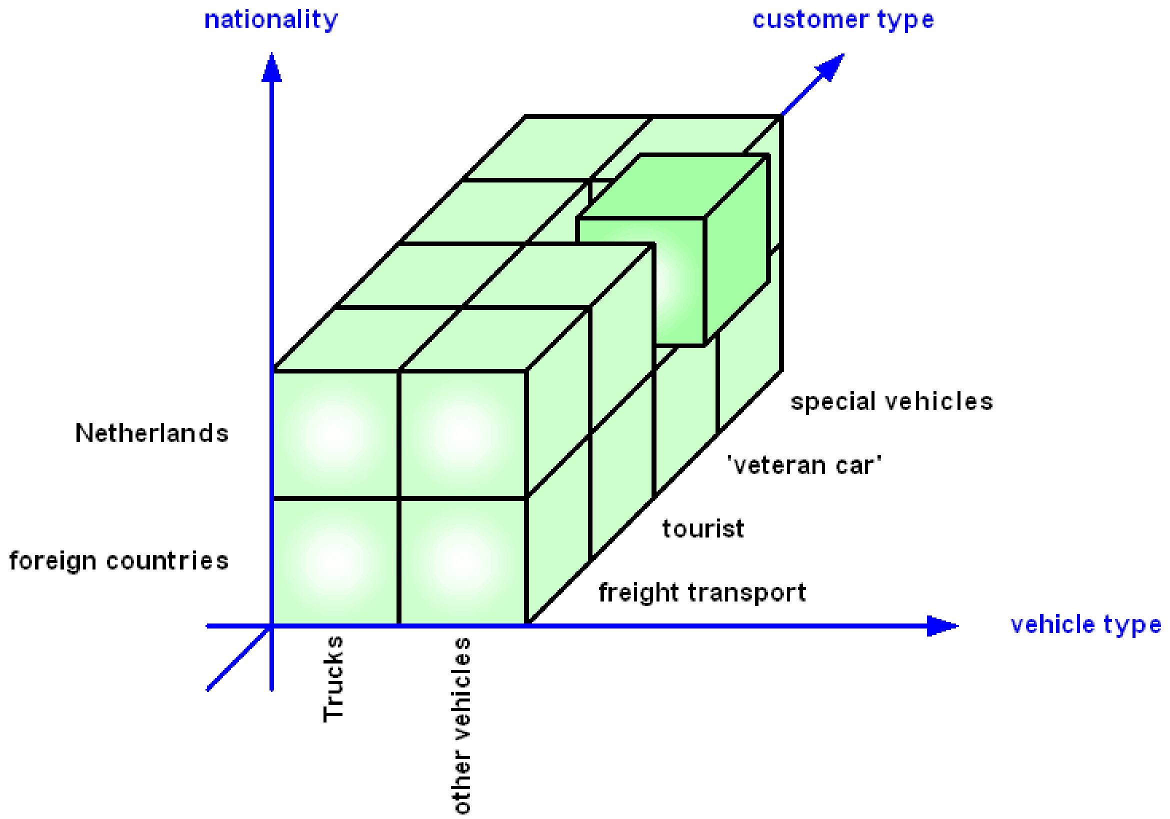

Figure 9: Occasional user classification (second approach)

Each of the resulting cubes can be mapped to a specific amount of occasional users, which would allow a corresponding selection of an occasional user scheme.

Besides the fact that the simple differentiation proposed above will already lead to 16 different groups it becomes obvious, that a group-specific occasional user scheme will be unfeasible.

The main focus should be targeted towards the reduction of occasional users (this would result in the shifting of the red dotted line in Figure 8 to the right). The final target is of course an interoperable OBU

- that can be used throughout Europe and
- that is mounted to all chargeable vehicles.

To cover the first assumption, following occasional user schemes are evaluated:

1. a commonly known vignette ('paper version')

Asset	Drawback
it is the cheapest variant	the granularity of the validity timeframe (1 year, 1 month, 1 week, an number of days) allows no adjustment to be comparable with the calculated fee for normal users
it can be easily distributed	it will not reflect the tariff scheme of the normal user
it is compliant to requirement 7 ('free flow')	it is not covered by the DSRC communication foreseen for the enforcement
it can be applied to any number of vehicles	

2. a DSRC tag ('electronic' version of the vignette)

Asset	Drawback
it is compliant to requirement 7 ('free flow')	as an active component a battery is required, so that the lifetime of the tag is limited (independent if on stock or operated in the vehicle)
it covers the DSRC communication foreseen for the enforcement	used as prepaid permission to use the Netherlands road system, the granularity of the validity timeframe allows no adjustment to be comparable with the calculated fee for normal users
it is more expensive as the paper version but still cheap enough to be used by a large number of vehicles	

3. pre-booking of route

Asset	Drawback
the pre-booking of the roads to be used during the trip through the Netherlands would allow applying the tariff scheme with the exception of the time dependencies	for users with no Internet access the pre-booking would require terminals at border crossings
the pre-booking can be done via Internet	a terminal based occasional user scheme is not compliant with the requirement 7 ('free flow')
	the costs for the initial installation of the terminals and their maintenance

	it is not covered by the DSRC communication foreseen for the enforcement. Using the License Plate Recognition (LPR) can mitigate this drawback

4. a DSRC tag with pre-booked route

Asset	Drawback
the pre-booking of the roads to be used during the trip through the Netherlands would allow applying the tariff scheme with the exception of the time dependencies	for users with no Internet access the pre-booking would require terminals at border crossings
the pre-booking can be done via Internet	a terminal based occasional user scheme is not compliant with the requirement 7 (‘free flow’)
	the costs for the initial installation of the terminals and their maintenance
	it is not covered by the DSRC communication foreseen for the enforcement. Using the LPR can mitigate this drawback
	the tags need to be equipped with a standard interface to be loaded with the data of the pre-booked route

5. a standard unit with prepaid functionality (DSRC, GNSS receiver, GSM/GPRS, Smart Card Reader)

Asset	Drawback
instead of a pre-booking, the tracking unit can perform the charging operation while driving (requires a precise positioning)	Distribution and Installation costs
the GSM/GPRS connection is only required to perform software and tariff data updates	
it covers the DSRC communication foreseen for the enforcement	
the billing is realized within the tracking unit as a pre-paid service	
the tracking unit would allow a high level of privacy (compliant to the requirement 24)	

5 Cost estimates

The following chapter will describe first the assumptions, procedures and approaches that have been made for the cost analysis. The details for development cost and the product cost will be described and summarized. An outlook will be given including trends that are seen today. Finally the installation costs will be estimated.

5.1 Facts, Assumptions, Approaches

Facts

Based on the requirements of the ministry 3 different variants of the Onboard Unit (OBU) are investigated.

Within this cost analysis results are reused from an activity that was started 3 years ago within the Telematics team of Alcatel Germany (now mm-lab) and continuously maintained. Within Alcatel the Telematics team performed a deep production cost evaluation for an OBU similar to the requirements for this project.

The analysis is based on the procedures, processes and requirements for automotive product development.

Assumptions

To allow a comparable cost estimation, the figures of the following chapter are based on one main assumption:

- All requirements as documented in [6] have to be fulfilled by the proposed road pricing system.

There might be options to reduce the overall OBU cost by defining priorities for the requirements or restricting them feature wise. To allow comparable results mm-lab has weighted all requirements equally as already described. Changes in the requirement should be triggered by the tasks of assignment 1 (see chapter 2.4 and [13]).

Approach

A breakdown of the OBU is done, leading to a set of functional modules. The physical implementation of each of these functional modules – and due to this the cost of the modules – is different for the three investigated OBU variants.

For this cost estimation mm-lab has sent out independent Request for Quotations (RFQ) to different suppliers being the current technology leaders for a corresponding functionality. To have comparable figures between the different suppliers and implementation possibilities, the following general rules have been applied for the RFQs:

- Volume delivery starting in year 2010
- One supplier for the total volume
- One contract for the total volume, i.e. guaranteed overall delivery volume
- No custom component development (e.g. custom Application Specific Integrated Circuit (ASIC)

- One common, standardized car interface (Controller Area Network (CAN), Odometer)

Based on the estimated cost of the functional modules, the cost drivers for each OBU variant are identified.

Nevertheless there are hidden links between the different modules. It has to be noted that the functional modules are not exchangeable between the different OBU variants.

To estimate the costs different procedures are used:

- For prices received the lowest trends are used for creating the cost indications considering the given requirement.
- Where no clear indication is received the costs are estimated based on experience of the own product and consultancy work mm-lab has performed.

5.2 Cost analysis for the OBU development

The cost analysis for the OBU development covers the full development life cycle for the hardware development as well as for the basic software development for the OBU. It includes all activities from OBU requirement analysis to OBU integration.

5.2.1 OBU development plan

5.2.1.1 General information

This chapter describes the principle development plan of the OBU. It is based on the development process used by automotive Original Equipment Manufacturers (OEMs) with respect to automotive environments. It covers the creation of different Hardware (HW) samples (so called A-, B-, C-samples leading to a mass production product as described later) for system development and evaluation purposes and includes all work required to enable mass production in accordance with automotive processes. For reference the plan includes preceding, parallel and subsequent tasks related to the system development.

It is assumed that the OBU supplier will provide a Software (SW) Application Programming Interface (API) including operating system services, which are accessed by operational software running on the OBU. The effort required to develop the operational software and any other software at the backend is not part of this report.

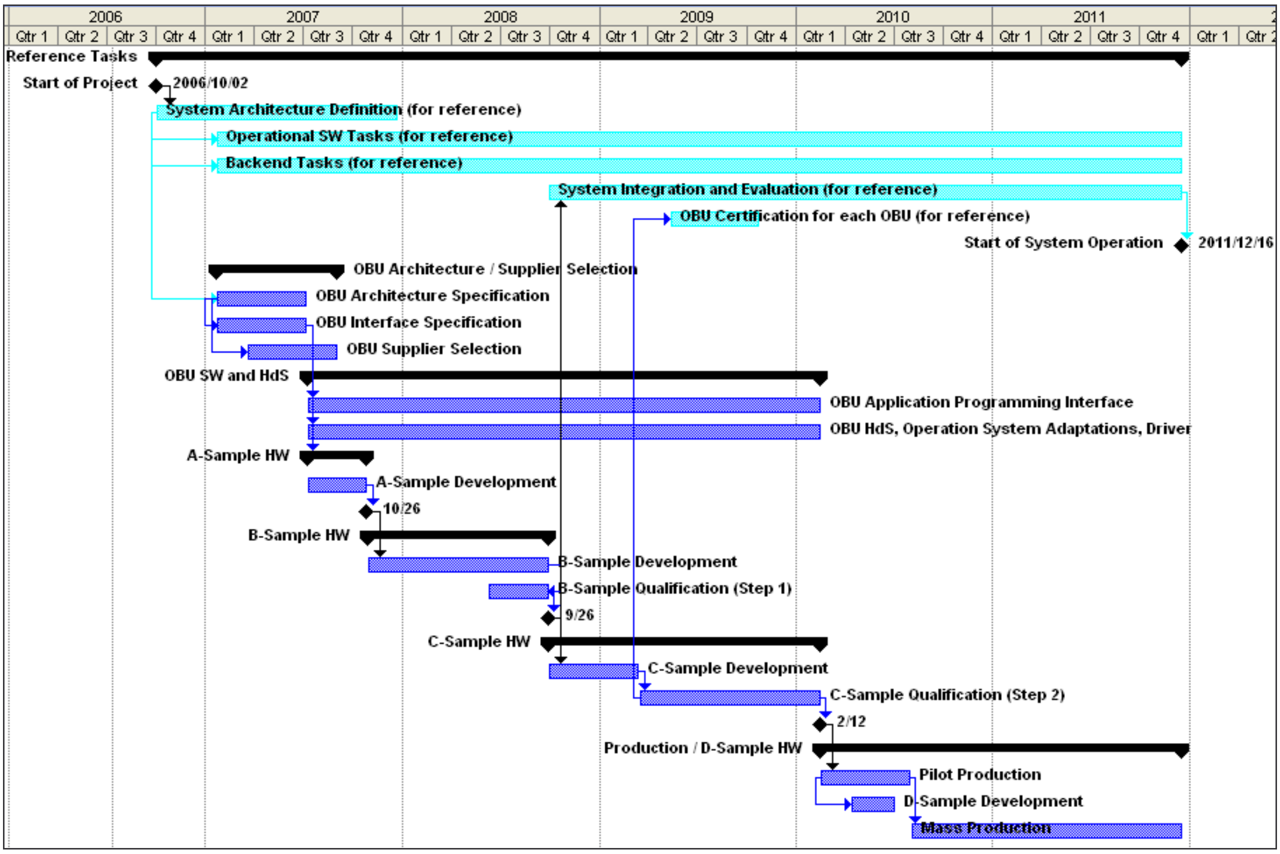

Figure 10: OBU development plan

5.2.1.2 Plan description

Preceding tasks

It is assumed, that requirements analysis are completed before the different vendors start their development process. During system architecture phase a detailed OBU interface description needs to be created. In addition the overall system definition influences the OBU architecture to some extends. For system key aspects like positioning methods and charge event detection procedures it should be considered to do pilot evaluations before defining the final requirements for the OBU.

OBU development tasks

The very basic plan shown here covers the creation of different HW samples to be used for hardware dependent software (HdS) and operational SW development and to support system evaluation.

The A-Sample is a basic solution having limitations with respect to function and form. It is required to be available very soon to support basic SW development at the OBU supplier covering operation system integration and HdS development. In addition A-Sample may support system and operational SW development. If suppliers are selected that can provide an A-sample this task of the project planning may be reduced in time and effort.

This option involves the suppliers at an early project state, so their knowledge and experience can contribute to the system definition.

The B-Sample provides all functions of the final product without any limitations, but it may have restrictions with respect to form and environmental specifications. In addition it does not focus on cost optimisation regarding component selection and production aspects. The B-Sample is used for first environmental qualification tests.

The C-Sample equals to the final product. It provides all functions, is finalized on component selection and ready for mass production. All production and test documents and tools are available. C-Sample development includes HW qualification and certification.

All following samples are made to optimise production processes during mass production. The effort for creating these samples is not included in the development cost, because any effort will reduce the production cost to some extend. That assumes that the manufacturer covers this effort. For the expected volume at least one D-Sample is to be expected.

Subsequent tasks

After finishing the development of the OBU production and installation will start. To start operation of the system on January 1st 2012, the installation will have to take place during 2011 for the majority of 8 million vehicles. Assuming a production volume of 500k OBUs per month, stable mass production needs to be available from mid of 2010 onwards. Mass production ramp-up will need to start beginning 2010.

The plan does not include any effort required for evaluation and documentation of the installation processes for different vehicles. This is seen as task of assignment 1 [13].

Parallel Tasks

In parallel to the OBU development the overall system development, evaluation and integration will need to take place. It is important to define common milestones mapped to A-, B-, and C-Sample availability.

In addition to the mentioned tasks overhead for central functions of the OBU supplier needs to be considered. These functions include project specific purchasing activities, component qualifications, supplier qualification, training and other tasks not directly related to the OBU production.

5.2.2 OBU development cost

According to the proposed plan the following effort is estimated. The effort estimation includes all HW, HdS and API development activities, documentation, test and production tool development as well as support to system integration.

Operational SW parts are not included because the effort depends on the overall system decomposition.

The majority of the system integration effort is seen outside the OBU development plan and needs to be considered at overall project level. A limited amount of effort is included at the OBU supplier for integration support doing error corrections and identifying enhancements during the integration phase.

Summary Task	Estimated Effort
OBU Architecture	2 PY
OBU API and HdS	10 PY
A-Sample	2 PY
B-Sample	7 PY
C-Sample	7 PY
D-Sample	2 PY
Total	**30 PY**

Table 11: OBU development effort

Based on values accepted for European Union (EU) funded projects the cost for one person-year is in the range of 140k to 180k EUR depending on the company. Assuming an average level of 160k EUR per person-year the overall development work cost is calculated to 4.8 million EUR.

In addition fixed cost for development tools, measurement devices, evaluation boards and other development equipment as well as costs for pilot production, test installations and preliminary qualification needs to be considered. The actual value depends on the supplier's capability and available resources but a lump sum between 1 and 2 million EUR can be expected.

Costs for manufacturing tool creation are included in the product- respectively production cost of the corresponding item. This is done to take into account the limited lifetime of the tools, by referring their production cost to the amount of units, which can be created using them.

Cost Source	Costs
Development	4.80 M
Development tools etc.	2.00 M
Sum	6.80 M
Margin	30%
Total fixed costs	8.84 M

Table 12: OBU overall development costs

The estimated project development time already assumes a high level of concurrent work. It is possible to reduce the time for OBU development, but especially architecture, C-Sample qualification and production ramp-up cannot be reduced in time.

5.3 Cost analysis for the OBU production

A similar cost estimation executed in 2004 indicates, that the cost drivers of the OBU HW design are related to a limited amount of key functions. These key functions are defining approximately 80% of the HW cost. The main functional items are:

- Cellular communication function
- Positioning function
- Enforcement function
- Processing function
- Human Machine Interface
- Power supply function
- Security function

The suppliers have been asked to provide their technology and cost outlook for the above-mentioned functional items, targeting a start of volume production mid of 2010.

A cost prediction for quantities of 100k, 1 million, and 8 million have been requested. Deviating responses have been extrapolated to the above-mentioned quantities. The RFQs have been sent out independently, as mentioned above. It was asked, that each supplier provided his own point of view. The experience shows, that a real RFQ process with competing suppliers, at least three negotiation rounds and challenging targets will lead to substantially lower prices. Nevertheless to do so, the technical and commercial details would need to be fixed. The findings are grouped to the above-mentioned functions and mapped to the three different investigated OBU variants.

Besides that, an outlook will be given for upcoming technology trends, which might have a cost reduction impact on the OBU cost. Nevertheless the availability and technical applicability of these trends for the requested OBU is not predictable right now. Consequentially these trends are not included in the current cost estimation.

5.3.1 The cellular communication function

From today's point of view, the cellular communication functionality is represented by a GSM/GPRS module or chipset.

The GSM/GPRS function represents the part with the highest cost. A data optimised solution without voice functions would be sufficient to fulfil the needs for road pricing system. Today there are no chipsets existing, which do not provide voice services so the overall saving of data-only implementations is rather limited. Nevertheless from a functional point of view the voice service requires processing power and additional analogue interfaces. Omitting these functions should lead to cost improvements. It is assumed that the additional effort to create the components and to certify them for use in GSM networks will eat up potential savings. This aspect should be discussed with mobile chipset suppliers.

Today, GSM modules with GPRS support are offered at approximately 35 EUR for volumes above 100k. Until 2010 the cost are expected to drop to about 20 EUR for more then 1 million units.

3G provides some interesting features for security and quality of service (QoS). There are only a few modules for machine-to-machine (M2M) usage on the market, but market share of 3G solutions in M2M market is expected below 1% for the next years. A reliable cost estimation can currently not be done.

5.3.2 The positioning function

The positioning function represents a key item of road pricing systems. The performance of the position function is closely linked to the overall system architecture and concept. Besides the proposed variant with sensor based Dead Reckoning (DR) a plain Global Positioning System (GPS) variant will be discussed.

When evaluating positioning solutions availability, accuracy and integrity aspects need to be taken into account.

Using high sensitivity components GPS based positioning systems provide a high availability. In tunnels and other problematic locations (e.g. deep urban canyons) with no or limited view to the sky, the position may be difficult to determine.

The accuracy of the position information is decreasing when only a few satellites are in view due to shadowing effects. The location of the received satellites might be inapplicable for position calculations. The reception of reflected signals (e.g. from buildings) further degrades the accuracy. Especially high sensitivity receivers evaluate very weak reflected signals, reducing the quality of the fix.

Other effects resulting in a reduced accuracy are ionospheric irregularities and GPS system internal parameters like accuracy of the satellites atomic clocks or undetected satellite failures. These effects are addressed with satellite based augmentation systems like European Geostationary Navigation Overlay Service (EGNOS) or in the future Galileo.

In order to increase accuracy and availability of the positioning information, incorporation of additional sensor-data is required. Today such dead reckoning solutions require distance information derived from vehicle interfaces and a gyro for direction data.

The positioning requirements requested in document [6] with respect to accuracy and availability can only be achieved using an augmented GPS implementation supplemented by DR.

Based on today’s affordable technologies, exact distance measurement can only be guarantied by the odometer interface in combination with GPS, in order to compensate for scale errors caused by the wear out of tires and variations of tire pressure. But this interface will produce the highest cost for installation as either a CAN interface or a direct interface to the odometer or any other sensor like a wheel sensor has to be provided. A short analysis is provided in the chapter 5.6.1.

A basic GPS implementation will be available starting from 7 EUR. There are cheaper options available for commercial use, but they do not fulfil the reliability and flexibility requirements.

The overall cost that include some additional memory and processing power on the chipsets as well as a gyro or a Micro Electro Mechanical System (MEMS) based acceleration sensor adds up to 10 EUR.

Companies providing dead reckoning solutions are evaluating the replacement of the gyros and odometer connections by using MEMS based three-dimensional accelerometers. This could result in a significant cost reduction on the installation task but the technology is today not proven and mature enough.

5.3.3 The enforcement function

It is proposed to provide the enforcement functionality by means of a Dedicated Short Range Communication (DSRC) Module or Chipset.

Although it is requested by the European directive on the interoperability of electronic road toll systems (EU-directive 2004/52/EC) to provide a 5.8Ghz Microwave DSRC system, it is not recommended for the enforcement functionality. This is due to the fact, that the DSRC modules are optimised to interoperate with a fixed installed roadside equipment but not with mobile enforcement tools. For example it is not allowed in Austria to use microwave enforcement due to the mandatory short distance to the vehicle (approximately 3 meters) and due to this, the high radiation value (and violation of minimum distance requirements between road users!).

Based on these facts, currently two principle options for DSRC are seen as possible:

- Pure Microwave DSRC functionality
- Combined Microwave and Infrared (IR) technology

The estimated cost for the combined option is targeted with 10 to 15 EUR. It is seen as an option to do a further integration of the currently existing modules. This can be done by designing a new ASIC which will integrate current discrete functionality. The Return Of Invest (ROI) of such a design is reached in case of volumes above 400K units and will lead to a saving of 5 to 6 EUR.

A microwave only implementation will further reduce the cost by 2 EUR but is not recommended.

All figures are based on the assumption, that the DSRC functionality is integrated in the OBU. In case of a standalone DSRC-Module the costs need to be multiplied by factor 2.

Conclusion: For all three OBU approaches a combined IR and Microwave DSRC module is proposed. The cost for such functionality will be approximately 12 EUR, which could be reduced to 7 EUR through higher integration.

5.3.4 The processing function

From the today's point of view, the processing functionality is represented by a Microprocessor or micro controller combined with the corresponding Flash- and Random Access Memory (RAM) Storage devices.

In the field of processing it is difficult to predict the technology trends, as the main suppliers have not given a clear strategy evolution till 2011. It is assumed that all main suppliers will continue their current product line and will have enhanced products available in the required timeframe. The processors will have additional basic Telematics features incorporated like integrated CAN interfaces, Security Application Module (SAM) interface or serial ports.

Based on the requirements it is assumed that the following processing capabilities will be needed:

- "Slim" OBU with 120 MIPS: 5 EUR
- "Smart" OBU with 300 MIPS: 7 EUR
- "Rich" OBU with > 600 MIPS: 10 EUR

The memory required for the road pricing application depends heavily on the overall system concept and has to be aligned with the tasks of assignment 1 [13]. Especially for the thin client the size of the flash depends heavily on the concept of data transmission, provided QoS of the mobile network operators, and data reduction algorithms used.

Based on the provided figures it is assumed that the following storage capabilities will be needed:

- "Slim" OBU with 64 Mbyte RAM (3 EUR) and 64 Mbyte Flash (7 EUR).
- "Smart" OBU with 128 Mbyte RAM (6 EUR) and 128 Mbyte Flash (13 EUR).
- "Rich" OBU with 256 Mbyte RAM (12 EUR) and 256 Mbyte Flash (25 EUR)

In the provided estimation it is assumed that all payment data (charging records) will be stored in a SAM module.

The "smart" OBU requires more flash and more processing power for the matching algorithm and the storage of the geo-objects to model the Dutch road network.

This results into the following cost figures for the processing function:

- "Slim" OBU: 15 EUR
- "Smart" OBU: 27 EUR
- "Rich" OBU: 47 EUR

The data model for the German toll collect system of today would fit into the processing system of the "slim" OBU. However the final processing requirements are heavily driven by the data management concept for the overall system.

The main cost driver is the memory requirement of the flash. As Value Added Services (VAS) are included in the Smart OBU concept the Flash and RAM memory size is doubled compared to the needs of a pure road pricing system (additional 9 EUR compared to the "slim" OBU).

5.3.5 The Human Machine Interface

The Human Machine Interface (HMI) incorporates the following functionality:

- Display
- Keyboard
- Sound indicator

From the requirements point of view, all investigated OBU concepts need to provide this functionality. The implementation will mainly differ in the size and technology for the display.

- Simple HMI

  Display:

  A simple 7-Segment / Symbol display is proposed. The implementation will be done using Liquid Crystal Display (LCD)-Modules with integrated controller and backlight. The cost is estimated at 2.5 EUR.

  Keyboard:

  Only a few (6) buttons will be provided for restricted interaction. The cost is estimated at 1 EUR.

  Sound Indicator:

  The sound indication will be provided by a piezo buzzer with integrated oscillator. The cost for such a solution is estimated at 0.5 EUR.

  Conclusion:

  The cost for the simple HMI will be in the range of 4 EUR. In case of reducing the requirements to show the tariff information to the user, the display might be replaced by a few Light Emitting Diodes (LED), which will reduce the overall cost to 2 EUR.

- Normal HMI

  Display:

  It is proposed to implement the display in this case as a monochrome graphical display with 128x64 pixel resolution. Today the implementation would be done by Film-Super-Twisted-Nematic (FSTN) LCD technology but it is assumed, that Organic Light-Emitting Diode (OLED) technology will reach a sufficient maturity level until 2010 to take over. The cost for such an OLED display is estimated at 8 EUR.

  Keyboard:

  A few buttons combined with a rotational encoder will allow for a more sophisticated interaction by being able to guide through menus on the graphical display. The cost is estimated at 2.5 EUR.

  Sound Indicator:

  Same implementation as for the simple HMI.

  Conclusion:

  The cost for the normal HMI will be in the range of 11 EUR assuming that OLED will solve the reliability issues at temperatures above 50° Celsius.

- Enhanced HMI

Display:

It is proposed to implement the display in this case as a colour graphical display with 320x240 pixel resolution called Quarter Video Graphics Array (QVGA). Today the implementation would be done by Thin Film Transistor (TFT) but it is assumed, that OLED technology will reach a sufficient maturity level until 2010 to take over. The cost for such an OLED display is estimated at 18 EUR.

Keyboard:

Instead of the keyboard, a touch screen implementation is most likely. The cost is estimated at 3.5 EUR on top of the display.

Sound Indicator:

Same implementation as for the simple HMI.

Conclusion:

The cost for the enhanced HMI will be in the range of 22 EUR assuming that OLED will solve the reliability issues at temperatures above 50° Celsius.

5.3.6 Power supply function

The power supply function can be broken down into the following sub items:

- Power unit

  This will be a pure power supply, which will provide the different supply voltages for the connected components. The power supply must be able to be connected to 12/24V systems and to provide the OBU power out of the internal battery.

- Power management

  Power management is directly linked to the used microprocessor. It will be part of the chipset of the processor and will not be implemented in a discrete manner. Beside the pure power state handling and power sequencing (based on the automotive requirements) it will be the task of the power management to provide the ability to support the required wakeup scenarios. One main wakeup reason is the wakeup on DSRC to allow the mobile enforcement on parked vehicles.

- Protection

  The protection function is needed to prevent against disturbances coming from the vehicle power supply (for example load dump). It is assumed that this will be implemented in a discrete manner and not be part of the power unit or power management.

- Internal battery

  To cope with intentional or unintentional disconnection from the vehicle power supply, the OBU needs to implement an internal battery, which will allow full functionality for a restricted timeframe. Together with the requested Mean Time Between Failure (MTBF) rate, the current solution would be a Lithium-Cell battery or a high performance capacitor. It is expected, that until 2010 the Li-Ion technology as accumulator will solve the current drawbacks like the restricted temperature range and deficiencies in the predicted reliability. Based on this expectation, an accumulator based internal power source is included for the cost.

Based on these assumptions, the power supply is estimated at 9.50 EUR for the "slim" and "smart" OBU, the "rich" OBU is estimated at a total cost of 12.50 EUR.

5.3.7 Security Module function

The security module is a major component in the security concept of the overall system. In general the following statement can be used as guideline.

The most secured way to store information is in the Security Application Module (SAM). This means that besides encryption keys, the SAM should also be used as storage device for all payment related data. This requires the SAM providing enough storage for these data.

In the following it is assumed that, similar to the German Toll Collect system, all charging data are stored in the SAM. For the thick client we assume a module with the memory size of 64 kByte compared to 192 kByte for the thin client.

Storing information encrypted in flash memory of the OBU is an option with the drawback of a reduction in security (fraud) and overall system reliability. The concept should be covered as part of the task for assignment 1 [13] and a final estimation can be given with availability of the detailed system specification.

Additionally the SAM can be used to store access rights and access keys for Value Added Service providers comparable with the SIM card used by mobile operators.

For the SAM two variants are proposed:

- "Slim" OBU 5 EUR.
- "Smart" and "rich" OBU 3 EUR.

5.3.8 Miscellaneous

Besides the key components mentioned in the chapters before, a set of additional components contribute to the total OBU HW cost. The following items are part of this section:

- Printed board of the OBU (4 EUR for the "slim", 6 EUR for the other types of OBUs)
- Housing (4 EUR for the "slim", 6 EUR for the other types of OBUs)
- Discrete Components like resistors, capacitors, connectors and other minor components (10 EUR for the "slim", 12 EUR for the other types of OBUs)

5.3.9 Interfaces

A low level maintenance or debug interface is mandatory for all mentioned OBU concepts. This will be provided by means of an RS232-Interface (or Universal Serial Bus (USB) interface) and is part of the processing functionality.

Especially if the OBU is intended for Value Added Services, additional interfaces might be required. An additional Bluetooth functionality is estimated with 4 EUR and an USB interface could be included at additional 2 EUR.

5.3.10 Production

Production costs are estimated based on the detailed study mm-lab has started 2004 as Telematics team of Alcatel. During this analysis 13 different contract manufacturers with different company sizes have been consulted including the market leaders in this domain. Since this time all data have continuously been monitored and maintained and result in the following figures:

- Labour cost assembly and test, Scrap, Material Handling, Selling General and Administrative (SG&A) and Margins for production are assumed with 16% of the bill of material (BOM).
- Final factory acceptance test is depending on the distribution concept of the OBU. It can be assumed with additional 3% and has to be aligned with the task of assignment 1 and is not included in this cost estimation.
- Cost for Packing and shipment: 4 EUR.

5.3.11 Externals

Based on today's regulations for radiation, it is assumed that a GSM antenna has to be installed outside the passenger cabin.

The required accuracy indicates the need for external GPS antennas. This is valid for all 3 variants of the OBU.

Externals include basic mounting kits for OBU installation, the GPS/GSM-Antennas and the connection to the CAN-Bus (12 EUR).

5.3.12 Software licenses

Licensees will be required for operating system as well as for special GPS related software (i.e. Galileo). It is assumed that based on 1 million devices the cost will remain in the range of 4 EUR for the basic system. For the "rich" OBU it is assumed that additional software platform cost for services will increase the SW license costs to 6 EUR.

5.3.13 Summary

Based on the described modules and items, the following table represents the production costs for the different variants. It does not include development costs, overheads and margins:

	OBU Version		
Functional units	Slim	Smart	Rich
Cellular communication	22.00 €	22.00 €	22.00 €
Positioning	10.00 €	10.00 €	10.00 €
Enforcement	17.00 €	17.00 €	17.00 €
Human Machine Interface	4.00 €	11.00 €	22.00 €
Processing	15.00 €	27.00 €	47.00 €
Security	5.00 €	3.00 €	3.00 €
Power supply	9.50 €	9.50 €	12.50 €
Miscellaneous	18.00 €	24.00 €	24.00 €
Interfaces	0.00 €	0.00 €	4.00 €
BOM	100.50 €	123.50 €	161.50 €
incl. Manufacturing and Shipment	120.58 €	147.26 €	191.34 €
Externals	12.00 €	12.00 €	12.00 €
SW licenses	4.00 €	4.00 €	6.00 €
Total	136.58 €	163.26 €	209.34 €

Table 13: Production costs of evaluated OBU variants

Several factors have been identified, which might influence the OBU cost. These factors are mainly related on how the production and system deployment is intended and are linked to the findings of the other assignments of the cost monitor program. The following influencing factors are not taken into consideration for the current OBU cost estimation.

Factors decreasing the OBU cost:

- Specific, custom development items (ASIC's, specific GSM modules)
- Early freeze of detailed requirements to allow suppliers to adapt their product roadmaps
- Benefits due to the product evolution on the commercial market
- Negotiations with different suppliers for the same component
- European road pricing system harmonization increasing the total volume
- Phased introduction to benefit from the annual component cost decrease

Factors increasing the OBU cost:

- Multiple sourcing of components to reduce dependence on one supplier respectively production site
- Splitting the total volume over several suppliers
- Full automotive qualification
- Different OBU variants
- OBU customisation and adaptation to the different vehicle interfaces

5.3.14 Final cost

The final cost for the OBU will heavily depend on the procurement (production and distribution) model that will be used and on the quantities that will be guarantied.

For different quantities the following table can be used as estimation to determine the potential cost variation. All above listed numbers are based on an assumed volume of 2 Mio. OBUs. Unfortunately the prices available for components and/or modules show different volume dependencies. Consequently a homogeneous extrapolation can't be produced. The given numbers are a preliminary estimation based on figures presented by suppliers as well as extrapolations performed by mm-lab. A potential cost variation is given as well as the working assumption from mm-lab:

Number	100K	500K	1Mio	2Mio	8Mio
Cost variation	35-45%	15-30%	2-4%	-	-4-6%
mm-lab assumption	40%	25%	3%	0%	-5%
Cost Slim OBU	191,21 €	170,73 €	140,68 €	136,58 €	129,75 €
Cost Smart OBU	228,56 €	204,08 €	168,16 €	163,26 €	155,10 €
Cost Rich OBU	293,08 €	261,68 €	215,62 €	209,34 €	198,87 €

Table 14: Volume depending OBU costs

The procurement model leads to additional factors that have to be included in the final OBU price. As this is a government-initiated project a ministry-controlled production process may not be feasible. Typically these contracts will be awarded in BOT projects to a consortium that will take care on the procurement process of the OBU. The following functional areas will increase the final OBU cost.

Development cost:

The development cost will lead to a mark-up based on the guarantied quantities. The development itself is estimated with 6.8 Mio EUR depending on the complexity and the given (tight) time schedule. Enterprises calculate with risk based mark-ups between 20-50% as well as over-time and bonus payments of about 10%. For this project complexity mm-lab assumes 30% risk and 10% bonus mark-up resulting in a final number of 10 Mio. EUR. Based on a share of 2 Mio OBUs this will result in additional 5 EUR per OBU.

Final Product price:

For the final product delivered to a main distributor, additional cost will be added for warranty, spare-pool, reserve for retrofit, reserve for fines and penalties, reserve for general risks and company margin.

As we are talking about significant initial investments, financial figures like cost of working capital and interest payments have to be calculated and added.

These numbers depend heavily on the risk associated with the contract. The lowest mark-up starts at about 25% but can easily add up to 80% on top of the pure production cost. For the cost calculation mm-lab assumes a mark-up of 30%.

This results in the following figures (based on 2 Mio. OBUs):

	OBU Version		
Functional units	Slim	Smart	Rich
Production Cost	136,58 €	163,26 €	209,34 €
Development mark-up	5,00 €	5,00 €	5,00 €
Company mark-up (30 %)	42,47 €	50,48 €	64,30 €
Distributor price	184,05 €	218,74 €	278,64 €

Table 15: OBU distributor prices

5.4 Cost analysis for the OBU test

The OBU development needs to be supported by intensive testing. The test definition needs to be linked to the OBU architecture taking into account the overall system test strategy. The test areas are:

- Design Verification Test
- Production Test
- Operational Test

According to the automotive process a second team independent of the development resources should perform the Design Verification Tests. The effort required for testing is included into the development efforts listed in section 5.2. A strapped down Design Verification Test may be re-used for the maintenance and repair tasks later on. By doing so, a special test environment would not be needed.

Due to the high production volume the production test needs to be reduced in time, but increased in depth. As both aims are conflicting, the Production Test effort needs to be optimised during production ramp-up. The development effort required for Production Test requirements are covered in the HdS and API development tasks, interactive test optimisation is seen as part of the D-Sample development.

The Operational Test is assumed as part of the operational SW development.

5.5 Cost analysis for the OBU certification and qualification

The OBU qualification and certification (Electromagnetic Compatibility (EMC), Electrostatic Discharge (ESD), environmental tests) are part of the development plan described in chapter 5.2.1. No additional costs are expected on top of this.

Dependent on the connection or interface to the car (especially the connection to the CAN-Bus) a certification of the OBU for the special vehicle supplier might be necessary. This is not part of this assignment.

5.6 Cost analysis for the OBU deployment

5.6.1 Installation cost

In this chapter a basic calculation is performed taking different vehicles and interfaces available for these vehicles into account. It is assumed that the installation for all 3 variants will be the same. Since no detailed statistical data are available, the results of this chapter are based on assumptions.

The installation cost for the OBU depends on the pre-condition of the vehicle (pre-condition means that cables, antennas and – if available – the access to the CAN bus of the vehicle is prepared).

An mm-lab internal survey has been performed to analyse the installation costs for Navigation system, GSM-phone installation kits and car radios with navigation. The related installation costs have shown a variance between 20 EUR up to 400 EUR.

The main cost drivers for the OBU are the mounting for the GSM, GPRS and DSRC antennas as well as the odometer interface, if required. Especially the odometer interface could require longer times for the installation in older cars. The odometer interface is required for vehicles where distance information cannot be accessed through the CAN interface or where no CAN interface is available.

Vehicles delivered today have typically a CAN interface available. With a regulation published by the government it is assumed that at least 90% of the cars delivered from 2008 will be prepared for the system and a CAN interface will be available for DR and can additionally be used for vehicle dependent Value Added Services. The remaining 10% will require medium adaptations.

For vehicles delivered from 2002 onwards it is expected that 50% of the vehicles have a CAN interface that could be easily used and other 30% where small adaptation are required. The remaining 20% installations will require medium adaptations.

For vehicles delivered before 2002 it is assumed that 50% will require small adaptations, 40% will require medium adaptations and 10% will require large adaptations.

It is assumed that a full replacement of cars will take 15 years (based on statistical data for Germany).

The estimated installation time is assumed to be:

- Prepared vehicles — 30 minutes
- Vehicles requiring small adaptations — 45 minutes
- Vehicles with medium adaptations — 1 hour
- Vehicles with large adaptations — 4 hours

Labour costs of 45 EUR per hour are assumed in the following figures (see [14]). Compared to typical labour cost in workshops and garages this is deemed to be rather low.

Based on 8 million vehicles and the above mentioned assumptions the following table establishes a basis for 2012 including the odometer interface:

Adaptation effort	number of vehicles	mounting costs per vehicle	total mounting costs
none (prepared)	4000000	22.50 €	90,000,000.00 €
Small	2030000	33.75 €	68,512,500.00 €
Medium	1550000	45.00 €	69,750,000.00 €
Large	420000	180.00 €	75,600,000.00 €
Total	8000000		303,862,500.00 €

Table 16: Installation costs of OBUs including odometer interface

The odometer interface is from installation point the interface that will require the longest installation time. It is assumed that for vehicles with CAN interface it is not required as this information is available on the CAN. The main impact removing the odometer interface is the reduction of installation time for the vehicles requiring large adaptations and for the vehicles requiring medium installation times.

However even without odometer older vehicles will require special treatments for the different types of antennas and the same categories can be considered with different adaptations efforts. Reasons are coated windscreens, power connections, and GSM antenna.

In the category “Large” the installation times will be reduced to 1.5 hours and the category “Medium” the installation times will be reduced by 5 minutes. The following table is valid for installations without odometer:

Adaptation effort	number of vehicles	mounting costs per vehicle	total mounting costs
none (prepared)	4000000	22.50 €	90,000,000.00 €
Small	2030000	33.75 €	68,512,500.00 €
Medium	1550000	41.25 €	63,937,500.00 €
Large	420000	67.50 €	28,350,000.00 €
Total	8000000		250,800,000.00 €

Table 17: Installation costs of OBUs without odometer interface

A pure windscreen solution could be an option but based on today’s technologies and trends this would be a pure additional box in the vehicle very limited to deal with Value Added Services. Even a pure windscreen solution has to deal with regulations for radiation, GPS accuracy, coated windscreens, steepness of the windscreen in cars, power connection, adjustment, temperature for components in direct sunlight, …

Based on the assumption on the mounting time the working days required to install all OBUs is shown in the following figure.

Adaptation effort	number of vehicles	mounting time per vehicle	total mounting time in days
none (prepared)	4000000	0.50	250000
Small	2030000	0.75	190313
Medium	1550000	1.00	193750
Large	420000	4.00	210000
Total	8000000		844063

Table 18: Installation time of OBUs

5.7 Outlook

The cost estimation given in this document is based on an expectation of future developments. The values are based on the knowledge of major component suppliers, which are rated on mm-lab's own experience. Nevertheless these estimations cannot include "non-linear" aspects due to new technologies in an accurate way. One example where such an effect is already included is the evolving OLED display technology, which may bring a significant cost improvement together with better environmental specifications compared to the mature LCD technology.

System Integration

A significant cost improvement may be achieved by further system integration. Today in total five to six processors are present in the same OBU. Some incorporate special functions required for GSM, DSRC or GPS, but others have a general feature set. In future functions like GSM and GPS will grow together due to more featured mobile phones in commercial markets and security functions like e-call in the automotive area. SW based GNSS solutions may run on the general-purpose processor used in Personal Digital Assistants (PDA) supporting smaller devices at a lower cost level. Looking at the enhanced applications running on modern smart phones today, it is obvious to consider implementing road-pricing applications using similar technology.

The major drawbacks of existing integrated solutions are the limited free processing power, missing automotive or even industrial grade qualification, the short lifecycle and certification issues on the GSM part. In addition special functions like fraud detection and security issues are not appropriately implemented. Taking into account the high reliability requirements and the mandatory flexibility in road pricing systems, only dedicated solutions can be considered today. Nevertheless road-pricing solutions will benefit from an increasing volume of Telematics applications.

A volume of eight million devices may justify custom developments. Stable system requirements are mandatory for suppliers to enable adequate risk analysis and evaluation of additional markets. We recognize that even technology leaders hesitate to start e.g. a new ASIC design without strong customer commitments or promising market forecasts.

Optimistically estimated a dedicated ASIC could cost half of the sum of the combined functions. Looking at the Smart OBU Version integration could cover GPS, GSM, main Processor and some parts of the miscellaneous block with total cost of ~18 EUR leading to a cost saving of around 9 EUR. We do not expect any integration of system memory into such kind of ASIC.

Combining GPS and GSM functions might decrease to the cost by ~6 EUR through further integration of processing functions and RF front-ends.

Positioning Function

As already mentioned in section 5.3.2 the positioning function is based on a sensor based DR implementation requiring a connection to the car. The cost resulting out of the required installation is calculated in section 5.6.1. Future evolutions of commercial DR implementations based on 3D accelerometers combined with more accurate satellite positioning by using augmentation systems may enable a system with simplified installation. For the OBU itself very limited cost saving is expected.

To achieve the required reliability and to enable system management, a SW based GPS solution is proposed. Especially the DR implementations are subject to ongoing development and the option to do a SW updates is seen mandatory for road pricing systems. There are cheap ROM (Read Only Memory) based single chip GPS solutions available for consumer use today, but during the next years the more enhanced solutions including DR may stabilise to such an extend that cheap ROM based solution will be available in this area as well. In addition the MEMS technology may enable the integration of sensors into other parts of the positioning chipset. A total cost saving of ~5 EUR may be possible.

Technology Trends

Independent of further integration of processing, cellular and positioning function already described above, evolutions in commercial processing devices may reduce OBU cost. Driven by audio, video and other digital data publisher Digital Rights Management (DRM) Solutions are more and more integrated into general-purpose processors. Depending on the SW and operating system support of such devices in embedded applications the separate Security Module may be omitted. Serial memory interfaces in contrast to parallel interfaces will save the number of pins required and simplify the board layout.

Low sized memory devices based on new technologies like Magnetoresistive Random Access Memory (MRAM) are just available in bigger volumes. Less complex technology, low current consumption and non-volatile behaviour may enable these devices to replace Flash and RAM at a lower cost level in automotive applications in future. Due to the highly speculative memory market development and the early development state of MRAM devices it cannot be estimated if the evolution is fast enough to support the road pricing project.

It can be assumed that further limited cost savings are achieved due to more integrated components, reduced power consumption, smaller component housings and new technologies. Significant cost reduction could be realised when such an improvement enables a change in the OBU implementation. As a very rough estimation a reduction of about 5% of the cost may be possible based on technology evolutions, but 10%-30% may be achieved when the OBU architecture can be simplified.

Compared to consumer markets the volume of devices required for road pricing systems is low, but it still outnumbers the volume of vehicle telematics systems by far. From our point of view further introductions of GNSS based road pricing systems in professional vehicles will prepare the market for cost optimised solutions to be introduced in all vehicles in a further step.

6 Test and deployment scenarios

As mentioned in chapter 2 system test as well as deployment scenarios are covered by other assignments of the cost monitor project. However, they have an important influence on the availability of a stable Onboard Units (OBU) and its implementation, particularly considering the specified time frame of the Road Pricing System.

6.1 Road pricing system test

OBU cost optimisation is not only a matter of choosing the right components at the right time with a low price. Overall system cost optimisation – strongly impacted by the OBU especially in the considered satellite based road pricing system – requires testing of functionality at an early stage to reduce the risk of late changes to the system design and as a consequence instability of the whole road pricing system.

mm-lab strongly suggests a testing phase at the very beginning of the system definition cycle. The road pricing system of the Netherlands should benefit from the available experiences and equipment. This allows starting with a first system trial for test purposes in 2007. Such an early testing phase should not only cover the emulation of road pricing functionality, but be accompanied by a continuous monitoring of system factors like communication, operation and management which will heavily influence the overall system costs. The results will support cost comparison activities between the different implementation variants and will deliver valuable inputs for a further cost monitor project as envisaged by the Ministry.

It's deemed advisable that an independent company experienced in the context of electronic road pricing (GSM/GNSS based) should execute such an assessment.

6.2 Deployment scenarios

The deployment of more then 8 million OBUs prior to the activation of the road pricing system is an unfeasible approach. The time frame between the mounting of the first and the last units is depending on following parameters:

- Availability of the OBUs: The needed amount of OBUs can most likely not be provided by one supplier due to technical reasons like the ramp-up of the production, availability of required components, etc. and due to legislative reasons like the commissioning to one supplier would lead to a monopoly.
- Installation timeframe: The mounting of an OBU has to be done in different ways depending on the type of vehicle (e.g. the optimal DSRC communication needs the DSRC antenna to be mounted at a certain angle and position on the windscreen). Referring to the mounting times as assumed in chapter 5.6 the total number of working days would reach 850.000. This result emphasizes the exceptional relevance of a well-defined and feasible deployment scenario for the introduction of the road pricing system.

The deployment of the OBUs should be phased. To avoid customer complaints with respect to the violation of equal treatment rights, the phases might be mapped to the vehicle types.

The deployment scenario is also an important factor for the negotiations with the suppliers of the OBUs and indirectly with the suppliers of the components. A Request for Quotation on a high volume of OBUs or components will lead in the most cases to the lowest price. There are exceptions e.g. when the ramp-up of the production requires the construction of new production lines, the costs for the OBUs will increase while a ramp-up on existing production lines will cause lower assembly costs. Giving a volume commitment over the time of the OBU deployment can mitigate this type of drawback.

The impact of the deployment scenario chosen needs to be taken into account by the assignment 1 [13].

7 Risk assessment results

The risk assessment results are published in an attached EXCEL sheet listing the risk type, the risk itself, the risk source, the probability and the consequences of a risk, the severity index, mitigation measures and the risk owner. A separate “remarks” sheet defines the meaning of the different parameters used in the “Risk Assessment Table”.

8 Comments to the requirement specification

As defined in the scope of work document [2] mm-lab is asked to comment on the system requirements. To understand the comments mm-lab provides in the chapters below a few remarks are necessary:

- The overall system is a very complex one. Complex relations on different levels exist between single requirements. As a consequence comments may not only influence the requirement they are attached to. A more comprehensive check of these interrelations would need a lot more time than available for this project.
- Different categories of comments may be found:
  - Technical comments e.g. on specific implementations
  - Process related comments on how to deal with a certain problem
  - General system related comments highlighting issues which have to be answered (or are already answered but the information is not accessible)

  The comments on requirement 1 are an example for these different categories.
- The main benefit for the Ministry is assumed to be the overall number of comments made from the different companies involved in the different assignments. Mm-lab considers their comments as a contribution to this number.
- Responses to the requirement questionnaire as requested in [6] are mainly dealt within chapter 5 otherwise given below the corresponding requirement.

8.1 Requirement 1 – Charge travelled distance

Comments to the requirement

For the collection of kilometres driven either the information via the vehicle Controller Area Network (CAN) might be used or alternatively an additional odometer. The odometer will increase the installation costs but can be used as verification information together with the information from the vehicle CAN interface (information redundancy to improve the reliability of the system) [technical comment].

There should be a granularity chosen for the KMP that will avoid the possibility, that a customer can get different results as consequence of the way the customer is driving (cut corners) [process related comment].

The driven kilometres for tractors, harvesters or construction vehicles are by a high percentage not mapped to roads. They are operated on private property (farm land, construction sites). This can be seen as contradiction to requirement 5. A tariff scheme has to be defined, which covers these vehicle types (e.g. a special tax on the fuel that can only be purchased for these vehicles, a toll that is calculated on base of the driven kilometres and the vehicle parameters but not taking into account changeable parameters like tractor is operated with/without trailer) [general system related comment].

8.2 Requirement 2 – Charge on base of time

Comments to the requirement

From mm-lab's point of view the charge on base of time may cause a number of acceptance problems for road users. While they might tolerate a limited number of time periods with increased toll fees – as long as they are transparent – a highly dynamic change (comparable to the tariff spectrum in mobile communication) will cause an acceptance problem for road users.

8.3 Requirement 3 – Charge on base of the location

Comments to the requirement

The increase of the "Kilometerprijs" (KMP) for areas where high traffic is expected, may force the customer to change the transport media (e.g. from car to public transport) or to better plan the trips into these areas (see approach of the of the London Congestion Charging scheme).

There should be a limit defined to what extend the location of a vehicle can influence the tariff. A differentiation should be made on the road type for the standard KMP (motorway, state routes, etc) with additions e.g. for congestion zones or special buildings like bridges or tunnels.

8.4 Requirement 4 – Charge on base of vehicle characteristics

Comments to the requirement

From our point of view the charging on base of vehicle characteristics is a generally accepted criteria for toll calculation. It allows covering the ecological aspects (e.g. pollution) as well as the damages caused by different types of vehicles (e.g. permissible maximum weight). It represents the principle that the party responsible is also liable for the damages.

Besides the location dependent charging (definition of road types or zones) these are the only parameters, which are available due to the motor vehicle registration and can therefore not be manipulated.

There needs to be an interface defined from the motor vehicle registration organization to the toll operator. This interface between two independent organizations has to be defined with special attention to the privacy regulations (EU-directive 95/46/EC).

8.5 Requirement 5 – Charge for all roads

Comments to the requirement

For the tariff definition of the road types to distinguish an analysis has been performed.

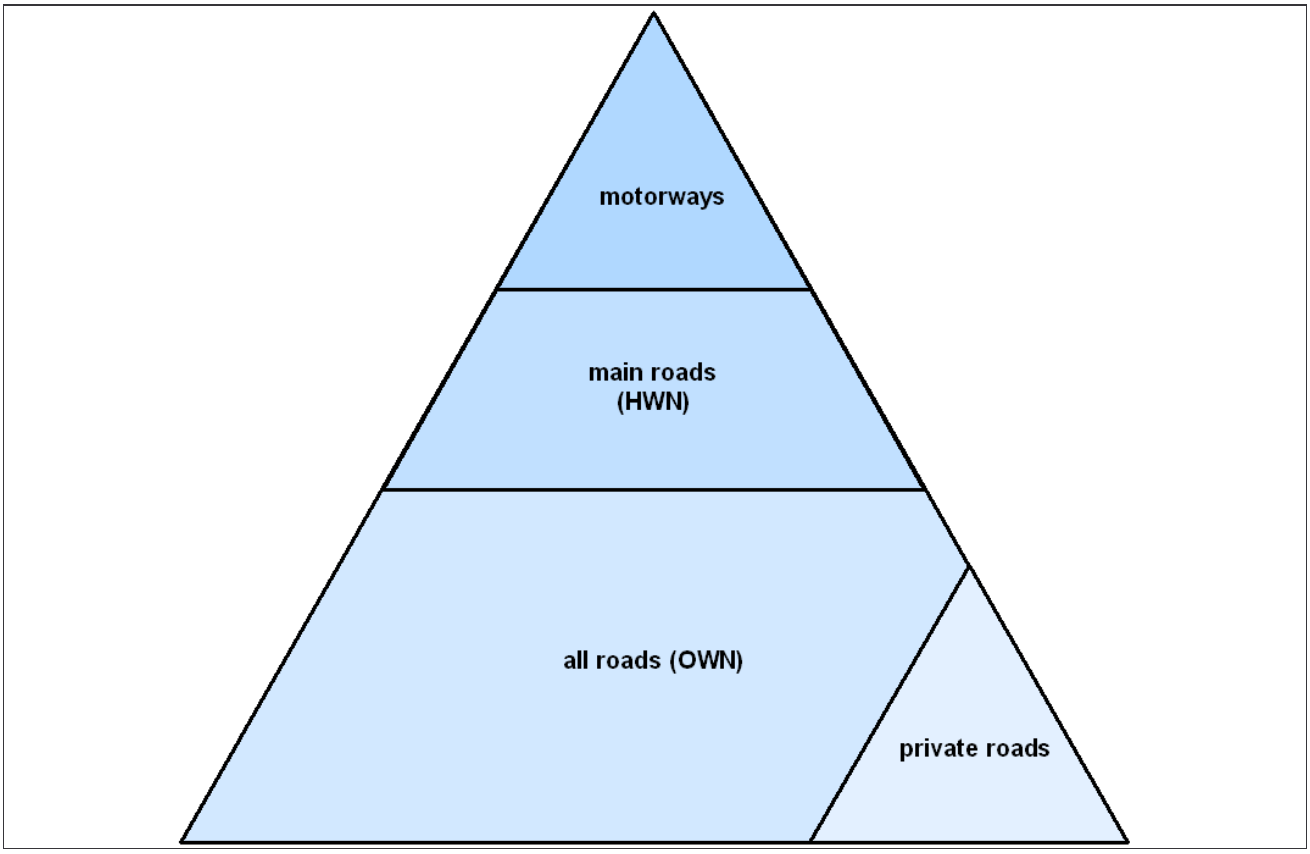

Figure 19: Road type classification

Taking the private roads into account (e.g. defining a tariff for private roads) would require a map matching. The complexity of this map matching may be a challenge even for an implementation in the Central Server (CS). Map matching in the CS requires detailed track records of all vehicles. This causes a deep impact on the privacy regulation and the communication costs.

The definition of a road type dependent tariff can be used to reduce the impact of localization decisions with a low reliability. The sum of each single road type dependent fee will be the total toll to be paid and is in both concepts identical, as shown in Figure 20. Nevertheless, the latter concept will reduce the "uncertain" toll (when the decision can not be made with an appropriate reliability, if the vehicle is on a normal road or on a motorway).

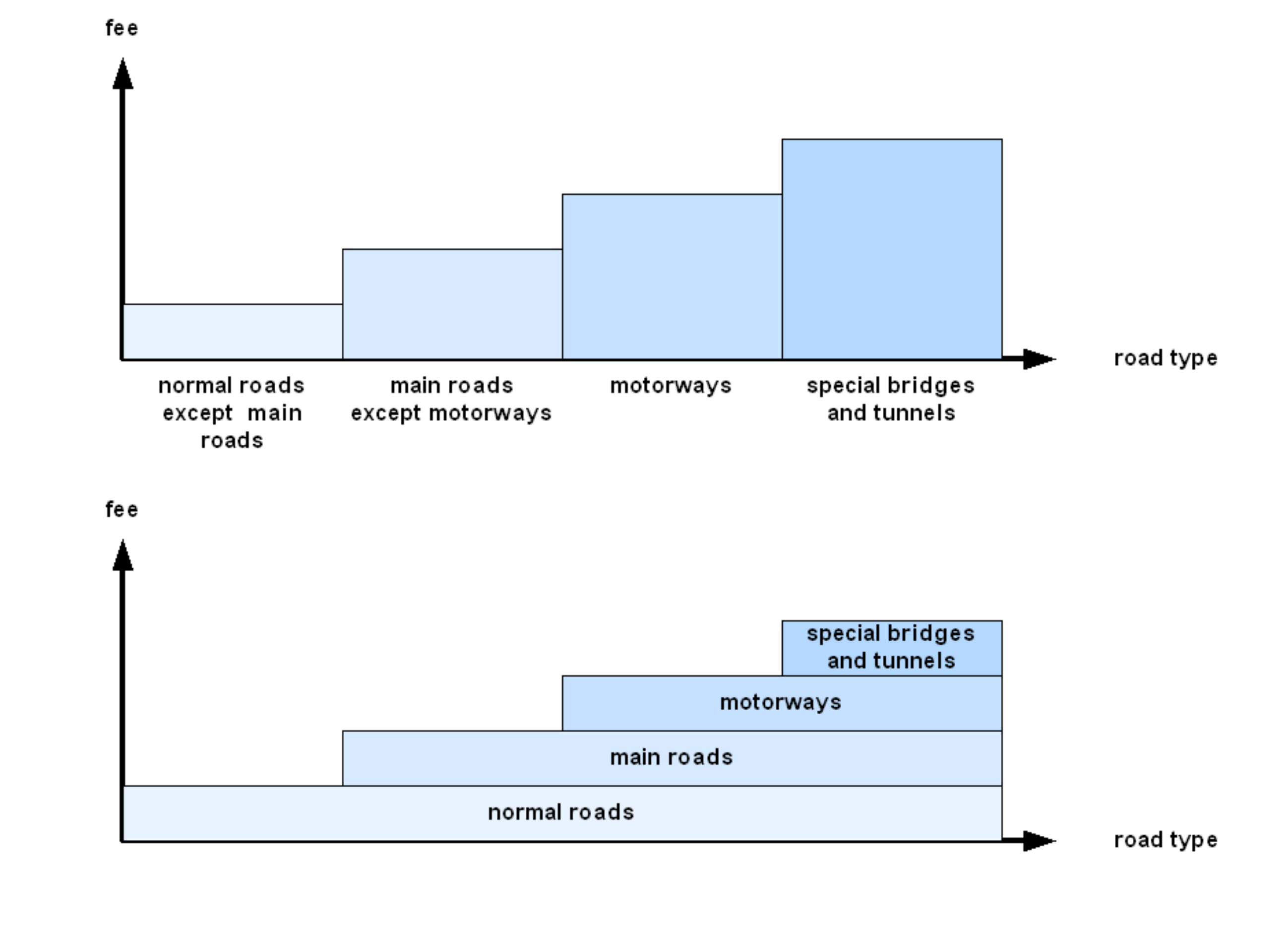

Figure 20: Tariff definition according to the road type classification

8.6 Requirement 6 – Flexibility to change charge parameters

Response to the questionnaire

The complex tariff structure resulting from the requirements 1 to 5 is most effectively realized using a database. The variations to be treated in terms of changeable parameters is then limited to the addition of new entries in the corresponding tables and the definition of the appropriate tariffs (e.g. new geographical objects can be defined to change the position dependent charging, new vehicle classes can be defined in case there are new types of vehicles to be treated (formally not charged vehicles may be added as new vehicle class).

A problem to be managed with additional costs is the change of vehicle parameters, which are not available for all vehicles and cannot be generated via an interface to the vehicle registration office. Adding the parameter itself to the tariff database is thereby not the problem but the compilation of the data.

It is therefore proposed to define a superset of vehicle parameters on which the tariff definition might depend on.

Comments to the requirement

The flexibility for the adaptation of parameters influencing the tariff depends on different organisations (local or regional traffic management and the Ministry) and requires therefore rather open interfaces. As the toll operator might not be a governmental organization, the tariff definition should not be part of the toll operators' responsibility.

8.7 Requirement 7 – Free-flow system

Response to the questionnaire

The main requirement for the OBU system architecture as presented in chapter 4.2 is the one for 'free flow'.

This architecture allows the identification of geographical events defined on base of the standard PrENV ISO 17575 [12]. The Localization allows thereby the identification of a zone like the Netherlands. Any vehicle, which is equipped with such an Onboard Unit(OBU), will detect the "start" charging event on entering and also the "stop" charging event on exiting the country without any roadside equipment.

The Dedicated Short Range Communication (DSRC) for the enforcement guaranties that the correct working of the OBU can be verified at any 'normal' vehicle speed.

The software update of the proposed system is realized via GPRS, so that no maintenance stops at certified repair centres are required.

8.8 Requirement 8 – Charge all road users

Comments to the requirement

The definition of "all road users" includes vehicles, which are not necessarily using the roads (e.g. tractor and harvester). To cover the requirement 5, the easiest and cheapest approach is, to measure the driven kilometres. Using this approach is fair with respect to the most motor vehicles as they are forced to use the roads, with minor exceptions for the use of parking lots, company premises and private roads. The mentioned vehicles like trucks and harvester will use the roads only for a limited time.

8.9 Requirement 9 – Charge occasional road users

Response to the questionnaire

See chapter 4.3.

Comments to the requirement

According to the 2nd interactive meeting this requirement shall not be focussed on, nevertheless it is an important issue to create a transition scenario between the actual situation in Europe, where several countries have their own road pricing system established and the optimal situation, where all vehicles are equipped with an interoperable OBU and an agreed toll roaming method.

8.10 Requirement 10 – Charge road users with foreign license plates

Response to the questionnaire

See chapter 4.3.

Comments to the requirement

To simplify the method for the treatment of occasional users, there should be only a limited number of different occasional users defined, in the ideal case only one.

8.11 Requirement 11 – Comply to EU-directive 2004/52/EC

Response to the questionnaire

According to the proposed OBU system architecture (see chapter 4.2) the communication of the OBU with the CS is realized via GSM/GPRS, the identification of geographical charging events is provided by the Localization, which is based on position information provided by an GNSS (GPS or GALILEO) receiver eventually enhanced with Dead Reckoning (DR) and the enforcement is based on the 5.8 GHz microwave DSRC technology. The proposed solution covers therefore all requested interfaces according to EU-directive 2004/52/EC [3].

8.12 Requirement 12 – Functional reliability

Comments to the requirement

Sending out a correct invoice is the result of an end-to-end process working correctly. Each of the OBU variants – as covered in this report – is one part of this process. Depending on the decisions of assignment 1 concerning the system architecture, the role of the OBU (thin or thick client) and the definition of the charging and billing process the OBU has to provide a specific level of functional reliability. The process defined in assignment 1 will therefore influence the functionality and consequently the cost of an OBU.

8.13 Requirement 13 – System reliability

Response to the questionnaire

The protection against the loss of charging data is established by following methods within the OBU:

- The charging data is stored on non-volatile memory.
- The charging data is securely transmitted via transaction handling (any transmission will only be defined as completed, where the OBU has received an acknowledgement). Only on successful transaction the related charging data is deleted from the OBU. This does not imply the source data on which

the charging data has been created. This source data is kept until the end of the objection time frame.

- The charging data is transmitted encrypted using security keys stored on the Security Application Module (SAM).

8.14 Requirement 14 – Protected against user discomfort

Comments to the requirement

A user discomfort (e.g. electromagnetic radiation) may be caused if an internal GSM antenna is used. It is therefore recommended to use an external antenna.

8.15 Requirement 15 – Display road charge

Response to the questionnaire

Taking the complex tariff system into account, which is requested according to the requirements 1 to 5, the driver should be informed just in time with the tariff information that is in force for the respective vehicle. This requires the timely availability of the corresponding tariff data and the correct detection of charging events.

Any use of long distance communication will need to take into account the possibility of a communication interruption. Therefore it is not advisable to transmit the tariff information from the CS to the respective OBU for displaying.

When the display of the tariff information is not wanted due to the possible distraction of the driver, the information should still be visualized to the driver in advance (e.g. when the vehicle is not moving). The tariff table relevant for the respective vehicle can be shown on request of the driver, but the number of different tariffs applicable for the vehicle should then be limited to a manageable amount.

Comments to the requirement

According to the second interactive meeting this requirement shall be treated with a lower priority as a display might distract the driver.

The distraction of the driver by a display depends on the location of the display and the displayed information. The driver does not notice the vehicle specific displays for the actual vehicle speed, driven kilometres, fuel level etc. as distractive displays. The same is to be expected by a display for the toll fee.

8.16 Requirement 16 – Safe and easy to use HMI

Response to the questionnaire

To design an easy to use and OBU that do not distract the driver can be reached by two approaches:

- The OBU does not require any interaction with the driver with the exception to show the status of the OBU. In case the OBU shows an error, a respective action by the driver is still expected. This might be reached by an OBU that has only a status Light Emitting Diode (LED). The drawback of this approach is the inability of the system to request vehicle specific information like track has trailer connected and the total number of axles.

- The OBU allows interaction with the driver and the required interaction can be visualized in a way, that any driver will be able to use the OBU. This can be reached with an appropriate user guidance like an online help function realized be a graphical display or an audio response.

In both cases the interaction is limited to activities to be performed by the driver before he starts the trip.

8.17 Requirement 17 – Cost limitation for development and implementation

Comments to the requirement

Proposed to be deleted.

8.18 Requirement 18 – Maximal annual costs for operation and enforcement

Response to the questionnaire

The costs for the enforcement related function on the OBU is limited to the software development costs, the costs for the security measures (SAM and security key distribution which is used also for other purposes) and the DSRC communication interface (HW and SW).

There is also a backend enforcement function required to treat the enforcement related messages from the OBU and to serve as interface to the enforcement agency.

Comments to the requirement

The costs for the enforcement should not be limited to s specific amount or percentage of the overall operation costs. Using the amount of penalties as a reference can increase the effectiveness of the enforcement. The target should be to reach a balance between the costs of the enforcement and the penalties assigned.

The operational cost for the toll collection system and the enforcement costs should be treated separately. The toll operation might be assigned to a private company but the enforcement is most likely a public task.

8.19 Requirement 19 – Allow migration of acceleration scenario developments

Response to the questionnaire

The OBU system architecture and the remarks given for requirement 5 provide a simple migration method for the acceleration scenarios. The definition of a tariff as an add-on fee to a given “base” fee together with the Localization on geographical events according to PrENV ISO 17575 [12] allows the identification of a road-segment or area. To this road-segment or area a specific tariff can be assigned, which leads to a corresponding increase of the fee to be paid without the acceleration scenario.

The definition of a new tariff is covered by the costs of the Tariff Management located on the CS. The same applies to the definition of the additional geographical events.

The only aspect to be taken into account is the “base” fee that is independent of geographical events and which can therefore not be deactivated temporarily.

8.20 Requirement 20 – Support different implementation scenarios

Response to the questionnaire

The proposed system architecture of the OBU allows the addition of Value Added Services (VAS) and also of other road pricing system schemes as long as they are limited to the foreseen communication interfaces.

The architecture of the road pricing system application itself allows the change of the charging scheme in terms of a different tariff model (assumingly no new interface to the vehicle has to be established), a new layout of the charging records and a change of the security keys.

The possibility for software updates without being obliged to visit a (certified) repair centre allows the implementation and installation of different road pricing system schemes. The activation of the new road pricing system scheme can be triggered time dependent. The distribution of the new software need thereby not be performed in a specific timeframe.

Comments to the requirement

The OBU hardware is currently defined on the given requirements, which are not identical to the term “different implementation scenarios”. There should be a limitation in the scope of “implementation scenarios” (the scenario 9 [11] does not necessarily require an OBU at all).

8.21 Requirement 21 – Allow incorporation of future developments

Response to the questionnaire

The proposed OBU system architecture allows the addition of new services as long as there are no new interfaces required. The VAS can be requested by the government (e-Call) and by private organizations ("Pay As You Drive®").

As shown in chapter 4.2 the collection and evaluation of traffic data can be realised as VAS. The question for the VAS is limited to the information, which has to be provided by the OBU (Is a Human Machine interface (HMI) required for driver inputs? Is the vehicle speed required? Is the location of the vehicle needed? Etc.).

An OBU without a display is most likely limited to data collection unless there is no speech recognition interface and an audio response. As soon the OBU is enriched with a display, this can be used e.g. by enforcement units.

The addition of new services is not limited to VAS. The toll collection schemes of other European (and even non-European) toll operators can be added/activated when required. This is granted by the compliancy to the EU-directive 2004/52/EC [3] providing all proposed communication methods. The open issue is related to the "Toll Roaming" method that has to be agreed on.

Comments to the requirement

mm-lab sees "future developments" limited to the software application part of the road pricing system to avoid any conflicts with the security requirements (e.g. OBU shall not be unsealed or opened). "Future developments" have to be taken care of by providing spare capacity.

8.22 Requirement 22 – Capacity of road pricing system

Comments to the requirement

The number of vehicles to be charged has impact on the dimension of the CS and on the communication costs between the OBU and the CS depending on the type of communication (e.g. continual transmission of tracking data vs. time and amount threshold triggered transmission of collected charging records).

The fewer data to be transmitted the lower the communication costs will be. The QoS of the used communication infrastructure is limited by a number of parallel open communication channels.

8.23 Requirement 23 – Security measures against fraudulence

Response to the questionnaire

Besides the mechanical measures to prevent the opening of the OBU a set of electronically detectable measures should be foreseen (e.g. electronic detection of the opening of the housing, detection of the disconnection from the power supply while moving). The extensive use of the encryption of collected data using securely stored keys will prevent any unregistered manipulation of the data. The access to the security keys is limited by the use of a SAM.

Comments to the requirement

There are limitations of the reestablishment of a system when manipulations are detected. In the most cases, the fraudulent use should be indicated to the security Management of the CS from where the enforcement authorities should be informed.

Requirement 24 – Comply to EU-directive 95/46/EC

Response to the questionnaire

The compliancy to the EU-directive 95/46/EC [4] for the proposed solution of the OBU architecture and system design is realized by the fact, that the charging data do not contain more vehicle and customer related data then required. All data related to the roads driven should be processed locally in the OBU and stored only until the end of timeframe to fill an appeal is reached and then it will be destroyed. In case the customer fills an appeal, he automatically agrees to make this data available to the Toll Collector to decide on his appeal.

Comments to the requirement

For the political decision-making the degree of surveillance still accepted by the citizen has to be respected. Therefore this requirement is not only important to fulfil the EU legislation but also to avoid massive public discussions on this issue.

9 Response to the questionnaire "Scenarios for Pricing"

For the first 4 questions a spreadsheet has been created where the evaluation results are documented [10].

9.1 Inclusion of receiving money through the system besides paying for KMP

The subject as described in the questionnaire requires

- either a defined interface between the tax office where vehicle related tax issues are treated and the Toll Operator, who is in charge for the collection of the toll
- or the presentation of the invoices from the Toll Operator by the customer to the responsible tax office

to exchange the information about the toll paid by the customer and to calculate the correct tax reduction for the uncompleted depreciation cycle.

The first option generates an additional interface between the Toll Operator and the Tax Office, which increases the risk for a violation of the EU-directive 95/46/EC [4].

Moving the responsibility for the provision of the needed data to the customer will reduce this risk. This method guarantees the full visibility of tax relevant data. On the other hand it increases the amount of information (e.g. invoices, contracts), the customer has to present to the Tax Office.

Nevertheless, it is recommended to follow the second option to be fully compliant to EU-directive 95/46/EC.

9.2 Requirement 25 – ownership of all traffic information

The ownership of traffic information is a subject to the negotiated contract between the government and the Toll Operator. The interface between the "collector" and the "user" of the traffic data can be set-up in following ways:

- Scenario A
  The traffic data is collected by the road pricing system application or an additional service on the Onboard Unit (OBU). When receiving the traffic data the traffic data "collector" immediately transfers this data to the traffic data "user" in an agreed format. The costs for the additional OBU service and the corresponding communication between OBU and Central Server (CS) remain on the side of the traffic data "collector". The traffic user pays the effort spent for the storage and the evaluation of the traffic data.
- Scenario B
  The traffic data is collected by the road pricing system application or an additional service on the OBU. Traffic data is sent to the traffic data "collector" and is stored by the "collector" in an agreed format. As soon as the traffic data "user" requires this data it accesses the data and processes it as required. The

costs for the additional OBU service, the corresponding communication and the storage remain with the traffic data “collector”, the evaluation costs are on the side of the traffic data “user”.

- Scenario C
  The traffic data is collected by a Value Added Service (VAS) on the OBU and directly transmitted to the traffic data “user”. The costs for the additional OBU service, the corresponding communication, the storage of the data and the evaluation for the data remains on the side of the traffic data “user”. This solution requires a guarantee that the VAS will not interfere with the road pricing system application.

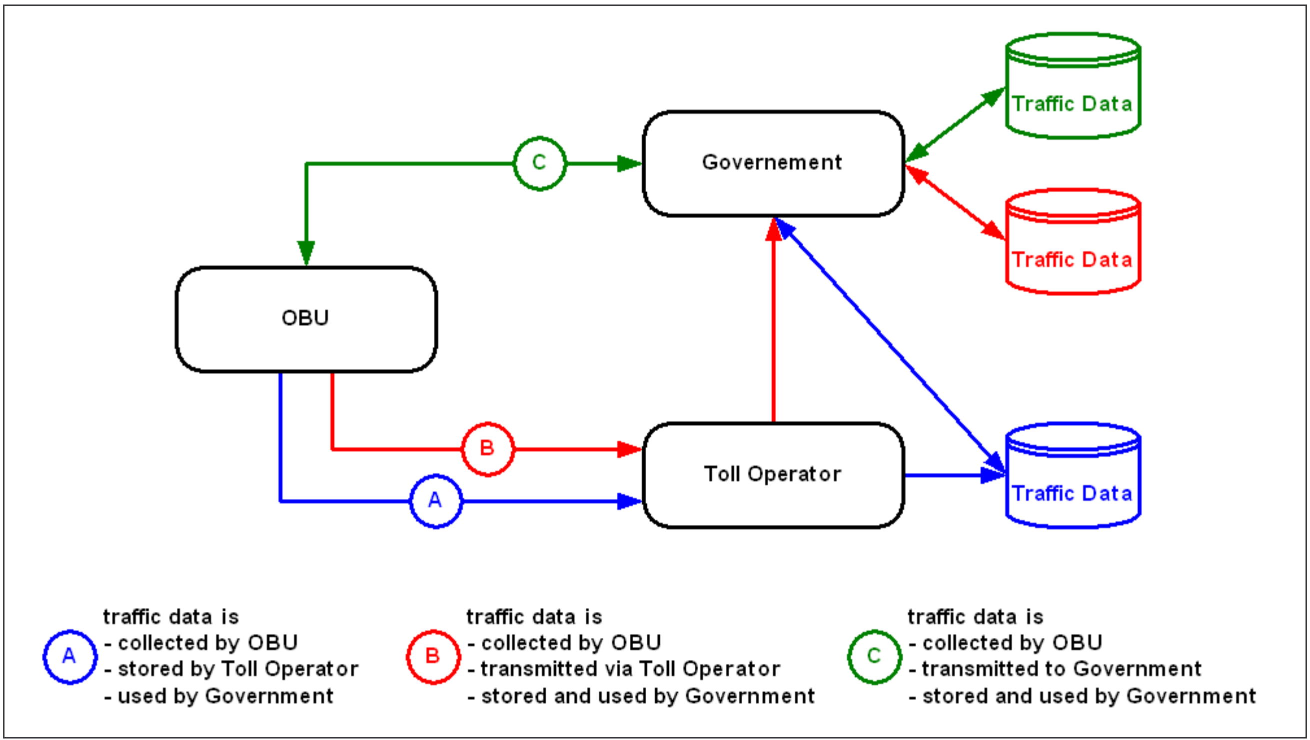

Figure 21: Traffic data collection scenarios

The application described above is one of the added services mm-lab referred on in other chapters of the report. Implementing such an application requires an answer on the question of privacy. This issue requires to suitable (technical or administrative) procedures for anonymous data collection.

Even if the traffic data are available due to the road pricing function the application to select suitable traffic data in the OBU (or the CS in case of thin client approach), the transmission towards the “user” and the storage and processing will cause some costs. However, this method is more flexible and more suitable for collecting dynamic traffic data than the static methods to collect this data currently used (loops in the road, counting devices).

10 Trends and Prospects

The previous chapters contain the assumptions and resulting deductions on the given requirements and questionnaires as identified and answered by mm-lab. This chapter is dedicated to the trends in Europe and the potential additional benefits of a road pricing system not restricted to calculation of toll fees only. It intends to highlight possible developments, which have impact on the overall costs of a future Road Pricing System in the Netherlands.

10.1 European Union

The European Union (EU) influences the evolution of tolling systems in Europe. The EU targets on a fair and interoperable tolling service all over Europe suitable to finance the huge invest for modernizing the European traffic infrastructure. From mm-lab's point of view three main consequences have to be considered for the Dutch Road Pricing Systems.

<u>EU Directives</u>

The EC published a number of directives directly or indirectly influencing the introduction of tolling systems. The EU directive 2004/52/EC clearly defines the technologies to be used and the preferences of the EU. Even if the directive allows three technologies and their combinations to implement tolling systems the EU clearly prefers the combination of Satellite based positioning and cellular network based communication (see [3] article 2, paragraph 3).

Directive 95/46/EC defines the rules for privacy to be considered in technical systems like road pricing systems. The consequences were highlighted in mm-lab's report. Introducing a road pricing system by law, a government obliges all citizens owning and using a vehicle to participate in a common road pricing system. Since there is no possibility to avoid participation, the system has to protect privacy of the users.

A third set of EU inputs to be considered is given by directives and fact sheets (e.g. eCall [15]) requiring the introduction of mechanisms to increase traffic safety. Requirements to introduce emergency call capabilities in every vehicle introduce an additional aspect to be considered: the use of a common infrastructure for different applications required by the EC.

<u>Galileo</u>

EU heavily drives the introduction of Galileo – the European counterpart of GPS. The point in time when Galileo will be completely established has been moved, but there is no doubt on the implementation of the Galileo project. First satellites were already launched. It is a clear target of Galileo that it is financed by fees for the services offered with a dedicated service level guarantee concerning availability and integrity of positioning information. Main civil applications relaying on these service are expected to be air navigation and road pricing applications.

EU projects

To push the evolution towards an interoperable road pricing service, the EU finances a number of projects via their research programs. Currently different EU projects have been initiated that will have impact on the overall system architecture for telematics and road pricing systems. The most interesting projects for this program are:

- RCI – focusing on interoperability between the tolling technologies already implemented in the European countries and demonstrating their interoperability based on defined system requirements.
- GST – defining an open standard for telematics services impacting certain architectural constraints for the overall system design as well as consequences for the architecture of an OBU.
- CVIS – focusing on the standardisation of the different communication interfaces based on CALM and providing/defining applications using the CALM based interfaces. (final results will be too late for this project)

These projects clearly highlights the trends towards an interoperable European road pricing applications as well as the intention to integrate these road pricing applications with telematics applications particularly improving the safety on European roads (e-call, hazardous goods tracking etc.). A universal OBU is seen as a basis to meet these requirements.

10.2 Cost sharing by introducing Value Added Service

One of the main potential cost savings not covered in detail by this report could be the share of the cost with other applications / services. The OBU required for a free-flow EFC system has similar requirements as telematics systems for different types of telematics services.

Short term OBU cost reduction mainly results in a shortened list of requirements and OBU capabilities optimised for a pure road pricing system. Consequently, it accepts the drawback of no or reduced extendibility not allowing to increase the usability of the onboard equipment. Besides the obvious ‘service’ of road pricing additional services are present or will be required in future which are not linked to road pricing but to the vehicles

Samples could be (Value) Added Services dedicated to the driver like e-call for safety or navigation for better driver comfort. Other services would support business users like fleet owners (logistics applications, remote diagnosis) or insurances (risk depending insurance contributions). Services which allow to gather traffic data anonymously or to supervise hazardous goods transportation are of public interest.

10.3 Field Trial

As already mentioned in chapter 6.1 it is urgently recommended to test the different approaches in a very early state. To validate the main concepts a "deployment" field trial with at least several hundred vehicles should be performed starting in 2007 to:

- Collect information for system dimensioning and requirements finalization.
- Evaluate the system reliability and accuracy of different approaches.
- Evaluate expected operational costs for different approaches. A thick vs. thin client architecture should be tested considering different road classes.
- Demonstrate feasibility of Value Added Services combined with a road pricing application running on the same platform (considering available results from EU projects like GST, RCI or CVIS).
- Demonstrate to the public the advantages of such a system at an early stage to create awareness, need and early acceptance for this system.

11 Abbreviations and Definitions

Abbreviation	Definition
AbvM	Anders Betalen voor Mobiliteit
API	Application Programming Interface
ASIC	Application Specific Integrated Circuit
BOM	Bill of Material
BOT	Build, Operate, Transfer
CALM	Continuous Air interface for Long and Medium range
CAN	Controller Area Network
CN	Cellular Network
CPU	Central Processing Unit
CS	Central Server
CVIS	Cooperative Vehicle-Infrastructure
DB	Database
DR	Dead Reckoning
DRM	Digital Rights Management
DSRC	Dedicated Short Range Communication
EC	European Commission
EFC	Electronic Fee Collection
EGNOS	European Geo-stationary Navigation Overlay Service
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
EU	European Union
EUR	Euro
FSTN	Film-Super-Twisted-Nematic
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communication
GST	Global System for Telematics
HdS	Hardware dependent Software
HMI	Human Machine Interface
HW	Hardware
IR	Infrared
ISO	International Organisation for Standardization
KMP	‘Kilometerprijs’
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LPR	License Plate Recognition
M2M	Machine to Machine
MRAM	Magnetoresistive Random Access Memory
MEMS	Micro-Electro-Mechanical Systems
MTBF	Mean Time Between Failure

Abbreviation	Definition
OBD	OnBoard Diagnosis
OBU	OnBoard Unit
OEM	Original Equipment Manufacturer
OLED	Organic light-emitting diode
PDA	Personal Digital Assistant
PMP	Project Management Plan
PPM	Pulse Per Minute
QoS	Quality of Service
RAM	Random Access Memory
RCI	Road Charging Interoperability
RfQ	Request for Quotation
ROI	Return of Invest
RTTT	Road Transport and Traffic Telematics
RSE	Roadside Equipment
SAM	Security Application Module (Secure Access Module)
SG&A	Selling General and Administrative
SW	Software
USB	Universal Serial Bus
VAS	Value Added Service

12 List of referenced documents

[1] "scope fase 2 marktconsultatie_bk_uk.doc"
Scope description phase 2 assignment “Anders Betalen voor Mobiliteit”

[2] "Statement of work subject 2 22mei061.doc"
Statement of work for the assignment 2 of the project “Anders Betalen voor Mobiliteit”

[3] Directive 2004/52/EC - OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29th April 2004 on the interoperability of electronic road toll systems in the Community

[4] Directive 95/46/EC – OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24th October 1995 on the protection of individuals
with regard to the processing of personal data and
on the free movement of such data

[5] “NL-2006-04-01_PMP.pdf”
mm-lab Project Management Plan for the assignment 2 of the Cost Monitor

[6] "ABvM requirements 0.2.pdf"
Requirement specification for the project “Anders Betalen voor Mobiliteit”

[7] “Minimum Interoperability Specification for Tolling on European Roads (MISTER)” eg9019 MISTER v2.8 March 4, 2006

[8] "scenarios for pricing.doc"
Questionnaire provided by the project “Anders Betalen voor Mobiliteit” to be answered within the assignment 2

[9] “Risk Assessment Table V2.0.xls”
Assessment results to the work package 4 of the mm-lab PMP

[10] “Questionnaire – Scenarios for Pricing V2.0.xls”
Evaluation results to [8]

[11] “NL-Andersbetalen.pdf”
Nationaal Platform Anders Betalen voor Mobiliteit, mei 2005

[12] prENV ISO 17575 - Road Transport and Traffic Telematics (RTTT) – Electronic Fee Collection (EFC) – Application Interface Definition for Global Navigation Satellite Systems and Cellular Networks (GNSS/CN)

[13] "Bijl1_Statement of work subject 1 19mei06.doc"
Statement of work assignment 1 of the project “Anders Betalen voor Mobiliteit”

[14] Clarifications on Price per Kilometre Cost Estimates 2005, version 12.04.2006

[15] eCall – saving lives through in-vehicle communication technology
European Commission, Fact Sheet 49, May 2006

13 List of referenced suppliers

The following table contains the main suppliers, manufactures and qualification companies mm-lab has worked with for the development of the Advanced Telematics Platform. Only a subset of them have been contacted specifically for the cost monitor project. Nevertheless, to provide the optimal information to the Ministry, all resources available have been used.

Type of company	related functional block	Company
Supplier	Cellular communication	ST Microelectronics
		Wavecom S.A.
		Telit Communications PLC
		Sagem Communication, Safran Group
	Positioning	Sirf
		Tyco
		µBlox
	Enforcement	Efkon AG
		CS
		Autostrade
		Advanced Semiconductor Business Inc.
	Processing	ARM
		Renesas
		Texas Instruments Deutschand GmbH
		Samsung Electronics America, Inc.
		Spansion International Inc.
		Micron Technology, Inc.
	Human Machine Interface	DENSITRON TECHNOLOGIES plc.
		Noritake Itron Corporation
		Siix Co., Ltd.
	Security	Cardag Deutschland GmbH
Manufacturer		Alcatel (CTI Nethouse)
		Unity opto
		USI
		Siix Co., Ltd.
		Sanmina
		Shinsei
		Jabill
		Foxconn
		Holux
		Elead
		Waverfar
		Falcon
		Hamgshing
Qualification & certification		TÜV Rheinland

Table 22: Referenced suppliers, manufactures etc.