Assessment of Telematic Applications for Road Freight Transport

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"I can’t change the direction of the wind, but i can adjust my sails to always reach my destination"

– Jimmy Dean (1928-2010)
Abstract
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To my family and friends for encouraging, supporting and motivating me, I say thank you.

Karlshamn, September 2010
Gideon Mbiydzenyuy
Preface

The research in this thesis addresses one of six research areas carried out by the National Post Graduate school on Intelligent Transport Systems (ITS), Sweden. The post graduate research school coordinate these six areas in different universities and all were initially mean to target the 15th world Congress on ITS that was held in 2009, Stockholm Sweden. The thesis work presented here was conducted under the area known as e-transactions whcih focus on the design and analysis of different ITS applications that can potentially improve industrial and societal goals such as economic efficiency and reduced environmental impacts. The work was carried out in collaboration with the project known as Mobil IT which aimed at identifying and analyzing ITS applications that can be implemented with the road user charging system. This resulted to five research articles that constitute this thesis. A number of project reports were also delivered and these have not been included in the thesis but some are similar to the publications in the thesis. The author of the thesis has contributed to all papers in relation to conducting experiments, analysing data and writing the papers. Papers I, II, III and IV in this thesis have been published as conference papers. PV has been accepted for publication as a conference paper. Three of the papers (PII, PIII and PIV) have been improved and submitted for publication as journal articles. The following papers are included:


III. Mbiydzenyuy, G., Person J., & Davidsson, P. (2010). Analysis of telem-


Papers II, III & IV are respective extensions of the following conference papers:


Related but not included in the thesis:

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Chapter 1

Introduction

The focus of this thesis is to investigate and develop relevant approaches for the evaluation, analysis and assessment of telematic systems for road freight transport. The aim is to support strategic decisions of different stakeholders related to choices of functional architectures and telematic services for road transport based on their costs and value to society. In particular, the thesis has contributed to the use of quantitative models, to analyze and evaluate different telematic systems and services for road freight transport. The thesis analyze and suggest the potential of platform concepts that can support multiple transport telematic services as the way forward for improving goods transport by use of telematic systems. This section will provide the background to the thesis and describe the context of the research. A summary of the research questions, method, related work, results and research contributions will then follow.
1.1 Background

1.1.1 Road Freight Transport

Transportation is fundamental to society. Freight transport enables goods to be produced and consumed in geographically distant separated areas. This is achieved through the use of infrastructure such as roads and vehicles. With the demand for transport services within the EU27 increasing up to 4091 billion tonKm, and 45.9% by road, as at 2008 (EUROSTAT 2010), it becomes necessary that either transport capacity is increased (e.g. by building roads) or the efficiency of operations is improved. In addition, transportation results to negative consequences for the society including: accidents, pollution, global warming etc just to name a few. Coping with increasing transport demand by expanding physical capacity of infrastructure is not only expensive but has been seen to lead to an increase in negative repercussions on the environment. To achieve a sustainable transportation system requires transport information to be analyzed and communicated fast. Consequently, transport systems are increasingly reliant on information processing technologies and this has evolved into what is known today as Intelligent Transport Systems (ITS) or telematic systems for road freight transport. As major infrastructure investment is increasingly becoming difficult due to financial, spatial and environmental problems, ITS can be a useful tool for improving existing infrastructure and thereby making the movement of people and goods sustainable (ECORYS 2005).

1.1.2 Telematic systems for road freight transport

Telematic systems for road freight transport are systems based on electronic transaction for Heavy Goods Vehicles (HGV) such as Electronic Fee Collection Systems (EFC) and navigation systems. ITS can deliver services that can reduce the negative influence of transportation and improve efficiency of transport systems. ITS involve a broad range of technologies and application areas but is sometimes narrowed down for instance to the science of sending, receiving and storing information via telecommunication devices (ASA 2008) or simply the transmission of useful information to and from a vehicle. In this thesis we will refer to ITS or telematics mainly in the context of road transportation to collectively refer to those systems with the capability of: collecting, communicating, processing, storing and sharing transport data in real time. ITS is delivered to end users or transport stakeholders in the form transport telematic services to enable them achieve different goals.

A Transport Telematic Service (TTS) consist of a product or activity targeted to a specific type of ITS user (ISO/TR-14813-1a 2007). TTSs are realized through the implementation of ITS systems such as EFC systems. More than one
TTS can be realized by a single ITS system (Marples, 2010). The benefits of such a system can be considered from the type and quality of resulting TTS. There are a large number of potential TTSs addressing different transport issues that can be deployed to improve transport resource utilisation and minimize externalities of road transport by HGVs. Examples of such services include intelligent speed adaptation, eCall (EC), Transport Resource Optimization (TRO), Route Guidance (RG), Road User Charging (RUC) etc. Systems offering these services are provided by different companies, installed onboard the vehicle and interactive with the vehicle through the driver as shown in Figure 1.1.

Figure 1.1: Transport telematic systems offering TTSs mounted on board the HGV.

Information from the systems can be shared with different transport stakeholders such as hauler companies, traffic controllers, and infrastructure owners through real time communication in order to support operational decisions. Some major limiting factors to the deployment of ITS systems that will realize various TTSs are concerned with information security, business, technological, political, ethical (integrity and privacy), and legal aspects. The business aspects have to do with the cost and benefits of systems that are often unknown at pre-implementation, as there is limited data for analysis and lack of understanding about suitable business models. Some reasons that most of these systems are not in the market today has been associated to lack of knowledge about impacts, lack of economies of scale, high costs of deployment and operations (ECORYS, 2005; Thill et al., 2004). Such a high costs is generated by the type of resources required to deploy the systems and also resources that are utilized by the different systems/services when in operation, mainly for data processing, geographic positioning and data communication networks. Even with available financing, there is lack of easy and efficient access to knowledge on benefits and costs of ITS systems and this is seen to be a key factor for slow investment (2DECIIDE, 2010). In the same way that internet and mobile applications each run on common platforms, one can imagine that suitable platforms for transport telematic applications can help to reduce the costs of TTSs, improve system interoperability and facilitate the emergence of new applications.
1.1.3 Transport telematic platforms or Multi-service Architectures

Functional specification of architectures with the potential to deliver multiple end-user TTSs are referred to in this thesis as multi-service architectures (MSAs). MSAs provide a potential for improving utilization of expensive telematic resources such as positioning and communication bandwidth through common use of such functionalities. It can be expected that in the future, MSA will provide a single window of interaction with the driver where TTSs can be accessed with a click of a button as in the case of computer applications and mobile phone applications as illustrated by Figure 1.2.

![Figure 1.2: Illustration of a potential platform with multiple TTSs.](image)

There are reference examples of efforts for developing MSAs such as Open Service Gateway Initiative (OSGi), [Ai et al. 2003] and Global System for Telematics (GST) [2010] as well as R&D initiatives such as Mobile.infor [2007] which aim at establishing a platform for radio based traffic information services capable of satisfying future standards. These efforts are important for achieving telematic services because of the potential advantages of multi-service architectures such as: 1) reduction in system economic costs through common use of functionalities, 2) encourage the development of new applications by providing base functionalities e.g. the potential of new applications with an open platform can be seen in the mobile telephone industry such as the nexus platform [Durr et al. 2004], 3) driving force for interoperability, standards and usability, 4) improvement of trust between public private co-operations through sharing of information 5) reduce the burden on the driver etc. Since these systems involve different stakeholders and businesses with varied goals [Kostevski 2010], the process of acquiring and deploying systems is complex. As a result, to achieve a good outcome requires careful planning with use of computer tools such as simulation and optimization.
1.1.4 ITS acquisition and deployment, a process view, stakeholder decisions

Planning is critical to successful introduction of telematic systems (both software and hardware) for road transport that meets the need of different stakeholders. Lack of a good planning process in most cases, is a plan for unsuccessful deployment. Several questions need answers during planning especially because the high costs of applications do not warrant experimentation. During planning stakeholders need to make decisions that will enable them attain their goals. Once the correct decisions are made, ITS system implementation then follows and the effect on society (extent to which goals are achieved) reflects the success of the decisions. Thus some key segments of the planning process are:

- **Decision makers**
  Several stakeholders are involved such as local national or regional government, telematic service providers, road haulers etc. The needs of each stakeholder are related to their goals that may include constitutional and legislative constraints, income re-distribution, financing consideration, social planning etc [Bekiaris and Nakanishi 2004].

- **Decisions**
  Each stakeholder faces a number of decisions and seeks to make the best decision that will enable them achieve their goal. Here there is a choice on whether to invest in a telematic system at all, what type of system, functional specification, architecture etc. These choices involve structured, unstructured and semi-structured decision problems.

- **Goals**
  Decisions are driven by the goals of the problem addressed with the system and the availability of information about solution alternatives. The goals reflect the needs which could either be to improve a situation or solve a problem. A stakeholder may directly determine their goal or base their goal on decisions that can have a potential impact on such goals e.g. the ability to finance a telematic system.

- **Effects on Society**
  The outcome of the goals and decisions are felt primarily by the targeted users and also by the non-targeted users in society. These could be in the form of faster or slow freight distribution, short or long time queues, increase or decrease in accidents etc.

For emerging ITS systems, information about alternative specifications, benefits and costs etc are limited making the decision environment uncertain. Consequently informed decision making, e.g. using computer decision support tools,
can be a critical tool for such a decision domain. The entire process of decision making can be simplified as shown in Figure 1.3.

Figure 1.3: A simplified representation of the complex decision process for ITS stakeholders.

The focus of this thesis can be seen from the dotted circle in figure 3. The decisions are unstructured and involve multiple criteria with no predefined procedures as well as unknown outcomes. The goals of the decision are based on the goals of various stakeholders concerned with the acquisition and deployment of telematic applications for road freight transport. This makes the task of assessing, analyzing and evaluating different decision alternatives cumbersome for stakeholders. To address these we consider some research questions.

1.2 Research questions and motivation

In this section we discuss the research questions that are addressed in this thesis and the relevance of these questions for road transport telematic systems.

**Main Research Question** How can computer-based models help in the strategic assessment of the functional specification of telematic systems for road freight transport?

To address this question, it is necessary to first identify potentially relevant telematic systems based on some form of criteria. Assessment of benefit and losses to stakeholders is central in strategic planning. Use of quantitative methods related to multi-criteria decisions is needed to address the multiple applications
with different stakeholder goals. As a result the thesis addressed the following sub questions:

**Sub-Questions**

- Sub Question 1 (SQ1): Which are the relevant telematic systems and services for road freight transport?
- Sub Question 2 (SQ2): What characteristics of telematic systems for road transport enable them to be analyzed?
- Sub Question 3 (SQ3): How can we quantify the value of transport telematic service in order to facilitate decision making?
- Sub Question 4 (SQ4): How can we formulate mathematical models for evaluation of telematic systems in road freight transport?
- Sub Question 5 (SQ5): How can we assess the potential benefits of multi-service telematic platforms for road transport?

Sub question 1 aims at identifying relevant telematic systems for road freight transport, sub question 2 identify the characteristics of the systems that can enable analysis, sub question 3 is aimed at quantification of the effects of telematic services on society and sub question 4 formulate mathematical models of some of telematic systems to represent the decision choices. Sub question 5 focuses on assessment and recommendations based the evaluation.

### 1.3 Research method

This thesis addresses the assessment, evaluation and analysis of telematic systems for road freight transport that can provide support for strategic decision making. Different methods are used in the thesis to evaluate outcomes of different decision choices mainly mathematical optimization, clustering and modelling the societal value of services. The following phases have been involved (not sequentially).

**Exploration of potentially relevant TTSs in road freight transport**

Relevant R&D projects at the national e.g. ARENA 2010, MOBILE NET 2006, European citepgiroads2007, easyway2010 etc and International FHA-US-DOT 2005, ITS-Japan 1999 levels were reviewed as well as research work within ITS. Most of the reviews of different project were carried out in the framework of a project called MOBILE IT 2009. In the course of this project, workshops, interviews and brainstorming activities helped to identify relevant telematic systems for freight transport.
Data collection

Potential telematic systems are critically examined to identify relevant important attributes that can be used for analysis. Various interest groups (stakeholders), domain of applications, TTS motives, functionalities, societal value etc are considered. MSA functional specifications and related characteristics are examined. TTSs characteristics, such as cost of functionalities, shared functionalities etc are extracted. Data about TTSs and MSA attributes are obtained from secondary sources ranging from project reports, statistic data basis (SRA, SIKA, SCB, BR etc) to scientific papers especially those reporting on results obtained from field trials e.g. RITA. Primary data sources have also been collected from workshops, discussions and open ended interviews. In some cases meta-analysis was carried (e.g. societal costs for fuel consumed by HGV) to pre-transform the data into a suitable form.

Modelling TTS applications

In this thesis modelling, refer to mathematical modelling. Mathematical modelling is an approach that enables real world behaviour of a system to be represented using mathematical formulas (variables, constants, relations and operators). Such models provide quantitative information that is easily comprehensible by human beings. However, obtaining an exact representation of real world behaviour in a mathematical equation is a difficult task and hence mathematical equations are based on assumptions. In the interpretation of results obtained from abstracted mathematical models such as optimization, it is very crucial to bear in mind the context of the assumptions from which the underlying mathematical model is obtained. If the decisions are represented using variables in such a way as to determine the objective without violating the conditions associated to the choices, then the process is known as mathematical optimization. The number of choices and influencing conditions in several real life cases are usually large e.g. the allocation of scarce resources to different applications sharing common platforms such as www internet platform, mobile phone platform, EFC platform. Therefore approaches such as optimization algorithms are often employed to systematically select the best decision choices. There are other mathematical models that can also be used to reduce the choices involved in a decision problem such as clustering which reduce a given set of data into categories with similar characteristics e.g. according to benefits. The success of any mathematical model is dependent on how well they are formulated to represent a real life situation and on the validity of the data used.
Evaluation and assessment

Generally, evaluation refers to the systematic determination of the merit of something e.g. a system objective or goals. It is this merit that guides the choice of a decision maker about alternative decision choices. Mathematical models can be seen as decision support models whereby the results of a mathematical model can be used to evaluate and assess a system. With the help of a decision support model, the decision maker can be provided with the ability to look into the future and use that knowledge to make informed current decisions. Recommended decisions based on such models can be compared with real world outcome in a way such as to validate the model. Any significant variations from the real world situation and expectations (from an expert) should be accounted for. Figure 4 presents an overview of the above research activities that have resulted to this thesis.

![Figure 1.4: Overview of research activities in this thesis.](image)

Thus, the work presented in this thesis is developed by systematically gathering established facts, expert opinions and scientific theories reported in projects, academic articles and books addressing related work at the junction of computer science, economics, transport, communication and vehicular technology. Interdisciplinary research such as ITS (resulting from a wide scope) can be pragmatic i.e. it should be approached from a prescriptive-driven perspective allowing the use of different methods in addressing different problem areas (Creswell 2003). With
such an approach, knowledge claims can take the form of identified design parameters, design criteria, generation of design alternatives, and rules and guidelines for choosing between alternatives (Peters et al., 2007). The use of conferences, workshops and reviewers opinions provided valuable feedback that helped to improve model validity. Internal validity was strengthened by sensitivity analysis.

1.4 Related Work

In this section, a summary of some research and development efforts relevant to the problem addressed in this thesis are highlighted. Detail reviews are presented on each paper.

The focus of this thesis is to support stakeholder strategic decisions related to choices of functional architectures and telematic services for road transport based on their costs and value to society. It is important to highlight a number of R&D projects with some connection to the research work in this thesis since answers to part of the research questions considered in this thesis are partly addressed by the said R&D projects. In addition some relevant scientific research is also presented.

Work presented in this thesis is partly a result of a number of R&D projects that have evolved under NetPort Karlskrona in the last decade. Initially, interest from government policy makers and commercial actors motivated a R&D project in Sweden with an aim of developing a future-oriented RUC system for heavy goods vehicles that will internalize the external costs of transport system (ARENA, 2010). Further, another related R&D project known as the EAST-WEST project then addressed prospects for using ITS as a tool for innovative actions in a corridor from China to Western Europe. This project targeted the use of a foreseen kilometer tax system as a platform for added value ITS services. Qualitative approaches were used in this project to assess potential candidate applications that can be implemented together with a potential thin client or thick client RUC system (Sjöström, 2007). An expanded concept of achieving multiple freight mobile systems was considered by another R&D project called Mobile Networks in Logistic Chains (MOBILE NET, 2006) which addressed the development of mobile IT applications for logistic systems. The ambition was to handle information flow along the logistic chain based on user needs that will facilitate product development at producers. MOBILE NET (2006) project came up with a description and suggestion of different types of mobile applications for different stakeholders that partly served as a starting point for this thesis.

Building on the developments mentioned above and particularly MOBILE NET (2006) and EAST-WEST projects, the R&D project called MOBIL IT project or ICT for cargo on the road (MOBILE IT, 2009), sort to identify and analyze relevant road freight transport telematic applications that can be inte-
grated with a potential Swedish RUC system. At the European level the study and analysis of applications based on GNSS in connection with road transport was initiated in a project known as GIROADS (2007). This project considered each application from a user requirement, business model, market study and regulatory framework perspectives. Similar to the Swedish project MOBILE IT (2009), the European EASYWAY (2010) project initiative identifies the set of necessary ITS European services to deploy, enabling stakeholders to achieve a coordinated and combined deployment of pan-European services. Similar initiatives are underway in the US (FHA) and Japan (?). For a full report on telematic application R&D projects and types of applications, see Mbiydzenyuy et al. (2009).

Common to all the above projects is the need to identify a uniform set of telematic services for use in different transport domains and demonstrate their potential impacts on society. Most of the R&D projects are expected to establish a base that will justify the deployment of one or several ITS applications. This subject is partly addressed in this thesis with focus on freight transport and generic methods of assessments. To develop such a base, models for the analysis and assessment of different applications, in different scenarios need to be developed. General ITS assessment methods have been discussed by Peng et al. (2000). The author proposed a framework for benefits assessment using benefit trees. Their review of assessment methods shows that there is a significant variation in the complexity and details in ITS evaluation methods. The choice of method should depend on the target of the assessment. Even though the proposed approach is generic it fails to provide quantitative models that can be used to address the assessment of ITS for supporting stake holder strategic decisions based on benefits as anticipated in this study. A related study has considered an assessment of the benefits and cost of ITS from a planning perspective (Thill et al., 2004). The study investigates the use of traditional traffic models, such as assignment models, and how such models can be extended to the evaluation of ITS costs and benefits. The study concludes that ITS benefits evaluation is increasingly marked by a need for explicit analytical or numerical modeling and for disaggregates data. The authors further argue that the scarcity of good tools for benefits and costs evaluation of ITS elements is a hindrance for the deployment of new ITS user services. Contrary to their use of traditional traffic models, Bekiaris and Nakanishi (2004), argues that traditional transport analysis approaches may not be appropriate in accurately and reliably assessing the economic impacts of ITS technologies. We argue that there is a need to attempt the use of alternative quantitative approaches such as optimization in the assessment of ITS applications. Quantitative analysis of ITS benefits is an important subject and has been at the focus of a European R&D project known as 2DECIDE (2010). The project 2DECIDE aims to develop a decision-support toolkit for investment decisions in
ITS applications and services. The toolkit should include a quantified evaluation of the economic, social, financial and operational impact and cover aspects such as user acceptance, life-cycle cost/benefit as well as the identification and evaluation of best practice for facilities procurement and deployment.

The research studies mentioned above did not pay any particular attention to specific ITS systems and their domain of use. R&D projects have used tailored approaches to address specific needs for specific ITS systems. However there are no generic methods aimed at assessing services within a framework that enable result comparison across different regions. Consequently, the research work in this thesis is intended to fill this gap. Recently, Crainic et al. (2009) conducted an assessment of ITS achievements with focus on different domains such as freight transport and identified challenges, opportunities, and promising research and development directions. One of the challenges identified in their study was in relation to the fact that governments and industry privilege up to now the hardware aspect to the detriment of the methodological aspect with lots of data still being processed and acted upon by the human operators with little, if any, decision-support tools. According to the authors, assessment of ITS systems must address application modeling with focus not only on the physical components of the systems considered and the associated flows of physical resources, but also on the adequate representation of the associated information and decision flows. Suggested models should be possible to be solved with efficient solution approaches with the ability to address large instances of formulations including integer-valued decision variables, nonlinear objective functions and constraints, and uncertain data. This thesis have formulated decision process faced by different stakeholders into quantitative models e.g. linear optimization, clustering etc that can be used to support the planning of telematic systems with focus on road freight transport.

1.5 Results and research contributions

This section summarizes the research contributions from each publication in relation to the research questions. The main research question is addressed by answering sub questions (SQ1 to SQ5). Contributions from five conference articles are included. Three of the five conference papers have been re-written and proposed for journal publications. All papers have been modified in order to fit to the thesis template.

Paper I

Gideon Mbiydzenyuy, 2009; Characterization Framework for Road Transport Telematic Services, 9th International Conference on Transport Systems Telem-
This paper has a main contribution in addressing sub question 2. The domain of freight transport telematic applications is characterized by different types of systems using different technologies to achieve a wide variety of goals. There is diverse understanding especially between regions in the use of terminology e.g. a system for charging the use of road infrastructure has been referred to as a road user charging system in Sweden, electronic toll collection system in Japan, electronic fee collection system in Germany etc and this situation extends to several other different telematic systems for transport. The paper has suggested a framework that reflects the operational characteristics of freight transport. These include domains such as driver support, fleet management, staff management, transport management, administration etc. There are several characterizations that have been suggested on a high level that are not useful for studying telematic systems for freight transport e.g. those suggested in the PIARC handbook. We suggest attributes for characterizing telematic systems such as motive, users, usage, functionalities, service options and quality of service. As such, we suggest a framework that can be used for high level analysis of services that support investment decisions. The framework is illustrated with some classification of telematic services for freight transport (according to the suggested domains) thus, partially contributing to answering sub question 1. The main contribution in this paper is a suggestion on a holistic view to telematic systems for freight transport based on the operational characteristics of freight transport. The main weakness is that the framework is general and fails to provide answers to very specific issues related to characterization of telematic systems e.g. system interoperability.

**Paper II**

Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2010; A Method for quantitative evaluation of road freight transport telematic services proposed for Journal publication

This is based on an extension of a conference paper: Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2009; The value of transport telematic services in road transport using heavy goods vehicles, EasyWay Annual Forum, 2009, Wien Austria

This paper contributes to answering sub-questions 1 and 3. Relevant telematic systems for road freight transport are identified. A total of 32 telematic services are seen to be relevant for freight transport using heavy goods vehicles. The relevance is considered from the perspective of freight transport in Sweden and based on the framework that was proposed in Paper I i.e. the motive of the service, the
domain being addressed, the users, usage etc. Computation of societal costs indicators (Performance Saving Indicators) that can be used to quantify transport telematic services is carried out. The computations uses statistical data obtained from freight transport in Sweden e.g. from national data bases such as SCB, SIKA etc. Nine such indicators were identified. Using quantified PSIs a method for assessing the decrease in marginal benefits when multiple services address a common societal issue is proposed i.e. the effect of dependencies. In the proposed method dependencies are modelled pair-wise. We showed that for small percentage changes, pair wise estimates are a good enough approximation for synergies with less than a 5% error margin. Using PSIs and their dependencies, we propose a method for assessing the societal values of TTSs. The proposed method is similar to what is used today by the Swedish Road Administration (SRA) in assessment of societal impacts of various projects (EVA system) except for the fact that we consider dependencies that are not taken into account by the EVA system. The proposed method is used to estimate quantitative societal values of the identified 32 TTSs in the context of freight transport in Sweden. Results suggest that important services with a significantly high societal impacts are transport resource optimization, theft alarm and recovery, road hindrance warning, accident warning, navigation, eCall, intelligent speed adaptation, en-route driver information, transport order handling, sensitive goods monitoring and road user charging. Assessed societal values in this study also provide a valuable input to quantitative analysis of service benefits using methods such as optimization, Cost Benefit Analysis etc. The major weakness in this paper is that we made some assessment of the ability of TTSs to reduce a PSI based on our judgements. Using experimental based percentage estimates will be excellent but we didnt have this information partly because some of the TTSs we examined are not in existence and partly because of the high costs of such experimentation.

**Paper III**

Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2010; Analysis of telematic systems and service in road based vehicle freight transport, *proposed for Journal publication*

This paper is based on an extension of a conference paper: Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2008; Analysis of added value services in road-based vehicle freight transports *15th ITS World Congress, 2008, New York*

This paper has contributed to addressing sub-questions 2 and 4. This paper investigates the relevance of characterizing telematic services for freight transport in clusters according to shared functionalities. We refer to the measure of such shared functionalities as a synergy measure. The main reasons clustering services are first to identify services that can be implemented on a common platform and
secondly to also assess the potential of reducing the total costs of services if implemented on a common platform. A quantitative method is proposed that can be used to estimate the synergy levels for groups of TTSs. The method is based on a modified hierarchical clustering used to determine clusters of TTSs with a cost reduction potential. The proposed method considers and examines common functionalities among various TTSs. The proposed method is illustrated with an analysis of synergies between TTSs and a killer application such as the Swedish RUC. A total of 32 relevant TTSs all based on 38 functionalities are analyzed.

Synergy estimate as proposed in this study depends much on the type of functionalities considered for each TTS and the underlying interpretation of functionality sharing. It is important to note that results are based on simplification that all functionalities could be achieved at the same costs. In reality the costs between functionalities do vary, however there is a costs reduction in common use of functionality and if such cost reduction can be estimated for a given set of applications under consideration, then can the potential of the proposed method be fully exploited.

**Paper IV**

Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2010; Optimization analysis of multi-service architecture concepts in road transport telematics, *proposed for journal publication*

This is based on an extension of a conference paper: Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2009; Optimization based modeling of multi-service architecture concepts in road transport telematics, *12th International IEEE ITSC 2009, St. Louis, MO, USA.*

This paper contributes to answering sub-questions 3, 4 and 5. While the societal value of a service may be used to understand it potential impact, the net benefit that takes the costs into account is even more useful. A model that can be used to support strategic decision making related to the design and investment in telematic systems and services for road based freight transport is proposed. Decisions of different stakeholders are abstracted as discrete, enabling the use of Integer Linear Programming optimization to address the selection of beneficial TTSs. The objective of the optimization was to select beneficial TTSs for implementation on common platforms while minimizing costs and service dependencies and maximizing sharing of functionalities. We illustrated the model decision prescription capabilities by selecting potential beneficial applications from a given set of applications for road freight transport with focus on the Swedish HGV transport context. With CPLEXs branch and bound capabilities, the solution to the model is generated from exhaustive simplex search iterations with guaranteed optimal solution. We showed how the number of applications to select from a
given set could be varied such that it is possible to prioritize TTSs according to their benefits. By changing the conditions we also illustrated that the model can be used to address what-if scenarios. To illustrate the what-if capabilities of the model we considered six different platforms and their potential effects on possible services that can be achieved from a benefit perspective. Results of the quantitative ILP optimization based method show that Navigation (NAV), Theft Alarm and Recovery (TAR), Transport Order handling (TOH), Road Hindrance Warning (RHW), En-route Driver Information (EDI), Accident Warning Information (AWI), Advanced Driver Logs (ADL) and Driver planning (DP) are candidate applications for to thin client platform based on their net-benefits. For a thick client based architecture, our model showed the possibility of achieving an even greater number of beneficial applications. The study provides evidence that it is possible to conduct high level multi-service analysis using quantitative models such as optimization. Another key benefit of the proposed model is the capability to simultaneously exploit synergies through common use of functionalities and minimize pair wise dependencies of selected services when they address a common transportation related issue. Additional benefit of the model is that it provides a means to approach the complex issue of developing a road transport telematic platforms such as EFC platforms. By showing that certain applications are beneficial if implemented in a given platform, the model can support stakeholder decisions related to such platforms. However, because architecture concepts are studied from a functionality perspective there are additional factors that merit consideration which are not currently addressed by the proposed model e.g. physical architecture layout, regional or national architecture requirement. Therefore the proposed model should be seen as a complement to other models that focus on addressing TTS related issues such as demand modeling, performance monitoring, quality of service etc. The major weakness in this study is related to the linearization of the decision processes involved in the selection of beneficial TTSs. This was necessary to generate guaranteed optimal solutions. More accurate representation of such process is more likely to result to non linearity which doesn’t guarantee optimal solutions.

**Paper V**

Gideon Mbiydzenyuy, Jan Persson, Paul Davidsson, 2010; Modelling service quality and benefits of multi-service architecture in road transport telematic applications, *16th ITS world congress, Busan, Korea.*

This paper contributes to answering sub-questions 4 and 5. In paper IV we used optimization to determine candidate TTSs for implementation on a common platform. In assessing the true benefits of such a platform it is important to consider the quality of the resulting services. This is because the quality of
service may be affected because of resource sharing on a platform. Paper V aims at improving an initial optimization model for evaluating ITS benefits to take into account the quality of service aspects. The use of MSAs will lead to resource sharing such as communication infrastructure and processing. The result will be high demand for different QoS attributes (performance) by different applications that may in turn affect MSA benefits if such demands are not met. The paper considers at the planning stage, resources employed by different applications (TTSs) and decision variables formulated into a mathematical model. Instances of the system behavior at run time can be analyzed with the model to estimate how the benefits of MSAs may be affected by QoS using a given resource allocation model. A system performance oriented QoS measure has been introduced providing a possibility to capture different quality attributes, desired performance levels, and even the possibility to introduce desired priorities between applications and quality attributes. Literature reviews within QoS and MSA benefits reveals that most of the studies carried out so far were eccentric to the subject matter investigated by our study. The main weakness in this study is that the proposed model has not been tested on real data.

The contributions to the research questions, of the papers discussed above can be summarized in Table 1.1:

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Table 1.1: summary of contributions of different research papers to different Sub-questions (SQ).

1.6 Conclusions and future works

This thesis has contributed to the analysis and assessment of ITS systems. The main contributions are to the research questions are:

- A review of R&D projects addressing development and analysis of TTSs.
- A proposed framework useful for analysis of telematic systems with focus on freight transport.
- The identification of some relevant TTSs for road freight based on the proposed framework.
- A formal description of the planning process for TTSs using quantitative models
- A mathematical model for assessing marginal societal value of TTSs which can be used to assess the value of telematic services to different stakeholders.
- A mathematical model for the analysis of cost reduction potential of shared platforms (MSAs) using clustering based methods.
- An optimization model for simultaneously exploiting synergies through common use of functionalities and minimize pair wise dependencies of selected services when they address a common transportation related issue.
- Illustration of the proposed optimization model to the analysis of TTSs relevant for freight transport in Sweden.
- A model for analysing and evaluating the effect of quality of TTSs on benefits of MSAs.

From the review of R&D projects, it is clear that there is significant interest and commitment from stakeholders such as governments and telematic service providers to develop ITS systems that will effectively address the challenges of road transport. While scientific research and commercial companies are focused on developing new systems, little seem to have been done at the high level of TTS assessments especially TTSs for road freight transport. This picture will need to be made clear in order to reveal the business potentials and efficiency of MSAs. Evidently, there are a large number of telematic systems that can potentially be used in the area of freight transport and the future will see even more telematic systems. As at now, most of the existing telematic systems have focused on the vehicle side. Quantification of TTS costs and benefits can motivate deployment of TTSs that will benefit society at large with much room for logistic and back office processes. Such quantification is difficult due to the often many assumptions needed. However, mathematical models can potentially be used for abstracting and studying important features of multiple TTSs in order to assess their societal benefits. An assessment of TTSs relevant for freight transport in Sweden shows that benefits of such applications are dependent on the context of existing applications.

The proposed quantitative models have several potential improvements that will need to be addressed. One such improvement is to attempt to simultaneously incorporate several features of shared platforms in order to understand the true benefits. In addition, a sub model addressing the choice of platform can further be developed, for instance to address different capacity requirements such as roadside equipments, communication etc. Paper II suggested a method to estimate the
societal value of TTSs. The method can be applied to estimate the societal value of different stakeholders. Paper V has suggested the model that is necessary to incorporate the effect of QoS on benefits. It is left now to implement and validate this model with real world data. The future trend for telematic services especially those addressing freight transport will see a convergence toward MSA solutions. This could be brought about for many reasons. The main reasons however will emerge from the desire to reduce the costs of the applications and the need for interoperability and standardization. In addition the growing number of telematic systems that are focused on the driver side will put demands on driver competence at which point their effect on driving may start to be perceived as negative. A MSA with single interface as shown in figure 2 will be the way forward with some similarities with today's computer systems except for the fact that processing will either be in the vehicle or outside the vehicle. However the complexities of such platforms as the number of applications increase (set to be inversely proportional to the square of the number of applications) will need to be considered. The key barrier today for MSA is not technology as such, a true business model will provide a strong motivation to the use of MSAs. Discrete systems for back office management and infrastructure management will continue to exist but their integration will be driven by the need to share information.
1.7 References


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Chapter 2

Paper I - Characterization framework for Transport telematic Services

In order to conduct analysis for the evaluation of benefits derived from Transport Telematic Services (TTSs) that supports decisions about architecture design options, it is necessary to establish a characterization framework. This study identifies potentially relevant TTSs for Heavy Goods Vehicle (HGV) Transport, potential users and domain of usage for the services and present these in a useful framework for conducting analysis toward a holistic understanding of telematic services e.g. impact analysis, benefits analysis etc. An illustrative example employing the framework has been presented.

2.1 Keywords

Transport Telematic Services, Framework, Characterization, Analysis.

2.2 Introduction

In order to conduct analysis to gain insight into the evaluation of Transport Telematic Service (TTS) benefits and evaluation approaches for decisions about various design options, it is necessary to establish a framework for characterizing TTSs. This is because the present approach for describing TTSs does not provide any suitable framework for conducting analysis. There is a need for es-
ablishing the values of different TTSs to society together with their functional connections for assessing resource sharing (synergies). Such analysis can lead to the assessment of potential Transport Telematic Application Systems (TTASs) for the deployment of efficient multiple coexisting TTSs. Basically, a TTS consists of a product or activity targeted to a specific type of ITS user \(^{[\text{ISO/TR-14813-1a, 2007}]}\). The phrase Transport Telematic Service is suitable because it conveys the fact that services are offered using telematic applications to users for addressing transportation challenges. This covers terminologies such as ITS User services, Value Added Services or Added Value Services for road transport etc. Against the background of numerous surface transportation challenges, the EU midterm review of the 2001 White Paper, Keep Europe moving sustainable mobility for our continent, a work program was designed to bring about significant further improvements in the quality and efficiency of transport in Europe by 2010. Electronic Fee Collection (EFC) systems based on interoperable technologies build into a network of interoperable toll booths emerged to be an interesting focus area. Thereafter, the Eurovignette directive established common rules related to distance-based tolls and time-based user charges for goods vehicles over 3.5 tons \(^{[\text{European-Comission (2006a), (European-Comission, 2006b)}]}\). Following these developments the Swedish Governmental Commission on road taxes proposed a distance based (a kilometer tax) charging system that covers all public roads, and all HGVs with a maximum laden weight exceeding 3.5 tons \(^{[\text{SOU, 2004}]}\). To that effect, a proposition was eventually discussed in the Swedish parliament to further investigate the potential of a distance based Road User Charging (RUC) system \(^{[\text{Proposition-2005/06:160, 2005; Sundberg et al., 2007}]}\).

Previous research work then addressed the importance of TTSs in relation to the Swedish RUC system and pointed out their potential to improve benefits (by sharing start up cost), attract the attention of multiple transport stakeholders and mobilize support for RUC application \(^{[\text{Sjöström, 2007}]}\). While TTSs may be developed on any existing platforms such as e-call \(^{[\text{Dietz, 2007}]}\) or intelligent speed adaptation \(^{[\text{Kenis and Wils, 2003}]}\), an EFC platform has a potential for hosting coexisting TTSs \(^{[\text{Sjöström, 2007; Sundberg, 2007}]}\) in order to return synergies of cost reduction benefits. As such the future of EFC systems in Sweden (and Europe) provide a potential base for developing TTSs. Since then further research work has continued within the Swedish Mobile IT project to identify and demonstrate in the 16th World Congress on Intelligent Transport, how TTS can be integrated with a Swedish EFC system. Additionally, a nation-wide demonstration of a GNSS-based road pricing hosting several TTS took place in the Netherland within the GINA (GNSS for INnovative road Applications-GINA) project \(^{[\text{ERF, 2009}]}\).

Such a common platform for TTSs is hard to achieve without a suitable analysis of TTSs that will influence how the system should be designed to maximize
the value and benefits of the services. For internet services, one way of maximizing such benefits has been to consider the cognitive ability, cultural background etc of the targeted users and segment the services according to user groups with common denominators (Hwang and Weiss [2008]). There is a significant difference with TTSs targeted toward organizations. One way to assess the extent to which existing services meet the needs of organizations is by studying how TTSs affects the stakeholders that are using such services. For Telematic Service Users (TSUs) individuals or organizations that receives and act on TTSs data [ISO/TR-14813-1b [1999] - the value associated to a service differs based on usage of TTS. For providers and investors, implementation takes unnecessarily long time windows and with a limited budget investment decisions are difficult. A good framework can provide users (e.g. governmental organizations) the opportunity to compare the impact of different TTSs.

The article aims at identifying important parameters for characterizing TTSs, use these parameters to suggest a framework of relevant TTSs in the context of HGV transport. The strategic purpose is to support a more detailed analysis of TTSs as a potential input to assessing the value of different services. In addition, attention is given to services considered relevant for HGV transport from a Swedish perspective thus providing a collective understanding of various TTSs (existing and conceptual) and potential users of such services which can serve as a bases for assessing the advancement of TTASs vis-à-vis HGV transport challenges. TTS are offered by Telematic Service Providers (TSPs) to different users (organizations and individuals). TSPs could be commercial, public or public-private organizations. We identified services relevant for HGV transport by making a preliminary assessment of problem domains (especially at the operational level) vis-à-vis the issues addressed by different services and synergies (based on shared functionalities) between the applications for various services. The rest of the paper consist of the following: section 2.3 motivate the need for a framework, section 2.4 presents a review of similar frameworks, section 2.5 focus on the operational characteristics of the HGV domain. A framework is then proposed in section 2.6 followed by some potential analysis (section 2.7) and a conclusion and future directions in section 2.8.

2.3 Motivation for a framework in transport telematic services.

Various TTS specifications [FHA-US-DOT 2005, ITS-Japan 1999, McQueen and McQueen 1999] emphasize the importance of meeting users needs. For a user, a TTS may serve more than one purpose e.g. emergency call (Ecall) can be used to notify rescue unit in case of an accident or indicate the presence of
road network interruption to a dispatcher. Depending on the user and usage, each TTS may offer more than one possibility. In addition the availability of one service to a user influences the value derived from other services. TTSs value and hence benefit thus depends on the usage. A framework for evaluating TTASs requires the identification of stakeholders and their objectives together with system functionalities (Verweij et al., 1995). Such objectives can help to identify intended usage which can be classified in terms of the domain of application such as driver support, vehicle management etc where each domain is supported by a number of services in providing different solutions. The user and usage domain relationships addresses how each stakeholder relate and interact with other stakeholders in a transport chain, the services and their users describe different interesting deployment possibilities while the functionalities and services specify possible system design options, see Figure 2.1.

Under ideal conditions a good service should be flexible enough to meet possible scenarios of its usability. Due to limited resources it is difficult to achieve such services. Therefore understanding the different options of a service, value and benefits for different users and domains of usage is important to decide on which services to offer from an investment perspective, thus improving investment decisions by potential investors such as governments. Further the functionalities shared by various services can influence the platform for designing such services and thus provide an input to system designers. This work will focus on the services, users and usage domain in the context of HGV transport.

2.4 Framework analysis for transport telematic services, a review.

Since TTSs have seen a rapid growth in number and type over the previous decade, a number of schemes have been established in different regions to attempt formalization of services into common understandable categories (Bossom)
Several reasons exist for formalizing services. One reason is to achieve a holistic view that provides a common operational picture in order to improve the efficiency of traffic and transport management activities (Robert and Simon, 2006), hence improving investment decisions for services that will effectively address such issues. The transportation of goods using HGVs involves a wide range of actors with different needs giving room for such scenarios as one truck making an equivalent distance in exactly the opposite direction where another truck is heading to pick up a package due to prevailing business structures. In the first half of 2006, of 79 million tons goods that were transported by 55779 Swedish registered HGVs, 22% was empty mileage accounting for about 145 million traffic work done on empty mileage (Sika, 2006). Such operations amount to significant losses to society. Implementation of TTASs has the potential to increase economic benefits and re-organise logistic structures (TR-1103-CODE, 1999). To address these concerns, services have targeted key segments of transport operations such as driver, vehicle, goods, road infrastructure, and back office activities (FHA-US-DOT, 2005; ITS-Japan, 1999). Interest on the vehicle side for TTSs is seen to come from the automotive industry in the area of driver assistance anti-collision avoidance, monitoring of fuel consumption and emergency assistance which have all been demonstrated in different ways (TR-1103-CODE, 1999). Intelligent speed adaptation has also been widely researched and even considered for it suitability as a platform for hosting a collection TTSs (Kenis and Wils, 2003). On the infrastructure side attention is given to route network utilisation, special infrastructure utilization such as bridges (Kulmala et al., 2008) and several techniques have been developed for improving the management of infrastructure and networks e.g. monitoring traffic and detecting incidents, network visualization (Robert and Simon, 2006; TR-1103-CODE, 1999) etc. TTSs are offered to users with different characteristics of interaction compared to interactions between systems e.g. that two systems providing two or more services can technically allow information exchange is not sufficient that the users of the services are willing to exchange such information. Thus, making it necessary to study the effects of different TTSs on different users e.g. individuals (drivers), commercial companies, Governmental agents and TSPs (TR-1103-CODE, 1999). At the operational level, most services in Europe are targeted toward real time or dynamic activities such as track and trace of goods under transport (Kulmala et al., 2008). At the tactical level data is collected and archived for improved decision making related to planning activities while at the strategic level investment decisions are addressed through services that collect and store data on a long term basis (Kulmala et al., 2008).

The resulting TTSs addressing the above issues are numerous and to avoid the risks of redundancies and achieve a common operational picture, the International
Standard Organization (ISO) has provided a set of standards at different levels to be followed ([ISO/TR-14813-1a 2007] [ISO/TR-14813-1b 1999]). In spite of these there still exist different approaches to formalising and classifying services that hinder analysis approaches for assessing service performance. 33 TTSs have been identified and categorize into service bundles based on the problem addressed as well as the technology (FHA-US-DOT 2005). Categories includes travel and traffic management, public transportation management, electronic payment, commercial vehicle operations, emergency management, advanced vehicle safety systems, information management and, maintenance and construction management. The aim has been to develop a TTSs repository and hence the framework is less helpful from an analysis point of view. In another case TTSs have been categorized based on functional characteristics to facilitate the design of the system (Bossom et al. 2004). Categories considered included demand management, traffic operation and control, travel and traffic information services, tolling, electronic payment and booking, collective transport systems, commercial vehicle operations and advanced vehicle safety systems. Development area/application domain of the service has been used to categorize services in (ITS-Japan 1999). Some 22 TTS are characterized into 9 development area/application domain. All 22 TTS are then systematically decomposed into 172 sub-services to support implementation work. Further 32 TTSs have been identified and classified into 8 categories including traffic management, traveler information, vehicle, commercial vehicle, public transport, safety, emergency, electronic payment (ISO/TR-14813-1b 1999). This has been extended in the new ISO ITS taxonomy of TTSs to 11 categories adding freight transport, weather and environment conditions, disaster response management and coordination, and national security (PIARC 2004).

In the above schemes no detail approaches were suggested that enables analysis (with the exception of [ITS-Japan 1999]) e.g. of benefits associated to different users. Transport of goods by HGVs merits consideration for several reasons e.g. frequent boarder transit, high infrastructure impact etc. While all these issues are not explicitly addressed in this study some inputs for TTSs analysis involving users and usage domains is provided e.g. benefits analysis.

2.5 Operational characteristics of Heavy Goods Vehicle Transport domains and transport telematic services.

The technical interoperability between services is not the same as the interoperability between transport actors. Thus to understand dependencies between different stakeholders including their usage of TTSs and how these may influ-
ence interactions between services, the following important operational domains in HGV transactions needs to be considered.

A. Driver Support: This category of services is important with respect to the needs of drivers e.g. planning and execution of a transport operation, safety etc. The overall aim is to improve driving operations including driver safety and also to minimise other traffic risks connected to driver activities. Existing advanced control systems, for driver support are mostly locally implemented in the car e.g. cruise control systems, collisions warning etc. Yet a number of TTSs require positioning functionality modelled externally from local vehicle systems. Services related to navigation, delays, road information etc all require positioning.

B. Administrative Support: These are supporting activities such as staff management, education, organizational welfare etc. Staff might be the most critical resource of most enterprises. Management of mobile personal is a lot more delicate than staff operating on site. The area of administrative support includes planning, supervising, documentation, follow up and other tasks, involving commercial, legal and salary issues that are vital for several demand groups. Most of the work in this domain can be considered as back office and plays an important role in enabling transport operational activities.

C. Fleet Management: Vehicles constitute an important resource for commercial transport companies. Good management strategies of HGV fleet are vital for the competitiveness of a transport company. Fleet management has an impact on revenues, costs as well as efficiency of the operations. With many services addressing the performance of a HGV as an entity, it is important to consider services that address overall performance of a fleet. There are several benefits that maybe realised through fleet management services e.g. efficient dispatch of fleet to meet customer needs, improve response time to driver and staff etc.

D. Transport Management: Transport management, covers services which directly address activities that take place in moving goods from one point to another. They constitute the core activities of transportation. Such activities includes locating and picking up the right packages, assigning vehicles to packages, reducing empty mileage etc

E. Traffic Management: These are services with as aim to improve the overall traffic flow in various ways. Major emphasis is made on traffic safety as well as mobility. This category is important because efficient traffic flow is not only important for traffic planners but affects the rest of the traffic actors. Thus, key services provide advisory measures (recommendations) to traffic planners and road users or in some cases corrective measures (interventions).

F. Infrastructure Management: Road infrastructure cost is high both economically and environmentally. Further, depreciation of existing infrastructure and the utility gains can be influenced by the utilisation efficiency. Thus, TTSs that address how to maximise the utility of these infrastructure as well as sustain
their availability will be considered in this category.

G. Environmental Management: Road transport constitutes a significant portion to environmental problems including emissions. In addition road construction significantly deforms earth surface structures. Therefore services aimed at improving the utilisation of existing route infrastructure and reducing emissions from vehicles are important to consider.

2.6 Transport telematic Services, a proposed framework

Large amount of data is generated in the transportation of goods by HGVs. The data can be about the vehicle, goods, road, traffic conditions or environment. The data is used for monitoring transport operations before, during and after an operation by different transport stakeholders. The data itself is of less value and often information resulting from the data is of interest and is provided in real time as TTSs to stakeholders involved in transportation. One way of developing TTSs is by studying problems stakeholders face under transportation and addressing these with appropriate TTSs. The nomenclature for TTSs isn’t standard but in most cases reflects the problem addressed by the service e.g. intelligent speed adaptation. In other cases names are used to reflect the technology e.g. geofencing etc. To each service is attached a service label which should be unique to avoid confusion with other services. Different names may be used in different regions targeting the same type of problem due to cultural and policy differences e.g. electronic toll collection service as in Japan, road user charging service as in Sweden both target the charging and collection of road fares etc. Such ambiguity maybe minimized by focusing on the usage of the service rather than the technology.

<table>
<thead>
<tr>
<th>TTS Label</th>
<th>Needs</th>
<th>Functionalities</th>
<th>Users</th>
<th>Options</th>
<th>User Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of TTS, unique and reflect usage</td>
<td>Problem addressed by TTS</td>
<td>Possible functionalities for developing TTS</td>
<td>Primary users of TTS</td>
<td>TTS options based on targetd primary users</td>
<td>Operational areas of usage of TTS within road transport</td>
</tr>
</tbody>
</table>

Table 2.1: A Framework structure for TTS

The needs of a TTS are closely related to the users and usability. Information
about users and usability can help to analyze the impacts of a service to society and assess the effectiveness of transport solutions provided by such services. Each TTS option can therefore be identified from its usage. Table 2.1 provides important aspects of a TTS potentially useful for analyses e.g. benefits analysis, impact analysis, architecture design analysis etc.

If TTSs can be described based on the proposed framework, their influence on transport stakeholders e.g. drivers, traffic controllers, and dispatchers can be analyzed. Within the project Mobil IT relevant TTSs for HGVs, were identified. Following the framework proposed above these services are presented with focus on user-options-user domains (table 2.2).

<table>
<thead>
<tr>
<th>TTS Label</th>
<th>Users</th>
<th>Options</th>
<th>User Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road User Charging</td>
<td>Drivers, billing agent, road infrastructure providers</td>
<td>Data processed by billing agent (thin client) or at driver terminal (thick client)</td>
<td>F</td>
</tr>
<tr>
<td>E-call</td>
<td>Drivers, road traffic inspectors, rescue agents, accident statistic agents, local authorities and goods owners</td>
<td>Ecall as network intervention report, Ecall detail report</td>
<td>A, D, E</td>
</tr>
<tr>
<td>Navigation</td>
<td>Drivers</td>
<td>Static, Dynamic</td>
<td>A, G</td>
</tr>
<tr>
<td>Weight Indicator</td>
<td>Drivers, bridge infrastructure providers, goods owners</td>
<td>Goods only, Total weight</td>
<td>A, E</td>
</tr>
<tr>
<td>Intelligent Speed Adaptation</td>
<td>Drivers, traffic inspectors, police dispatchers, insurance companies</td>
<td>Enforcement possibility, recommendation possibility</td>
<td>A, E</td>
</tr>
<tr>
<td>Accident Reporting</td>
<td>Drivers, traffic inspectors, police, dispatchers, accident statistic agents</td>
<td>Detail information, Statistically (interruption)</td>
<td>A, D, E</td>
</tr>
<tr>
<td>Automatic Driver Logs</td>
<td>Drivers, police, staff or personnel managers</td>
<td></td>
<td>A, B</td>
</tr>
<tr>
<td>Staff Monitoring</td>
<td>Commercial Fleet operators</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Transport Resource Optimization</td>
<td>Commercial Fleet operators, road infrastructure providers</td>
<td>Fleet Scheduling, Road utilization, Driver planning</td>
<td>B, C, F</td>
</tr>
<tr>
<td>Vehicle Follow-up</td>
<td>Dispatchers, HGV fleet owners and operators</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Remote Monitoring</td>
<td>Dispatchers, vehicle fleet owners</td>
<td>Fault prediction, Fault detection and repair</td>
<td>C</td>
</tr>
<tr>
<td>TTS table</td>
<td>Users</td>
<td>Options</td>
<td>User Domain</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------------------------------</td>
<td>---------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Goods Identification</td>
<td>Customs, good owners, terminal operators</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Real Time Track and Trace</td>
<td>HGV fleet operators, police, goods owners</td>
<td></td>
<td>C, D, E</td>
</tr>
<tr>
<td>Sensitive Goods Monitoring</td>
<td>Goods owners, Goods quality control inspectors, customs</td>
<td>Dangerous goods only, All goods</td>
<td>D</td>
</tr>
<tr>
<td>Traffic Information</td>
<td>Traffic controllers, drivers, dispatchers, road and bridge infrastructure owners</td>
<td>Prognosis, Real time</td>
<td>E</td>
</tr>
<tr>
<td>Route Guidance</td>
<td>Drivers, drivers in transits, intervention units e.g. police, emergency</td>
<td>In transits, non-transit, sensitive segments</td>
<td>E, G</td>
</tr>
<tr>
<td>Theft Alarm</td>
<td>Vehicle fleet owners, drivers, good owners, police</td>
<td></td>
<td>A, C, D</td>
</tr>
<tr>
<td>Geo-Fencing</td>
<td>Vehicle fleet owners, infrastructure owners, gate operators, vehicle parking operators, loading/unloading units</td>
<td>Mobile, Corridors and gates</td>
<td>C, D, F</td>
</tr>
<tr>
<td>Transport Order Handling</td>
<td>Dispatchers, good owners, drivers</td>
<td></td>
<td>B, D</td>
</tr>
<tr>
<td>Pay as You Drive</td>
<td>Insurance companies, vehicle fleet owners, environmental controllers</td>
<td></td>
<td>E, G</td>
</tr>
<tr>
<td>Variable Speed Limit Road Signs</td>
<td>Traffic controllers, police</td>
<td>Report speed violations, Determine speed limit</td>
<td>E, F</td>
</tr>
<tr>
<td>Driver Planning</td>
<td>Dispatchers</td>
<td></td>
<td>B</td>
</tr>
</tbody>
</table>

Table 2.2: Relevant TTSs for HGV Transport (KEY: A-Driver support, B-Administrative support, C-Fleet management, D-Transport management, E-Traffic management, F-Infrastructure management, G-Environmental management). No options for empty cells.

2.7 Potential analysis

By expressing services as in the framework above, one potential analysis is to identify and quantify the benefits of different services for different users. (see figure 2.2). Identification of potential benefits is a preliminary step in evaluating...
the impact of services on society such as reduction in accidents, driving distance, time etc on HGV units.

Figure 2.2: Example of analysis relating services, users and potential benefits.

2.8 Conclusions and Future Work

This article has conducted a qualitative study to point out the need for a framework in the analysis of TTSs. For organizations faced with investment decisions such as governmental agents, there is a need for a common operational view on transport processes and how to improve such processes with the help of TTSs. A framework provides a preliminary step into supporting high level analysis of services that support investment decisions. One such framework has been proposed and illustrated, and TTSs identified and classified within the context of the Swedish HGV transport. In the future, this framework can be validated through various analyses of TTSs following suggestions presented in the framework.
2.9 References


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Chapter 3

Paper II - Method for Quantitative Valuation of Road Freight Transport Telematic Services

While there is an increasing deployment of telematic services that support private, non-commercial road users (drivers and passengers), there are few existing services today that meet the needs of Heavy Goods Vehicle (HGV) transport. This article describes Transport Telematic Services (TTSs) for road-based HGV transport and suggests a method for assessing quantified societal value of different TTSs. For decision making related to the selection of services to promote by potential investors, e.g. governmental organizations and service providers, quantified service value can simplify the decision process by enabling comparison between TTSs. Furthermore, these values can serve as inputs to quantitative analysis of service architectural system designs. We suggest a method for assessing the societal values of TTSs using Potential Saving Indicators (PSIs), which we estimated in the context of the Swedish HGV freight transport. Based on the proposed approach, 32 services are discussed, and their societal values quantified and compared for the Swedish HGV market. Results indicate the following HGV-based TTSs to be of high societal potential: transport resource optimization, theft alarm and recovery, road hindrance warning, accident warning, navigation, eCall, intelligent speed adaptation, en-route driver information, transport order handling, sensitive goods monitoring and road user charging.
3.1 Introduction

While there is an increasing deployment of services that support private, non-commercial road users (drivers and passengers), there are few existing services today that meet the needs of Heavy Goods Vehicle (HGV) transport. Faced with rapidly increasing road cargo, commercial road freight industry is experiencing several challenges (e.g. improved resource utilisation), that makes it necessary to channel potential opportunities from telematic applications. Telematic systems have the potential to significantly improve road freight transport using HGVs by reducing negative societal effects like emissions, congestion and accidents. This article describes Transport Telematic Services (TTS) for road-based HGV transport, most of which were identified in the Mobile IT project (MOBILE IT, 2009). A previous study was carried out within Mobil IT project to identify TTSs with a potential connection to the anticipated Swedish Road user charging system (Mbiydzenyuy et al., 2008). Thereafter, a framework was developed (Clemedtson et al., 2008; Mbiydzenyuy(a), 2009) to help analyze the services. To conduct quantitative analysis such as optimization and simulation, it is important that the value of a TTS is quantified.

Different TTSs aim at addressing one or several different but related issues associated with freight transport, such as emissions, congestion, accidents, fuel consumption, and infrastructure maintenance. Consequently, there is a need to conduct a generic level analysis in order to compare different TTSs and support decision making related to the selection of services to promote by potential investors, e.g. governmental organizations, service providers. We use criteria established in previous studies (Clemedtson et al., 2008; Mbiydzenyuy(a), 2009) to characterize TTSs (Mbiydzenyuy et al., 2008). The purpose is to develop a systematic approach for quantifying the societal values (valuation) of TTSs. A TTS can be specified following a range of general to specific dimensions, i.e. motivation, user domain, users, functionalities, value and performance based Quality of Service (QoS) (Mbiydzenyuy(a), 2009). The value of a TTS is assessed by the extent to which each TTS can reduce the cost of identified Potential Saving Indicators (PSIs), e.g. accidents, emissions, noise. In addition to providing decision support, quantitative values can increase public acceptance of a TTSs. Furthermore, an important purpose of putting values on TTSs is to be able to evaluate the benefits of the different application design alternatives or system platforms.

The main advantage of a generic approach for analyzing different TTS is for identifying potentially beneficial TTSs in order to deploy on system platforms based on their functional characteristics. System platforms that can result in several applications have received attention from both the private and public sectors such including work done in Kanoshima and Hatakenaka (2008), MOBILE IT (2009). Additionally, several different research projects, such as the Swedish
project Mobile Networks (MOBILE NET, 2006), Mobil IT (MOBILE IT, 2009), HeavyRoute (HEAVYROUTE(a), 2010) etc, have addressed different aspects related to system platforms. Our study contributes to research on methods for valuating applications for common system platforms based on potential societal benefits. We suggest nine PSIs related to HGV transport in Sweden for studying the societal effects of a TTS and we estimate the total annual costs for each of the PSIs. These PSIs are then used together with estimated percentage changes to obtain quantitative values of different TTSs. Section 3.2 presents a short review of work related to the valuation of services, section 3.3 proposed an assessment criteria for valuating TTS, section 3.4 presents Potential Saving Indicators, section 3.5 discuss the different services considered in the study while section 3.6 present the results, and section 3.7 some conclusions and discussions.

3.2 Service Valuation: Related Approaches

Generally services can be valued from two major perspectives, both connected to the service quality. On one hand, value based on subjective user perception (Parasuraman SERVQUAL method) (Parasuraman et al., 1988), whereby a user of a service provides subjective information about how much a service is worth to them depending on the utility derived from the service. On the other hand, value based on what a service can achieve as a result of its functionalities and performance, the so called Grnroos approach (Grönnroos, 1984). Both these methods have been widely used for studying the QoS generating value for business services in a customer relations context. Such services differ from TTSs in many ways, for instance, TTSs are highly dependent on and can be improved through system performance (Li and Liu, 2004), while customer relation services are dominated by the process of service delivery (Parasuraman et al., 1988). The Grönroos based approach (performance based) may not necessarily accurately represent the users utility and may not directly support quantitative analysis. However, from a societal perspective, a performance-based service valuation can be helpful in assessing the societal value of TTSs. We consider value in the context of TTS performance capability to reduce PSIs. There are a number of measures used in investment analysis, for instance Net Present Value (NPV) (discounting payments to present times) and return on investment measure, i.e. what is the gain (or loss) in relation to invested capital. We aim for an approximation of the yearly benefits i.e. we are interested in the yearly positive value. However, we allow for compensation in case one service takes a significantly longer time to achieve positive effects than another by discounting (by the number of years it takes to materialize), hence the associated yearly value is computed as

\[
V = \frac{V}{(1 + R)^t}
\]

(3.2.1)
Where \( V \) is the estimated societal value of the TTS, \( R \) denotes the interest rate and \( t \) the number of years it takes for the application to start producing some positive benefit. The equation (3.2.1) is based on the assumption that once a TTS starts to generate value, such a value remains constant over the years. This assumption then allows us to use the value generated by a service in the first year in comparison with other services. The time component of equation (3.2.1) is the year when this value begins and may be different for different services. The value of a service may vary from year to year, in which case the NPV should be considered. For the purpose of this study, we simplify the NPV by limiting it only to an average expected value when a TTS generates value. Similar approaches to NPV have been used for assessing, analyzing and prioritizing transport investments projects (including ITS) for governments (SRA, 1997). Our approach is similar to Grnroos performance-based QoS in that we are using different attributes to estimate the value of a TTS. The value \( V \), is the reduction of some societal cost based on system performance. Since we focused on establishing the value of the TTSs in order to compare them, we argue that a performance-based approach will be more consistent than for instance Willingness-To-Pay.

### 3.3 A Set of Criteria for Assessing Transport Telematic Services

A systematic analysis for TTSs and their potential economic value requires some criterion or criteria because the impacts of TTSs are seen in a number of diverse indicators. A complete specification that will take into account TTS benefits will need to include dimensions such as technology costs, functionality and QoS components for each TTS. PSIs such as fuel costs, distance-based costs, time-based costs etc are discussed (section 3.4) and the social costs estimated. PSIs of different TTSs are estimated for each of these indicators and the value assessed by estimating the percentage reduction of each PSI, obtaining the total reduction for all PSIs by a given service with the assumption that a certain level of service penetration is attained. Furthermore, the model considers how to estimate the decrease in marginal benefits given that some TTSs can target a common PSI. Lets consider the following notation:

\[
S(D \subseteq S) \quad \text{Set of Services.} \\
P \quad \text{Set of PSIs.} \\
0 \leq T_i, i \in S \quad \text{Number of years to start to generate value.} \\
0 \leq \varepsilon \quad \text{Discounted interest rate.} \\
0 \leq P_k k \in P \quad \text{Value (societal costs) of PSI.}
\]
\[0 \leq \alpha_{ik}, i \in S, k \in P\] Potential percentage savings

\[0 \leq V_{ii}^*, i, \hat{i} \in S\] Pair wise value assessment considering dependencies between TTSs.

We now consider TTS value where TTSs are considered independent of any similar TTSs addressing a common PSI, \(V_i \in S\) based on (1) to be given by:

\[V_i = \frac{1}{(1 + \varepsilon)T_i} \sum_{k \in P} P_k * \alpha_{ik}, i \in S\] (3.3.1)

Then the value for two TTSs \((i, \hat{i} \in S\) can be given by

\[V_{ii}^* = \frac{1}{(1 + \varepsilon)T_{ii}} \sum_{k \in P} P_k * (\alpha_{ik} + \alpha_{i\hat{k}} - \alpha_{ik} * \alpha_{i\hat{k}})\] \(i, \hat{i} \in S\) (3.3.2)

\[V_{ii}^* = V_i + V_{\hat{i}} - \frac{1}{(1 + \varepsilon)T_{ii}} \sum_{k \in P} P_k * \alpha_{ik} * \alpha_{i\hat{k}}, i, \hat{i} \in S\] (3.3.3)

where \(T_{ii}\) denotes the average time for services \(i, \hat{i} \in S\). From above, the last term of equation (3.3.3) determines the pairwise dependency between any two services \(i, \hat{i}\) whose values are obtained as in (1). This is due to the expected decrease in marginal benefits of two services that address a common issue. Equation (3.3.3) can estimate dependencies between two TTSs (pairwise) for a given number of PSIs. To estimate the dependencies for a set of more than two TTSs (\(D\)), it is necessary to consider a generalized form of equation (3.3.3):

\[V_D^* = \frac{1}{(1 + \varepsilon)T_D} \sum_{k \in P} \left[\left(\sum_{d \subseteq D} (-1)^{d+1} \prod_{i \in d} \alpha_{ik}\right)\right] \] (3.3.4)

The value of \(T_D\) is an approximation since each TTS will have a different discount factor. The saving assessment for each TTS (corresponding to \(0 \leq \alpha_{ik} \leq 1, i \in S, k \in P\) in the above equations (equations (3.3.1) to (3.3.4))) takes into account results reported from various TTSs implemented around the world. There have been many field operational tests for different applications (as in \(\text{Rakhal et al. (2003); SRA (2009)}\)), but most results are not reported in concrete terms that could directly be transferred to other studies. Most of the applications achieving these savings are implemented for road transport including both commercial vehicle transport and private cars. In addition, the degree to which each transport system is improved by TTSs depends on the prevailing conditions of the transport system before the service was implemented.
3.4 Potential Saving Indicator (PSI) Calculations for Valuation of Transport Telematic Services

We have chosen to assess the values of services by connecting the effects of a service to a set of areas (attributes) where, potentially, resources can be saved or some costs reduced and thereby generate societal value. High level societal attributes related to fuel, vehicle and road maintenance, administration costs, accidents, noise, congestion, and emissions contribute to different types of transport costs (SARH 2008) and, hence, incur a loss to society. We suggest the following general PSIs:

3.4.1 Fuel costs

This PSI measures the costs of fuel excluding Value Added Tax (VAT) and constitutes a large share of HGV operational costs (Aspholmer 2006). According to the current fuel pricing mechanism in Sweden, this cost (assumed to be 1€ per litre in this study) also includes external costs of CO2 emissions. Therefore in calculating other externalities we have exempted CO2 emissions costs. Fuel consumption depends on several factors such as weather, road topology, tire pressure, vehicles total weight, engine type, and speed, making it difficult to estimate consumption per Vehicle Kilometre (VKM). Different studies have suggested the following values: 0.43 l/VKM (Hammarström and Yahya 2000), 0.52 l/VKM (Aspholmer 2006) and 0.5 l/VKM (Björnfot 2006). Assuming that 2.875 €/10VKM (Aspholmer 2006) is the average cost of fuel consumption for an average loaded HGV (which was 15.2 tons in 2008), and that the 66846 Swedish registered HGVs with a total weight of at least 3.5 tons had a total mileage of 2.9 billion KM on Swedish roads in 2008 (SIKA 2008), we get the total cost associated with fuel consumption for 2008 is 0.287*2.9 = 0.612 billion €.

3.4.2 Distance-based costs

This PSI is estimated based on a vehicles vehicle depreciation and maintenance. A study suggests the variable costs of road transport to be 46.52/10VKM (Aspholmer 2006). This cost includes fuel (2.875€/10VKM), vehicle depreciation (0.421€/VKM), tyres (0.379€/VKM), and vehicle maintenance including servicing (0.977€/10VKM). The total mileage of 2.9 Billion KM in 2008 will correspond to a Km cost (excluding fuel) = (4.652 - 2.875)*€/VKM = 1.770€/10VKM = 0.177€/KM resulting in a total distance cost of 0.290 * 1.770 billion €= 0.513 billion €

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3.4.3 Time-based costs

This involves costs for driver and vehicle time during, driving including activities such as loading and unloading. The main cost is the drivers salary estimated at 17.5 €/hour including retirement and insurance benefits (Aspholmer, 2006). Congestion also contributes to time-based costs. In 2008, the average speed for HGVs in Sweden was assumed to be 70KM/Hour (Mikhailov and Tsvetinov, 2004), which could be lower if loading and unloading time are taken into consideration, and hence the number of hours will be much more than suggested below. Time-based costs for the vehicle have been ignored. Hence corresponding time is

\[ \text{Distance}/\text{Speed} = \frac{2.9 \text{ BillionKM}}{70 \text{KM/Hour}} = 41.43 \text{ million hours} \]

resulting in a total driver costs = 41.43million * 17.5 € = 0.725 billion €

3.4.4 Transport administration

Transport administration has been calculated to cost 7.5€ per driver hour in Sweden (Aspholmer, 2006). Assuming this value is an average cost for all hauler companies, the total costs resulting from this will depend on the total number of driver hours driven given by average speed/total distance = 2.9 billion KM/70KM/hour =41.429 million hours. With cost per hour = 7.5 €, we have a total costs = 41.429 * 7.5 = 0.311 billion €

3.4.5 Accidents

Costs of accidents are considered to include severely and slightly injured persons in road traffic that were hospitalized or died as a result. HGV-related road accidents in Sweden during 2009 resulted in 87 dead and 1953 severe and serious injuries (Åsa., 2009). A total of 9500 people were hospitalized for at least one day as a result of road traffic accidents in 2008, costing the hospitals 69 million € in total (Åsa., 2009; Sika, 2006). This is underestimated because the secondary effects of such accidents such as job loss to the individual involved are not taken into consideration. Assuming a similar average cost structure in 2009 as in 2008 with statistical life as 2.15 million € (Jonsson, 2005), i.e. (69 million €)/9500=7663.16 €, the total costs of injury (HGV only) = 7663.16 €* 1953 = 0.014 billion € and cost of deaths = 21.5 * 87 =187.05 million € resulting to a total costs of all accidents = 0.201 billion €.

3.4.6 Infrastructure maintenance costs

This PSI attempts to assess the costs associated with infrastructure maintenance such as roads, bridges and tunnels. This is usually considered as the cost of wear and tear and has been estimated to be 1.15 €/100VKM for private cars with
depreciation 50 years (Fridtjof, 2003). Considering that HGVs produce twice as much effect on road depreciation as private cars, we approximate cost for HGVs to be 2.3 €/100VKM. Hence, for total distance 2.9 billion (2008) and cost of maintenance per VKM = 0.023 €, we get a total cost = 2.9 * 0.023 = 0.067 billion € which is 17% of the total road maintenance cost reported by the SRA in 2008 (398.1) million € (SRA, 2008).

3.4.7 Noise and related external costs

This PSI estimates the societal costs related to external effects excluding CO2 emissions (considered to be included in fuel costs in Sweden) e.g. particle emissions estimated at 0.033€/VKM and 0.110 €/VKM (in urban areas and cities respectively (Johansson, 2007) for trucks weighing at least 3.5 tons) and cost of noise estimated at 0.0398€/VKM (SIKA, 2003). Hence, with total driven KM for all vehicles on city roads = 22 Billion KM and total driven KM for all vehicles on all roads = 52 Billion KM, we estimate the ratio of driven KM on city roads to total driven KM on all roads in 2008 = 22/52 = 0.42. Using this % for HGVs we get 0.42X2.9 Billion = 1.23 billion KM. Thus HGV external environmental costs excluding CO2 in cities = 1.23 billion KM*0.110€/VKM = 0.1353 Billion €. Driven distance in areas other than city roads = (2.9-1.23) billion KM = 1.67 billion KM Resulting to emission costs of 1.67 billion * 0.033 €=0.55 billion €. With the total costs of noise = 2.9 billion*0.0398 €/VKM = 0.11542 billion €, we get the total costs of noise and related external costs = 0.1353 Billion € + 0.05511 billion € + 0.11542 billion € = 0.306 billion €.

3.4.8 Building of new infrastructure

This PSI is aimed at estimating costs of infrastructure expansion and related external costs, e.g. population displacement. TTSs can potentially influence the utilization of road infrastructure and other resources such that physical expansion of infrastructure is minimized. The SRA calculates the building of new road infrastructure and associated annual costs to be 913.3 million € and 982.6 million € for 2007 and 2008 respectively (SRA, 2008). Thus we can approximate an annual costs of building new roads to be about 970.5 million € per year. With a utilization level for HGV of 42% we calculate the corresponding demand on new infrastructure for HGVs as 0.42*970.5 million € = 407.64 million € = 0.408 billion €.

3.4.9 Costs of missing and delayed goods

Theft cases involving HGVs reported in Sweden went down in 2008 to 2140 cases compared to 2377 cases in 2007 (Nilsson and Rosberg, 2008) and related costs
were estimated for HGV in 2008 at 0.2435 billion € in Sweden (Gustafsson et al., 2009), including secondary effects such as the value of goods and possible costs as results of business obstructions. Cost of crimes in 2008 in Sweden was estimated at over 0.1 billion €, allocating a theft value of 47 million € and incremental costs of 58.4 million € with an additional 0.14 billion € that accounted for customer aspects and marketing costs. Thus we approximate total cost of HGV-related theft at 0.24 billion €(0.1 billion €+ 0.14 billion €), especially as the study did not cover all of Sweden. Furthermore, HGV can accumulate for about 100 short delays of up to 15 minutes each which add costs (Lind et al., 2007). While most of these are associated to traffic conditions (congestion), about 20-30% are assessed to be related to other aspects, such as weather conditions, accounting for an estimated cost of 3.5 million € excluding loading and unloading costs (Lind et al., 2007). Therefore we assess a total costs associated to theft and delays = 0.244 billion €(0.24 billion €+ 3.5 million €)

![Cost Distribution of different indicators](image)

Figure 3.1: Results of cost distribution for PSIs as a relative percentage

The different PSIs calculated above can be summarized as in figure 3.1. In a related work that uses simulation to calculate HGV cost distribution for the HeavyRoute project (HEAVYROUTE(b), 2010), we observe that there are significant differences in time-based costs 45% for the HeavyRoute project compared to the 22% estimate in this study. This is partly due to the distribution of cost functions as this study considered the costs of infrastructure expansion, transport administration and the costs of missing and delayed goods which were not separately considered in HeavyRoute. On the other hand, climate cost is considered as a separate cost function by HeavyRoute, which we considered as fuel (CO2).
3.5 Potential Road Freight Transport Telematic Services

We discuss TTSs in the context of vehicles, goods, drivers, owners, infrastructure and other stakeholders that in one way or another contribute to road transport operations, with some already existing and others proposed within the Mobile IT project.

<table>
<thead>
<tr>
<th>TTS</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWI</td>
<td>Accident Warning Information will disseminate accident information to nearby vehicles to enable informed decisions that will reduce the effect of accidents, e.g. queue build up, chain accidents, fire, rear end collisions (considered to make up to 13.5% of accidents in Sweden in 1999 (Biding and Lind, 2002)). Freeway incident warning systems have shown that travel times could be reduced by 21% (Shawn and Smadi, 2000) and fuel and delays by up to 3% and 7% respectively (Wunderlich et al., 1999).</td>
</tr>
<tr>
<td>ADL</td>
<td>Advanced Driver Logs is aimed at accurately recording various time-based activities for drivers and helping the driver to avoid influential driving due to external factors such as alcohol, which has been shown to account for up to 16% of driver accidents in 2008 (HEAVYROUTE(b), 2010).</td>
</tr>
<tr>
<td>DP</td>
<td>Driver planning will improve driver performance through planning by considering factors as time of day, route, vehicle, product, season, etc that suit individual drivers.</td>
</tr>
<tr>
<td>DTI</td>
<td>Dynamic Traffic Information service will provide real time traffic information and contribute to reducing costs related to delays, congestions etc (Eliasson, 2006).</td>
</tr>
<tr>
<td>EC</td>
<td>eCall is aimed at reducing the time taken to locate and rescue victims of an accident as well as the vehicle and its contents. Trials in Stockholm suggest the accident reduction potential to be between 5% and 15% (SRA, 2005).</td>
</tr>
<tr>
<td>ETM</td>
<td>Emission Testing and Mitigation for measuring environmental performance to support policy making.</td>
</tr>
<tr>
<td>EDI</td>
<td>En-Route Driver Information for specific route information to load/unload goods including communication with back office.</td>
</tr>
<tr>
<td>ETA</td>
<td>Estimated Time of Arrival for monitoring the current traffic situation and evaluating arrival time dynamically. Reliability inaccuracies may costs up to 2.2 € per vehicle trip (Leviakangas and Lahesmaa, 2002).</td>
</tr>
<tr>
<td>TTS</td>
<td>Explanation</td>
</tr>
<tr>
<td>-----</td>
<td>-------------</td>
</tr>
<tr>
<td>FM</td>
<td>Freight Mobility for communicating real time freight data between drivers, dispatchers, goods owners etc.</td>
</tr>
<tr>
<td>GEO</td>
<td>Geofencing for access control to specialized areas such as corridors, military areas, accident areas, parking areas, tunnels, etc without using any physical barriers</td>
</tr>
<tr>
<td>GI</td>
<td>Goods Identification to improve goods handling (loading/unloading, declaration etc) using contactless identification.</td>
</tr>
<tr>
<td>IRM</td>
<td>Information About Infrastructure Repair and Maintenance for providing real time information on the status and maintenance history of infrastructure, i.e. similar to preventive maintenance that has been considered to potentially reduce maintenance costs by 25% (Hammarström and Yahya 2000).</td>
</tr>
<tr>
<td>XXL</td>
<td>Information on the transportation of XXL cargo for drivers, public authorities and back office, including legal obligations.</td>
</tr>
<tr>
<td>ITP</td>
<td>Information on Truck Parking for providing parking information in real time to drivers and facility owners. Similar systems have been reported with about a 1% to 2% reduction in parking location time (Lindkvist et al. 2003) and 9% in travel time (SIAC 2007).</td>
</tr>
<tr>
<td>ISA</td>
<td>Intelligent Speed Adaptation for providing dynamic information about the current speed limit that could lead to a reduction in accidents and fuel consumption, with trial results in Sweden showing a reduction estimated to be 20% to 30% if all cars were equipped with an ISA system (SRA 2009).</td>
</tr>
<tr>
<td>NAV</td>
<td>Navigation Through a Route Network with the help of map information and HGV-relevant information that can reduce delays. NAV has contributed to reducing queue times and delays for previously unknown destinations up to 5% to 20% (Planath et al. 2003).</td>
</tr>
<tr>
<td>ODM</td>
<td>On-board Driver Monitoring for real time monitoring of driver conditions like health, and sending information to traffic and transport managers including rescue units. Accidents related to driver fatigue have been estimated at 15% in Sweden (Asa. 2009).</td>
</tr>
<tr>
<td>OSM</td>
<td>On-board Safety and Security Monitoring helps the driver to constantly monitor the vehicle and its contents without manual checks, e.g. temperature for refrigerated products.</td>
</tr>
<tr>
<td>PYD</td>
<td>Pay as You Drive for providing location related information to insurance companies to help reward excellent drivers and reinforce good driving. Studies show a reduction of 10% in mileage and fuel consumption and 15% in total crashes (Litman 2009).</td>
</tr>
<tr>
<td>Acronym</td>
<td>Explanation</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>TTS</td>
<td>Real Time Track &amp; Trace of Goods providing information such as speed, location and status of goods to good owners, transport managers, etc that can enable tracking such goods if necessary.</td>
</tr>
<tr>
<td>RTT</td>
<td>Remote Declaration for sending declaration information electronically at gates, control stations, loading/unloading stations, etc to reduce delays.</td>
</tr>
<tr>
<td>RED</td>
<td>Remote Monitoring to minimize costs related to vehicle breakdown through preventive maintenance.</td>
</tr>
<tr>
<td>RHW</td>
<td>Road Hindrance Warning information in real time and possible suggestions to avoid queues.</td>
</tr>
<tr>
<td>RUC</td>
<td>Road User Charging for collecting charges related to the use of road infrastructure based on location, time, road type and vehicle type similar to most systems anticipated in Europe (Kågeson and Dings [2000]). Trials have led to a reduction in traffic growth (5%), vehicle trips (8%), and empty trips (20%) (Elvika et al. [2007]), while congestion schemes in Stockholm have led to reduced traffic (10% to 15%), shorter queue time (30% to 50%), lower emissions (2.5%) and fewer accidents (5% to 10%). Broaddus and Gertz [2008] as well as 16% less congestion (Algers et al. [2006]).</td>
</tr>
<tr>
<td>RG</td>
<td>Route Guidance for information relevant to specific corridors related for instance to zebra crossing, school children, etc and also help infrastructure owners influence the use of a given route. Studies have shown a reduction in travel times under average congestion conditions for all vehicles (Wunderlich [1998]).</td>
</tr>
<tr>
<td>SGM</td>
<td>Sensitive Goods Monitoring for providing information about sensitive goods such as perishable food products, drugs and other goods classified as dangerous goods (about 0.32% of goods in Sweden [SCB, 2008]) to transport managers and government control units.</td>
</tr>
<tr>
<td>SM</td>
<td>Staff Monitoring for collecting information related to health, fatigue, etc about commercial transport company staff and for staff administration and control, e.g. by police, labour unions etc.</td>
</tr>
<tr>
<td>TAR</td>
<td>Theft Alarm and Recovery for real time location and status information about stolen goods and vehicle to goods owner, traffic and transport managers, etc.</td>
</tr>
<tr>
<td>TOH</td>
<td>Transport Order Handling for real time order information sharing between goods owner, transport manager, driver etc, as well as feedback when orders are satisfied.</td>
</tr>
</tbody>
</table>
TTS Explanation

TRO Transport Resource Optimization for optimization of overall resources including road infrastructure, vehicle capacities, vehicle trips, etc so that the optimization of subsystems (e.g. routing, driver planning) may not negatively affect other systems (e.g. road maintenance).

VF Vehicle Follow-up for collecting and analyzing vehicle performance-related data, e.g. empty mileage, fuel consumption, vehicle statues, etc, then reporting such data to different interested groups, e.g. fleet owners, vehicle inspection agencies, etc.

WI Weight Indication for sharing real time information about the vehicles total weight and the infrastructure conditions, road conditions and potential height restrictions with driver and infrastructure owners. Theoretical statistical analysis of weigh-in-motion at stations for HGVs in the UK shows a 36% potential time savings at gates, improved accuracy of weight information and shorter delay (Rakhal et al., 2003).

Table 3.1: Suggested TTSs Relevant for Freight Transport

3.6 Results of Transport Telematic Service Valuation

The proposed model (section ??) is implemented in an Excel spreadsheet and the value of each application assessed under the following conditions: (a) The values were calculated considering the costs of HGV transport in Sweden, (b) Focus was on the societal effects of HGV transport. Societal effects from other road users, such as private cars, motorcycles etc, were disregarded, (c) The time period for which services were considered to start generating the calculated values was one year for all services, (d) TTS values were based on suggested percentage reductions of PSIs (in section 3.2) according to authors perception of TTSs in section 3.4 (e) The dependencies between TTSs were assumed to be pairwise as in equation (3.3.2).
Table 3.2: Key to table 3.3 below

Based on these assumptions the results shown in Table 3.3 were obtained.

<table>
<thead>
<tr>
<th>Notation</th>
<th>PSI</th>
<th>PSI Value in M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Fuel Costs</td>
<td>612.00</td>
</tr>
<tr>
<td>P2</td>
<td>Distance based cost</td>
<td>513.30</td>
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<tr>
<td>P3</td>
<td>Time based costs</td>
<td>725.00</td>
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<td>P4</td>
<td>Transport administration Accidents</td>
<td>310.70</td>
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<tr>
<td>P5</td>
<td>Accidents</td>
<td>201.24</td>
</tr>
<tr>
<td>P6</td>
<td>Infrastructure maintenance costs</td>
<td>66.70</td>
</tr>
<tr>
<td>P7</td>
<td>Noise and related external costs</td>
<td>305.83</td>
</tr>
<tr>
<td>P8</td>
<td>Costs of building new infrastructure</td>
<td>407.64</td>
</tr>
<tr>
<td>P9</td>
<td>Costs of missing and delayed goods</td>
<td>243.5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>TTS</th>
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<td>0.001</td>
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<td></td>
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<td>0.001</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.89</td>
</tr>
</tbody>
</table>
Most of the studies seen above show that for PSIs that cover a large scope, percentage reductions are usually small (in the order of 0.01%), whereas trials that cover very narrow scopes typically report high percentage impacts. Since our PSI calculations were based on aggregated values, it was found necessary to consider correspondingly small percentage assessments as in table 3.3. For small percentage estimates, $0 \leq \alpha_{ik} \leq 0.15$ $i \in S, k \in P$, equation (3.3.3) can be approximated to equation (3.3.4) (see section 3.3) in estimating dependencies between TTSs e.g. For example, suppose that transport administration costs about 310 M€ per year in Sweden and can be reduced by EDI, GEO and GI with 0.001%, 0.002% and 0.003% respectively and interest rate 4%. From equation (3.3.3), estimated total benefits = 0.190 907907 M€, and from equation (3.3.4), estimated total benefits = 0.190 909075 M€, which can be approximated within an error of margin of less than 5%. Therefore, if the $\alpha$ values are relatively small then we can ignore higher order terms in equation (3.3.3) and hence approximate equation (3.3.4) with equation (3.3.3). The result of TTS societal valuation without dependencies is shown in figure 3.2 below:

<table>
<thead>
<tr>
<th>TTS</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
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<th>P6</th>
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</tr>
</tbody>
</table>

Table 3.3: An assessment of percentage savings and values (M€) of TTSs for HGV transport in Sweden
Where relevant in our assessment we referred to similar experimental results obtained in assessing potential savings of similar applications. The assessed values of the TTSs are obtained assuming each service is deployed independently of other TTSs. If the effects of other TTSs are taken into consideration, the above values will further decrease depending on the TTSs considered and the targeted PSIs e.g. suppose EC and ISA are implemented, each with the potential to reduce HGV-related accident cost by 15%. The resulting potential reduction will be $15\% + (100\%-15\%)\times15\% = 0.15 + (1-0.15)\times0.15 = 0.2775$ or $27.75\%$ and not $30\% = (15+15)\%$. Thus the dependency $\%$ of $2.25\%$ has to be reduced from the original value of both EC and ISA combined. While the proposed approach worked well for pairwise dependencies, we observed that it was complex for handling combinations with more than two services. The cumulative contribution of the above TTSs in reducing the societal costs for each of the PSIs shows that there is much room for applications targeted toward infrastructure costs, whereas accidents and time-based costs are most likely to experience significant impacts under the current situation (see figure 3.3).
3.7 Conclusion and future work

The purpose of this study was to use the criteria established in a previous study (Mbiydzenyuy(a), 2009) and characterize TTSs in such a way as to enable quantitative analysis that will support decision making in selecting TTSs for investment. In order to achieve this purpose, a method for assessing societal value of TTSs was proposed. The method uses identified PSIs and calculate their societal costs. Percentage savings potential of different services for various PSIs was suggested and used to assess the value of different TTSs. Pairwise dependency calculations were introduced to account for redundancies that maybe involved when two TTSs address a common PSI. It was shown that pairwise dependencies could be approximated to dependencies involving more than two TTSs. Results show that important TTSs with significantly high societal impacts are transport resource optimization, theft alarm and recovery, road hindrance warning, accident warning, navigation, eCall, intelligent speed adaptation, en-route driver information, transport order handling, sensitive goods monitoring and road user charging. The method is simple, straightforward, and useful for organizations such as governments and telematic service providers. Since suggested PSI values and utilized percentage effects for different services still need further validation, the results provided in this work are not conclusive and should be used with care. Assessed societal values also provide a valuable input to quantitative analysis of service benefits using methods such as optimization, Cost Benefit Analysis, etc. In the
future these values need to be improved, e.g. by obtaining better projections of service impacts and fine tuning the different parameters used in the model.
3.8 References


HEAVYROUTE(b) (2010). *Intelligent Route Guidance for Heavy Vehicles*. Deliverable 4.2, development path of HeavyRoute systems impact and socioeconomic consequences.


Chapter 4

Paper IV - Optimization
Analysis of Multi-Service
Architecture Concepts in
Road Transport Telematics

Transport telematic systems are expensive to implement but the services they provide may have great benefits. However, what services that the system can provide depends on the architectural choices made, which also affects the cost of the system. In order to make a more informed decision before investing in a multi-service transport telematic system, we propose an optimization model. The model evaluates the possible choices of services and architectures, and aims to maximize the total net societal benefits. The cost of necessary functionalities, and benefit of resulting road transport telematic services, given limited resources, makes it difficult to determine which services are beneficial for a given architectural choice. We argue that the optimization model can provide support for strategic decisions by highlighting the consequences of adopting different system architectures, including both societal value and cost. This can be useful for decision makers, such as, road administration agents, road transport telematic service providers, and commercial road freight transport operators.
4.1 Keywords

Transpor, Telematic, Services, Architecture, Evaluation, Modelling, Optimization, Integer Linear Programming.

4.2 Introduction

Transport Telematic Application Systems (TTASs) or Intelligent Transport Systems (ITS) are today considered a suitable approach for addressing surface transportation problems, e.g. reduction of road fatalities. The extent to which such problems are addressed can be considered in terms of the benefits of the resulting Transport Telematic Services (TTSs). TTSs can deliver important benefits, such as improved emergency response, reduced travel times and emissions. TTSs can co-exist on a TTAS. We view a TTAS as consisting of an architecture specification and the resulting TTSs. Several approaches have been used to address the benefits of individual TTSs, most notably Cost Benefits Analysis (CBA) despite many shortcomings that are associated to CBA (Bekiaris and Nakanishi 2004, Leviakangas and Lahesmaa 2002, Levine and S. 1996). Methods used in the assessments of transport systems are seen to be limited for the assessment of ITS systems (Brand 1999). Benefits of different applications can be influenced by the type of platform used for implementing applications. Examples of anticipated platforms are the European Electronic Tolling system based on Global Navigation Satellite System (GNSS), (Leinberger 2008) and the emergency call service platform (Ditz 2007). These platforms have the characteristic that many TTSs can be developed by an extension of existing functionalities. In such a situation, evaluation of TTSs will need to take into consideration the existence of other TTSs. Hence, the choice of a system influences the possibility of efficiently implementing TTSs. Further, the cost of functions, the benefits of TTSs, and limitation in resources, makes it difficult to determine a set of beneficial TTSs for a given architectural choice. Hence we use optimization to account for these trade-offs. In addition, for multiple TTSs sharing common functionalities, use of a CBA-based approach is limited because of the difficulty in capturing multi-dimensional synergy effects. The scarcity of good tools for benefit and cost evaluation of ITS systems is seen to be a hindrance for deployment of new ITS user services (Thill et al. 2004).

The purpose of this article is to develop an optimization model that can support strategic decisions about choices of investing in different conceptual TTAS architectures that support multiple services (Multi-Service Architectures (MSAs)). Using estimated values for TTSs benefits to society (Mbiydzenyuy et al. 2009) and the cost needed to realize such TTSs based on required functionalities, the choice of services to prioritize for implementation is modeled as
an optimization problem that maximizes societal benefits. The model supports the analysis of choices of MSAs, based on the choice of TTSs, and functionalities needed to achieve those TTSs. Results of the model consist of a selection of various TTSs and MSAs according to perceived net total societal benefits. While this work may not lead to answers surrounding the challenges that face the implementation of MSAs, it can provide support for high level decisions by highlighting the consequences of adopting given architectures, from a system perspective, including both societal benefit and cost. In the rest of this paper, sections 4.2.1, 4.3 and 4.4 respectively, provide definitions of key terms used, related work and a discussion of MSAs for TTSs. In sections 4.5, 4.6, 4.7 and 4.8 are a proposed optimization model, a case study that employs the proposed model, results and analysis, conclusions and future work, respectively.

4.2.1 Definition of terms

A. Functionalities
Functionalities are the basic properties that can be implemented in a system and, when combined together, can achieve a TTS, e.g. map matching, position coordinates. It is assumed that essential functionalities for achieving each TTS can be specified. Such functionalities can be used commonly by TTSs incurring different amount of costs.

B. Transport Telematic Service (TTS)
A Transport Telematic Service (TTS) consists of a product or activity, targeted to a specific type of ITS user, addressing given user needs (ISO/TR-14813-1a, 2007). A TTS is specified by its functionalities and provides value to society.

C. Multi Service Architectures (MSA)
This is considered as the conceptual specification of transport telematic system architecture. It is assumed that this is an open system consisting of several functionalities, and that it can potentially host multiple co-existing TTSs with different types of restrictions. The functionalities provided can be shared by different TTSs. We consider architecture functionalities as resources.

4.3 Related work

Evaluation of TTAS architectures is a subject of interest that has been addressed by many studies, such as [Pearman and Shires (1997); Persson et al. (2007); Taiying (2008); Wees and Hertzberger (2000)]. All these studies have been aimed at understanding the potential benefits of ITS systems using different methods.
evaluation studies, the approach employed (e.g. formative or summative) should depend on the goal behind the evaluation (McQueen and McQueen 1999). We differ from these existing approaches, in that we are looking at the benefits in the context of multiple applications, an aspect that has not been considered by most of the existing evaluation studies. A good evaluation approach can help distinguish between different conceptual architecture options and corresponding services in terms of associated benefits to society. Therefore, the task of evaluating such options is in principle, concerned with how to identify, quantify and compare for all alternatives, all impacts, on all people and organizations, in all affected areas, over all time (Bekiaris and Nakanishi 2004). However, in practice such an evaluation goal is optimistic due to the complexities involved, especially for MSAs. Thus, it is important to abstract conceptual architecture system characteristics for evaluation (Xu et al. 2006) to help understand the potential impacts of a real system.

Wees and Hertzberger (2000) uses discrete event based simulation to abstract and identify interacting components and states for ITS evaluation. Their work did not consider the evaluation of multiple co-existing services, as their tool was aimed at single service evaluation. Benefits of individual TTSs have been evaluated on the basis of indicators, such as traffic volume increase, emission decrease, system construction cost and vehicle equipment cost for Electronic Fee Collection (EFC) systems (Tai-ying, 2008). Their approach did not consider the potential use for studying other ITS applications. Models for specific indicators have been suggested, e.g. reliability model for ITS systems (Kabashkin, 2007). It remains to be demonstrated that these indicators can be used for modeling and evaluating other services that can potentially be implemented on EFC platforms. Candidate EFC systems have been evaluated based on charging accuracy, system costs and societal benefits, flexibility and modifiability, operational aspects, and security and privacy (Persson et al., 2007). The work by Persson et al. (2007) considers the support for multiple services (flexibility) and provides a qualitative evaluation of architecture concepts, but does not quantify such benefits. We assess MSAs according to quantified TTSs benefits and costs.

The use of optimization requires that TTSs be quantified. While many studies on the evaluation of TTSs have not quantified benefits, approaches based on the economic and goal evaluation methods have addressed the question of benefits quantification (Peng et al. 2000). Their study provided a framework for benefit assessment using benefit trees and other emerging methods of analysis for benefit studies. They observed that there is significant variation in the complexity and details of ITS evaluation methods. Such variation in evaluation approaches, and choice of criteria has partly been explained by the dependency on the end user of the evaluation results (Thill et al., 2004). As a consequence, most evaluation methods are based on very specific approaches, for specific end users, making it
hard to compare results on a general level. This issue has been partly addressed by [Thill et al. (2004)] using ITS Option Analysis Model-(ITSOAM) for forecasting the benefits of ITS elements and estimating the deployment cost. They addressed decisions related to system benefits, in which each ITS system should be considered separately and their benefits evaluated independently of each other. Our view about benefits differs from their study, since we consider such benefits to be context dependent e.g. on the given TTSs collection and on the given platform due to the common functionality usage.

In addition to the studies mentioned above, other studies addressing ITS evaluation e.g. [TransCORE (1998)]; [Weissenberger et al. (1995); Xu et al. (2006)] are diverse in the type of method used, e.g. multi-criteria analysis, analytic hierarchy process, benefit trees. How, and which of, these approaches may be suitable for the evaluation of platforms that can potentially host multiple services remains an open question. It is unclear how to formulate or apply any of these approaches to MSAs. The use of optimization models for evaluating TTAS architecture concepts, as advocated in this study, has not been explored so far. One reason could be related to the variation in the scope of ITS applications, resulting in commercial actors focusing on very specific applications. Furthermore, quantitative models could be very challenging from a data perspective [Levinson and Chang (2003)]. One way to manage data challenges is to conduct extensive sensitivity and break-even analysis when quantitative models are used [Peng et al. (2000)].

MSAs sharing functionalities with TTSs will result in synergies and improved benefits. Such synergies can be studied using CBA if all costs and benefits can be specified explicitly. However, two or several applications with synergies with an MSA also have synergies between themselves. Thus there are multiple dimensional synergies that are difficult to study using approaches based on CBA. Such complexities can be addressed using optimization.

### 4.4 Multi-Service architecture for transport telematic services

The concept of MSAs used in this work refers to the basic environment necessary for realizing different TTSs. This embodies the system architecture (software and hardware) and additional infrastructure. Architecture concepts employ different communication technologies, such as Dedicated Short Range Communication (DSRC), satellite base and, General Packet Radio Service (GPRS), each of which have implications on the processing system, e.g. more communication bandwidth implies increased data volume and, hence, increased demand on processing resources. To understand the differences between various architecture concepts, it is necessary to describe important features of ITS architectures that can help in
modelling potential MSAs.

4.4.1 Features of multi-service architectures

We consider that each specification of an architecture concept can support different functionalities for communication and processing of data. The following key functionalities are considered:

**Communication** ITS applications are based on data communication infrastructure either between vehicles or between vehicles and roadside infrastructure including back office.

- Two-way data communication
  Communication is in two directions, uplink and downlink. Depending on the type of communication network, the demand for transmission bandwidth will vary according to data type and signal features. For simple data communication, such as text collected through sensors, like temperature, weather, vehicle speed etc, bandwidth requirements are less demanding compared to video and audio data. Typical data communication can range from 0.5Kbps to 11Mbps (Fukang et al., 2008), and the amount of data generated per traffic camera can reach up to 16GB in one day (Esteve et al., 2006).

- Data broadcast
  Data broadcasting involves the transmission of data to multiple users simultaneously. All the different types of communication seen above can be transmitted to multiple users simultaneously, or to each user on request. Such communication in ITS applications is largely influenced by multimedia applications. Different ITS applications communicate data at different rates (Sheldon, 2001).

**Data processing** Another important feature of a MSA is how data is processed. We consider the following alternatives:

- On-Board Unit (OBU) data processing
  These are typically small computers fitted into vehicles, with the capability of limited data processing, graphical display, and storage. For ITS applications, depending on the desired purpose, it may be necessary to process application data onboard, especially in the situation of limited external communication. Different architecture concepts anticipate for different OBU designs and capabilities.
• Centralized Server Processing
The idea is that all information is processed by one server, or possibly by multiple servers which communicate with each other, and share a database. A system with multiple servers sharing tasks can also be considered as centralized processing.

• Distributed server processing
This feature describes a situation where two or more servers processing data do not need to communicate in order to accomplish the task, i.e. working in parallel. This feature is potentially the case if one considers the situation where different transport Telematic Service Providers (TSPs) offer different services.

Positioning and road side equipment Positioning is an important feature in the field of ITS. It is often required by different applications, either with self positioning capability, e.g. using satellite signals, or remote positioning, e.g. using roadside beacons.

• INFORBEACON
INFORBEACON typically refers to mounted roadside equipments which can communicate with moving vehicles. Roadside equipment serves different purposes from short range (DSRC) communication and can even be used as retransmission antennas. Such equipment will therefore have to address transmission bandwidth and data storage or buffering. Some architecture concepts necessitate the installation of beacons along road networks, e.g. the Japanese Electronic Toll Collection System.

• Satellite positioning
A satellite-based positioning functionality, such as the one being developed by the European Geostationary Navigation Overlay Service (EGNOS), uses a constellation of satellites to determine the position of an object on the earth surface by measuring signal propagation time, and then calculating the distance based on the constancy of the speed of light. This is accomplished with the help of a GNSS receiver. In the presence of interference, ionospheric effects, scrambling and limited direct-line-of-site, especially for terrestrial applications, there is a limit to the accuracy of positioning vehicles using a satellite.

4.4.2 Concepts of transport telematic architectures
System architecture in the context of ITS generally focuses on the reference, logical (conceptual architecture) and physical architecture specifications. A logical
architecture consists of an overview of the activities and functionalities necessary to achieve the required TTSs. This study focuses on MSA conceptual and logical specifications. TTSs require a combination of different functionalities especially related to communication, processing and positioning. These major functionalities provide resources for realizing different applications in the same way as the internet network provides support for internet applications. Architecture design choices affect whether one or more functions are included or not (Xu et al. 2004). We can illustrate the different decisions and possible combinations for communication and processing as shown in figure 4.1. Each arrow indicates whether communication between the two entities is allowed or not, i.e. yes/no decision. In each link the communication can either be in one direction or in both directions.

Figure 4.1: Illustration of architecture concept decisions

Combinations of link decisions (in figure 4.1) will lead to a given MSA specification. For different architecture concepts, it will be possible to achieve different applications offering different TTSs. The benefits of each architecture concept will depend on the possible TTSs achievable.

We view some MSA functionalities as highly important and consider them as resources or key functionality. This is because they have a high costs and are also needed to support other functionalities. For instance, satellite positioning will support all application functionalities that require positioning, such as road congestion data, origin-destination data, etc. Considering these key functionalities as resources, we therefore specify a binary (0-1) matrix that determines the resource requirements of each functionality, and another binary matrix indicat-
ing the resources available in each MSA. Thus, the MSA concept in this study is specified by a set of key functionalities such as vehicle-to-vehicle communication, OBU, and GNSS positioning.

4.5 A proposed optimization modeling approach for multi-service architecture in road transport

Optimization models represent choices as decision variables and seek values that maximize or minimize the objective function of the decision, subject to constraints on variable values expressing the limits on possible decision choices (Rardin, 2000). In this paper, the decision choices are related to the type of MSA, TTSs and the functionalities for realising the services, as illustrated in figure 4.2:

Figure 4.2: Generic Model Diagram illustration

To understand what this model does, we will explain important assumptions necessary to consider, some set notation, the decisions considered, the objective and constraints.

Assumptions

A1. In order to design a service, a system engineer considers a set of possible functionalities that could be used in the system. The preliminary design is about which functionalities to include (or not include) in the system. This decision depends much on the specification of the system by the user (see Appendix C). We assume that all decisions related to functionalities have the same weight. In some cases different functionalities may be given different weights.

A2. If there are two applications that require the same type of functionality, it is possible to design the system such that the applications can use the same functionality without having to implement it twice.

A3. Quantified societal value (in monetary terms) is created by an application if it is implemented based on all of its specified functionalities.


A4. The total societal value of two applications addressing a common societal aspect, such as accidents, is reduced compared to the sum of the independent benefits when such applications are implemented together.

Sets

\[ S \quad \text{set of all TTSs (see Appendix B)} \]

\[ F \quad \text{Set of all functionalities (see Appendix A)} \]

\[ A \quad \text{Set of all architectures} \]

\[ R \quad \text{Set of system resources, e.g. data communication, related to special MSA functionalities.} \]

\[ R_1 \quad \text{Set of processing resources subset of } R \]

\[ R_2 \quad \text{Set of processing resources subset of } R \]

The model will select the TTSs and functionalities that maximize the total benefit. If a service is selected, all its functionalities (and hence costs) will have to be satisfied as specified by the input matrix (see Appendix C). The model determines the cost based on the costs of functionalities used by selected TTSs. This is similar to work done by Shaoyan and Chuanyou (1998) in evaluating the cost of data communication services, except that they focused on establishing tariffs. The value estimate for a service is based on identified service indicators and the service dependency with other services. The total net benefit of the architecture (based on selected services) is obtained mainly from the difference between the total value of the services and the total costs of functionalities. The following decisions are considered:

**Decisions Explained**

TTSs: This decision is about the choice of TTS to implement. This is a decision faced by a government agency, local authority or telematic service provider. An application is either implemented or not. Therefore we consider this as a 0/1 decision, i.e.

\[
x_i = \begin{cases} 
1, & \text{if } i \in S \\
0, & \text{if } i \notin S 
\end{cases}
\]

Functionalities: This decision is about the type of functionality to achieve a service. Therefore we again model this decision as 0/1:

\[
f_j = \begin{cases} 
1, & \text{if } j \in F \\
0, & \text{if } j \notin F 
\end{cases}
\]

Architecture: The type of MSA for implementing the application: The model has not explicitly made a choice between different architectures, rather we have considered one architecture choice at a time and then compared the results. The MSA decision was considered as 0/1.
\[ z_t = \begin{cases} 
1, & \text{if } t \in A \\
0, & \text{if } t \notin A 
\end{cases} \]

Additional decisions considered in this model include a total penalty cost \( \omega_t, t \in A \) that depends on: costs incurred if a functionality is not supported by an architecture \( o_j, j \in F \) and the cost for data buffering for each TTS when data is not processed in real time \( o_i, i \in S \). The amount of buffered data \( \epsilon_r, r \in R1 \) is determined by the difference between the data generated by functionalities according to the resource that is being used \( U_r, r \in R \) and the number of units of a given resource required to process data \( \psi_r, r \in R1 \) given an estimated processing capability of each unit \( \bar{U}_r, r \in R1 \).

**Parameters**

\[
\begin{align*}
V_i, i \in S & \quad \text{The value of each TTS.} \\
C_j, j \in F & \quad \text{The fixed cost of each functionality.} \\
C_{ir}, i \in S, r \in R & \quad \text{The variable cost of each TTS for a given resource.} \\
P_r, \geq 0, r \in R2 & \quad \text{The fixed cost of each functionality.} \\
D_{ii}, \geq 0, i, \hat{i} \in S, i \neq \hat{i} & \quad \text{Pair wise dependency between two services.} \\
T_{jr}, j \in F, r \in R & \quad 1 \text{ if functionality requires resource, } 0 \text{ otherwise.} \\
\bar{P}_r, \geq 0, r \in R & \quad \text{Cost of resource usage.} \\
M_{ij}, i \in S, j \in F & \quad 1 \text{ if service requires function, } 0 \text{ otherwise.} \\
A_{tr}, t \in A, r \in R & \quad 1 \text{ whenever a resource is used, } 0 \text{ otherwise.} \\
B_{ir}, \geq 0, i \in S, r \in R & \quad \text{Estimated resource needs for each service e.g. communication in mbps.} \\
U_r, \geq 0, r \in R & \quad \text{Data generated per resource unit.} \\
Z_t, t \in A & \quad 1 \text{ if choice of architecture is considered, } 0 \text{ otherwise.} \\
\bar{U}_r, \geq 0, r \in R1 & \quad \text{Processing capacity per unit of processing unit e.g. connected centralized servers.}
\end{align*}
\]

**Variables**

\[
\begin{align*}
x_i, i \in S & \quad 1 \text{ if service is selected, } 0 \text{ otherwise.} \\
f_j, j \in F & \quad 1 \text{ if functionality is selected, } 0 \text{ otherwise.} \\
y_{ij}, i \in S, j \in F & \quad 1 \text{ if both functionality and service are selected, } 0 \text{ otherwise.} \\
\hat{f}_{ir}, i \in S, r \in R & \quad 1 \text{ if service select function and function is not supported by architecture, } 0 \text{ otherwise.}
\end{align*}
\]
\( \vartheta_{ii} \geq 0, i, \hat{i} \in S, i \neq \hat{i} \) 1 when services \( i \) and are selected, 0 otherwise.

\( o_{jr} \geq 0, j \in F \) The penalty for including a functionality that is not supported by an architecture type.

\( \bar{o}_i, \geq 0, i \in S \) Data buffer penalty for any selected application.

\( \omega_{it}, \geq 0, t \in A \) The total penalty cost for a given architecture.

\( \eta \geq 0 \) Integers denoting how many services are considered currently.

\( \varepsilon_r, \geq 0, r \in R_1 \) The amount of data that needs to be buffered.

\( \mu_r, \geq 0, r \in R_2 \) The amount of data communicated at an instance of time.

\( \psi_r, \geq 0, r \in R_1 \) Number of units for data processing (depends on unit capacity).

Objective Given \( t \) in \( A \), maximize:

\[
\sum_{i \in S} V_i \times x_i - \sum_{i \in S} C_{ir} \times x_i \times i - \sum_{j \in F} \sum_{r \in R} C_j \times f_j \times t - \sum_{A_{tr} \times \bar{P}_t \times Z_t} \sum_{i, i \in S, i \neq \hat{i}} \vartheta_{ii} - \omega \quad (4.5.1)
\]

Constraints

\( C_1: x_i \times M_{ij} \leq f_j, i \in S, j \in F \)
Whenever a service is 1, all its functionalities are also 1.

\( C_2: D_{ii} \times (x_i + x_{\hat{i}} - 1) \leq \vartheta_{ii}, i, \hat{i} \in S, i \neq \hat{i} \)
Whenever a pair of services are selected, the value of the dependency \( D \) is considered.

\( C_3: T_{jr} \times f_j \leq A_{tr} \times Z_t + \tilde{f}_{jr}, \ j \in F, t \in A, r \in R \)
Whenever an architecture concept is considered, the resources are restricted accordingly.

\( C_4: \sum_{j \in F, r \in R} \tilde{f}_{jr} \leq 2 \)
We relax 2 functionalities.

\( C_5: (x_i + f_j - 1) \leq y_{ij} \ i \in S, j \in F \)
Determine when a service and functionality are selected.

\( C_6: o_{i} \geq C_j \times f_{jr}, j \in F, r \in R \)
Additional cost (penalty) for functionalities not supported by architecture.
\[ C7: \sum_{i \in S, j \in F, r \in R} (U_r \ast T_{jr} \ast y_{ij}) \leq \sum_{r \in R1} (\bar{U}_r \ast \psi) + \varepsilon t \in A \]

All data generated by functionalities is either processed or buffered.

\[ C8: \quad B_{ir} \ast \tilde{o}_i \geq P_r \ast \varepsilon_r, i \in S, rin \in R1 \]

Whenever data is buffered the variable costs of the application is increased by a penalty.

\[ C9: \quad \sum_{i \in S, j \in F, r \in R} (U_r \ast T_{jr} \ast y_{ij}) \leq \sum_{r \in R2} \mu_r \]

All data generated by functionalities is communicated in real time.

\[ C10: \quad \omega \leq \sum_{i \in S, j \in F} (\tilde{o}_i + o_j) \]

We calculate the total penalty incurred by all functionalities and services.

\[ C11: \quad \sum_{i \in S} x_i \leq \eta \]

Given maximum number of services allowed to select (running from 2 to 32).

A scenario of the above model is solved using AMPL/Cplex. AMPL provides a modelling interface and a high-level programming environment for building mathematical programming models, while CPLEX provides a suitable optimizer for solving ILPs based on branch and bound.

### 4.6 Case study of the ILP optimization model

We assume that the functionalities studied can be quantified in terms of data received/transmitted or processed within a static time period, e.g. one month, and hence data rates can be used as a proxy parameter from which cost values are generated. Capacity utilization values, e.g. for communication, are obtained by considering average data transfer rates, and values for processing by considering memory utilization, etc. For communication, a threshold minimum bandwidth has to be available. We used estimated data rates for computing the variable costs of a service, assumed as shown on table 4.1. Based on this, we can make
approximate estimate for how much bandwidth or processing is needed by multiple applications.

<table>
<thead>
<tr>
<th>Type of Resource Supported</th>
<th>Parameter Value (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data communication</td>
<td>0.5Kbps to 11Mbps</td>
</tr>
<tr>
<td>Voice communication</td>
<td>4.8Kbps to 32Kbps</td>
</tr>
<tr>
<td>Video/Picture communication</td>
<td>3Mbps to 6 Mbps</td>
</tr>
<tr>
<td>OBU data transfer rate</td>
<td>250Kbps (uplink), 500Kbps (downlink)</td>
</tr>
<tr>
<td>OBU data processing/storage</td>
<td>64 bytes RAM, (272 Kb flash)/1.6 Kb</td>
</tr>
<tr>
<td>Distributed server processing</td>
<td>4GHz processing speed, 100 GB RAM</td>
</tr>
<tr>
<td>Centralized Server Processing</td>
<td>2 GHz processing speed, 50 GB RAM</td>
</tr>
<tr>
<td>INFORBEACON ARIB-STD T75</td>
<td>Transmission (1024 kbps) position frequency 1/10 KM</td>
</tr>
<tr>
<td>Satellite positioning</td>
<td>250Bps (downlink)</td>
</tr>
</tbody>
</table>

Table 4.1: Data rate requirements for communication and processing ITS data.

The estimated resource requirements for each application $B_{ir} \geq 0$ is determined by the linear sum $B_{ir} = \sum_{j \in F}(b_r * f_{jr})$ where $b_r$ is the average data for resource type $r$ in table 4.1 generated by functionality $f_r$ and the sum is taken over all data types. We assume a scenario where applications are accessing the communication bandwidth simultaneously such that the network is almost saturated. The fixed costs $C_j$ are essentially the entry costs necessary to acquire hardware/software for providing the functionality, and discounted according to the life span of such products (typically 10 years). Fixed cost data was mostly obtained from market prices set by manufacturing companies. The values of the services are assessed for a one year period with a discount rate of 5% and interest rate of 0.2% as these values are typically used for ITS investment planning [Xu et al., 2004]. For this analysis we used the values suggested in table 4.1.

Most telecommunication companies set prices based on maximum capacity usage by clients. For instance, in Sweden, data communication service companies such as tre.se charge 49SEK/month for unlimited data transfer. Statistical data shows that an average of 2000MB/month was communicated per user in 2009 [PTS 2009], which gives an average cost of 49/2000 SEK/MB. Since this value is a market price, it includes other costs such as mobile terminal (phone) which is some cases is freely distributed by the company as well as Value Added
Tax (VAT). We assume that the actual cost of data transfer is therefore just a fraction of the price. We estimate this cost to be about 10% of the market price i.e. 0.00245 SEK/MB. This will lead to a monthly cost range of 315 SEK/month to 1227 SEK/month per user for all TTSs investigated in this study for independent applications, which we think is reasonable compared to some of the prices offered today. The major cost components are the fixed costs of infrastructure. Considering each application is to be achieved independently of all the others, the estimated total annual cost for a fleet of 65000 (registered Heavy Goods Vehicle (HGV) fleet in Sweden) and 10% coverage of roadside installations (where necessary) has been considered. The societal value for each application is based on an earlier study [Mbiydenyuy et al., 2009]. The societal value for TTSs applications will depend on the cluster of TTSs implemented due to dependencies. Pair wise dependencies were considered as an approximation to the total dependencies in a cluster of selected TTSs.

4.7 Results and analysis

The results of the optimization model consist of a selection of various TTSs drawn from the case study. The following analyses considered to be interesting:

Q1 What type of TTSs are selected, if in one case, we use a basic specification of a Road User Charging (RUC) system as a base application and in another case, we use an advanced specification (RUCA)?

Q2 What is the effect of forcing a particular TTS to be implemented?

Q3 What is the effect of using different MSA specifications?

The basic RUC system, according to the Swedish RUC ARENA specification [Sundberg et al., 2007], consist of the following functionalities: global positioning (e.g. based on GNSS, GPS), secured vehicle smart card register (obu), vehicle data differentiating between vehicle class (vd), time of the day (ts), road type (mp). Additional requirements not considered are: interoperability with EETS systems and compliance control. The advanced versions (RUCA) have, in addition to the RUC, the capability to control congestion (rc) by redirecting traffic to specific roads (rm) and road infrastructure data (ind) collection. Detailed results for each of the above cases are discussed below.

4.7.1 Effects of selecting different types of TTSs (Q1)

The selection of TTSs here is independent of MSA specification.
(a) Selected number of TTSs based on synergies with RUC and RUCA alternatives.

The RUCA shows high potential synergies with several TTS applications. Of 31 applications considered in the model, RUC and RUCA alternatives resulted in the selection of 26 applications and 32 applications respectively. The difference between the selected applications was in IRM, XXL, ISA, RG and WI that were not selected with RUC, whereas with RUCA alternative, the said applications showed positive synergies and were hence selected. Results of the selection process with given restrictions of the number from which to select are shown in the graph below (figure 4.3). In the graph, we run the optimization model with a restriction of the selection of services from 2 to 32 (horizontal-axis) and plot this against the number of applications selected by the model (vertical-axis). The RUCA service was not selected until the model was allowed to consider at least 20 applications. The RUC was selected from the beginning and dropped when the model was allowed to consider more than 3 TTSs, then selected again when the model was allowed to select at least 10 applications. TTSs other than RUC and RUCA can be studied.

![Graph showing number of TTSs selected with RUC and RUCA alternatives](image)

Figure 4.3: Number of applications selected with RUC and RUCA alternatives

Figure 4.3 further shows that there are potentially better synergies with a RUC than RUCA. This may be related to the underutilization of many RUCA functionalities. As the number of potential applications is increased, RUCA could become more suitable as a base application while synergies with RUC will remain same.
(b) Profit of TTSs selected for RUC and RUCA functionalities based on functional synergies

In this case, we studied how the total profit (net benefit) of selected applications varies between the selection with RUC and RUCA. On one hand, common sense may suggest that more applications may lead to greater profit, but it can also be expected that the choice of applications influence the profit. Figure 4.4 shows that even though RUC may only select a few applications, the benefits are likely to be more than RUCA despite many applications selected (see figure 4.3).

![Figure 4.4: Total profit (net benefit) for applications selected with RUC and RUCA.](image)

From figure 4.4, the two RUC alternatives indicate that between 5 and 10 applications there is a significant increase in total net benefit from the inclusion of applications. The total net benefit for RUCA then becomes less than RUC until all 31 applications have been included.

### 4.7.2 Effects, on profit, of enforcing different types of TTSs (Q2)

The total net benefit for RUCA will be negative until at least five applications are included as can be seen in figure 4.5. This is in line with results from figure 4.3 since the selection of applications for RUCA did not take place until at least three applications are included.
Figure 4.5: Net benefit variation with enforcement for RUC and RUCA.

From figure 4.5, the total net benefit of RUC is not affected by enforcement, while enforcement is likely to lead to a negative total net benefit if RUCA is implemented. The model can also be used to study the consequences of mandating certain applications by law, such as ISA and EC in order to understand their impacts in the context of multiple potential applications.

In table 4.2 we show the priority of selection of all applications when studying the RUC and RUCA alternatives in figures 4.3, 4.4, 4.5 above. TTSs with small priority number in table 4.2 can be regarded as having a high net benefit relative to the rest of the TTSs considered (except for zero which means the TTS was never selected at all, e.g. ISA).

<table>
<thead>
<tr>
<th>TTSs</th>
<th>**</th>
<th>*</th>
<th>TTSs</th>
<th>**</th>
<th>*</th>
<th>TTSs</th>
<th>**</th>
<th>*</th>
<th>TTSs</th>
<th>**</th>
<th>*</th>
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</thead>
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<td>25</td>
<td>GEO</td>
<td>26</td>
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<td>OSM</td>
<td>21</td>
<td>16</td>
<td>SGM</td>
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<td>14</td>
<td>TAR</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
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<td>4</td>
<td>XXL</td>
<td>30</td>
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<td>20</td>
<td>TOH</td>
<td>6</td>
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</tr>
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<td>RM</td>
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<td>13</td>
<td>TRO</td>
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<td>ISA</td>
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<td>VF</td>
<td>11</td>
<td>15</td>
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<tr>
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<td>12</td>
<td>NAV</td>
<td>3</td>
<td>6</td>
<td>RUC</td>
<td>20</td>
<td>10</td>
<td>WI</td>
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</table>

Table 4.2: Order of selection of different applications for RUC and RUCA alternatives (**=RUCA, & *=RUC)
4.7.3 Effects of including MSA specification on selected TTSs (Q3)

We have considered six candidate multi-service architecture concepts, extended from previous work [Brasche et al., 1994; Persson et al., 2007]. For each concept, where relevant, we discuss a similar example, and summarize the key functionalities for a given MSA in table 4.3. The main differences between MSAs are based on communication, processing, roadside equipment, positioning, etc, that have been discussed in section 4.4 and are shown in table 4.3 below:

<table>
<thead>
<tr>
<th>Type of Resource Supported</th>
<th>Z1</th>
<th>Z2</th>
<th>Z3</th>
<th>Z4</th>
<th>Z5</th>
<th>Z6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle to vehicle com</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
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<td>Roadside to server com</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
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<tr>
<td>Vehicle to server com</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle to roadside com</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Satellite to roadside com</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>OBU data processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple server processing</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Single central server processing</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Satellite positioning</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Data broadcast</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3: Features of different architecture concepts

- **Vehicle-to-Vehicle (V2V) with centralized communication (Z1):** This is similar to a proposed emergency system known as eCall+ [Martínez et al., 2009], which is a variant of the eCall architecture. The eCall architecture has been considered as a potential MSA [Ditz, 2007].

- **Thin client with central server data processing (Z2):** For this, vehicle position is recorded with the help of an OBU and communicated to a central unit that calculates the corresponding charge e.g. the Switzerland tolling scheme [Bernhard, 2003].

- **Thick client with decentralized data processing (Z3):** This is based on using satellites to track vehicles equipped with an OBU that is capable of processing data. The results are reported to the control unit for the infrastructure owner and service provider e.g. the German tolling scheme [Mckinnon, 2006].

- **Vehicle-to-Vehicle (V2V) with decentralized communication (Z4):** This is based on distributed V2V communication ad-hoc network with complete...
flexibility. A similar example is addressed in a study where vehicles are seen as autonomous units, with a possibility of allocating vehicles into groups using common communication protocols that can potentially share the same carrier frequency [Sakata et al., 2000].

- Vehicle to Infrastructure (V2I) with decentralized communication (Z5): This is based on mounting roadside equipment that can provide functionalities to enable both communication and processing. A similar example is the Austrian tolling system [Biffl et al., 1996; McKinnon, 2006] based on a 5.8 GHz DSRC (CEN-DSRC) between OBU and roadside equipment.

- Vehicle-to-vehicle to Infrastructure (V2V2I) Hybrid architecture (Z6): This architecture combines the advantages of the V2V and V2I options that are discussed above. This is similar to the architecture described by Miller [2008], in which the author suggests the use of a single vehicle (super-vehicle) for communication in a given zone, in charge of communication with a central server. It was shown that V2V2I can serve 2850 vehicles in each zone with only 13.4Kbs bandwidth transmission in both directions (Miller, 2008).

In section 4.4.1, we discussed a number of important functionalities that can be used to specify an architecture concept. We now use those functionalities to define architectural constraints that influence the selection of TTSs in an optimization model according to table 4.3. We interpret the impacts of different MSAs in terms of the type of resources available (as shown in table 4.3). In the following cases, we choose to consider the RUC alternative alongside other applications for different platforms.

(a) Selected number of TTSs based on MSA specification. First we consider the number of TTSs selected when different platform restrictions are enforced. The current results were obtained with some soft constraints, where we allowed for a selection of two additional functionalities not supported by the architecture resources (at additional costs). The results shows that a hybrid V2V2I architecture, Z6, will enable the selection of more applications (29 out of 32), followed by a thick client with decentralized data processing, Z3 (26 out of 32) and then a thin client architecture with centralized data processing, Z2 (10 out of 32). While Z4 or V2V with decentralized communication only leads to 3 applications, Z1 (or V2V with centralized communication) and Z5 (or V2I with decentralized communication) only resulted in one application each. The progressive selection of applications with given restrictions (from 2 to 32) is shown in figure 4.6.
Figure 4.6: Selection of TTS applications for different choices of platforms

Figure 4.7: Total net benefits of selected applications for different choices of MSA concepts.

(b) Total net benefit for selected TTS on different MSA platforms As before, we consider the total net benefit of selected applications. The results (as seen earlier in figure 4.4) shows that Z6 could lead to several more applications but smaller net benefits compared to a thick client architecture with
decentralized processing, Z3, with few applications (see figure 4.7). This can likely be explained by the choice of applications selected and cost of resources (communication and processing) for the various platforms. A graph of total net benefit against the given number of applications shows that Z3 will be most suitable under the conditions of the scenario. Higher benefits for Z3 may partly be based on the fact that a decentralized architecture may reduce the demand for communication infrastructure compared to a centralized architecture.

(c) Total dependency of selected TTSs for different MSA platforms The net benefit increase for different selections of TTSs on different platforms may be partly due to the dependencies between the applications i.e. reduced marginal benefits when two or more TTSs target a common goal. Applications addressing common issues, such as accidents, will lead to reduced benefits when all are implemented compared to implementing only one such application i.e. if the applications are not orthogonal in the space of targeted goals. The total dependency $\vartheta_{i, \hat{i}}$, $i, \hat{i} \in S, i \neq \hat{i}$, variation for selected applications in different platforms shows that Z3 leads to the highest dependencies compared to the rest of the platforms (figure 4.8). This indicates that TTSs selected with Z3 are targeted toward closely related domains.

Figure 4.8: Dependency variation of selected applications for different platforms

We present the priorities of selected TTSs in tables 4.4, 4.5, & 4.6 for Z1 to Z6 indicating the order in which each application was selected for a given architecture.
Table 4.4: Order of selection, for each TTS application on different platforms part I

<table>
<thead>
<tr>
<th>Z</th>
<th>AWI</th>
<th>ADI</th>
<th>DP</th>
<th>DTI</th>
<th>EC</th>
<th>ETM</th>
<th>EDI</th>
<th>ETA</th>
<th>FM</th>
<th>GEO</th>
<th>GI</th>
</tr>
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<td>Z1</td>
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</tr>
<tr>
<td>Z2</td>
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<td>21</td>
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Table 4.5: Order of selection, for each TTS application on different platforms part II

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<th>Z</th>
<th>RHW</th>
<th>XXL</th>
<th>ITP</th>
<th>ISA</th>
<th>NAV</th>
<th>ODM</th>
<th>OSM</th>
<th>PYL</th>
<th>RTT</th>
<th>RED</th>
<th>RM</th>
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</thead>
<tbody>
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<td>0</td>
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<td>0</td>
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<td>0</td>
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<td>12</td>
<td>9</td>
<td>11</td>
<td>18</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4.6: Order of selection, for each TTS application on different platforms part III

In tables 4.4, 4.5 & 4.6 a zero means the application was not selected at all, and a high number indicates the application was selected only after several other applications have been selected and hence has a low priority. The above case study shows a potential influence of MSA choices on various TTSs. Results obtained are dependent on the costs of the functionalities and the benefits of different TTSs using different MSAs as well as on the common use of functionalities with TTSs.
4.8 Conclusion and future work

This article has proposed a model that can be used to support strategic decision making related to the design and investment in MSAs and TTSs for road-based freight transport. The decisions were abstracted as discrete, enabling the use of ILP optimization to address the selection of beneficial TTSs. We showed that it is possible to conduct high-level multi-service analysis using quantitative models such as optimization. The types of strategic decisions addressed by the model are those faced by policy makers, such as government authorities, to identify and invest in applications that will meet long term transport policy objectives. The model can also be beneficial to telematic service providers facing long term decisions related to the implementation of telematic applications with multiple services as well as ITS system designers. We illustrated the model decision prescription capabilities by selecting potential beneficial applications from a given set of applications for road freight transport with focus on the Swedish Heavy Goods Vehicle (HGV) transport. By changing the conditions, we also illustrated that the model can be used to address what-if-analysis scenarios. To illustrate this, the model considered six different MSA concepts and their potential effects on possible TTSs that can be achieved from a benefit perspective.

Studies that have addressed similar subjects to this study show varying results because of the use of different approaches, e.g. Sjöström (2007) used qualitative analysis to show that road status monitoring, hazardous goods monitoring, transport service payment, and tracking and tracing of cargo are likely suitable applications for a thin client while speed alert, preferred network guidance and traveller information services were recommended for a thick client. Kim et al. (2005) proposed a telematic system platform and demonstrated its suitability for supporting real time traffic information, location and entertainment services.

We used a quantitative ILP optimization based method to show that Navigation (NAV), Theft Alarm and Recovery (TAR), Transport Order handling (TOH), Road Hindrance Warning (RHW), En-route Driver Information (EDI), Accident Warning Information (AWI), Advanced Driver Logs (ADL) and Driver planning (DP) are candidate applications for to thin client platform (Z2) based on their net benefits (see figure 4.7). For a thick client (Z3) based architecture, our model showed the possibility of implementing an even greater number of beneficial applications. We cannot expect these results to be the same, one reason being that the applications considered in the two studies vary significantly. However most of the studies all demonstrate that a common platform for multiple applications will lead to more benefits, but they have used different approaches to analyzing such benefits.

In the future, the model can further be validated by improving the quality of data, experimenting different case studies, incorporating quality of service fac-
tors, and studying additional constraint on resources such as communication and processing. This study also found that even though TTS benefits maybe context dependent, multi-service architecture evaluation has not been widely researched. However, this will become an important research area in the future because of the growing number of new TTSs. We plan to improve the optimization model by explicitly addressing the resource allocation model for various functionalities instead of binary selection, as is currently the case.

4.9 Appendix

<table>
<thead>
<tr>
<th>FUN.</th>
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<th>FUN.</th>
<th>Label</th>
<th>FUN.</th>
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<td>Driver data</td>
<td>mp</td>
<td>Map position and updates</td>
<td>src</td>
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<td>Global (absolute)</td>
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<td>Monitoring</td>
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<td>gds</td>
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<td>Vehicle data/ID logger</td>
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Figure 4.9: Functionalities considered in the optimization model
### Table 4.10: Transport Telematic Services Considered in the Optimization Model

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<th>TTSs Label</th>
<th>TTSs</th>
<th>TTSs Label</th>
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<td>ETM</td>
<td>FTP</td>
<td>RM</td>
<td>TRIO</td>
<td>TRIO</td>
</tr>
<tr>
<td>EDI</td>
<td>ISA</td>
<td>RHW</td>
<td>VF</td>
<td>VF</td>
</tr>
<tr>
<td>ETA</td>
<td>NAV</td>
<td>RUC</td>
<td>WI</td>
<td>WI</td>
</tr>
</tbody>
</table>

### Figure 4.10: Transport telematic services considered in the optimization model

### Figure 4.11: Relationship between TTSs and functionalities
4.10 References


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Chapter 5

Paper V - Modeling service quality and benefits of multi-service architectures in road transport telematic applications

Modeling benefits and Quality of Service (QoS) for Multi-Service Architectures (MSAs) is important to enable service providers offer the best Transport Telematic Services (TTSs) with high societal benefits to users. This study models how different QoS characteristics may influence potential benefits of MSAs for road based freight TTSs. This is achieved by modeling the QoS degradation under conditions of shared resources and including costs associated to such degradation to determine the benefits as the difference between the costs and societal value of the applications. A system performance oriented QoS measure has been introduced in coming up with a MSA benefits model, providing a possibility to capture different quality attributes, desired performance levels, and even the possibility to introduce desired priorities between applications and quality attributes.

5.1 Keywords

Quality of Service, Multi-service architecture, benefits.
5.2 Introduction

The purpose of this study is to model how different Quality of Service (QoS) characteristics such as timeliness, availability, accuracy and completeness may affect the costs and hence potential benefits of Multi-Service Architectures (MSAs) for road based freight Transport telematic Services (TTSs). Transport Telematic Applications (TTASs) must meet a certain level of performance in order to be beneficial to the society. Such performance will affect the quality of the resulting services. The underlying concepts of bandwidth, throughput, timeliness (including jitter), reliability, perceived quality and cost are the foundations of what is known as QoS and has mostly been addressed in relation to telecommunication system efficiency (Chalmers and Sloman, 1999). MSAs on the other hand are essentially system platforms with the potential capability to support multiple services (Malyan and Lenaghan, 2003; Mbiydzenyuy(b) et al., 2009) such as Electronic Fee Collection (EFC) system platforms and hence improve benefits through resource sharing. An earlier study addressed benefits of MSAs for achieving a range of TTSs in the context of road freight transport (Mbiydzenyuy(b) et al., 2009).

Because of their potential to improve overall system benefits by providing functionalities that can be shared between different applications, MSAs have gained a lot of interest in different areas ranging from internet applications to ITS applications (Ai et al., 2003; Cheng and Marsic, 2000; Malyan and Lenaghan, 2003; Mbiydzenyuy(b) et al., 2009). With an increasing number of new applications in transport telematics based on wireless communication infrastructure, it is necessary to analyze MSA benefits in the context of shared resources. While resource sharing may increase total system benefits, the eventual outcome is not obvious because the service quality may degrade for certain applications during run time. Further, non-predictable users preferences for what is a good QoS, in the context of multiple applications with choices, adds the complexity (MacKie-Mason and Varian, 1995). Conversely, it is not enough to maximize QoS without considering the overall system benefits. Modeling benefits and QoS for MSAs is important to enable service providers offer the best TTSs with high societal benefits to users.

MSAs have been proposed as a potential approach for achieving TTSs that makes use of synergies between functionalities to improve system benefits (Mbiydzenyuy(b) et al., 2009). The proposed model (Mbiydzenyuy(b) et al., 2009) did not take into account the varying QoS preferences between applications. Building on earlier work (Mbiydzenyuy(b) et al., 2009), we introduce the QoS dimension to study how performance based QoS may influence the system benefits. Studies show that service benefits have a relationship with the QoS (Lee, 2001) though this relationship has not been further investigated. There are models aimed
at studying the performance quality of communication systems (Malyan and Lenaghan, 2003) and processing systems (Huang and Cha, 2001; Menascé and Bennani, 2003). Until now, no study found so far has addressed QoS explicitly in relation to benefits for multi-service applications in road-based HGV transport. Instead several studies have addressed QoS in relation to network resources for telecommunication systems with focus on satisfying service level agreements or comparing service offers between providers (Sánchez-Macián et al., 2008). Models for measuring different quality aspects related to telematic services have been proposed (Siergiejczyk, 2008), but they did not include the effect on benefits of such services.

In this work, QoS will refer to the systems performance quality which is assumed to characterize the end users perception of quality. Unlike internet applications it is not clear how the QoS may be affected if several ITS applications are deployed on a common platform sharing several functionalities. Different applications will require different levels of QoS characteristics such as reliability, timeliness, completeness, costs and availability depending on the priority and goal for which such applications were designed. The impact of quality aspects to the benefits of a service have been summarized and categorized as alignment to reality in; time, space, content and the number of informed users (QUANTIS, 2009). The problem addressed in this study is to establish a benefits model that takes into consideration the QoS metric. Such a model will help service providers understand the benefits or losses associated to service quality. This study is an extension of a previous model (TTS benefits model) (Mbiydzenyuy(b) et al., 2009) to incorporate a quality based cost function. The model can then be solved as a resource allocation problem with given QoS parameters which can be varied to study the overall system benefits. The structure of the rest of this paper is as follows: section 5.3 establishes the relevance of the problem, section 5.4 takes a closer look at QoS and MSAs while section 5.5 establishes a mathematical model of MSAs that takes into accounts system benefits. Section 5.6 present concluding remarks, followed by acknowledgement and references.

5.3 Relevance of the study

5.3.1 Motivation

ITS applications for HGV transport are aimed at achieving several goals e.g. improving the utilization of different types of transport resources, minimizing the external effects of different transport activities etc. Therefore in a Multi-service architecture platform, it is to be expected that several applications sharing resources will operate to maximize different goals for which they were designed. Such resources could be communication network resources e.g. bandwidth, com-
communication channels etc or computer processing resources e.g. memory, hard disk etc. For applications making common use of a given functionality and sharing resources, deadlock situations may arise during run time if the resources are insufficient or not carefully allocated. This will imply that certain applications will need to be associated priorities over others to manage such situations. Additionally, performance quality of the application may degrade when the demand for such resources are limited. Therefore there will be a need to prioritize which quality attributes be given preference when resources are limiting at runtime. In order to assess the benefits associated to applications in a MSA, potential trade-offs from different applications need to be taken into consideration. Depending on the application emphasis could be on different quality attributes and because several applications share a platform, there are several tradeoffs that will need to be addressed. For instance applications oriented toward safety of life maybe may focus on time accuracy while applications oriented toward commercial benefits may focus on costs (see Figure 5.1) i.e.

![Figure 5.1: Concept illustration of QoS and ITS benefits.](image)

Different applications will impose different quality requirements on shared resources that will have an influence on the benefits of the entire system. Quality attributes such as availability, completeness, timeliness, precision etc set to different levels, with varying relative priorities for different applications will have an influence on the costs and hence benefits of various applications.

### 5.3.2 Related work

A survey carried out to investigate QoS attributes for general communication systems identifies the need for flexible and generic QoS models (Chalmers and Sloman 1999). Based on the survey results (Chalmers and Sloman 1999) key
factors for such models in a heterogeneous environment are the ability to define perceived QoS at the user interface level; how to relate this to underlying QoS supported within the underlying system, and how QoS aware interacting applications can adapt. The importance of such generic models could be to enable comparison of quality attributes between different applications. Of all the models that were studied in this survey (Chalmers and Sloman 1999) there was none that focused on how system benefits are related to various quality attributes. A related study has synthesized the profit consequences of service quality and the relationships with service quality and found out that the relationship between profit and service quality as an area within social sciences require further research (Zeithaml 2000). For computer network resources, a study proposed a QoS approach based on analytic performance models in which computer systems can self adjust their parameters to constantly ensure that QoS requirements are satisfied (Menascé and Bennani 2003). The proposed model (Menascé and Bennani 2003) measures the deviation of a given resource utilization from the maximum performance value and hence is generic enough to be applied to other application resources. Based on their approach (Menascé and Bennani 2003), we proposed a similar measure of performance QoS for TTSs and incorporate this to the cost function of the proposed benefit model (Mbiydzenyuy(b) et al. 2009). For TTSs, a knowledge-based system and architecture for the formalization of QoS characteristics and measurement methods, and for the collection, distribution and assessment of the QoS information has been addressed (Sánchez-Macián et al. 2008). Their work (Sánchez-Macián et al. 2008), makes an attempt to develop an ontology for comparing QoS attributes for multiple TTSs but no attempts on how to model the relationship with the architecture benefits. To determine the right parameters for the QoS in transport telematic services, a study suggests the suitability of service accessibility, service operability, stability, achievability and network performance as relevant parameters that can be used to quantify QoS (Siergiejczyk 2008). Even though their work (Siergiejczyk 2008) acknowledges the dependency between the level of service and the maintenance costs, the effects of such service levels on system benefits were never considered.

Work done on the management of web based content distribution in the form of telematic services shows that with increasing data volume and QoS demands, a thick client solution in which processes are distributed and executed at client stations could be better than a thin client solution where content data is distributed to users (Oguchi et al. 2003). Even though their work (Oguchi et al. 2003) is focused on distributing web content, the results are indicative of the potential of MSAs to influence service quality. An illustration of how a layered scheme for QoS provision (in wired and wireless IP networks) for a user-domain multi-service architecture can be used as an experimental test bed, has not specifically studied the benefits of MSAs (Cheng and Marsic 2000). Benefits of different applications
have been addressed following resource management approaches. For instance a QoS driven resource management for network computing that maximizes the total benefit provided to the applications is used to design the dynamic scheduling algorithms (Maheswaran, 1999). Abstracted benefit functions were used in this study (Maheswaran, 1999) and a simulation model was used to study the performance of the proposed algorithm. A related study fulfilling the need for a generic QoS model identified above (Chalmers and Sloman, 1999), addresses the QoS based resource management for multi-media applications, resulting to a proposed new analytical and generic resource management algebraic based model (Lee, 2001). Application benefits functions and resource demand functions are used to represent the system configuration and to solve the resource demand problem (Lee, 2001). The proposed model (Lee, 2001) did not provide an explicit modeling of benefits. However we found that the proposed generic model (Lee, 2001) was suitable for extending the benefit model in (Mbiydzenyuy(b) et al., 2009) so as to take into account the application priorities.

Relating QoS and benefits, a research project investigates the relationship between ITS service quality and benefits/costs, with the objective to determine the optimum service quality in four European service cases, identify levels of data quality providing optimal service quality and to give a recommendation for European guidelines for quality assurance of traffic data (QUANTIS, 2009). This paper differs from previous work (QUANTIS, 2009), in that we focus on modeling how the benefits of a MSA may be affected by QoS and in particular the introduction of multiple services on a common platform. In a related study, MSAs have been suggested as a support to mobile IP applications, with end user enabled control of QoS in heterogeneous wireless networks (Malyan and Lenaghan, 2003). Their work (Malyan and Lenaghan, 2003) was focused on web based applications and multimedia traffic with no explicit modeling of resulting benefits of such MSA with end-user enabled QoS control. We aim to establish a relationship between QoS and benefits using a quantitative based model.

It can be seen that, a number of studies have addressed QoS for communication and processing resources of various applications as a network resource utilization problem (Chalmers and Sloman, 1999; Lee, 2001; Malyan and Lenaghan, 2003; Menascé and Bemani, 2003) and also to characterize usage of networks in terms of effective bandwidth (Jiang and Jordan, 1996). Few example studies were found with focus on transport telematic services (Sánchez-Macián et al., 2008; Siergiejczyk, 2008) and no study was found, as at now, with focus on services targeted toward road based HGV transport. Finally the study of MSA benefits and QoS in general has partially been touched (Malyan and Lenaghan, 2003; QUANTIS, 2009). However QoS and benefits perspective used in (QUANTIS, 2009) does not consider MSAs, while the MSA perspective in (Malyan and Lenaghan, 2003), has not considered benefits. This leads to the conclusion that
QoS and benefits relationship for road based TTSs for HGVs have not been addressed up to this point in time. From the studies considered, MSAs have not been at the center of any study as a means for increasing overall system benefits, instead, quality issues for similar applications like web based contents have been addressed (Oguchi et al., 2003) and different approaches (Lee, 2001; Maheswaran, 1999) have been used to study different application benefits.

5.4 QoS and multi-service architectures in ITS

5.4.1 QoS attributes

Different types of service quality attributes can be considered such as timeliness, availability etc that can be used to differentiate MSA resource utilization at planning level. A detail description of these attributes has been provided in the QUANTIS project (QUANTIS, 2009). The following are some examples of important QoS attributes to consider for transport telematic MSAs.

I. Timeliness This is a sensitive quality attribute especially for safety critical applications such as eCall, accident warning information, route guidance etc. The value of many services will largely depend on the ability of the system to respond in time.

II. Availability The percentage of time the system is available or system uptime will determine it usage. End-user desired level may be different for different applications.

III. Completeness This QoS attribute determines both the system geographic coverage and content of the information delivered to the end user. Different applications will offer different levels and content that may not necessarily meet users desires.

IV. Precision The level of information precision is another important attribute that could vary significantly for different applications sharing resources e.g. accuracy of positioning location. Table 5.1 is an example of how quality attributes and levels may vary for different applications.
Table 5.1: Example of QoS levels for different attributes and applications

<table>
<thead>
<tr>
<th>TTSs</th>
<th>Timeliness (sec)</th>
<th>Availability</th>
<th>Completeness</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXL</td>
<td>≤ 5</td>
<td>90%</td>
<td>89%</td>
<td>80%</td>
</tr>
<tr>
<td>RED</td>
<td>≤ 10</td>
<td>90%</td>
<td>95%</td>
<td>90%</td>
</tr>
<tr>
<td>ITP</td>
<td>≤ 2</td>
<td>95%</td>
<td>90%</td>
<td>92%</td>
</tr>
<tr>
<td>ODM</td>
<td>≤ 2</td>
<td>97%</td>
<td>99%</td>
<td>95%</td>
</tr>
<tr>
<td>OSM</td>
<td>≤ 1</td>
<td>99%</td>
<td>99%</td>
<td>95%</td>
</tr>
</tbody>
</table>

These quality attribute will generate demands on MSAs which need to be satisfied by employing resources provided by the architecture.

5.4.2 Multi-service architecture resources

A MSA is a system architecture on which multiple applications can be deployed. Examples are seen in wired and wireless IP networks providing telecommunication services, [Ai et al. 2003; Cheng and Marsic 2000; Malyan and Lenaghan 2003]. ITS service platforms have not yet developed to the same level as telecommunication service platforms as seen in projects such as COOPERS, HEAVYROUTE, and MOBIL IT etc. Such platforms would be based on different types of architecture concepts such as: Vehicle-to-Vehicle, centralized/decentralized data processing Vehicle-to-Vehicle-to-Infrastructure hybrid architecture etc. A common characteristic is that platforms are generally opened ended, flexible, scalable and expandable and they differ in the type of end user services anticipated and hence in the technologies. A MSA provides the ability to collect, communicate, process and share data and information using different types of technologies (tools & methods) that can be seen as architecture resources.

I. Data collection Architecture concepts are different in the data collection technique employed which can be seen in two broad categories; intrusive and non-intrusive methods (Leduc 2008). Intrusive data collection methods are based on technologies such as pneumatic road tubes, piezoelectric sensors, magnetic loops and non-intrusive data collection methods are based on remote observations such as manual counts, passive and active infra-red, passive magnetic, micro-wave radar etc. Thus MSAs will have different quality attributes requirements depending on the type of data method employed.

II. Data communication Data communication for ITS architectures is mainly wireless communication with prioritized characteristics centered on real-
time, autonomous, high reliability and handover features (Tokuda, 2001). Anticipated communication systems are GPRS, GPS, and DSRC etc each of which offers different possibilities in terms of communication resources and costs e.g. the transmission data rate for ETC is 1024 kbps, Optical beacons (VICS) 1.024 Mbps (downlink) and 64 kbps (uplink), radio beacons (VICS) 64 kbps (GMSK) and 1 kHz (AM), and FM multiplex (VICS/D-DPS) 16kbps (Tokuda, 2001).

III. Data processing Computer data processing may not be seen as a limitation, given today’s computer processing capabilities, but because of real time demands that will be made by different applications running concurrently, the resulting processing capacity offered by each MSA will depend for instance on the computer processing network configuration.

IV. Data and information sharing A large amount of data and information (obtained by processing data) will be generated resulting to large data collection, communication and processing requirements that can be reduced through sharing e.g. it may be redundant for two HGVs to report road condition data if they are at the same location. This is because data and information sharing will affect communication capacity and processing capacity differently depending on the architecture concept used. The paradigm for reusable and modular software has been used to provide reusable components for interfacing data with the outside world with mechanisms for managing concurrent applications, and share derived streams across ITS applications (Bouillet et al., 2007).

5.5 Mathematical modelling

This study is about how to model the QoS degradation under conditions of shared resources and including costs associated to such degradation to determine the benefits for different potential MSAs. In this study resources, refer to communication (bandwidth and channel availability) and processing (memory usage) resources. If a system performs at maximum capacity, during run time, and the current work load is satisfied, the quality for which the system was designed can always be achieved. However, if the workload is more than the application can handle at run time then resources become limiting at that particular moment and the QoS will likely degrades. For telematic applications at pre-implementation, system behavior at run-time cannot be determined. However different resource allocation models (based on different MSAs) can provide understanding of how the QoS may vary in real time. A basic approach for estimating such QoS is to estimate the deviation from the expected maximum performance (Menascé).
Thus we aim for a model that will maximize the benefits (Mbiydenyuy(b) et al., 2009) such that the QoS requirements are satisfied. This means that instead of considering only services that are beneficial (Mbiydenyuy(b) et al., 2009), idling system resources may lead to a penalty based on the extent to which the QoS requirement are satisfied. The modeling makes a number of assumptions:

- A MSA provides different resources based on which services can be implemented i.e. the type of resources and constraints determine the type TTSs achievable in a MSA.

- A desired (or required) QoS level can be set in advance to system implementation.

We then consider the following sets:

**Sets**

- **S** TTSs targeted for freight transport e.g. road user charging, navigation, eCall etc
- **F** Functionalities required to achieve each service in S e.g. GNSS position etc
- **H** QoS attributes for TTSs such as timeliness, availability, completeness, precision etc.
- **R** Resources such as processing, communication etc
- **A** MSA concepts; such as thin client, thick client etc, in terms of respective resource constraints e.g. communication and processing

Thus MSA (set A) can be seen as resources that are employed by different functionalities (set F) which results to a service (set S) that should meet the QoS specification (set H) as shown in the figure 5.2. For each QoS attribute, the desired QoS level with respect to system performance (will be referred to as maximum system performance in the model) is specified and compared to the QoS level achieved (will be referred to as current system performance in the model) under a given resource allocation model. Both the maximum and current system performance for each QoS dimension, are not necessarily the same for different services. In addition, transport policy requirements may lead some prioritization of the different QoS attributes.

**Assumptions**

The following assumptions are taken into consideration.

- **A1** Applications can be prioritized over others.
- **A2** It is possible to estimate resource demand.
Figure 5.2: Diagram of a generic model showing how the sets A, F, S and H are related.

A3 Priority is given some quality attributes relative to others.

A4 Applications incur a start up costs.

A5 Applications incur a cost based on usage of resources.

A6 Ratio of quality deviation equal increase in corresponding resource cost.

**Parameters**

- $B_i, i \in S$ is the (net) benefit of the service (or application).
- $B_t$, is the total benefits (real number).
- $V_i, i \in S$ is the estimated societal value of the service.
- $\beta_i \geq 0, i \in S$ is the relative priority of the service. (see A1)
- $\tilde{A}_{qi} \geq 0, i \in S, q \in H$ is the resource demand constant (see A2)
- $\tilde{f}_{qi}(x) \geq 0, i \in S, q \in H, x \in R$ is the resource (x) demand function
- $W_{qir} \geq 0, i \in S, q \in H$ is the priority of quality attribute for a shared resource (see A3)
- $C_j \geq 0, j \in F \geq 0$ is the fixed cost of a functionality resource (see A4)
- $C_{ir}, i \in S, i \in R \geq 0$ is the variable cost of each TTS for a given resource. (see A5).
- $C_{qir}, i \in S, j \in F, q \in H \geq 0$ is the variable costs of a resource for a given service and quality level (see A6).
- $M_{iq_{max}}, i \in S, q \in H \geq 0$ is the maximum service quality (desired).
- $M_{iq}, i \in S, q \in H \geq 0$ is the current service quality (attained).
- $\tilde{P}_r \geq 0, r \in R$ is the cost of resource usage.
\[ A_{tr}, t \in A, r \in R \] is 1 whenever a resource is used by architecture and 0 otherwise.

\[ \omega_t, \geq 0, t \in A \] is the total penalty cost for a given architecture.

\[ Z_t, t \in A \] is 1 if architecture is selected, 0 otherwise.

**Variables**

\[ x_i, i \in S \] is 1 if service is selected, 0 otherwise.

\[ f_j, j \in F \] is 1 if functionality is selected, 0 otherwise.

\[ \vartheta_{ii}, \geq 0, i, \hat{i} \in S, i \neq \hat{i} \] is the pairwise dependency between two services.

\[ B_t = \sum_{i \in S} \beta_i \ast B_i \left( \sum_{t \in S, q \in H} \tilde{A}_{qi} \ast \tilde{f}_{qi}(x) \right) \tag{5.5.1} \]

Where \( B_i, i \in S \) is the benefit function for application with resource demand function \( \tilde{A}_{iq} \ast \tilde{f}_{qi}(x), q \in H, i \in S, x \in R, \) for resource \( x \). This model can be extended to ITS service benefit model \( \text{[Mbiydenyuy(b) et al., 2009]} \) where benefits have been estimated by

\[ \hat{B} = \sum_{i \in S} V_i \ast x_i - \sum_{i \in S} C_{ir} \ast x_i - \sum_{j \in F} C_j \ast f_j - \sum_{r \in R} A_{tr} \ast \tilde{P}_r \ast Z_t - \sum_{i, \hat{i} \in S, i \neq \hat{i}} \vartheta_{ii} - \omega \tag{5.5.2} \]

From \( (5.5.1) \), if the application priority \( \beta_i \geq 0, i \in S \) is taken into account, the societal value of the application and the costs function in the benefits equation \( (5.5.2) \) will change, thus:

\[ B_t = \sum_{i \in S} \beta \ast V_i \ast x_i - \sum_{i \in S} C_{ir} \ast x_i - \sum_{j \in F} C_j \ast f_j - \sum_{r \in R} A_{tr} \ast \tilde{P}_r \ast Z_t - \sum_{i, \hat{i} \in S, i \neq \hat{i}} \vartheta_{ii} - \omega \tag{5.5.3} \]

From equation \( (5.5.1) \), benefits can be related to the QoS if we consider the definition of QoS with respect to system performance (as above) for given MSA.
resource allocation model, i.e. a measure of the deviation from the expected maximum performance \cite{Menascé and Bennani 2003}. Generalizing this assertion, for any given MSA resource and quality level, we obtain:

\[
Q_i = \sum_{q \in H, r \in R} W_{qir} \nabla Q_{qi} = \sum_{q \in H} W_{qir} \left( \frac{M_{qmax} - M_{iq}}{\max\{M_{qmax}, M_{iq}\}} \right), \quad i \in S \quad (5.5.4)
\]

The costs function in equation (5.5.2) can now be redefined to include a usage based cost \(C_{qir} \geq 0, q \in H, i \in S, r \in R\) that depends on the systems performance quality i.e. a deviation from maximum system performance suggested in equation (5.5.4) above, will lead to a corresponding fractional increase in the usage cost of the resource considered. Intuitively, the new costs function with a general QoS matrix can therefore be given by

\[
C_{qir} = C_{ir} + C_{ir} \sum_{q \in H, r \in R} W_{qir} \nabla Q_{qi} \quad i \in S \quad (5.5.5)
\]

Where the second term will increase the use based cost if the quality of service degrades. This can be compared to the resource cost function defined by Y. Huang & B. Chao (2001) which is essentially the weighted sum of the ratio of current-to-maximum available resources \cite{Huang and Cha 2001}. Therefore the new benefit function with consideration for QoS can be given by

\[
B_i = \sum_{i \in S} \beta_i V_i x_i - \sum_{q \in H, i \in S} C_{qir} x_i - \sum_{j \in F} C_j \cdot f_j - \sum_{r \in R} A_{tr} \cdot \tilde{P}_r \cdot Z_i - \sum_{i, i \in S, \quad i \neq i} \vartheta_{i i} - \omega \quad (5.5.6)
\]

Two subjective measures in equation (5.5.6) are \(\beta_i \geq 0, W_{qir} \geq 0, q \in H, i \in S, r \in R\), which gives priority to certain applications, and quality attributes (for given resources), respectively. The function (5.5.6) estimates the benefits of different system applications with consideration for the QoS related to desired system performance.

### 5.6 Concluding remarks and future work

This work proposes a mathematical modeling that can be used to study how QoS characteristics may influence potential benefits of MSAs for road based freight TTSs. MSAs are considered to provide application resources like communication...
infrastructure and processing and QoS attributes create a demand on these resources (performance) leading to reduced MSA benefits, if such demands are not met. At the planning stage, resources employed by different applications (TTSs) are estimated in quantitative parameters and decision variables formulated into a mathematical model. Instances of the system behavior at run time can be analyzed with the model to estimate how the benefits of MSAs may be affected by QoS using a given resource allocation model. A system performance oriented QoS measure has been introduced providing a possibility to capture different quality attributes, desired performance levels, and even the possibility to introduce desired priorities between applications and quality attributes. Literature reviews within QoS and MSA benefits reveals that most of the studies carried out so far were eccentric to the subject matter investigated by our study.
5.7 References


Chapter 6

Appendix: Elaborate description of transport telematic services

This section provides an elaborate discussion of all Transport Telematic Services (TTSs) that are analyzed in papers II, III and IV. These TTSs are considered in the context of vehicle, goods, drivers, owners, infrastructure and other stakeholders that in one way or another have a contribution to road transport operations. These services may not be directly linked with the physical transportation activities but they contribute to solidify the information backbone that underlines such activities since logistic transactions are incomplete until the information flow accompanying the physical flow is completed. Some services have been deployed and already in existence e.g. eCall, Road User Charging etc. Others are at different stages of their development e.g. Intelligent Speed Adaptation, while some are preconceived within the Swedish project Mobil IT for Goods Transport according to identified needs of the HGV industry in Sweden.

6.1 Accident Warning Information - AWI

How fast information about an accident spreads determines the aftermath effect of an accident e.g. queue build up, chain accidents, fire, rear end collisions considered to be 13.5% of accidents in Sweden in 1999 [Biding and Lind (2002)] etc. In addition dynamic information sharing about accidents will help improve driving attitude especially on roads with high frequent accident reports. AWI service is similar to on-board safety and security monitoring service except that AWI
is focused faster dissemination of accident information. Additional information such as fire, contingent agents released into the air etc will help the driver and traffic controllers to take appropriate decisions without delay, thus reducing the negative impacts related to the accident. This service will therefore contribute to driver support, traffic management and transport management. Functionalities such as accident sensors, alarm signals, data broadcast, data storage, digital tachographs, LCD driver display, local or reference positioning, OD data logger, ramp metering, road congestion sensors, time stamping, weather forecast, vehicle data and vehicle speed meters are necessary to achieve this service. Freeway incident warning systems have shown that travel times could be reduced by 21% (Shawn and Smadi, 2000) and fuel and delays can be reduced by up to 3% and 7% respectively (Wunderlich et al., 1999). These results can be compared to theoretical results obtained by simulation which show that if information is received in 20 minutes time lag to an incident, the result could lead to decisions that will save as much as 10% trip times (Wunderlich, 1998). In the case of HGV transport in Sweden we anticipate a small reduction in total accidents (0.15%), total fuel consumed (0.1%) and delays (0.2) and a relatively higher reduction in total travelling time, 5%.

6.2 Automated Driver Logs - ADL

There is a need to accurately record various timely based activities for drivers, which is complicated due to their constant mobility. It does not only cost time to manually register all activities along the way and submit them back to the main office, but such manual work may lead to inaccuracies. In addition the driver may unintentionally be under the influence of external factors such as medication or alcohol that could possess a risk to his own life and other road users. Of a total of 247 drivers who died in road accidents in Sweden during 2008, 16% had an intolerant (<0.2% pommel) alcohol level in their blood some of which were HGV drivers (HEAVYROUTE(b), 2010). This service contributes to driver support and administrative support. The service offers a possibility of automatic data registration e.g. driver work hours, overtime, sick leave, vacation, allowances, driver condition etc, to the appropriate department in a company e.g. accounting system. Thus the primary beneficiary includes the personnel management department and the drivers of HGVs. Functionalities include data broadcast, driver data recorder, local positioning, time stamp, vehicle data logger and voice communication. This service will contribute to reduce administrative work for the driver and back office. Since the time use to manually log driver data and calculate salaries is a small process of the entire administrative work, we assess a 2% reduction in the total administrative work and 0.01% in total driver time. An added functionality to this service could take into account the
drivers alcohol blood level and report this data to back office. This will have a slight influence on accidents related to alcohol (0.1%).

6.3 Driver Planning -DP

Different HGV drivers have different preferences and experiences that maybe difficult to realise when planning a considerable number of drivers and their tasks e.g. time of day, route, vehicle, product, season etc. Changing conditions impose a seamless requirement on the process of driver planning which becomes complex when dealing with a large number of drivers. It should be noted that driver planning is considered separately from fleet scheduling because it involves additional constraints e.g. work hours, personal preferences etc. This service is required to balance work among drivers and maintain a seamless plan that meet driver preferences. For this reason the driver planning service will facilitate staff administration and improve job satisfaction. The service is primarily for personnel manager dealing with driver planning. Data encryption and broadcasting, digital tachographs, driver data, goods data, local positioning, OBU, OD data logger, time stamping, weather forecast and vehicle data logger are necessary functionalities. Optimizing driver planning has the potential to reduce administrative costs (0.3%) especially because such planning and time based costs (0.1%).

6.4 Dynamic Traffic Information -DTI

Insufficient traffic information leads to delays, congestion and eventually high costs for society (Eliasson, 2006). There is a need for road users and environmental management agents to constantly remain informed about traffic conditions in order to achieve better solutions that will counteract dynamic traffic changes such as traffic flow speed, weather etc. This service therefore supports drivers, traffic management, fleet management, environmental management and infrastructure management. Users are individual drivers, traffic control agents, dispatchers, environmental agents, and infrastructure operators. Functionalities are accident sensors, data broadcasting, data updates, digital tachographs, driver LCD display, global positioning, infrastructure damage sensors, infrastructure data, OBU, OD data logger, ramp metering, road congestion sensors, signal delay, tidal flow control and traffic priority, signal delay, time stamping, weather forecast, vehicle speed meter and voice communication. Dynamic traffic information will help users take appropriate decision in responding to current traffic situation according to their needs. Such decisions will potentially lead to an overall small percentage of total time savings which we assess at 0.5%. The value of such time (suggested to be 5.8€/ vehicle hour, for passenger transport, thereby increasing the value
of time considered to be at 11.5€/vehicle in Petersson (2007) will be higher for HGVs. By providing dynamic traffic information in real time, this will lead to reduced congestion and hence reduced delays (0.01%) and less fuel consumption (0.02%). Real time traffic information will also lead to better utilization of infrastructure capacity assessed in this study at 0.01%.

6.5 E-Call -EC

There is need for reducing the time taken to locate and rescue victims of an accident and as well as the vehicle and its contents. The service will improve traffic management, transport management and provide support to drivers and other vehicle occupants. Primary users include drivers, emergency units, traffic controllers, and goods owners. To achieve this, functionalities to detect accidents (sensors), alarm signals, automatic trigger, camera vision, data broadcasts, data updates, digital tachographs, driver data logger and LCD display, global positioning, sensors for detecting good damages and possible involvement of human beings in the accidents, goods data logger in case there are secondary effects from the goods, reference or local positioning, maintenance history for possible cause of accidents, map position and updates, network optimization, OBU, ramp metering, road congestion sensors, short range communication such as DSRC, traffic signal delay, tidal flow control and traffic priority, time stamping, vehicle damage sensors, vehicle data, speed and voice communication are all necessary. An estimated life saving potential of 2500 lives is expected every year and reducing the severity of injuries for thousands more should this service be implemented in entire Europe (ERTICO-eSafety 2009). The service has a potential to reduce the duration of obstacles on the road. This will lead to reduction in vehicles total time based costs. Accidents costs and impacts will also be reduced. Previous studies in Stockholm, suggest the accident reduction potential between 5% to 15% SRA (2005). For HGV transport we anticipate a reduction in accidents costs of 15% in Sweden because often HGV accidents have a higher material cost than private cars. Clearing accident scenes faster will potentially reduce delays and lost goods (0.1%) while reducing the total travel time by a small percentage (0.1%).

6.6 Emission Testing and Mitigation -ETM

With increasing environmental awareness there is a need to measure emissions so as to evaluate environmental performance indices for vehicles, roads or traffic continuously in order to support policy making e.g. attain anticipated emission reductions. In addition environmental performance information is necessary to
help road users adopt more responsible behaviour toward the environment and this is increasingly encouraged today in the form of eco-driving. The service also provides a means to control traffic in air quality sensitive areas. The service supports environmental management and is directed primarily to agents in charge of environmental management related to road traffic for HGV. Vehicle owners and drivers can use the service to understand and improve their impact on the environment. Functionalities include data broadcast, data storage, driver interface (LCD), emission data, global positioning, map positioning and updates, monitoring, OBU, road congestion, short range communication and vehicle data. Attempts to reduce emissions will lead to a reduction in total fuel consumption (e.g. by users practicing eco-driving) assessed at 0.1% and other related external emissions such as nitrogen and particles (0.4%).

6.7 En-Route Driver Information -EDI

HGV transport involves navigating through accessible areas in order to load and unload goods. Drivers frequently have to drive different routes whereby the need for route information is critical to successfully completing their mission. In addition the driver needs to exchange some information with back office staff based on order changes made while the driver is en-route. Thus the service is similar to route guidance except for the fact that in addition there is information relay both with the back office and with the loading/unloading docks. This is a driver support service that seeks to provide general but accurate information about traffic, transit, road conditions, weather conditions, traffic controls, cameras and road traffic intervention. The service can facilitate the task of individual drivers and fleet operators. Data updates, driver LCD interface, local positioning, map position and updates, OBU, OD data logger, road congestion, short range communication, tidal flow control and traffic priority, weather forecast, vehicle speed and voice communication. Accurate en-route information can potentially reduce both driving time and distance since information about loading/unloading locations become more precise. Thus we anticipate a 1.5% reduction in total driving time with en-route driver information and a small reduction in the cost of administration and delays (0.1%) because back office activities can be coordinated with driver en-route information.

6.8 Dynamic Estimated Time of Arrival -ETA

Inaccuracy in the prediction of traffic changes leads to difficult decision making in the different links along a supply chain system and not the least in estimating the arrival time of cargo. This brings about a need to continuously monitor
traffic situation and evaluate the current arrival time estimate, dynamically so as to feed reliable information back to down-and-upstream processes in the supply chain. Today’s solutions are led reliable because travel times are calculated on the basis of speeds pre-defined for specific road categories. This makes it difficult to dynamically consider travel time interference such as signal delays and queue build up, accidents and other road hindrances. The service will help in the domain of transport management and fleet management. The primary users are goods owners and dispatchers. Functionalities are data broadcasting, digital tachographs, global positioning, goods data logger, monitoring, network optimization, OD data logger, road congestion sensors, signal delay functions, time stamping, weather forecast and vehicle speed. By dynamically estimated the time of arrival considering the current traffic situation such cost can be reduced. We anticipate that the total administrative cost can be reduced by 2%.

6.9 Freight Mobility -FM

This service will provide real-time communications between commercial vehicle drivers, freight data users, and intermodal transportation providers to locate, dispatch and track commercial vehicles, with focus on freight data and freight movement. Such data can be used for different purposes including transport administration, goods control and research e.g. estimating the value of goods, the value of time, costs of delays, costs of damages etc. This service will support transport management, infrastructure management and environmental management. Primary users are research and infrastructure investment agencies, transport planners, and infrastructure owner as well as researchers. Functionalities are data encryption, digital tachographs, global positioning, goods data loggers and goods damage sensors, monitoring, OBU, OD data logger, short range communication, time stamping, and vehicle data. By providing information on the movement and type of good, this service is expected to have a small reduction (0.5%) on the total transport administration.

6.10 Geo-fencing-GEO

There is a need to control access to particular areas such as corridors, military areas, accident areas, parking areas, tunnels etc without using any physical barriers. This can be achieved with a service that set up a virtual electronic demarcation round designated areas of interest. This service will enhance transport management, fleet management as well as infrastructure management and security. Users of the service include infrastructure owners, dispatchers, and good owners. Functionalities include alarm signals, automatic trigger, camera vision, data
broadcasts, digital tachographs, global positioning, network optimization, ramp metering, short range communication, time stamping, and vehicle data. A geofence will potentially lead to a small reduction in total time and administration (0.003%) of access rights to secured areas as well as a relatively larger impact on intrusion detection that may reduce goods theft (0.2%).

6.11 Goods Identification -GI

There is a need to identify goods without coming into physical contact with such goods e.g. in order to determine the handling process at loading and unloading docks. In addition control and inspection of freight e.g. by custom officers, requires that the goods are identified. This service addresses the core transportation management activities like loading and unloading of goods. Users of the service include the owner of the goods, gate controllers, terminal operators, goods inspectors, custom officers and emergency units in case of an incident. Important functionalities to this service are sensors for identifying different classes of goods. As with dangerous goods, goods could be classified into categories to enable such identification. Automatic trigger, and data encryption, broadcasts, updates as well as global positioning, goods data and good damage sensors, map position and updates, monitoring, OBU, OD data logger, time stamp, vehicle data and speed are all necessary to deliver this service. are a required. A GI service can potentially reduce administrative time and delays at control stations. There is a higher potential to reduce administrative time compared to delays assessed at 0.4% and 0.1% respectively.

6.12 Information about Infrastructure Repair and Maintenance -IRM

Preventive maintenance can prolong the life cycle of infrastructure and reduce maintenance costs as much as 25% (Hammarström and Yahya, 2000) and thus increasing benefits derived from such infrastructure. This service will support infrastructural management and environmental management measures. Users will be infrastructure operators such as road repair and maintenance unit, or agents operating bridges (e.g. Oresund bridge between Malm and Copenhagen), tunnels, corridors or ferry links. Functionalities are global positioning, sensors for determining damage to infrastructure, infrastructure data logger, maintenance history, map position and updates, monitoring, road congestion, short range communication and weather forecast. The societal value of this service can be generated by a reduction in the maintenance costs of infrastructure employing the service. HGV transport constitute a significant component of this maintenance costs today and
this service can potentially reduce this cost through the provision of information at an early stage enabling such damages to be fixed. Additionally if road users are provided with information on the state of the infrastructure they utilize there could be some positive attitude toward the use of infrastructure that could lead to sustainability of such infrastructure. Therefore a 10% reduction in such cost can be achieved on the assumption that all HGVs and corresponding roads and provided the necessary equipments. Improving infrastructure life span will lead to a small reduction in funding new infrastructure which we assess as 0.4%.

6.13 Information on the Transportation of XXL Cargo (exceed regulations) -XXL

In Sweden it is required that the transport of XXL cargo is granted special permit according to a regulation called vgtrafikfrordningen, SFS 1998:1276. Once granted, such permits apply to certain route types, given dimensions of cargo and is usually for a time limit. There is a need for drivers and administrators, especially in case of cross boarder transport, to ensure that regulations are met by both parties and minimize risk associated to XXL traffic through constant monitoring. The service contributes to support infrastructure management, transport management, and traffic management, providing authorized vehicles with real time information and the authorizing agent with the current situation on the use of infrastructure by XXL cargo HGVs. Users are infrastructure owners or operators (granting permission for XXL transport), traffic or transport controllers for the road administration and hauler companies and to a lesser extent, goods owners. Necessary functionalities include; global positioning, camera vision (external), data broadcast, digital tachographs, driver LCD display, goods data logger, infrastructure damage sensors, infrastructure data, map position and updates, monitoring, OBU, OD data logger, route congestion, tidal flow control and traffic priority, time stamping, weather forecast. Vehicle data and vehicle speed. Commercial company will experience a reduction in transport administration time used to obtain permits and information related to permissible roads. In addition real time information will be provided in case of changes in road conditions during driving that will help in decisions that can minimize delays. For the national road administration, time used to attain to different XXL transport infrastructure enquiries will be significantly reduce and the accurate use of road infrastructure through provision of real time information will sustain the life span of the infrastructure and reduce maintenance costs. However because of the relatively small amount of XXL traffic relative to HGVs in Sweden today (2%), the reduction of the total administrative time and maintenance costs will be rather small, thus we assess 0.1% reduction in both administrative costs and
6.14 Information on Truck Parking -ITP

There is a need to provide accurate dynamic information about parking areas to reduce time spent in locating a parking facility. In addition limited parking facilities require better approaches to managing available facilities. Real time parking information will contribute to driver support, infrastructure management and traffic management. Users of the service are drivers and parking infrastructure providers. Functionalities are local positioning, OBU, automatic trigger, camera vision (outward), driver LCD interface, data broadcasting, infrastructure data, map positioning and updates, network optimization, short range communication, time stamping and vehicle data. HGV drivers will experience a small reduction in total travel time by reducing time used to search and locate parking areas (and hence in delays). Lack of parking information is the reason why drivers are sometimes compelled to drive for too long hours than necessary. This leads to fatigue that may results to accidents. Such accidents can be slightly reduced by providing drivers with dynamic parking information. Practical experiences of an advanced parking management system have led to a reduction of 1% to 2% in traffic search time [Lindkvist et al. 2003] and 9% in travel time [SIAC 2007]. We anticipate that traffic search time (or delay) for HGV in Sweden can be reduced by 1% whereas the total trip time costs can be reduced by 0.1%.

6.15 Intelligent speed adaption -ISA

As a result of changing weather conditions, static speed recommendation on road marks does not provide drivers with accurate speed information. In some cases static speed recommendations or even violation of speed limit could lead to accidents. In addition a violation of speed limit or over speeding is a major cause of many traffic accidents. Drivers need to stay informed about current speed limit, and traffic controllers need to dynamically control vehicle speed based on current traffic situation. This service contributes to driver support, and traffic management. Users of the service are drivers, traffic inspectors, police and insurance companies. Functionalities are accident sensors, data broadcast, camera vision, data broadcasts, data driver LCD interface, global positioning, infrastructure damage sensors, maintenance history, map position and updates, monitoring, OD data logger, ramp metering and route congestion, signal delay, tidal flow control and traffic priority, weather forecast, vehicle data and vehicle speed. Studies estimating the value of ISA show that urban speed management can be valued at 140238K€ while Police enforcement will create an additional
value of 3311767€ the service [Eliasson 2006]. Trials of ISA in Sweden show that if every car was equipped with an ISA system, injuries could reduced by 20% to 30%, and each vehicle will experienced a small reduction in fuel consumption while travel times remain unchanged [SRA 2009]. For HGVs one cannot expect a 30% reduction in accidents because this study didn’t focus particularly on HGVs with varying speed characteristics relative to passenger cars. We anticipate a reduction in accidents of 15% and 0.1% for fuel consumption in the case of HGVs.

6.16 Navigation through a route network -NAV

As route network are built into an ever complex mesh, the number of miles driven due to drivers inability to understand the route network can be decreased with a navigation service. There is a need for improved information on route network that will help to minimise route search and associated delay. This service will contribute to driver support, and improve environmental management. Users of the service are individual drivers and commercial hauler companies, environmental agents etc. Functionalities are global positioning, driver LCD interface, network optimization, OBU, OD data logger, ramp metering, route congestion sensors, short range communication (DSRC), weather forecast, vehicle data and vehicle speed. Studies conducted in Sweden indicates that the highest effects of dynamic navigation system will be on vehicle delay for equipped vehicles in case of incident and relatively smaller effects will be on time saved for trips to previously unknown destinations and waiting time at queues [Lind 2008] reported to be between 5% to 20% savings [Planath et al. 2003]. In this study, we anticipate that a navigation service is likely to lead to a reduction in total travel time (3%), total fuel consumption (1%), and total travel distance (2%). Time spent to identify the right road will be reduced and this may lead to a reduction in travel distance and fuel.

6.17 On-board driver monitoring -OBD

For the vehicle owner, traffic inspectors and goods owners, there is a need to ensure that the drivers conditions e.g. with respect to health, during transportation do not endanger other road users, the vehicle as well as the goods. The driver also needs to be protected in case of sudden degradation in his health statues. All these bring about a need for ways of monitoring especially the drivers health conditions. This service will contribute to traffic management, administrative support, and transport management. Users of the service are drivers, traffic inspectors (e.g. police), goods owners, vehicle owners, company personnel unit, and dispatchers. Functionalities are accident sensors, alarm signals, data broadcast,
driver data, global positioning, human (driver) sensors, monitoring e.g. reaction
time etc, OBU, time stamping, digital tachographs, vehicle damage sensors, ve-

cicle data and vehicle speed. This service can reduce accidents related to driver
fatigue which have been shown to account for an average of 15% of road fatali-
ties in Sweden [˚Asa., 2009]. We assess that half of fatigue related accidents can
be reduced by monitoring the drivers health situation and this can potentially
reduce 1% of the costs of road accidents related to HGVs.

6.18 On-board safety and security monitoring - OSM

The driver has to constantly ensure that the vehicle (also monitored through
remote monitoring service) and it content does not provide or become exposed
to high risk. In transportation of certain products like dairy products, the driver
has to occasionally stop the vehicle and manually check the statues of the goods.
This is not only strenuous but result to delays. In addition the vehicles OBU that
will be used for other telematic applications will need to be monitored to ensure
it statues is correct. All these make it necessary for on-board safety and security
monitoring. The service will contribute to driver support and transport man-
agement. Users of the service include individual drivers, vehicle inspectors and
telematic service providers making use of vehicle OBU. Functionalities include
alarm signal, camera vision (inward), digital tachographs, global positioning,
goods damage sensors, human sensors, vehicle maintenance history, monitoring
e.g. driver attention, fatigue etc, OBU, short range communication, vehicle dam-
age sensors, vehicle data and vehicle speed. For more information about this
service see [Cooper et al., 2007]. We anticipate that this service will potentially
influence total cost of HGV related accidents by 1% because it will be left to the
driver or intervening authority to act on the information provided by the service
as the service will not directly intervene with the driving. A relatively small im-

cpact on total HGV time based costs (0.1%) and administrative costs (0.1%) can
also be expected since the driver will not manually monitor the goods and back
office can receive information about the statues of the goods that can be relayed
to the good owner.

6.19 Pay as You Drive -PYD

In addition to the need for accurate evaluation of traffic insurance for car owners
good driving can get rewarded with low insurance premiums. The same principle
could also be employed in rewarding drivers who make an effort to limit their
emissions. Such a service is expected to leave an impact on drivers behaviour
in traffic and with respect to the environment, and help in forging environmen-
tal control policies thus contributing to traffic management and environmental
management. Users of the service are insurance companies, drivers and environ-
mental management agents. Accident sensors, automatic trigger, data encrypt-
tion, data broadcasting, data storage, driver data global positioning, maintenance
history, monitoring, OBU, OD data logger, route congestion sensors, time stamp-
ing, weather forecast, vehicle damage sensors, vehicle data and vehicle speed are
functionalities require to achieve this service. Charging per use insurance has the
potential to redundant trips leading to reduced mileage, time spent on road and
fuel consumed. Related studies in the US suggest the potential of 10% reduction
in mileage and fuel consumption as well as a 15% reduction in total crashes (Lit-
man 2009). In the Swedish case we suggest a small reduction in fuel of 1% and
even small reduction in time, distance and accidents costs of about 0.1% each
because we anticipate that PYD for HGV will be less than for passenger cars.

6.20 Real Time Track & Trace of Goods -RTT

As a result of changes in traffic conditions, sometimes vehicles are delayed leading
to late deliveries, disruption of the supply chain, increased damages and failure
in scheduled plan etc. This brings about a need for real time track and trace
of goods as opposed to todays solution in which goods are scanned at terminals.
With real time information, associated supply chain activities like production
planning or distribution can be adjust to meet the current statues and location
of the goods. On the other hand, changes in the supply chain activities could
necessitate the track and trace of goods in real time. This service support activi-
ties of transport management, fleet management and traffic management. Users
of the service include goods owner, dispatchers, and traffic controllers. Func-
tionalities for achieving the service are data broadcasting, data updates, digital
tachographs, driver data, driver LCD interface, global positioning, goods data,
map position, network optimization, OBU, route congestion sensors, short range
communication, time stamping, weather forecast, vehicle data and vehicle speed.
By tracking HGVs in real time, there is a potential of optimizing their schedule
based on production changes or customer choices which can ultimately lead a re-
duction in the HGVs total travel time. We anticipate a small reduction in travel
time by this service and hence suggest 0.1%. The possibility to locate and trace
a vehicle at real time will also reduce administrative costs (0.1%) as well as the
cost of missing and delayed goods 2%.
6.21 Remote Declaration -RED

During transportation, goods are declared at gates for loading, unloading or consolidation; customs check points and taxation authorities for control. These multiple declaration points contribute to increase delay in delivery, congestion and additional cost for companies. There is a need to minimise goods declaration time at gates and check points. The service will support transport management, and traffic management. Users of the service are goods owners, gate controlling agents, loading and unloading terminals, customs, police and tax agents. Functionalities for this service are camera vision, data encryption, data broadcast, data storage, local positioning, driver data, driver LCD interface, goods damage sensors, goods data, OBU, OD data logger, short range communication, time stamping, vehicle data and voice communication. By reducing time spent in the declaration and control goods at gates (mostly manual today), this service will contribute to reducing vehicle fuel costs and time (waiting time) based costs. Considering that gating time does not constitute a significant portion of vehicle journey time, a reduction of total journey time from this service will be small and we assess this to be 0.1%. A similar small reduction will be experienced in fuel consumption (0.1%). The road haulers administrative cost will experience a small reduction (0.1%). There will be improved information flow on goods that will lead to a reduction in missing goods.

6.22 Remote Monitoring -RM

Vehicle breakdowns result to cost, delays and in some cases accidents. Vehicle maintenance accounts for a significant cost to trucking companies and as much as 45% of inspected HGVs in 2009 by the Swedish Vehicle Inspection Agency, bilprovning, were not approved [Kågeson and Dings 2000]. The cost of maintenance can be minimised through remote monitoring that will enable preventative maintenance. A RM service collects vehicle performance data and predicts faults in the vehicle thereby helping to recommend maintenance to the appropriate unit. The service provides support to fleet management. Primary users of the service are dispatchers, individual drivers and maintenance units. Enabling functionalities include accident sensors, alarm signals, automatic trigger, data storage, data updates, global positioning, maintenance history, map positioning, monitoring, OBU, short range communication, time stamping, vehicle damage sensors, vehicle data and vehicle speed. The service has a potential to reduce time spent because of vehicle faults by eliminating potential faults through preventive maintenance and also reducing diagnostic time when there is a breakdown. We assess a higher potential to reduce time based costs (1%) compared to costs of accidents and delays (0.1%).
6.23 Road Hindrance Warning -RHW

Road hindrance can potentially lead to queue build up, delays in deliveries, increased emissions or even disrupt the entire supply chain processes etc. While a great number of services already provide information related to road hindrance in different ways, it is important that this information is used to provide some solution in the different scenarios that may occur in relation to road hindrance e.g. alternative roads, recommended driving speed, estimated hindrance duration etc. This will contribute to driver support and fleet management domains. Individual drivers and fleet operators are the direct users of this service. The functionalities for realizing this service are accident sensors, alarm signals, digital tachographs, local positioning, map position and updates, network optimization, OBU, OD data logger, ramp metering, route congestion sensors, signal delay, tidal flow control and traffic priority, time stamping, weather forecast and vehicle speed. The service has the potential to locate hindrance early enough for the driver to take appropriate actions in order to avoid queue build up leading to a reduction in total travel time assessed at 5% and a reduction in accidents as a result of hindrance (0.3%) and a slight reduction in total fuel cost (0.1%).

6.24 Road User Charging Service -RUC

Building seamless transport on roads requires that the collection of road charges should not bring about additional delays as is the case with toll booths. In addition to this, road infrastructure is expensive and there is need for more efficient and accurate approaches to charge and collect road fares especially to internalise the external costs of road transport. In particular RUC system as anticipated in Sweden can provide the possibility to avoid congested roads and redirect traffic to desired roads. Relevant systems are under consideration by most European countries today (Kågeson and Dings, 2000). This service will contribute to improving the management of road infrastructure and support driver activities by minimising delays at toll booths. The main users of this service is the road infrastructure operators and users such as hauler companies, government agents responsible for road operations, other agents overseeing the task of collecting charges for road usage etc. Important functionalities required to achieve these are; data encryption, data storage, global positioning, infrastructure damage sensors, infrastructure data, map position and updates, OBU, OD data logger, ramp metering, route congestion sensors, tidal flow control and traffic priority and time stamping. Based on the Swedish concept for the RUC differentiated according to time of the day, vehicle type, road type, and driven distance, societal effects can be expected in fuel, distance, time (mostly congestion), infrastructure maintenance and road capacity expansion related costs. Trials of Electronic Fee Collection
systems show a reduction in traffic growth (5%), vehicle trips (8%), and empty trips (20%) (Elvika et al. 2007) while congestion schemes in Stockholm have led to reduced traffic (10% to 15%), less queue time (30% to 50%), less emissions (2.5%) and less accidents (5% to 10%) (Broaddus and Gertz 2008) as well as 16% less congestion (Algers et al. 2006). Considering that the PSIs in this study are calculated for the entire HGV fleet in Sweden, high savings are unlikely to be achieved on such a large scale. Therefore we assess a relatively small savings on fuel and time of 1% and even a smaller reduction of 0.1% in distance based costs, infrastructure maintenance and infrastructure capacity.

6.25 Route Guidance -RG

While a navigation service addresses problems of driving through road networks, there is a need for more specialised information for HGV drivers on a given road. To provide details such as zebra crossing, lane change, school children etc special real time information is needed when a driver has settled down to drive on a given route. The service is similar to en-route driver information except that focus is on specialized information along a given route and not on relaying information with back office as with en-route driver information. In addition, there is a need for infrastructure owners and traffic controllers to be able to influence the use of a given road. Thus a road guidance service will support drivers, infrastructure management, and traffic management. Primary users are drivers, infrastructure operators, and traffic control agents. Functionalities are driver LCD interface, global positioning, infrastructure damage sensors, infrastructure data, map position and updates, monitoring, network optimisation, OBU, OD data logger, ramp metering, route congestion sensors, tidal flow control and traffic priority, weather forecast and vehicle speed. Research on RG has reported significant reduction in travel times under average congestion conditions for all vehicles (Wunderlich 1998). This service is expected to bring about total travel time saving and hence savings in fuel and delays assessed to be 1% each. Travel time reliability will also be more accurate with a route guidance service.

6.26 Sensitive Goods Monitoring -SGM

Sensitive goods such as perishable food products, drugs, fuel, alcohol, weapons, nuclear material and other goods classified as dangerous goods that can be harmful to human beings, animals, environments or other goods if not properly handled, needs to be monitored for various reasons e.g. to ensure that the product transportation is secured and legal, that it is transported on correct roads etc. Legal responsibility for certain types of goods needs to be controlled. The service
supports the domain of transport management and is of high interest to governmental agents in charge of inspection and control of goods such as customs and, local and regional authorities. The following functionalities are necessary to achieve this service; data encryption, data storage, data broadcast, digital tachographs, driver data, emission data, global positioning, goods data, map position and updates, monitoring, OD data logger, route congestion sensors, tidal flow control and traffic priority, vehicle data and vehicle speed. Based on SCB statistics, dangerous goods constituted 0.31% of total traffic in Sweden and were involved in some 346 accidents in 2008 [SCB 2008]. We anticipate that sensitive goods monitoring service will reduce cost related to transport administration by 5%, total number of HGV related road accidents by 0.2% and more information will lead to about 0.1% reduction in the costs of missing and delay goods.

### 6.27 Staff monitoring -SM

A study addressing fatigue for Swedish drivers indicate that fatigue alone constitutes some (10-20) % cases of fatal accidents under less intense traffic conditions [SRA 2005]. Information about driver fatigue and other important data is however not accessible to the hauler administrative staff, police or traffic controllers and in some cases drivers may underestimate the risks associated to fatigue during driving. Staff monitoring service is similar to on-board driver monitoring service except that staff monitoring focus on all company staff, collecting driver data to facilitate administration and traffic management, whereas on-board driver monitoring is focused on security and safety of the driver and other onboard elements during travel. This service offers direct support to staff administration by providing accurate information on driver alertness and behaviour e.g. reaction time, mischievous behaviour in fuel stations etc. This will enable the road haulier administrators to monitor advice and assign task according to the driver capabilities and minimise risks associated to fatigue. Necessary functionalities are vehicle data, vehicle speed, data encryption, data broadcasts, data storage, driver data, global positioning, map position and updates, monitoring, OD data logger and time stamping. A significant contribution of this service is expected in reduced administrative burden (Hauler Company) and accidents related to fatigue at 0.05% and 0.01% respectively.

### 6.28 Theft Alarm and Recovery -TAR

As a result of their constant mobility, there is need to improve security for the vehicle, driver and content. Numerous cases of sabotage to HGV drivers and their load are reported every year, about 2140 for HGVs in 2008 [Nilsson and Rosberg]
of the total of 27900 car related crimes (BRÅ, 2008). This service will contribute to supporting driver, transport management and fleet management. Users of the service are drivers, goods owners and dispatchers. The service supports measures against theft while facilitating location and recovery of vehicle if stolen. Functionalities include automatic and manually activated alarm systems, camera vision, data broadcast, data storage, digital tachographs, driver data, global positioning, goods damage sensors, goods data, human sensors, map position and updates, route congestion sensors, time stamping, vehicle damage sensors, vehicle data and vehicle speed. Improved control of vehicle access is expected to lead to a reduction in total costs of theft. Assuming that all HGVs in Sweden acquire the necessary device for this service a great reduction can be achieved in the number of thefts 15%. This will lead to a reduction in total vehicle time based costs as well as administrative costs spent to locate and recover the vehicle when stolen assessed at 0.1%.

6.29 Transport Order Handling -TOH

As orders are received continuously by a transport planner, location (origin and destination) for loading and unloading changes frequently and so does the fleet plan bringing about a need for a dynamic approach to order handling e.g. contract terms fulfilment, reassignment of vehicle, drivers, changes in production plan etc. To meet customer orders there is need for accurate real time information flow from customers to transport planners and then to drivers and vice versa. This service directly supports administration and transport management. Users of the service include transport planners with the responsibility of handling orders as well as goods owners to be aware if and when their orders are being handled. To achieve this service it is necessary that functionalities are data encryption, data broadcasts, data updates, driver data and LCD display, local positioning, goods data communication, OBU, location (of goods and vehicle), intersystem communication e.g. with accounting department system are required, map positioning, OBU, OD data logger, route congestion, time stamping, weather forecast, and vehicle data. Real time electronic order handling has a significant potential to save total travel time for the driver and back office time for the administrative staff. We assess the saving potential to be 3% of total time and 0.2% for transport administration.

6.30 Transport Resource Optimization -TRO

Limited resources are deployed in order to execute a transport operation whereby unpredictable traffic conditions make it necessary to improve overall resource
utilisation through optimization. While there exists systems for planning and optimization of specific tasks e.g. fleet, personnel, infrastructure utilization etc, overall resource optimization in real time will minimize significant negative effect of one system or operation on the others. The service therefore supports administration, fleet management and other processes such as inventory management. Direct users are administrators, dispatchers and infrastructure operators. Functionalities are data encryption, data broadcasting, data updates, driver data logger and LCD display, data storage, digital tachographs, emission data, global positioning, goods data, infrastructure data, map position and updates, monitoring, network optimization, OBU, OD data logger, route congestion sensors, signal delay, tidal flow control and traffic priority, time stamping, weather forecast, vehicle data and speed as well as voice communication. Commercial transport optimization packages such as TourSolver are reported to reduce up to 20% cost in overall transport activities and signal delay alone has been shown to reduce delays by 16.5% to 24.9% [Alexander 2001]. Resource optimization has the potential to reduce total fuel consumption and total distance travelled especially empty mileage. We assess the potential of such optimization models to reduce up to 3% of total time and distance based costs, less reduction of 2% in total fuel costs, and a 1% in externalities such as noise and NO₂.

6.31 Vehicle Follow Up -VF

There is a need for an assessment of vehicle performance. Such performance evaluation will enable understanding the different impacts associated to HGV transportation and this will help vehicle owners to make maximum use of the vehicle e.g. vehicle mechanical statues may not permit it to be used for certain tasks. A lot of data about HGVs, drivers and goods made available to back office in real time will combine to help in the planning and decision process. Vehicle follow up service is focused on collecting and analyzing vehicle performance related data e.g. empty mileage, fuel consumption, vehicle statues etc then reporting such data to different interested groups. The service directly appeals to fleet management and environmental management agents concerned with vehicle emissions as well as back office staff. Dispatchers will use this service to properly plan their fleets to meet different performance needs and maintenance unit to schedule vehicle maintenance. Functionalities for this service are data encryption, data broadcasting, data storage data updates, digital tachographs, driver data and LCD display, emission data, global positioning, maintenance history, map position and updates, monitoring, OBU, OD data logger, route congestion, time stamping, vehicle damage sensors, vehicle data and speed. A VF service is expected to attain a 0.3% reduction of total fuel costs since it will provide performance based advice to driver and fleet manager. An implementation of
this service can also lead to reduced time based costs and administration because performance data will enable administrative processes and reduce time used to manually collect and analyze such data assessed at 0.1%.

### 6.32 Weight Indication -WI

To better make use of road infrastructure such as bridges and tunnels, drivers and control agents need to share information of the Vehicles total weight and the infrastructure conditions and limitations that may constantly change over time. Infrastructure such as roads bridges and tunnels tend to degrade rapidly partly due to violation of restrictions (directive 96/53/EC) such as maximum weight limit (60 tons on Swedish roads), height, vehicle length etc, by HGVs using such infrastructure. In addition utilization of infrastructure such as bridges and tunnels may require understanding key instructions that could be difficult for first time users. Road construction companies make use of WI data in pavement design while inspection agencies may use it for control of overloaded vehicles. There is need to continuously monitor the weight of a HGV under transportation and this is sometimes referred to as weigh-in-motion. Most WI system in existence today are located on the infrastructure sight, whereas we anticipate a WI system on board a HGV where the total weight of the HGV is communicated to appropriate units on a continuous and regular base. This will provide support for drivers as well as traffic managers. This service will be used by drivers and traffic controllers in charge of special infrastructure such as tunnels, bridges, special road segments etc. Functionalities include alarm signals, automatic trigger, camera vision, data updates, driver LCD display, global positioning, goods data, infrastructure damage sensors, infrastructure data, map position and updates, monitoring, short range communication, weather forecast, and vehicle speed. Theoretical statistical analysis of weigh-in-motion at stations for HGVs in the UK shows a 36% potential time saving at gates, improved accuracy of weight information and less delay [Rakhal et al., 2003]. With a WI service the number of vehicles that will conform to infrastructure restrictions will increase and this will improve the utilization the utilization of such infrastructure and hence less maintenance cost. Thus we assess a 5% reduction in road infrastructure maintenance costs, 0.1% reduction of total travel time due to reduced gate time.
6.33 References


HEAVYROUTE(b) (2010). *Intelligent Route Guidance for Heavy Vehicles*. Deliverable 4.2, development path of HeavyRoute systems impact and socio-economic consequences.


