

ASSESSMENT OF TELEMATIC SYSTEMS FOR ROAD FREIGHT TRANSPORT

Gideon Mbiydzennyuy

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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

The focus of this thesis is the assessment of telematic systems for road freight transport from a planning perspective. The aim is to support strategic decisions related to architectural choices for such systems, with the possibility to achieve synergies by supporting multiple telematic services. The past decade has witnessed enormous growth in cargo volumes resulting in increasing demand for transport capacity. To match this increasing demand only with expansion of infrastructure, e.g. road and vehicles, does not seem to be a sustainable strategy. One of the few approaches with the potential to improve the use of current transport capacity is the integrated use of modern information and communication technology, otherwise known as telematic systems for road transport, an important component within Intelligent Transport Systems (ITS). This type of systems can deliver multiple services that can be used to improve the efficiency and safety of road freight transport. However, attempts to unleash the potential of telematic systems and make maximum possible use of the available transport capacity have been hindered by several challenges ranging from planning and design to development and deployment.

Considering the large scope of possible telematic services that can potentially be deployed in road freight transport, this thesis suggests a framework in order to enable structured assessment of telematic systems. Based on the suggested framework, a set of potential transport telematic services are identified and a method for quantifying the value of the services to society is developed. The suggested method takes into account the expected impact on different transportation challenges, such as accidents, fuel consumption, and infrastructure maintenance. Quantitative methods are provided for studying the value of services sharing a common infrastructure. Using quantified benefits of services and costs of various functionalities required by telematic services, the concept of a multi-service architecture is investigated using optimization methods, which handles the multi-dimensional relations between different services that are otherwise difficult to analyze with traditional cost-benefit analysis. The analyses show which telematic services can be achieved with different approaches, such as vehicle-to-vehicle communication, vehicle-to-infrastructure communication, etc.

Although multi-service architectures are promising, several challenges need to be overcome, including security, service quality, privacy, and business models. The knowledge gained from the work presented in this thesis can be valuable for different stakeholders, such as governments, service providers, and transport service users, in fostering the planning, design, development, and deployment of telematic systems in transport.

Acknowledgments

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I would like to thank my supervisors Paul Davidsson and Jan Persson for their support during this research. I would like to thank my colleagues of the post graduate research school and the senior researchers for their invaluable feedback during the seminars. I would also like to acknowledge and thank my colleagues of the DISL group and members of the COM department, the library staff and supporting departments at BTH. I also received support from project partners including MOBIL IT, ARENA and EAST-WEST, thank you for your support. NetPort Karlshamn has also supported this research with funding and by creating an inspiring environment where most of the work has been done.

To my family and friends for encouraging, supporting and motivating me, I say thank you.

Karlshamn, December 2010
Gideon Mbiydzennyuy

Preface

This thesis can be seen as a continuous effort similar to or building on a number of Research and Developments (R&D) projects over the last decade both in Sweden and Europe at large. Initially, interest from government policy makers and commercial actors motivated a R&D project in Sweden with an aim of developing a future-oriented Road User Charging (RUC) system for heavy goods vehicles that will internalize the external costs of transport system within the project called ARENA. Further, another related R&D project known as the EAST-WEST then addressed prospects for using Intelligent Transport Systems (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 user 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 (MOBNET) 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. MOBNET 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 MOBNET and EAST-WEST projects, the R&D project called MOBIL IT project or ICT for cargo on the road, sort to identify and analyze relevant road freight transport telematic applications that can be integrated with a potential Swedish RUC system. At the European level the study and analysis of applications based on Global Navigation Satellite Systems (GNSS) in connection with road transport was initiated in a project known as GIROADS. This project considered each application from a user requirement, business model, market study and regulatory framework perspectives. Similar to the Swedish project MOBIL IT, the European EASYWAY project initiative identifies a set of necessary ITS services

to deploy at the European level, enabling stakeholders to achieve a coordinated and combined deployment of pan-European ITS services. Similar initiatives are underway in the United States and Japan. For a full report on R&D projects addressing different telematic applications, see Mbiydzennyuy et al. (2009).

In collaboration with MOBIL IT project this thesis consists of four research papers. 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, analyzing data and writing the papers. All papers in this thesis have been published as conference papers. Three of the papers (Paper II, Paper III and Paper IV) have been improved and submitted for publication as journal articles. The following papers are included:

- I. Mbiydzennyuy, G. (2009). Characterization framework for road transport telematic services. *The 9th International Conference on Transport Systems Telematics, Archives of TST, ISSN 1899-8208, Volume 2, Issue 4 Katowice-Ustroń, Poland.*
- II. Mbiydzennyuy, G., Persson J., Clemedtson P. O., & Davidsson, P. (2010). A Method for quantitative evaluation of road freight transport telematic services. *Submitted for Journal publication.*
- III. Mbiydzennyuy, G., Persson J., & Davidsson, P. (2010). Analysis of telematic systems and service in road based vehicle freight transport. *Submitted for Journal publication.*
- IV. Mbiydzennyuy, G., Persson J., & Davidsson, P. (2010). Optimization analysis of multi-service architecture concepts in road transport telematics. *Submitted for Journal publication*

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

- V. Mbiydzennyuy, G., Persson J., Clemedtson P. O., & Davidsson, P. (2009). The Value of transport telematic services in heavy goods vehicle transport *The 2nd EasyWay Annual Forum (2009), Vienna Austria.*
- VI. Mbiydzennyuy, G., Persson J., & Davidsson, P. (2008). Analysis of added-value services in telematic systems and service in road based vehicle freight transport *In the proceedings of the 14th World Congress on Intelligent Transport Systems, New York, USA.*
- VII. Mbiydzennyuy, G., Persson J., & Davidsson, P. (2009). Optimization based modeling of multi-service architecture concepts in road transport

telematics. *In the proceedings of the 12th IEEE Conference on Intelligent Transport Systems, St. Louis, MO, USA.*

Related but not included in the thesis:

- VIII.** Mbiyzenyuy, G., Clemedtson P. O., & Persson J. (2008). Added value services for road transport, MOBIL IT Report (part of the services in this report are in Appendix A).

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Introduction

The focus of this thesis is the assessment of telematic systems for road freight transport from a planning perspective. The aim is to develop approaches that support strategic decisions concerning the architecture of such systems. In particular, the thesis contributes to the analysis of the potential net benefits of architecture concepts that can support multiple transport telematic services. This section will provide the background to the thesis and present the research questions addressed. A description of the research methods used and a summary of the research contributions will then follow.

1.1 Background

Transportation is fundamental to society. Freight transport enables goods to be produced and consumed in geographically 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 of 2008 (EUROSTAT, 2010), it becomes necessary to either increase transport capacity (e.g. by building roads) or improve the efficiency of operations. In addition, transportation results in negative consequences for society, including accidents, pollution, global warming and so forth. 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 environmental repercussions. To achieve an efficient transportation system requires fast analysis and communication of transport information. The reason for this is that several factors influencing transportation are changing continuously, e.g. traffic conditions, customer orders, etc. These dynamics require transport stakeholders to take quick and accurate decisions. As a consequence, transport systems are increasingly reliant on modern information and communication technologies and this has evolved into what is known today as telematic systems for road transport, an important component of Intelligent Transport Systems (ITS). As major infrastructure investment is becoming increasingly difficult due to finan-

cial, spatial and environmental problems, telematic systems can be a useful tool for improving existing infrastructure and thereby making the movement of people and goods sustainable (ECORYS, 2005).

1.1.1 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 (EFC) and navigation systems. Services delivered by telematic systems can contribute to reducing the negative influence of transportation and improving efficiency of transport systems. They involve a broad range of technologies and application areas but are 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. This thesis refers to telematic systems mainly in the context of road transportation to collectively imply systems with the capability of collecting, communicating, processing, storing and sharing transport data in real time. Two important aspects considered in the thesis are the architectures for realizing telematic systems and the resulting services from these systems. Telematic systems are a cornerstone for ITS which, in addition to collecting, communicating and processing data, also address a broad range of issues such as human factors, privacy etc. The benefits of telematic systems are delivered to end users or transport stakeholders in the form of transport telematic services to enable them achieve different goals for improving transport efficiency.

1.1.2 Transport Telematic Services

A Transport Telematic Service (TTS) consists 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 telematic systems. More than one TTS can be realized by a single telematic system (Marples, 2010). The benefits of such a system can be considered from the type and quality of the resulting TTS. There are a large number of potential TTSs addressing different transport issues that can be deployed to improve transport resource utilization and minimize the external effects of road transport, such as emissions, accidents, and noise. A list of such services is provided in Appendix A, including Intelligent Speed Adaptation (ISA), eCall (EC), Transport Resource Optimization (TRO), Route Guidance (RG), Road User Charging (RUC) etc. Today, systems offering these services are often provided by different companies, installed on board the vehicle, and interact with the vehicle through the driver as shown in Figure 1.1.

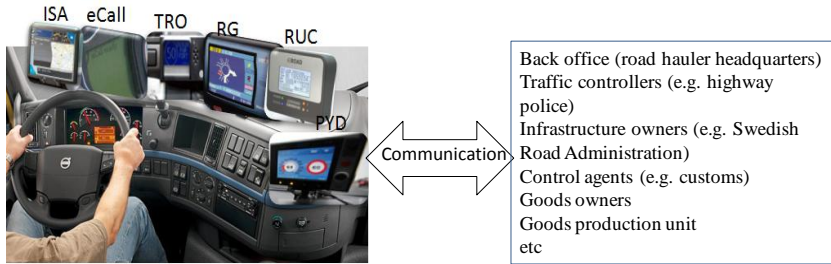


Figure 1.1: Transport telematic systems offering TTSs mounted on-board the HGV (modified with permission from “Volvo Image Gallery”, T2005 – 1949 – 1)

Information from systems delivering the services (Figure 1.1 above and Appendix A) 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 telematic systems are concerned with information security, business, technological, political, ethical (integrity and privacy), and legal aspects. Further, lack of knowledge about impacts, lack of economies of scale, high costs of deployment and operations etc are considered to be some of the reasons behind limited deployment of telematic systems in transport (ECORYS, 2005; Thill et al., 2004). Such a high cost is generated by the type of resources required to deploy the systems and also by resources that are utilized by the different systems 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 about benefits and costs of telematic systems and this is seen to be a key factor for slow investment (2DECIDE, 2010). In the same way that Internet and mobile applications each run on common platforms, one can imagine that suitable platforms for transport telematic services can help to reduce the costs of TTSs, improve system interoperability and facilitate the emergence of new services. However, there is limited understanding about the costs, benefits and other system implications of architectures that can deliver multiple end-user TTSs using shared resources.

1.1.3 Multi-Service Architectures For Telematic Systems

Specification of architectures with the potential to deliver multiple end-user TTSs are referred to in this thesis as multi-service architectures (MSAs) or sometimes generally system platforms. Most existing telematic systems today can be described as specialized islands or silo solutions, tailored according the needs and requirements of individual fleet operators (TCA, 2008). As a result the user

has to pay for duplicate functionalities when dealing with multiple TTSs. 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, (modified with permission from “Volvo Image Gallery”, T2005 – 1949 – 1)

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 Research & Development (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:

- Reduction in system economic costs through common use of functionalities
- Facilitate the development of new services 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).
- Driving force for interoperability, standards and usability.
- Improvement of trust between public-private co-operations through sharing of information.
- Reduce the burden on the driver etc.

Since MSAs with a potential for delivering multiple TTSs 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, e.g., with use of computer tools such as simulation and optimization.

1.1.4 Challenges of Deploying Telematic Systems in Road Transport

Planning is critical to successful introduction of telematic systems in road transport that meets the needs of different stakeholders. Lack of a good planning process, in most cases, is a cause of unsuccessful deployment. Several questions need answers during planning, especially because the high costs of systems do not warrant experimentation. During planning, stakeholders need to make decisions that will enable them attain their goals. Such decisions will influence the type of TTSs that are implemented. Different TTSs will lead to different costs and benefits for society. The societal effects resulting from implemented TTSs can be used to evaluate the success of stakeholder decisions in reaching their intended goals. Thus, the decision process for the deployment of telematic systems involves key entities such as:

- **Decision Makers**
Several stakeholders are involved such as local national or regional government, telematic service providers, road haulers etc.
- **Goals**
Decisions are driven by the goals addressed with the system and the availability of information about solution alternatives. The needs of each stakeholder are related to their goals, which may include constitutional and legislative constraints, income re-distribution, financing consideration, social planning etc (Bekiaris and Nakanishi, 2004). The aim of such goals is to improve a given situation or solve a problem within transportation. A stakeholder may directly determine their goal or base their goal on decisions that can have a potential impact on such goals, e.g. investment in a telematic system.
- **Decisions**
Each stakeholder faces a number of decisions and seeks to make the best decision that will enable them to achieve their goal. Here there is a choice, for example, on whether to invest in a telematic system at all, what type of system, functional specifications, architecture, expected impacts, financing etc. These choices involve structured, unstructured and semi-structured decision problems.
- **Effects on Society**
The outcome of the decisions are felt primarily by the targeted and non-

targeted users in society. These could be in the form of faster or slower freight distribution, shorter or longer queues, increase or decrease in accidents, increase or decrease in congestion etc.

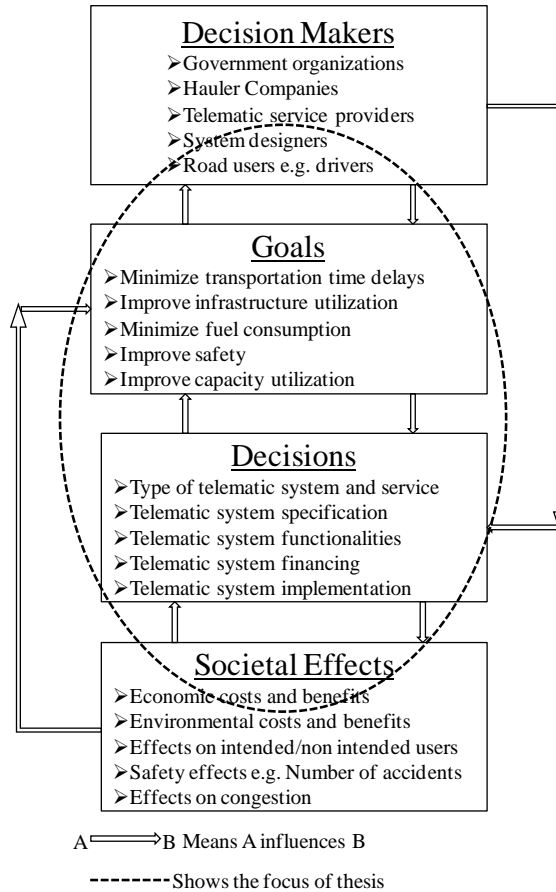


Figure 1.3: A simplified representation of the complex decision process for ITS stakeholders.

For emerging telematic systems with the potential to deliver multiple TTSs, information about alternative specifications, expected benefits and costs, etc are limited, which makes 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.

The focus of this thesis is illustrated by the dotted circle in Figure 1.3. The decisions are unstructured and involve multiple criteria with no predefined procedures and 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

This section presents the research questions addressed in this thesis and motivates the relevance of these questions for road transport telematic systems.

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

To address this question, it is necessary to formulate and use suitable criteria to first identify potentially relevant telematic services. Assessment of benefits and losses to stakeholders is central in strategic planning. As a result, the following sub-questions have been considered:

Sub-Questions

- Sub Question 1 (SQ1): Which are the relevant telematic services for road freight transport?
- Sub Question 2 (SQ2): How can telematic systems and services for road freight transport be characterized in a way that enables them to be analyzed?
- Sub Question 3 (SQ3): How can we quantify the value of a transport telematic service in order to facilitate decision making?
- Sub Question 4 (SQ4): How can we evaluate telematic systems for road freight transport?

SQ1 aims at identifying relevant telematic systems for road freight transport, SQ2 identifies the characteristics of the systems that can enable analysis, SQ3 is aimed at quantification of the effects of telematic services on society, and SQ4 formulates models of telematic systems to represent the decision choices.

1.3 Research Method

This thesis addresses the assessment 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 modeling. Generally, evaluation refers to the systematic determination of the merit of something e.g. a system objective or goals (EVT, 1999). It is this merit that guides the choice of a decision maker about alternative decision choices. The following (iterative) phases have been involved in the research presented in this thesis.

Literature Review

Relevant literature was reviewed in order to explore potentially relevant TTSs and systems in road freight transport. In the review, a number of R&D projects at the national and international levels were considered. Additionally, workshops, interviews and brainstorming activities helped to identify relevant TTSs.

Mathematical Modeling (Model Building)

By mathematical modeling we, refer to the task of building models using mathematical formulation. Mathematical modeling enables real-world behavior to be represented using mathematical formulas (variables, constants, relations and operators). In operations research mathematical models are typically abstract models of a real system as opposed to descriptive models. The key advantage of building and using mathematical models is the high accuracy of representation and concise manipulations that can benefit from the use of computer processing in the search for solutions (Rardin, 2000). The key disadvantage is that the majority of interacting components of the real world are far too complicated to represent mathematically and, hence, such models often require some simplification (Rardin, 2000). Further, mathematical models are criticized for not being able to satisfactorily quantify most of the data in the systems that are being modeled, e.g. putting a cost or utility on a given social value (Williams, 2003). Therefore, 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. Further, even with a good mathematical model, accurate input data is required in order to obtain meaningful results. Such models provide quantitative information that is easily comprehensible by human beings. An outline of the mathematical modeling process can be simplified as shown in Figure 1.4.

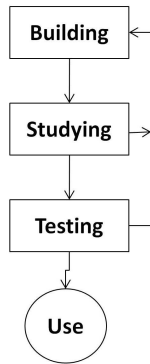


Figure 1.4: Simplified process of mathematical modeling.

Mathematical models are used in many research disciplines, including engineering, operations research, natural sciences and social sciences. For telematic systems, modelling is considered to be an appropriate method of appraisal as it enables system-wide impacts of individual responses to be predicted (Chatterjee et al., 1999). Many different types of standard models, such as simulation, optimization etc, and non-standard models have been used in operations research, especially as decision support for problems that involve alternative plans or decisions (Williams, 2003). If such 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 infrastructure, 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 reduces a given set of data into categories with similar characteristics, e.g. according to benefits. Other types of mathematical models are used to make current estimate of expected future earnings of an asset, e.g. Net Present Value (NPV). Usually, the use of NPV requires that some compensation is made against the expected future inflation. This thesis has made use of a mix of mathematical models, including optimization, clustering and NPV, all of which can collectively be referred to as analytical models. Analytical models are called close form solutions because they provide analytic functions that can be used to describe changes in a system as opposed to numerical methods.

Data Collection

Conducting experiments with analytic models requires data and such data often has to be pre-treated to fit the model requirements. Data collection for the assessment of telematic systems is a well known problem within ITS research because of the high costs of prototyping (PIARC, 2004). In this thesis, potential telematic systems identified in literature reviews are critically examined to identify relevant attributes that can be used for analysis. Various interest groups (stakeholders), domains of usage, TTS motives, functionalities, societal value etc are considered. MSA functional specifications and related characteristics are examined. Relevant data about characteristics of TTSs and MSAs, such as cost of functionalities, shared functionalities, resource utilization etc, is assembled from different sources (see Appendices A & B). Secondary sources ranging from project reports and statistical data bases (e.g. provided by Statistiska Centralbyrån (SCB), Statens institut för kommunikationsanalys (SIKA) in Sweden) to scientific papers, especially those reporting on results obtained from field trials, e.g. Research and Innovative Technology Administration (RITA) provided most of the data used in this thesis. Primary data sources have also been collected from workshops (MOBIL, IT), discussions and open-ended interviews. In some cases, meta-analysis was necessary (e.g. societal costs for fuel consumed by HGV) to pre-transform the data into a suitable form.

Verification and Validation

Validation is about the extent to which conclusions drawn from a mathematical model align with conclusions drawn from the real system represented by the model. Verification is about checking if the model behaves as intended. Usually, to study the behavior of a mathematical model requires that some data is inputted in the model and the output critically examined. The model parameters are continuously adjusted (sensitivity) until its behavior is seen to be good enough. For this reason, it is useful that validation of a model is made on data that was not used during model tuning (Bender, 1978). Mathematical models can be seen as decision support models, whereby the results of a mathematical model can be used to evaluate a system. With the help of a decision support model, the decision maker can be provided with the ability to understand the future and use the knowledge gained to make informed current decisions. Recommended decisions based on such models can be compared with real-world outcome in such a way as to validate the model. Any significant variations from the real-world situation (e.g. expert's opinion) should be explained (Williams, 2003). Conferences (in papers I to IV), workshops (MOBIL IT) and reviewers opinions provided valuable feedback that helped to improve the validity of the models proposed in this thesis. Internal validity was strengthened by sensitivity analysis.

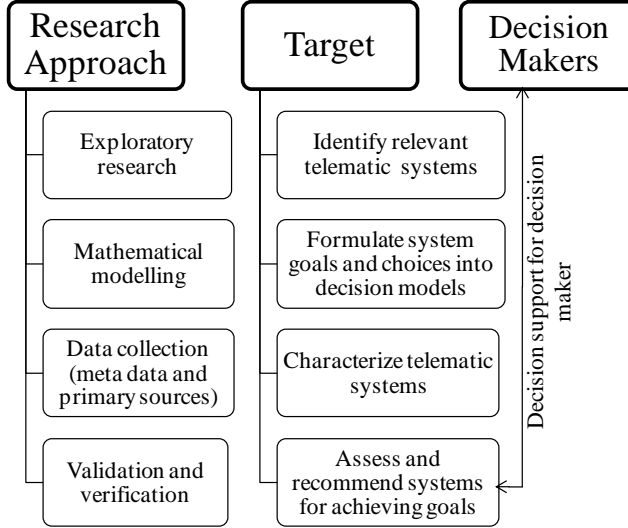


Figure 1.5: Overview of research activities in this thesis.

Figure 1.5 presents an overview of the research approaches aimed at achieving a number of targets in order to address SQ1 to SQ4. In summary, the work presented in this thesis is a result of systematic synthesis and analysis of established facts based on expert opinions and scientific theories reported in projects, academic articles and books. Sources of information addressing related work at the junction of computer science, economics, transport, communication and vehicular technology, made it that the research in this thesis can be regarded as interdisciplinary. Such interdisciplinary research can be prescriptive-driven or pragmatic, making it possible to use 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).

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. More detailed reviews are presented in each paper.

Generally ITS assessment has been addressed by a number of authors such as Bekiaris and Nakanishi (2004); Lind (1997); Peng et al. (2000) and many others. The work by Peng et al. (2000) 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 of 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 stakeholder strategic decisions based on benefits, as anticipated in this study. A related study has considered an assessment of the benefits and costs 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 disaggregate data. The authors further argue that the scarcity of good tools for benefit and cost 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) argued 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 to use alternative quantitative approaches such as optimization in the assessment of ITS applications.

In a review of the strategic assessment of ITS, Lind (1997) argues that existing modeling systems are not sufficiently adapted to the assessment of ITS and hence suggests approaches for assessment based on Delphi studies, compilation of field trial results, micro-simulations of regions or corridors, etc. A study on the diffusion of vehicle services advocates the need to view vehicle services different from the vehicles, allowing the services to go beyond organizational and technical boundaries (Kuschel, 2009). Both of these studies (Kuschel, 2009; Lind, 1997) indicate the increasing need for open Telematic Systems in order to enable accurate assessment and achieve diffusion of such services. In this thesis, we consider the use of quantitative models in assessing the possibilities of open system platforms rather than isolated systems. 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 tool-kit for investment decisions in ITS applications and services. The tool-kit includes a quantified evaluation of the economic, social, financial and operational impacts 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 Telematic Systems that can support multiple services. R&D projects have used tailored approaches to address needs for specific Telematic Systems and user groups. However there are no generic methods aimed at assessing multiple

services within a framework that enables result comparison. 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 a 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 have in the past privileged the hardware aspect to the detriment of the methodological aspect with a lot 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 able to be solved with efficient solution approaches with the ability to address large instances of formulations, including integer-valued decision variables, non-linear objective functions and constraints, and uncertain data. This thesis has formulated decision process faced by different stakeholders into quantitative models, e.g. an Integer Linear Optimization model, 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

The following section summarizes the research contributions from each publication in relation to the research questions. The main research question is addressed by contributions from different research papers in answering sub-questions (SQ1 to SQ4).

Paper I: Characterization Framework for Transport Telematic Services

This paper has a main contribution in addressing SQ2. The paper suggests a holistic view to Telematic Systems for freight transport in a framework based on 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 but which 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. The framework can be used for high-level analysis of services that supports investment decisions. To illustrate the use of the framework, we provide a classification of telematic services for freight transport

(according to the suggested domains), thus, partially contributing to answering SQ1. The domain of freight transport Telematic Systems is characterized by different types of solutions using different technologies to achieve a variety of goals. However, there is diverse understanding, especially between regions, in the use of terminology for these solutions, e.g. a system for charging for the use of road infrastructure is known as a Road User Charging system in Sweden, Electronic Toll collection System in Japan, Electronic Fee Collection System in Germany etc, and this situation is similar for several Telematic Systems and services used in transportation. As a consequence, an assessment of Telematic Systems will require more information than just the name of the systems in question. Paper I addresses this by suggesting a framework that reflects the operational characteristics of freight transport.

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

This paper contributes to answering SQ1 and SQ3. Relevant Telematic Systems for road freight transport are identified. A total of 32 telematic services are identified as being relevant for freight transport using heavy goods vehicles. The relevance of TTSs is considered from the perspective of freight transport in Sweden following 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 cost indicators (Performance Saving Indicators) that can be used to quantify transport telematic services is carried out. The computations use statistical data obtained from freight transport in Sweden e.g. from national data bases such as SCB, SIKa etc. Nine such indicators are 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 modeled pairwise. We showed that for small percentage changes, pairwise estimates are accurate approximations 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 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. A weakness in this paper is that the values are not well validated, mainly due to the fact that some services are not even in existence but also due to the limited amount of information about the effects of services in existence. Possibilities of improving the accuracy of PSI reduction values include simulation of services, gathering opinions of experts, comparisons with similar services etc.

Paper III: Analysis of Telematic Systems and Services in Road-Based Vehicle Freight Transport.

The main contribution of Paper III addresses SQ2 and SQ4. Paper III 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 behind the clustering of TTSs are: first identify TTSs that can be implemented on a common MSA; second, assess the potential of reducing the total costs of TTSs if implemented on a common MSA. An analytical method is proposed that can be used to estimate the synergy levels for groups of TTSs. The method is based on a modified hierarchical agglomeration. The proposed method considers and examines common functionalities among various TTSs. The method is illustrated with an analysis of synergies between TTSs and also between TTSs and a killer application such as the proposed Swedish RUC. A total of 32 relevant TTSs all based on 38 functionalities are analyzed. Result shows that with focus on integrating TTSs based on contribution to absolute cost reduction, transport resource optimization, dynamic traffic information, eCall, and vehicle follow services could be more beneficial than any other cluster with four TTSs. If the relative net benefit (reduction in costs) is taken into consideration then staff monitoring, sensitive goods monitoring, vehicle follow up and pay as you drive will form the most beneficial cluster. Synergy analysis with a potential Swedish RUC system shows that dynamic traffic information, eCall and information on extra large goods possibly have a high synergy compared to the rest of the TTSs in the study. In-vehicle Telematic Systems such as on-board safety and security monitoring, on-board driver monitoring and geofence appeared in a similar cluster indicating least net benefit if integrated with RUC. 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 the simplification that all functionalities could be achieved at the same costs. In reality the costs between functionalities do vary, however there is a cost reduction in common use of a functionality and, if such cost reduction can be estimated for a given set of applications under consideration, then the potential of the proposed method can be fully exploited. The

current method for synergy estimates does not recommend the best TTS cluster; rather it shows the resulting synergy for different TTS clusters.

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

Paper IV contributes to answering SQ3 and SQ4. While the societal value of a service may be used to understand its potential impact, the net benefit that takes both the societal value and 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. We formulate the problem as an Integer Linear Programming problem, i.e. an optimization model, to address the selection of beneficial TTSs. The objective of the optimization model is to select beneficial TTSs for implementation on common MSAs while minimizing costs and service dependencies and maximizing sharing of functionalities. The model's capability of selecting the most beneficial set of TTSs from a given set of TTSs for road freight transport is illustrated with focus on the Swedish HGV transport context. With CPLEX's branch and bound capabilities, the optimal solution to the model is generated by using a tree-based search. We show that the choice of MSA influences the selection of TTSs and resulting total net benefit. By changing the conditions, we also illustrate that the model can be used to address what-if scenarios. We consider six different MSAs and their potential effects on possible services that can be achieved from a benefit perspective. Results of the 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 a thin client platform based on their net benefits. For a thick client based architecture, our model shows the possibility of achieving an even greater number of beneficial TTSs.

Another key benefit of the proposed model is the capability to simultaneously exploit synergies through common use of functionalities and pairwise dependencies of selected services when they address a common transportation-related issue. An additional benefit of the model is that it provides a means to approach the complex issue of choice of MSA for Telematic Systems in road freight transport such as EFC platforms. By showing that certain TTSs are beneficial if implemented in a given MSA, the model can support stakeholder decisions related to such architectures. However, because MSA 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. 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 relationships involved in the selection of beneficial TTSs. In reality such decisions may have complex relationships that are not all linear. This was necessary to generate guaranteed optimal solutions. More accurate representation of such processes is more likely to result in non-linearity which does not guarantee optimal solutions. Also the model has not addressed some of the difficulties related to MSAs, such as quality of service, security, privacy etc.

To summarize, the contributions from Papers I to IV in addressing SQ1 to SQ4 can be seen on Table 1.1.

	SQ1	SQ2	SQ3	SQ4
Paper I		⊗		
Paper II	⊗		⊗	
Paper III		⊗		⊗
Paper IV			⊗	⊗

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

1.6 Conclusions and Future Work

This thesis has focused on the analysis and assessment of Telematic Systems for road transport. The main contributions to answering the research questions are:

- A review of R&D projects addressing development and analysis of TTSs and systems (SQ1).
- A framework useful for long-term analysis of Telematic Systems with focus on freight transport (SQ2).
- The identification of relevant TTSs for road freight based on the proposed framework (SQ1).
- A formulation of decisions, goals and societal effects involved in the strategic planning of TTSs and required systems using quantitative models (SQ4).
- A mathematical model for assessing marginal societal value of TTSs (SQ3).
- A mathematical model for the analysis of cost reduction potential of MSAs based on clustering methods (SQ2, SQ4).

- Improved assessment of societal value of TTS by considering dependencies or decrease in marginal benefit when such TTSs address a common societal issue(SQ3).
- An optimization model for finding the optimal selection of TTSs for different MSAs based on total net benefit (SQ4).
- Illustration of the proposed optimization model to the analysis of TTSs and architectures relevant for freight transport including RUC system and potential architectures (SQ4).

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 Telematic Systems that will effectively address the challenges of road transport. While scientific research and commercial companies are focused on developing new systems, little seems to have been done at the high level of multiple TTS assessments, especially in the area of road freight transport. It is necessary to shed more light on the assessment of multiple TTSs in order to reveal the benefit potential 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 of the time of this thesis, 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 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, a detail modeling of MSA resource management, different possible implementations of TTSs etc. Paper II suggested a method to estimate the societal value of TTSs. The method can be applied to estimate the value for different stakeholders e.g. what is the benefit of an ISA system to hauler companies, road infrastructure owners etc. Different approaches to functionality sharing can further be investigated using experiences from resource allocation models in existing platforms such as mobile phones and computer systems.

The future trend for telematic services especially those addressing freight transport, will see a convergence towards MSA solutions with companies like

Satellic, TomTom, Skymeter etc, already focusing on the delivery of multiple TTSs using a single device. This could be brought about for many reasons. The main reasons, however, will emerge from the desire to reduce the costs of the systems and the need for interoperability and standardization. In addition the growing number of Telematic Systems that are focused on the driver side will put constraints on driver competence, at which point their effect on driving may start to be questionable. A MSA with single interface, as shown in Figure 2, will be the way forward with some similarities with todays computer or mobile phone systems, except for the fact that processing will either be in the vehicle or outside the vehicle or both. However the complexities of such architectures as the number of applications increases (said to be inversely proportional to the square of the number of applications (Marples, 2010)) will need to be considered. The main barrier today for MSA is not technology as such; a true business model will provide a strong motivation for the use of MSAs. With a good MSA and business model, the backbone for generations of Telematic Systems for use in transportation can be established. 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.

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Paper I

Characterization Framework for Transport Telematic Services

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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.

Keywords

Transport Telematic Services, Framework, Characterization, Analysis.

2.1 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 establishing 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 consist of a product or activity targeted to a specific type of ITS user (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 inter-operable technologies build into a network of inter-operable 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 tones (European-Commission (2006a), (European-Commission, 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 (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 (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 (Sjöström, 2007). While TTSs may be developed on any existing platforms such as eCall (Dietz, 2007) or intelligent speed adaptation (Kenis and Wils, 2003), an EFC platform has a potential for hosting coexisting TTSs (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 Netherlands within the GINA (GNSS for INnovative road Applications-GINA) project (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 2.2 motivate the need for a framework, section 2.3 presents a review of similar frameworks, section 2.4 focus on the operational characteristics of the HGV domain. A framework is then proposed in section 2.5, followed by some potential analysis (section 2.6) and a conclusion and future directions in section 2.7.

2.2 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.

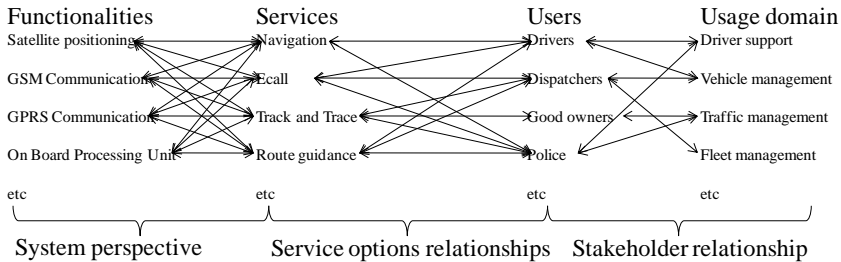


Figure 2.1: Example of functionalities, services, users and user domain choices.

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.

2.3 Framework Analysis for Transport Telematic Services, 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 et al., 2004; FHA-US-DOT, 2005; ISO/TR-14813-1b, 1999; ITS-Japan, 1999). 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-organize 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 its suitability as a platform for hosting a collection TTSs (Kenis and Wils, 2003). On the infrastructure side attention is given to route network utilization, 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 formatting and classifying services that hinder analysis approaches for assessing service performance. 33 TTSs have been identified and categorized into service bundles based on the problem addressed as well as the technology (FHA-US-DOT, 2005). Categories include 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 TTSs are characterized into 9 development area/application domain. All 22 TTSs 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.

2.4 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 influence 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 minimize 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 modeled 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 realized 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 utilization efficiency. Thus, TTSs that address how to maximize 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 utilization of existing route infrastructure and reducing emissions from vehicles are important to consider.

2.5 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 is not 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. ge-fencing 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 may be minimized by focusing on the usage of the service rather than the technology. 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.

TTS Label	Needs	Functionalities	Users	Options	User Domain
Name of TTS, unique and reflect usage	Problem addressed by TTS	Possible functionalities for developing TTS	Primary users of TTS	TTS options based on targeted primary users	Operational areas of usage of TTS within road transport

Table 2.1: A Framework structure for TTS

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).

TTS label	Users	Options	User Domain
Road User Charging	Drivers, billing agents, road infrastructure providers	Data processed by billing agent (thin client) or at driver terminal (thick client)	F
ecall	Drivers, road traffic inspectors, rescue agents, accident statistic agents, local authorities and goods owners	Ecall as network intervention report, Ecall detail report	A, D, E
Navigation	Drivers	Static, Dynamic	A, G
Weight Indicator	Drivers, bridge infrastructure providers, goods owners	Goods only, Total weight	A, E
Intelligent Speed Adaptation	Drivers, traffic inspectors, police dispatchers, insurance companies	Enforcement possibility, recommendation possibility	A, E
Accident reporting	Drivers, traffic inspectors, police, dispatchers, accident statistic agents	Detail information, Statistically (interruption)	A, D, E
Automatic Driver Logs	Drivers, police, staff or personnel managers		A, B
Staff Monitoring	Commercial Fleet operators		B
Transport Resource Optimization	Commercial Fleet operators, road infrastructure providers	Fleet Scheduling, Road utilization, Driver planning	B, C, F

TTS label	Users	Options	User Domain
Vehicle Follow-up	Dispatchers, HGV fleet owners and operators		C
Remote Monitoring	Dispatchers, vehicle fleet owners	Fault prediction, Fault detection and repair	C
Goods Identification	Customs, good owners, terminal operators		D
Real Time Track and Trace	HGV fleet operators, police, goods owners		C, D, E
Sensitive Goods Monitoring	Goods owners, Goods quality control inspectors, customs	Dangerous goods only, All goods	D
Traffic Information	Traffic controllers, drivers, dispatchers, road and bridge infrastructure owners	Prognosis, Real time	E
Route Guidance	Drivers, drivers in transits, intervention units e.g. police, emergency	In transits, non-transit, sensitive segments	E, G
Theft Alarm	Vehicle fleet owners, drivers, goods owners, police		A, C, D
GeoFencing	Vehicle fleet owners, infrastructure owners, gate operators, vehicle parking operators, loading/unloading units	Mobile, Corridors and gates	C, D, F
Transport Order Handling	Dispatchers, good owners, drivers		B, D
Pay as You Drive	Insurance companies, vehicle fleet owners, environmental controllers		E, G
Variable Speed Limit Road Signs	Traffic controllers, police	Report speed violations, Determine speed limit	E, F
Driver Planning	Dispatchers		B

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.

2.6 Potential Analysis

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

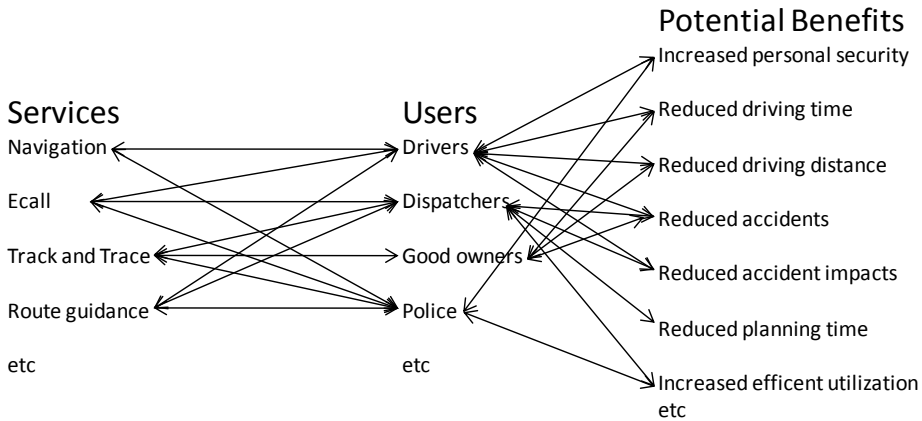


Figure 2.2: Example of analysis relating services, users and potential benefits.

2.7 Conclusion 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.

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Paper II

Method for Quantitative Valuation of Road Freight Transport Telematic Services

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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 and suggests a method for assessing quantified societal value of Transport Telematic Services (TTSs) for road-based HGV transport. For decision making related to the selection of TTSs to promote, quantified service value can simplify the decision process by enabling comparison between TTSs and as inputs to quantitative analysis of TTS architectural designs. We suggest a method for assessing the societal values of TTSs using Potential Saving Indicators, which we estimated in the context of Swedish HGV freight transport. Based on the proposed approach, 32 TTSs are discussed, and their societal values quantified. Results indicate the following 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.

Keywords

Societal Value, Transport Telematic Service, Dependency, Performance Saving Indicator.

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 utilization), 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 (MOBIL 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 (Mbiydzennyuy et al., 2008). Thereafter, a framework was developed (Clemedtson et al., 2008; Mbiydzennyuy(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; Mbiydzennyuy(a), 2009) to characterize TTSs (Mbiydzennyuy 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) (Mbiydzennyuy(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); MOBIL IT (2009). Additionally, several different research projects, such as the Swedish project Mobile Networks (MOBNET, 2006), Mobil IT (MOBIL IT, 2009), Heavy-Route (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 Grönroos approach (Grönroos, 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. There are other proposed approaches to valuing weather services based on the functions of society i.e. impacts on societal activities (Leviäkangas and Hautala, 2009). 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

$$\frac{V}{(1 + R)^t} \tag{3.2.1}$$

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.

Let's consider the following notation:

$S(D \subseteq S)$	Set of Services.
P	Set of PSIs.
$0 \leq T_i, i \in S$	Number of years to start to generate value.
$0 \leq \varepsilon$	Interest rate.
$0 \leq P_k \quad k \in P$	Value (societal costs) of PSI.
$0 \leq \alpha_{ik}, i \in S, k \in P$	Potential percentage savings
$0 \leq V_{\hat{i}\hat{i}}^*, i, \hat{i} \in S$	Pairwise value assessment considering dependencies between TTSs.

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

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

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

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

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

where $T_{\hat{i}\hat{i}}$ 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 because TTS value is generated by a fractional reduction of a PSI. As a result, the value of the PSI decreases and any other TTS will address a reduced value of the same PSI i.e. decrease in marginal benefit. 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):

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

The value of T_D is an approximation since each TTS will take different periods to generate value. In the assessment of saving potential for each TTS (corresponding to $0 \leq \alpha_{ik} \leq 1, i \in S, k \in P$ in equations (3.3.1) to (3.3.4) above, it is necessary to take into account results reported from various TTSs implemented around the world. The challenge is that despite many field operational tests for different applications (as in Rakhal et al. (2003); SRA (2009)), most results are not reported in concrete terms that could directly be transferred to other studies.

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 liter in this study) also includes external costs of CO_2 emissions. Therefore in calculating other externalities we have exempted the costs of CO_2 emissions. 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 Kilometer (VKM). Different studies have suggested the following values: 0.43l 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 as $0.287 * 2.9 = 0.612$ billion €.

3.4.2 Distance-based Costs

This PSI is estimated based on a 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), tires (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) = $(4.652 - 2.875) * \text{€}/\text{VKM} = 1.770\text{€}/10\text{VKM} = 0.177\text{€}/\text{KM}$ resulting in a total distance cost of $0.290 * 1.770 \text{ billion €} = 0.513 \text{ billion €}$

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 (SIKA, 2008), 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 = Distance/Speed = $2.9 \text{ Billion Km}/(70\text{KM}/\text{Hour}) = 41.43 \text{ million hours}$ resulting in a total driver costs = $41.43\text{million} * 17.5 \text{ €} = 0.725 \text{ billion €}$

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 = $2.9 \text{ billion KM}/70\text{KM}/\text{hour} = 41.429 \text{ million hours}$. With cost per hour = 7.5 €, we have a total costs = $41.429 * 7.5 = 0.311 \text{ billion €}$

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 (Berglind, 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 (Berglind, 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 CO_2 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 CO_2 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 € =0.055 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 $0.42 \cdot 970.5$ 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, HGVs transport may incur 100 short delays of up to 15 minutes each in one month 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 €)

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 costs. A summary of the PSI values suggested above is shown in Figure 3.1.

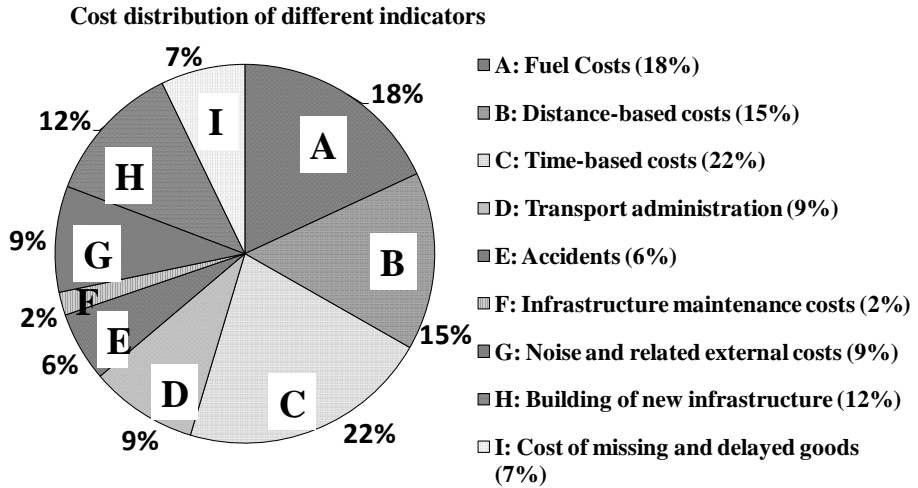


Figure 3.1: Results of cost distribution for PSIs as a relative percentage

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.

TTS	Explanation
AWI	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).

TTS	Explanation
ADL	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).
DP	Driver planning will improve driver performance through planning by considering factors as time of day, route, vehicle, product, season, etc that suit individual drivers.
DTI	Dynamic Traffic Information service will provide real time traffic information and contribute to reducing costs related to delays, congestions etc (Eliasson, 2006).
EC	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).
ETM	Emission Testing and Mitigation for measuring environmental performance to support policy making.
EDI	En-Route Driver Information for specific route information to load/unload goods including communication with back office.
ETA	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).
FM	Freight Mobility for communicating real time freight data between drivers, dispatchers, goods owners etc.
GEO	Geofencing for access control to specialized areas such as corridors, military areas, accident areas, parking areas, tunnels, etc without using any physical barriers
GI	Goods Identification to improve goods handling (loading/unloading, declaration etc) using contact-less identification.
IRM	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).

TTS	Explanation
XXL	Information on the transportation of XXL cargo for drivers, public authorities and back office, including legal obligations.
ITP	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).
ISA	Intelligent Speed Adaptation for providing dynamic information about the current speed limit that could lead to a reduction in accidents and fuel consumption. Trials in Sweden show these estimated reduction between 20% to 30% if all cars were equipped with an ISA system (SRA, 2009).
NAV	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).
ODM	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 (Berglind, 2009).
OSM	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.
PYD	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).
RTT	Real Time Track & 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.
RED	Remote Declaration for sending declaration information electronically at gates, control stations, loading/unloading stations, etc to reduce delays.
RM	Remote Monitoring to minimize costs related to vehicle breakdown through preventive maintenance.
RHW	Road Hindrance Warning information in real time and possible suggestions to avoid queues.
RUC	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).

TTS	Explanation
RG	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).
SGM	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.
SM	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, labor unions etc.
TAR	Theft Alarm and Recovery for real time location and status information about stolen goods and vehicle to goods owner, traffic and transport managers, etc.
TOH	Transport Order Handling for real time order information sharing between goods owner, transport manager, driver etc, as well as feedback when orders are satisfied.
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 etc, then reporting such data to different interested groups, e.g. fleet owners.
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.

Table 3.1: Suggested TTSs Relevant for Freight Transport

3.6 Results of Transport Telematic Service Valuation

The proposed model (section 3.3) 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 ($0 \leq \alpha_{ik} \leq 1, i \in S, k \in P$) of PSIs (in section 3.2) according to authors perception of TTSs in section 3.4. This is a weakness in the studies and in the future these values can be validated and improved as more field operational tests results are reported from different trials, (e) The dependencies between TTSs were assumed to be pairwise as in equation (3.3.2).

Notation	PSI	PSI Value in M€
P1	Fuel Costs	612.00
P2	Distance based cost	513.30
P3	Time based costs	725.00
P4	Transport administration Accidents	310.70
P5	Accidents	201.24
P6	Infrastructure maintenance costs	066.70
P7	Noise and related external costs	305.83
P8	Costs of building new infrastructure	407.64
P9	Costs of missing and delayed goods	243.50

Table 3.2: Key to table 3.3 below

Based on these assumptions the values of TTSs shown in Table 3.3 were obtained.

TTS	P1	P2	P3	P4	P5	P6	P7	P8	P9	V
AWI	0.001		0.050		0.001				0.001	37.31
ADL				0.001	0.005					1.32
DP			0.001	0.003						1.66
DTI	0.002		0.005					0.001	0.001	5.50
EC			0.001		0.150				0.001	31.15
ETM	0.001						0.004			1.84
EDI	0.001	0.015	0.030	0.001					0.001	30.62
ETA				0.020						6.21
FM				0.005					0.001	1.80
GEO				0.003					0.002	1.42
GI				0.004					0.001	1.49
IRM						0.100		0.004		8.30
XXL				0.001		0.001				0.38
ITP			0.001						0.010	3.16
ISA	0.001				0.150				0.001	31.04

TTS	P1	P2	P3	P4	P5	P6	P7	P8	P9	V
NAV	0.010	0.030	0.020							36.02
ODM					0.010					2.01
OSM			0.001	0.001	0.010					3.05
PYD	0.010	0.001			0.001					6.83
RTT			0.001	0.001					0.020	5.91
RED	0.001		0.001	0.001					0.001	1.89
RM			0.010	0.001	0.001				0.001	8.01
RHW	0.001		0.050		0.003					37.47
RUC	0.010	0.001	0.010			0.001		0.001		14.36
RG	0.001		0.001				0.001		0.001	1.89
SGM				0.050	0.002				0.001	16.18
SM					0.005					1.01
TAR			0.001	0.001					0.150	37.56
TOH			0.030	0.001						22.06
TRO	0.020	0.030	0.030				0.001		0.001	49.94
VF	0.003	0.001	0.001							3.07
WI			0.001			0.050				4.06

Table 3.3: An assessment of percentage savings and values (M€) of TTSs for HGV transport in Sweden

The result of TTS societal valuation without dependencies is shown in Figure 3.2:

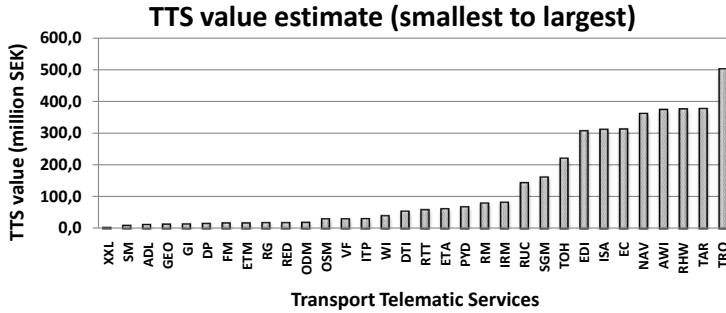


Figure 3.2: Chart showing the assessed TTS societal values ($\times 10^{-1}$ million €) for HGV transport in Sweden

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, $0 \leq \alpha_{ik} \leq 0.15 \quad i \in S, k \in P$, equation (3.3.3) can be approximated to equation (3.3.4) (see section 3.3) in estimating dependencies between TTSs. 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 908707M€, and from equation (3.3.4), estimated total benefits = 0.190 909075M€, which can be approximated within an error of margin of less than 5%. Therefore, if the α 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).

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 $15\% + (100\% - 15\%)*15\% = 0.15 + (1 - 0.15)*0.15 = 0.2775$ 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.

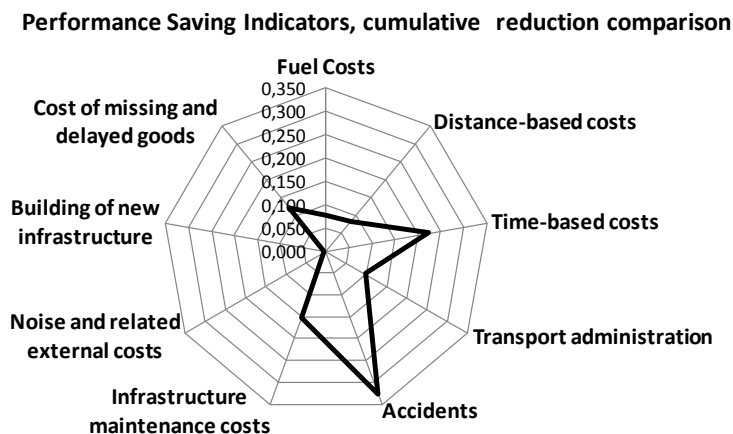


Figure 3.3: The extent of PSI reduction from the cumulative contribution of different TTSs

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 TTSs in reducing the societal costs for each of the PSIs (see Figure 3.3) 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.

3.7 Conclusion and Future Work

The purpose of this study was to use the criteria established in a previous study (Mbiydenyuy(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, straight forward, 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. In addition, most of the applications achieving reported savings from different sources are for both commercial vehicle transport and private cars and hence their use for valuating TTSs in freight transport need careful consideration. Attention should be given to the fact that the degree to which each transport system is improved by TTSs depends on the prevailing conditions of the transport system before implementation of TTS. 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.

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Paper III

Analysis of Telematic Systems and Services in Road-Based Vehicle Freight Transport

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This paper focuses on exploring potential contribution to net benefits (cost savings), based on synergies related to sharing functionalities between road Transport Telematic Services (TTSs). Such analysis will help in planning the design of telematic systems providing multiple TTSs for road-based freight transportation. TTSs such as emergency call, intelligent speed adaptation, and electronic fee collection, have gained the attention of public authorities, industry and the private sector. Rather than developing separate systems for each TTS, there is a possibility to support multiple TTSs through sharing of functionalities, e.g. related to communication & positioning. An analytical method for studying such synergies is proposed based on a variant of hierarchical agglomeration, the use of which is then illustrated by analyzing the possible synergies between 32 different TTSs (based on 38 different functionalities). Results of the example show that if telematic systems are to be integrated according to their contribution to net benefits, transport resource optimization, dynamic traffic information, eCall, and vehicle follow-up services could be more beneficial than any cluster with four TTSs.

Keywords

Transport Telematic Service, Functionalities, Synergy, Clustering, Architecture Platform, Electronic Fee Collection System.

4.1 Introduction

This paper is focused on exploring potential cost savings, or contribution to net benefits, based on synergies related to sharing functionalities between road Transport Telematic Services (TTSs). Synergy analysis provides one approach for identifying telematic systems that can be implemented on a common platform sharing functionalities. This is because synergies can lead to reduced costs and minimize redundant implementation of functionalities. Methods for assessing synergies are required for planning system design, especially in the case of multi-service platforms, i.e. ITS conceptual architectural design that can deliver multiple TTSs, e.g. open Electronic Fee Collection (EFC) systems. There is an increasing demand for ubiquitous road TTSs that are available at any time. Such TTSs are becoming an important prerequisite for an efficient road transport system (Ghosh and Lee, 2000; Yonglong, 2000). For freight transport, there is a need for accurate and fast information handling. The basic feature of TTSs (or telematic applications for freight transport) is their ability to share information in real time. As a result, interest is not only seen from commercial actors but also from public authorities in telematic systems such as road user charging, eCall, speed control, etc and respectively road guidance, track and trace of goods, estimated time of arrival, etc (SRA, 2006). Therefore, there is need to analyze potential cost reduction for integrating or isolating such telematic systems that may lead to minimizing the total system cost. In addition, the market for TTSs can be stimulated by developing the services on EFC platforms (Appelt and Schwieder, 2002).

For public authorities, it is important to support policy issues related to general transport system efficiency, security, safety, collection of charges, management of infrastructure, etc, while the interest of the commercial sector is predominantly profit related. In either case, it is necessary to make informed choices of TTSs that can help attain long-term goals. Such choices are influenced by factors such as implementation cost for different stakeholders, ease of system design, interoperability with other systems, etc. The costs of TTSs are influenced by the functionalities required to achieve necessary telematic systems. If synergies between such functionalities can be analyzed at the level of system design, the contribution to net benefits of the resulting TTSs can be improved (Springer, 2007). This is similar to a component-based software design approach which enables multi-use of software functionalities (Feng et al., 2007). However, the use of synergy of functionalities in system design is difficult because of the

challenges of assessing such synergies (Mbiydzenyuy et al., 2008b). To the best of our knowledge, there are no existing methods for TTS synergy assessment (of contribution to net benefit), yet there is a great possibility for improving the net benefits of TTSs by using synergies.

Synergies exist between TTSs on account of their functionalities. The problem of identifying synergies between TTSs may be regarded as that of selecting objects (TTSs) in sets according to some desired properties (shared functionalities) and is thus similar to a combinatorial problem (Hubert, 1974). TTSs constitute the data points and shared functionalities describe the similarity between each pair of TTS, from which synergies can be obtained, e.g. using a clustering method. Such methods (as clustering) will classify objects into different groups (or clusters) according to a similarity relationship. If the relationship between TTSs and cost of their required functionalities can be represented as a metric measurement, TTSs with the most common functionalities (and high cost savings) can be assigned into collections of groups using clustering-related methods. If a cluster of TTSs is identified with high synergies, it can serve as a motivation for an architecture design choice targeted to such services. Also, given an architecture choice, additional TTSs that can be developed based on synergies with architecture functionalities can be identified. This is useful for service providers and financing bodies like national governments. The work in this paper is built upon previous work that led to a method for assessing the synergy of TTSs sharing functionalities (Mbiydzenyuy et al., 2008b). Different measurements for synergy assessment are proposed in this paper. Some of these measures are demonstrated on a set of 32 TTSs based on 38 functionalities.

Research on developing multi-service platforms is being driven through a number of initiatives, e.g. Open Service Gateway Initiative (OSGi) (Ai et al., 2003; Hackbarth, 2003) and Global System for Telematics (GST, 2010), both geared toward in vehicle automotive telematics for private users. For freight transport EFC systems are being assessed for their use as platforms for TTSs (Sjöström, 2007; Springer, 2007). Alternative platforms such as eCall are also under consideration (Ditz, 2007). The choice of platform for freight-based TTSs could involve several factors and poses a challenge to all ITS stakeholders. To ease the burden, an EU directive has specified the functional capabilities of an EFC platform (2004/52/CE), e.g. the system should make use of modular approach and interfaces such as GSM/GPS antennas, etc. Some of the functional capabilities of these systems can and will be used by other relevant TTSs, such as intelligent speed adaptation, route guidance, etc and that will possibly lead to cost minimization. Early examples of EFC systems are emerging, including the German Tolling Systems (LKW-MAUT) and the Austrian Tolling System operated by ASFINAG. In Sweden there are ongoing discussions of possibilities for a Road User Charging (RUC) system (Rydmeil, 2006) within the ARENA project and

possible synergies with freight TTSs (MOBIL IT, 2009). Most of the proposed systems aim for achieving more than tolling services. This work partly addresses the identification of relevant TTSs with synergies to the Swedish RUC system.

So far there has been work describing and comparing concepts of how to design architectures that meet the demand of TTSs integrated on a common platform focusing on EFC systems (Persson et al., 2007; Sjöström, 2007). Technical analysis of the pre-conditions for integrating TTSs based on inter-operable EFC systems have been addressed (Ditz, 2007). In our case, greater attention is dedicated to TTSs and shared functionalities, different specifications of functional architectures (ITS platforms) and a more generic approach for analyzing TTS cost reduction possibilities. A method to estimate the synergy level for a group of TTSs at an early stage of system design is proposed. Synergy analysis is based on hierarchical agglomeration, which has been tested in several engineering and planning domains (Bacher, 2000; De Lucia et al., 2007; Everitt et al., 2001; Romeburg, 2004) including the general analysis of ITS projects in which a judgment matrix has been proposed (Hu and Shi, 2002). This paper proposes a distance metric for assessing the possibility to reduce the total costs of a cluster of services. Based on the assessment, the services can be implemented together or in isolation. The proposed measure is similar to functional transformations for normalizing compromise optimization problems (Marler and Arora, 2004). The net benefit in using such an approach is to help capture both the subjective and objective evaluation measures and thereby provide a consistency mechanism that can help detect weaknesses in the chosen measures. We illustrate the use of the proposed method in this article by analyzing the potential synergies between 32 different TTSs (based on 38 different functionalities). The rest of the work is organized as follows: Section 4.2 presents the relationship between TTSs, functionalities and architectures, Section 4.3 presents a theoretical background, in Section 4.4 we propose a method for synergy analysis, while section 4.5 discusses a case study that was addressed with the proposed method. Results are presented in Section 4.6, discussion in Section 4.7 and conclusion and future work in Section 4.8 followed by an acknowledgment and references.

4.2 Relating Services (TTSs), Functionalities and Architecture Solutions

We consider TTSs from a users perspective to mean the telematic services addressing distinctly identified user needs within freight transport e.g. eCall, navigation, track and trace, remote vehicle diagnostics, etc. Functionalities describe the features that need to be implemented in order to realize a given TTS, e.g. a systems ability to provide global positioning and keep track of distance covered.

For some TTSs the functionality requirements are obvious, e.g. navigation needs positioning ability, map matching, etc. Each functionality adds costs to the system. Different functionalities will add different costs and the same functionality will have different costs for different TTSs.

A conceptual architecture for a system such as the RUC system also consists of a specification of functionalities. Therefore, there exist common functionalities for different TTSs and also for TTSs and functional architecture specifications. This situation creates a synergy potential between TTSs and also between TTSs and different architecture specifications. Depending on the specification, an architecture can deliver many TTSs.

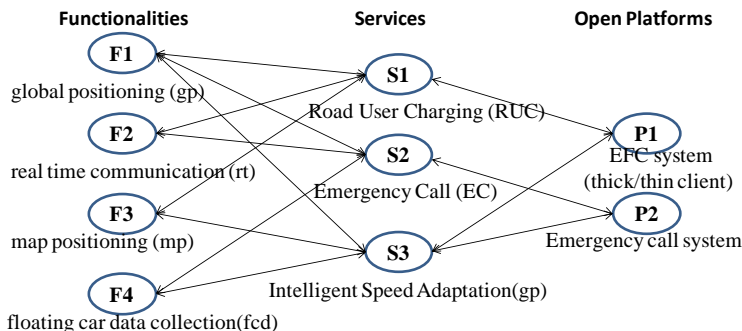


Figure 4.1: Possible interconnections between TTSs, functionalities and solution.

If we isolate the implementation of each TTS independently, some functionalities will be implemented several times. The result of such repetitions will be high costs that will eventually be passed on to the user and hence to society at large. On the other hand, integrating TTSs together is not trivial because such integration needs to be motivated by any potential contribution to net benefits (cost savings). It is, therefore, obvious that TTSs and functionalities are interconnected, and we assume that the choices of the functionalities could influence which TTSs are achievable. One TTS may require several functionalities while others may use functionalities in common thus making the relationship non-trivial (see Figure 4.1), e.g. road charging and eCall both require positioning. Furthermore, the choices of TTSs can influence the decision of which architecture option to implement.

4.3 Theoretical Background

The decision to isolate or integrate telematic systems can influence the implementation costs of TTSs. Costs reduction estimates as a result of synergies can be used to support such decisions. Given a set of TTSs and functionalities, we try to establish a measure of synergy that reflects the cost reduction potential on account of shared functionalities for all possible subsets of TTSs. We will consider a functionality as shared if it is required by two or more TTSs.

Assumptions

Some necessary assumptions for modeling this problem are:

- I. For each TTS, it is possible to specify whether a functionality is required or not.
- II. The cost of a TTS is the sum of the costs of the functionalities it uses, (isolated implementation).

Let's consider the following notation for sets

S denote a set of TTSs

F denote a set of functionalities

Let $P \subseteq S$, be an arbitrary subset such that $|P| \geq 2$ i.e. at least two elements.

Let $d_{ik} \geq 0$, $i \in P, k \in F$ denote the cost of TTS i using functionality k with no synergies

Consider the total costs of TTS without synergies (U): This is the total cost obtained under the condition that a set of TTSs are implemented in isolation given by

$$U_P = \sum_{k \in F} U_{kP}, \quad U_{kP} = \sum_{i \in P} d_{ik} \quad \forall k \in F, \quad \forall P \subseteq S \quad (4.3.1)$$

We define the minimum cost of a TTS (G): This is the least possible cost of a set of TTSs under conditions that they are implemented together in a platform according to the functionalities shared together:

$$G_P = \sum_{k \in F} G_{kP}, \quad G_{kP} = \max_{i \in P} \{d_{ik}\} \quad \forall k \in F, \quad \forall P \subseteq S \quad (4.3.2)$$

We propose the cost of TTSs due to synergy (V) such that $G_P \leq V_P \leq U_P$ always i.e.

$$V_P = (1 - \beta_P) * (U_P - G_P) + G_P, \quad \forall P \subseteq S \quad (4.3.3)$$

where $0 \leq \beta_P \leq 1$ is a parameter for representing the relative cost reduction where $\beta_P = 1$ is interpreted as perfect synergy and $\beta_P = 0$ imperfect or no synergy. Based on the above, we propose the following measures of synergy (will be referred to as $f(P), \forall P \subseteq S$)

$$\begin{aligned}
 f^a(P) &= U_P - V_P & (a) \\
 f^b(P) &= \frac{U_P - V_P}{U_P} & (b) \\
 f^c(P) &= V_P - G_P & (c) \\
 f^d(P) &= \frac{V_P - G_P}{U_P - G_P} & (d)
 \end{aligned}
 \tag{4.3.4}$$

The formulations in equation 4 can easily be interpreted following Figure 4.2:

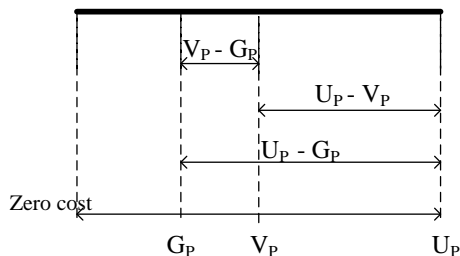


Figure 4.2: Diagram representation of the components in equation (4)

- I. **Absolute net benefit, $f^a(P)$**
This is the contribution to the net benefit resulting from the difference between cost with synergies and cost without synergies.
- II. **Relative net benefit, $f^b(P)$**
This measures the contribution to net benefit relative to the total cost.
- III. **Absolute net loss, $f^c(P)$**
This is similar to $f^a(P)$ and measures the net loss from achieving a perfect synergy situation.
- IV. **Relative net loss (to total potential gain), $f^d(P)$**
This is the ratio of the relative net loss ($f^c(P)$) to the total potential gain with perfect synergies.

There are other measures in addition to the above cases. Whichever formulation used could be argued to depend on the interest of measurements. In order to

assess the cost due to synergy (V_P), we consider the cost for each functionality in F the value of (V_{kP}) and obtain the total cost for a set of TTSs by:

$$V_P = \sum_{k \in F} V_{kP} \quad \forall P \subseteq S \quad (4.3.5)$$

The cost incurred by each TTSs per functionality can now be assessed by introducing a parameter β_k , $k \in F$. We find it convenient and possible to estimate β_k , $k \in F$ per functionality. This is an assessment of the relative cost reduction due to synergies between TTSs for a given functionality. For example a functionality such as an antennae will have fairly the same value of β_k , $k \in F$ irrespective of the TTSs using functionality. We now assume that we have the value of $\beta_k, k \in F$ and obtain

$$V_{kP} = (1 - \beta_k) * (U_{kP} - G_{kP}) + G_{kP} \quad \forall k \in F \quad \forall P \subseteq S \quad (4.3.6)$$

Solving for β_P in equation 4.3.5 and 4.3.6 we obtain

$$\beta_P = \left[\frac{1}{U_P - G_P} \right] * \left[\sum_{k \in F} \beta_k (U_{kP} - G_{kP}) \right] \quad \forall P \subseteq S \quad (4.3.7)$$

This is the estimated costs reduction for a group of services as a function of $U_{kP}, G_{kP},$ &, β_k which are all quantities we believe can be assessed. The value of β_k can reasonably be assessed by a system design expert for a given functionality and using equation 4.3.7 we can approximate this measure for a subset of TTSs. Now let suppose set $P = \{i, j\}$, $\{i, j\} : i \neq j, \quad i, j \in S$, i.e. consider pairs of services, then:

$$V_{ijk} = \left(1 - \beta_k \right) * \left((d_{ik} + d_{jk}) - \max \{d_{ik}, d_{jk}\} \right) + \max \{d_{ik}, d_{jk}\} \quad \forall i, j \in P, \quad \forall k \in F$$

This will result to

$$V_{ijk} = \left(1 - \beta_k \right) * \left(\min \{d_{ik}, d_{jk}\} \right) + \max \{d_{ik}, d_{jk}\} \quad \forall i, j \in P, \quad \forall k \in F \quad (4.3.8)$$

For this paper we choose to assess the synergy of an arbitrary set of TTSs by considering their pairwise relations. This is because our main interest is on assessing the contribution to net benefit resulting from synergies using a simple and practical approach, i.e. to determine the minimum group (in terms of costs)

of functionalities that can achieve the maximum number of TTSs. (For work on multidimensional metrization of power sets using combinatorial analysis see Silverman (1960).) We consider the interpretation of different values of $\beta_k, k \in F$ in the following cases:

- 1 Perfect synergies between functionalities (no additional cost for sharing a functionality). This is the situation where the sharing of functionalities by two or more telematic systems does not add more costs to the shared functionality compared to when it is being used by one TTS only, e.g. satellite signal broadcasting. This could be the case because of capacity under utilization of functionalities. Thus $\beta_k = 1, \forall i, j \in P, \quad \forall k \in F$.
- 2 Imperfect synergies between functionalities (no shared functionality). For this case the cost reduction estimate is always zero i.e. $\beta_k = 0 \quad \forall i, j \in P, \quad \forall k \in F$
- 3 A percentage reduction in total costs of TTSs. It is assumed that good domain knowledge can enable, for a given functionality, an assessment of the potential reduction in cost of functionality due to sharing between two TTSs, i.e. pairwise. In most cases the value of the reduction depends on the utilization level of the TTSs and will exist in the interval $0 \leq \beta_k \leq 1 \quad \forall i, j \in P, \quad \forall k \in F$.

4.4 A Method for Finding Clusters Based on Synergy From Cost Reduction

A method for finding clusters of TTSs with the synergy measure calculated according to equation 4.3.4 is presented in this section. The proposed method is a variant of hierarchical clustering that takes into consideration the costs of functionalities $d_{ik} \geq 0, \quad i \in P, k \in F$ required by the TTSs and the pairwise synergy estimate $\beta_k, k \in F$ for each pair of functionalities. If the proposed measures in equation 4.3.4 are to be used in a clustering algorithm, it is necessary that they satisfy basic metric properties (Hubert, 1974): symmetry meaning $f(ij) = f(ji), \quad \forall i, j \in P$, positivity meaning $f(ij) \geq 0 \quad \forall i, j \in P$, and nullity meaning $f(ij) = 0 \leftrightarrow i = j, \quad \forall i, j \in P$. These properties are applicable to pairs of points in a two dimensional coordinate. To ensure that equation 4.3.4 satisfy the above properties (also known as symmetric and isometric properties) and also to have a common interpretation on the results e.g. increasing or decreasing with contribution to cost reduction or net benefits we have further modified the measurements in equation 4.3.4 as follows:

- $f^a(P)$ is a real valued continuous function that increases with increasing cost savings and hence $\frac{1}{f^a(P)}$ decreases with increasing cost savings.
- $f^b(P)$ is a real valued continuous function that increases with increasing cost savings in $[0,1]$, hence $1 - f^b(P)$ decreases with increasing cost savings in $[0,1]$
- $f^c(P)$ is a real valued continuous function that decreases with increasing cost savings.
- $f^d(P)$ is also continuous and decreases with increasing cost savings.

$\frac{1}{f^a(P)}, 1 - f^b(P), f^c(P)$ & $f^d(P)$ are suitable for use in a clustering algorithm as all functions are monotonic (increasing or decreasing) and continuous. The contribution to net benefits (cost savings) increases with decreasing distance. We define the situation where there are no synergies to mean that such points are infinitely separated from each other and the situation for which the two points are the same to be zero i.e. the distance between a point and itself. If the value of $0 < f^a(P) < 1$ or $0 < f^c(P) < 1$, then the values can always be scaled so that they are greater than one e.g. 0.5 and 7 can be represented as 5 and 70. We believe that this is correct because the results of the measures are intended to compare different levels of synergy. Thus we propose the following algorithm .

Algorithm: Modified Hierarchical Agglomeration

An agglomerative algorithm begins by placing distinct data points in a cluster (each data point taken as a cluster in itself) and successively merging the different clusters to form a bigger cluster based on some similarity measure until all elements are contained in a single cluster (Hubert, 1974). In the proposed method, the algorithm begins with an empty cluster and adds data into the cluster until all data points have been considered. The similarity measure is the level of shared functionalities between every pair of TTSs as discussed in Section 4.3. Given a set of services and functionalities (costs), the algorithm consists of the following main steps:

- Step 0 : Obtain a distance matrix for a given set of services S and functionalities F according to section 4.3 (equation 4.3.4) i.e. MXM symmetric matrix where $M = |P|$, is the cardinality of set P .
- Step 1 : Initiate $P = \{\}$, i.e. the empty set. Select the TTS, with the highest net benefit i.e. $\arg \min \{i, j \in S\} f(\{i, j\}), i \neq j$, and add to P
- Step 2 : Select $i \in S$, such that $i = \arg \min \{i \in S, i \notin P\} f(i \cup P)$ and add to P .
- Step 3 : Go back to step 2 until $P = S$.

Observe that the notion of distance required for clustering occurs between two points (pairs). The underlying difference in clustering methods is how this

distance is calculated and how the aggregate measure between multiple points is calculated. Different methods are possible with the above algorithm such as single linkage (euclidean distance between two points and nearest neighbor to the set of points already in the cluster), complete linkage, average linkage etc. A block diagram of the proposed method can be summarized in Figure 4.3.

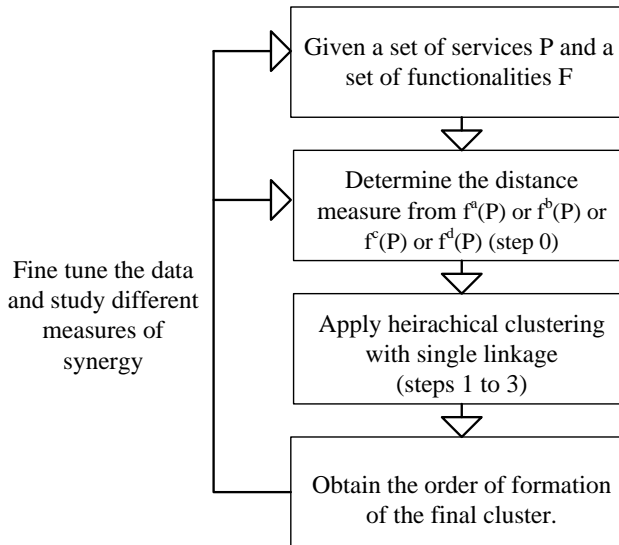


Figure 4.3: A block diagram of the proposed method for estimating cost reduction synergies.

In step 0 we pre-treat the data to obtain a distance matrix based on the synergy resulting from cost reduction. Then, the algorithm loops through steps 1 to 3 to form clusters of TTSs. The clusters are formed such that the first iteration considers each data point as a cluster and each iteration is a successive improvement of the proceeding iteration, i.e. single linkage. In single linkage, the (Euclidean) distance between two clusters is the distance between their closest neighbors (Hubert, 1974). This is suitable in our case as we want to move from the best to the worst point in the data space. As a result, we use single linkage with Euclidean distance to determine the next nearest neighbor from one iteration to the next. This means that the subset (in this case pairs of TTSs) with the smallest value of (a distance measure) is considered before the next subset with the next smaller value and so on. This is because the smaller the similarity measure (synergy measure), the higher the possibility that the cluster will contribute to more cost reduction. The value established from this approach indicates a

measure of the cohesion between TTSs; the smaller the value, the stronger the cohesion, i.e. less time, effort and resources shall be needed for acquiring the given class or group of TTSs if they are integrated together. We executed the algorithm with data from a case study using XLMiner (2010), which is implemented as a data mining add-in for excel and used for both research and commercial purposes.

4.5 Case Study: Estimating Synergy Levels for Transport Telematic Services

The proposed method for estimating synergy levels in Section 4.4 was employed in the Mobil IT project. The aim was to study which TTSs for use by public authorities, such as a RUC system for HGVs, can be integrated with other commercially useful TTSs for road freight transport. An initial assessment of different TTSs and their target areas was carried out and 32 TTSs were identified out of a total of 59 (Mbiydzennyuy et al., 2008a). These 32 TTSs have been used as input for this case study, in which we aim to find clusters of TTSs with high contribution to net benefits based on some or all of the functionalities shown in Table 4.1.

F	Description
F	Description
as	accident sensing e.g. using sensors for detecting the occurrence of an accidents
asg	alarm signaling in vehicle for use during the occurrence of an event e.g. accidents.
at	automatic triggering for initiating events in vehicle e.g. over speeding theft
btb	back office-to-back office communication e.g. using Internet
cv	camera vision (observation) for collecting video data in or out of vehicle environment
lrc	long range two way communication to and from vehicle
da	data anonymity for sensitive data that require advanced encryption into and from vehicle
db	data broadcast for sending data to multiple vehicles with receivers/antennas
ds	data storage for saving data within a certain time period in a vehicle
du	data updates for downloading data into a vehicle from a database
dt	event timer in the vehicle e.g. clock, obu

F	Description
dd	driver data logging for collecting data about driver such as id, health statuses etc
fed	floating car data collection e.g. using road side equipments
gp	global positioning for determining the position of a vehicle internally
gds	goods damage sensing for determining unusual changes to goods data
gd	goods data logging for collecting and storing goods data
hs	human sensing for detecting the presence of a person e.g. in accidents
ids	infrastructure damage sensing for detecting unusual changes to infrastructure
ind	infrastructure data logging for collecting and storing infrastructure data
lp	local positioning for location determination with respect to a reference point
mp	map positioning and updates for calculating and updating map position
m	monitoring for frequent report of small changes e.g. of a bridge, vehicle etc
no	network optimization for determining the best possible route in a network
obu	on-board unit processing of vehicle data
obu1	on-board unit long range communication of vehicle data
obu2	on-board unit storage of vehicle data
odd	origin-destination data information availability of goods/vehicles
rm	ramp metering for regulating traffic flow in given road segments
rc	route congestion information for determining the average HGV density on route segment
di	driver information display e.g. LCD display
ed	emission data logging for collecting emission data e.g. CO_2 in a region/vehicle
src	short range communication for transmitting small amount of data e.g. DSRC between the vehicle and road side
sd	signal delay information for pre-empting traffic light signals
tfc	tidal flow control and traffic priority assignment for associating priority to given vehicles
ts	time stamping for logging the time an event of interest occurred
wf	weather forecasting information e.g. from weather station
vds	vehicle damage sensing for detecting unusual changes to vehicle conditions
vd	vehicle data logging e.g. vehicle number, category etc
vs	vehicle speed information collection e.g. using odometer
vc	voice communication for transmitting audio signals

Table 4.1: Functionalities (F) for achieving different TTSs

Functionalities (Table 4.1) are mostly considered in relation to tools (data loggers, cameras, sensors, etc) for collecting different types of data, such as goods data (gd), e.g. temperature, weight, etc; environment data (ed), e.g. emission,

noise etc. We describe functionalities independent of the technologies, but for purposes of practical analysis a functionality will need to be connected with a specific technology in order to help assess its costs and other specific properties. If we assume that the same functionality required by different TTSs can be used in common, then the corresponding total fixed cost of a shared functionality between two TTSs is reduced. This is a simplification because, in addition to the fixed costs, there is a cost component that also depends on the usage of a functionality by each TTSs and even other costs for combining functionalities. e.g. labor costs, administration, etc. The functionalities in Table 4.1 obtained from our specification of TTSs as shown in Table 4.2. Since the choice of functionalities needed by a given TTS can be debated and depends, to a greater extent, on how each TTS is interpreted, we have specified our interpretation in Table 4.1. Moreover, in Table 4.1, we suggest minimum required functionalities for each of the TTSs.

F	Description
TTS	Suggested functionalities
AWI	as, asg, db, ds, dt, di, lp, odd, rm, rc, ts, wf, vd, vs
ADL	db, dd, lp, ts, vd, vc
DP	da, db, dt, dd, gd, lp, obu, odd, ts, wf, vd
DTI	as, db, du, dt, di, gp, ids, ind, mp, obu, odd, rm, rc, sd, tfc, ts, wf, vd, vs vc
EC	as, asg, at, cv, db, du, dt, dd, di, gp, gds, gd, hs, lp, mh, mp, no, obu, rm, rc, src, sd, tfc, ts, vds, vd, vs, vc
ETM	db, ds, di, ed, gp, lp, mp, m, obu, rc, src, vd
EDI	du, di, lp, mp, obu, odd, rc, src, tfc, wf, vs, vc
ETA	db, dt, gp, gd, m, no, odd, rc, sd, ts, wf, vs
FM	da, ds, dt, gp, gds, gd, m, obu, odd, src, ts, vd
GEO	asg, at, cv, db, dt, gp, m, rm, src, ts, vd
GI	at, da, db, du, dd, gp, gds, gd, mp, m, obu, odd, ts, vd, vs
IRM	gp, ids, ind, mh, mp, m, rc, src, wf
XXL	cv, db, dt, di, gp, gd, ids, ind, mp, m, obu, odd, rc, tfc, ts, wf, vd, vs
ITP	at, cv, db, di, ind, lp, mp, no, obu, src, ts, vd
ISA	asg, cv, db, di, gp, ids, mp, m, rm, rc, sd, tfc, wf, vs
NAV	di, gp, lp, mp, no, obu, odd, rm, rc, sd, wf, vd, vs
ODM	as, asg, db, dt, dd, gp, hs, m, obu, ts, vds, vd, vs
OSM	asg, cv, dt, di, gp, gds, gd, hs, mh, m, obu, src, vds, vd, vs
PYD	as, at, da, db, ds, dt, dd, gp, mh, m, obu, odd, rc, ts, wf, vds, vd, vs
RTT	db, du, dt, dd, di, gp, gd, mp, no, obu, rc, src, ts, wf, vd, vs
RED	cv, da, db, ds, du, dd, di, gds, gd, mp, obu, odd, src, ts, vd, vc
RM	as, asg, at, ds, du, gp, lp, mp, m, obu, src, ts, vds, vd, vs
RHW	as, asg, db, dt, lp, mp, no, obu, odd, rm, rc, sd, tfc, ts, wf, vs
RUC1	da, ds, gp, ids, ind, mp, obu, rm, rc, tfc, ts
RG	di, gp, ids, ind, mp, m, no, obu, odd, rm, rc, tfc, wf, vs
SGM	da, db, ds, dt, dd, ed, gp, gd, mp, m, odd, rc, ts, wf, vd, vs

F	Description
SM	da, db, ds, dd, gp, mp, m, odd, ts, vd, vs
TAR	asg, at, cv, db, ds, dt, dd, gp, gds, gd, hs, mp, rc, ts, vds, vd, vs
TOH	da, db, du, dd, di, gd, lp, mp, obu, odd, rc, ts, wf, vd
TRO	da, db, ds, du, dt, dd, di, ed, gp, gd, ind, mp, m, no, obu, odd, rc, sd, tfc, ts, wf, vd, vs, vc
VF	da, db, ds, du, dt, dd, di, ed, gp, mh, mp, m, obu, odd, rc, ts, vds, vd, vs
WI	asg, at, cv, du, di, gp, gds, gd, ids, ind, mp, m, src, wf, vs

Table 4.2: Suggestion of TTS functionality specification (refer to appendix section for TTS abbreviations)

Due to data limitations, we have only considered $d_{ik} = 1, i \in P, k \in F$ when a TTS requires a functionality and zero otherwise. We assumed here that the number of functionalities is representative of the cost of a TTS. We believe this information is more accurate for analysis in the absence of accurate cost data. In such a situation we can approximate $U_P = \sum_{k \in F, i \in P} d_{ik} \forall P \subseteq S$ to be the total number of functionalities that is required by a TTS and $V_P \forall P \subseteq S$ the total number of functionalities shared (used in common) by TTSs. Also $G_P = U_P \forall P \subseteq S$ in such a situation means that we can only apply $f^a(P), \& f^b(P), \forall P \subseteq S$ in equation 4.3.4. Further, we consider $\beta_k = 1, \forall i, j \in P, \forall k \in F$ for perfect synergies and zero for imperfect synergies. We then use this information to determine which TTS clusters possibly have high contributions to net benefits. We then apply the proposed method (modified hierarchical agglomeration), where similar points with low costs are successively built into a cluster, starting with the best pair of TTSs to the worst, i.e. using single linkage as described above.

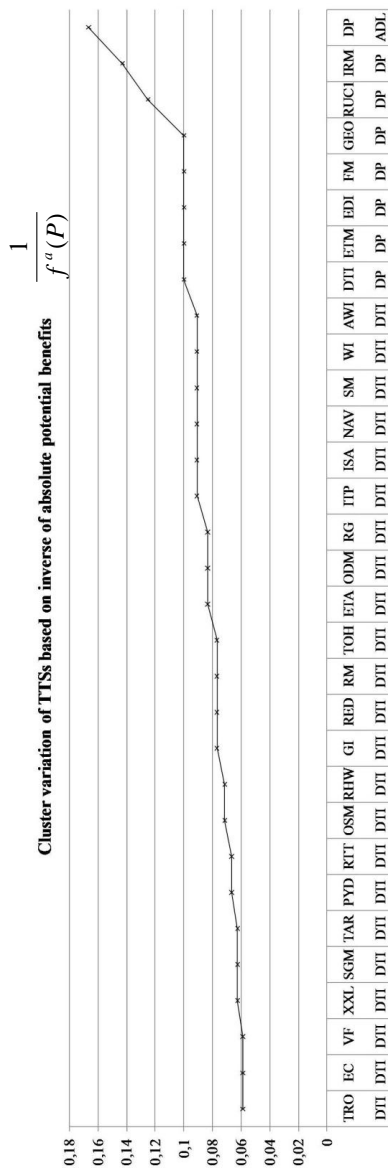
4.6 Results

4.6.1 Scenario A

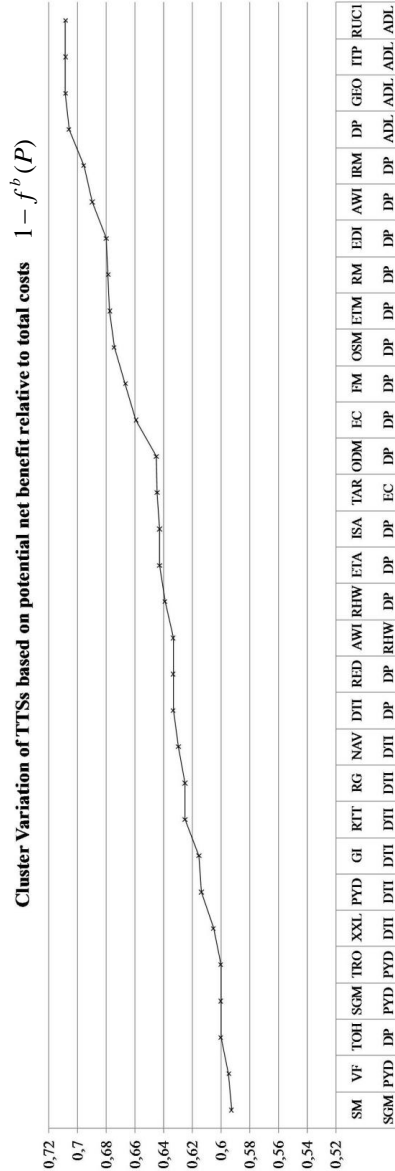
For a given set of TTSs, a system designer or TTS provider may be interested in identifying the most potentially beneficial group of TTSs based on common use of functionalities in order to save cost. With a single linkage hierarchical clustering of pairwise synergies taken as the inverse of the contribution to net benefits ($\frac{1}{f^a(P)}, \forall P \subseteq S$ equation 4.3.4), we obtain the results in Figure 4.4 (a).

Figure 4.4 (a) shows the first two TTSs that were most similar (in terms of cost reduction measure taken as the inverse of $f^a(P), \forall P \subseteq S$) to be TRO and DTI. Then, the next most similar TTSs added into the cluster were the pair EC and DTI, and so forth until all TTSs were added. If, rather, we are interested in a synergy measure as the ratio of the contribution to the net benefit relative to the total cost, then we consider $f^b(P), \forall P \subseteq S$ equation 4.3.4. Instead of plotting $f^b(P), \forall P \subseteq S$ directly, we have considered the component $1 - f^a(P), \forall P \subseteq S$ in the interval $[0, 1]$. In this way we can interpret the results shown in Figure 4.4 (b) in a similar way as in Figure 4.4 (a).

The different results indicate that the type of TTSs to be integrated in a system platform depends on the reasons for integration, e.g. net profit will lead to different TTSs as opposed to relative profit measure of synergy. In the net profit case, there is a chance that one TTS may dominate an entire cluster, making such a cluster appear beneficial, whereas such chances are minimized in the relative profit case. In Figure 4.4 (a), regions with constant slopes indicate that the addition of TTSs does not lead to change in net benefit.



→ Cluster variation of TTSs based on inverse of absolute potential benefits



→ Cluster Variation of TTSs based on potential net benefit relative to total costs

Figure 4.4: (a) Results of clustering TTSs using pairwise synergies based on inverse of absolute cost savings measured in terms of number of functionalities, (b) Relative synergy estimate for incremental TTS clusters.

4.6.2 Scenario B

A public authority, system designer or TTS provider may be interested in finding out which additional TTSs (to a given killer application) can be achieved in a strategic perspective. Furthermore, a given ITS system such as RUC may have more than one possibility of implementation, and the decision of a good choice may be argued according to how each given choice supports additional TTSs. An existing example is the satellics integrated tolling platform (Kirn, 2009). Similar issues are under consideration in the Swedish RUC system ARENA project (Sundberg et al., 2005). We consider two variants, a basic road user charging system denoted by RUC and an advanced system denoted by RUC1. RUC1 system can be achieved with functionalities such as: da, ds, gp, ids, ind, mp, obu, odd, rm, rc, tfc and ts. If we now introduce an offset to the base functionalities by assuming that RUC can be achieved with local positioning (lp) instead of global positioning (gp), and without data storage (ds) and obu, then the resulting synergy with other TTSs based on inverse cost savings, $\frac{1}{f^a(P)}$, $\forall P \subseteq S$ equation 4.3.4, appears as shown on Figure 4.5.

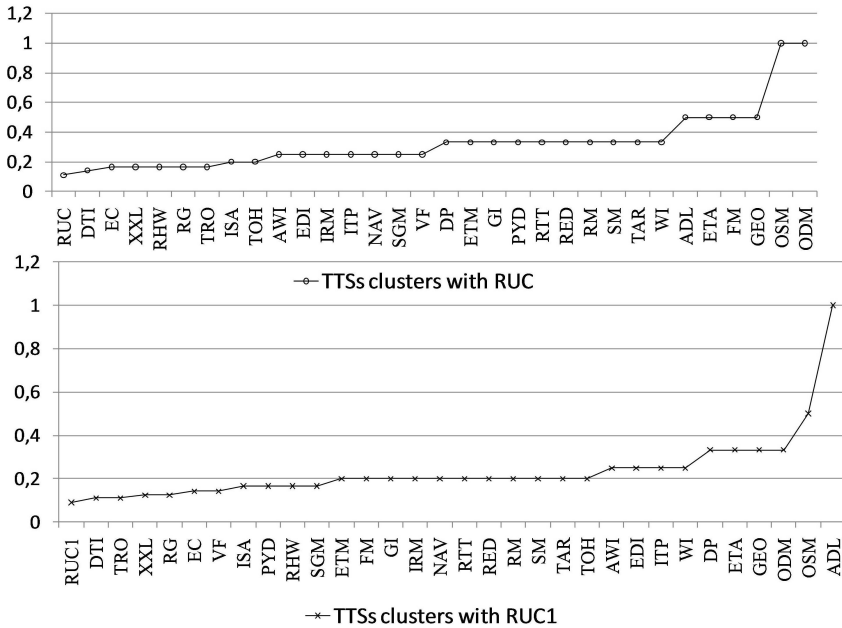


Figure 4.5: Relative synergy assessment of the RUC.

The difference between the two results for RUC and RUC1 (which are similar

to thin and thick client versions of the RUC (Persson et al., 2007)) is the order in which the TTSs appear. While for RUC, DTI, EC and XXL form a cluster with possibly high cost savings, DTI, TRO and XXL form a much more beneficial cluster with RUC1. The major difference between Figures 4.4 (a), 4.4 (b) and Figure 4.5 is that in Figures 4.4 (a) and 4.4(b), each TTS is clustered taking into account all TTSs that are already in the cluster, whereas Figure 4.5 considers only the relationship with RUC and RUC1. The horizontal segments in Figure 4.5 indicate the possibility to include several TTSs with steadily increasing cost savings.

4.7 Discussion

The focus of the paper was to analyze potential cost reduction, based on synergies, related to sharing functionalities between road freight TTSs. Given the costs of shared functionalities and pairwise assessment of cost reduction for integrating the TTSs, we showed that such data can be converted to interval data resulting in a two-dimensional matrix that can then be used by a distance-based clustering algorithm such as hierarchical agglomeration. This conversion was necessary to enable us to capture the required features of the data and hence to improve the quality of the hierarchical agglomeration results, which is not as good for nominal data (Žibera et al., 2004). Hierarchical agglomeration with nearest neighbor was chosen because we wanted to compare the likely reduction in total cost of different clusters of TTSs. Depending on the formulation of the synergy measure, it may be possible to use other types of clustering (as K-means). However, the choice of recommending one clustering method over another is rather difficult (Everitt et al., 2001) due to a number of disadvantages, e.g. how to determine the number of clusters, stopping criteria or scaling. Even though we chose to consider clustering-based methods, there are alternative solution approaches such as K-minimum (or maximum) spanning trees that can potentially be used to address similar problems to the one in this paper. The major difficulty in the above results

is to determine the optimal cluster from a cost reduction perspective and this is a setback associated with all clustering methods. However, it is possible to further perform a sensitivity analysis to determine the effects of adding every given TTS in the cluster. In Figure 4.6, we provide a one-dimensional sensitivity analysis where synergies between TTSs without RUC (such as between DTI and RG) are not taken into consideration. Such dimensions cannot directly be interpreted from the above model. However, by referring to Table 4.1, the number of additional functionalities resulting from each TTS can be identified. For instance, in order to achieve RG, it is necessary to implement driver interface (di), monitoring (m),

weather forecast (wf) and vehicle speed (vs) functionalities. If we further include DTI, which also needs wf and di in addition to other functionalities, we take into account the fact that these functionalities are already included because of the inclusion of RG, i.e. a secondary level synergy. Following this same approach, we could go further and determine any additional functionalities and TTSs until a convenient level is attained, e.g. based on policy priorities. Additionally, one could also study the synergy based on other killer telematic systems than RUC, e.g. eCall.

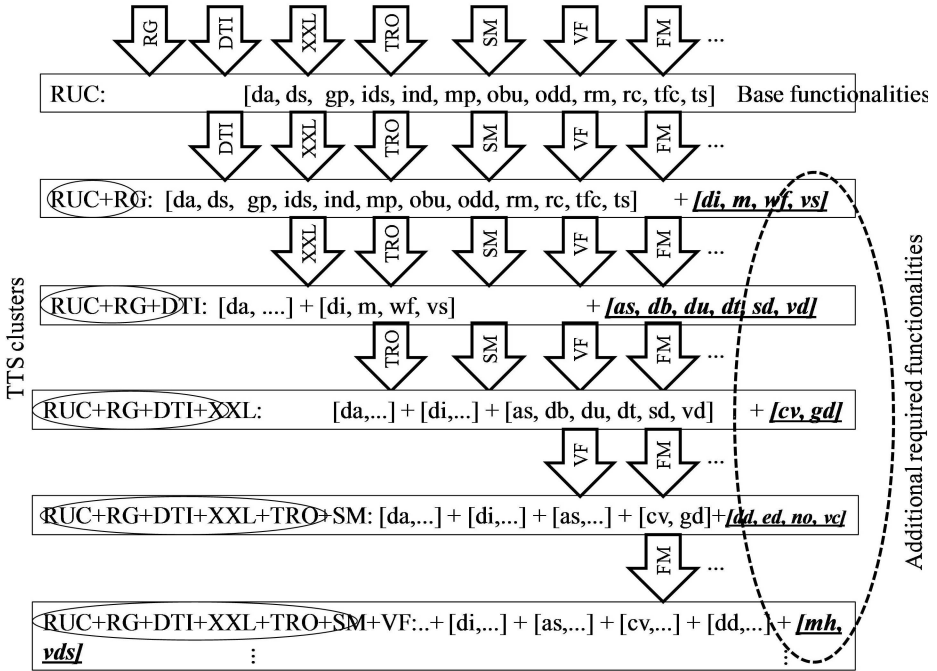


Figure 4.6: Analysis of additional TTS functionalities for different synergy levels with the RUC.

4.8 Conclusion and Future Work

This paper has proposed a method for analyzing potential contribution to net benefit, based on synergies, related to sharing functionalities between road Transport Telematic Services (TTSs). The method takes into account the functionalities between TTSs, costs of sharing functionalities (if available) and, for a simplified case, returns a pairwise synergy measure between the TTSs concerned.

This value is then used in a distance-based hierarchical clustering algorithm and the results ordered from the most similar to the most dissimilar cluster. The proposed method was used to analyze synergies between clusters of 32 relevant TTSs (identified in the Mobil IT project) all based on 38 functionalities. It is important to note that results were based on the simplification that all functionalities could be achieved at the same costs. In reality, the costs between functionalities do vary. However, there is a cost reduction in the common use of a functionality and if such cost reduction can be estimated for the given set of TTSs under consideration, then can the proposed method be fully exploited. Figures 4.4 (a) and 4.4 (b) shows that with focus on integrating TTSs based on contribution to absolute cost reduction, transport resource optimization, dynamic traffic information, eCall, and vehicle follow services could be more beneficial than any other cluster with four TTSs. If the relative net benefit is taken into consideration then staff monitoring, sensitive goods monitoring, vehicle follow up and pay as you drive will form the most beneficial cluster. This could be the case if we want to prioritize sharing of expensive functionalities such as satellite positioning.

Further we also investigated the synergy of TTSs with a killer telematic system such as the Swedish RUC system. Analysis of this RUC system and the rest of the TTSs (31), show that dynamic traffic information, eCall and information on extra large goods possibly have a high synergy compared to the rest of the TTSs. In-vehicle telematic systems such as on-board safety and security monitoring, on-board driver monitoring and geofence appeared in a similar cluster with the least net benefit to integrate with RUC. The greatest difference in the cost savings between RUC and RUC1 is noticeable with a cluster size of at least seven. The two solutions agree almost entirely in terms of types of TTSs with cluster sizes up to seven elements. After this, RUC1 shows higher contribution to net benefits than RUC. Therefore, with fewer than seven TTSs (as shown above), RUC or RUC1 may be an interesting solution from a net benefit perspective, whereas with greater than six TTSs, RUC1 is better than RUC. Regarding implementation, it is reasonable to start by implementing a simple RUC system with few TTSs and expand the system with more TTSs over time. Synergy estimates, as proposed in

this study, depends greatly on the type of functionalities considered for each TTS and the underlying interpretation of functionality sharing. The nature of this dependency is a subject for further investigation, e.g. requiring that functionalities be characterized in such a way as to identify separate attributes, finding whether attributes are in favor of common or separate use of functionalities by each TTS, and testing other clustering methods. The synergy is an indication of duplicated functions that maybe avoided and yet achieve the same utility in terms of the number of TTS offered. This presents a possibility for minimizing the cost of implementation in telematic systems. The current method for synergy estimates

does not recommend the best TTS cluster; rather it shows the effect of combining different TTS clusters. In the future, approaches that may handle multidimensional analysis that may lead to recommending an optimal TTS cluster can be investigated, e.g. using optimization. Also, it is difficult to take into consideration the value of the TTSs using the proposed method. This is because some TTSs may still have a high societal value even though their possibility for cost reduction in an integrated platform is low. If the proposed method is followed, such TTSs may be disregarded and, therefore, an analysis that takes the TTSs value into consideration is important.

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Paper IV

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

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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 multiple-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. 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, governments, road transport telematic service providers, and commercial road freight transport operators.

Keywords

Transport, Telematic, Services, Architecture, Evaluation, Modeling, Optimization, Integer Linear Programming.

5.1 Introduction

Transport telematic systems or Intelligent Transport Systems (ITS) are today considered a suitable approach for addressing surface transportation problems, e.g. reduction of road fatalities. The effectiveness of such approaches can be seen in terms of the benefits of implemented Transport Telematic Services (TTSs). TTSs can deliver important benefits, such as improved emergency response, reduced travel times and emissions. TTSs can co-exist on the same telematic system. We view a transport telematic system 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) mainly because ITS is focused on soft concepts such as information accuracy, responsiveness etc which cannot be easily measured in monetary terms. A platform or telematic system architecture that can deliver multiple services is more likely to lead to higher net benefits. 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 the analysis of 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 transport telematic architectures that support multiple services (Multi-Service Architectures (MSAs)). Using estimated values for TTSs benefits to society (Mbiydzennyuy 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 net societal benefit. The benefit of modeling MSAs, and TTSs is to improve our understanding of their potential effect on society. Further, modeling can help our understanding of the dependencies that

exist between multiple TTSs and therefore improve how we assess potential benefits of such TTSs. The model supports the analysis of choices of MSAs, based on the choice of TTSs, available resource capacities and functionalities needed to achieve TTSs. Resource utilization by each functionality, and costs of realizing functionality contributes to the costs of 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. 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 connected to 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 5.1.1, 5.2 and ?? respectively, provide definitions of key terms used, related work and a discussion of MSAs for TTSs. In sections 5.4, 5.5, 5.6 and 5.7 are a proposed optimization model, a case study that employs the proposed model, results and analysis, conclusions and future work, respectively.

5.1.1 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, such as map matching, position coordinates and so on. 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 14813-1, 2007). A TTS is specified by its functionalities and provides value to society.

C. Multi-Service Architectures (MSA) for a Transport Telematic System

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 connect MSA specification to functionalities by allowing a certain set of resources.

5.2 Related Work

Evaluation of ITS architectures is a subject of interest that has been addressed by many studies, such as Pearman and Shires (1997); Persson et al. (2007); Tai-ying (2008); Wees and Hertzberger (2000). All these studies have been aimed at understanding the potential benefits of ITS systems using different methods. Most approaches used can be seen as formative or summative depending on the goal behind the evaluation (McQueen and McQueen, 1999). We differ from existing evaluation approaches, in that we are looking at the net benefits in the context of multiple TTSs, 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 net 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 ITS 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 challenging because they require large amount of accurate data in order for the results to be reasonably interpreted Levinson and Chang (2003). One way to manage the lack of data for validating quantitative models 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 net 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 a 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.

5.3 Multi-Service Architectures for Transport Telematic Services

The concept of MSAs for telematic systems 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. System architecture in the context of ITS generally focuses on the reference, logical (conceptual architecture) and physical architecture specifications. A logical architecture in ITS consist of an overview of the system and necessary functionalities. This study focuses on MSA logical specifications. Architecture concepts can use different communication approaches, such as Dedicated Short Range Communication (DSRC), satellite based communication and, General Packet Radio Service (GPRS), each of which have implications on the amount of data that can be processed, e.g. more communication bandwidth implies a large amount of data can be transmitted, hence, increased demand on processing resources. The specific characteristic for distinguishing between two MSAs can be called MSA key features. In the proposed optimization model we interpret key features as available of certain resources that are used by functionalities of different TTSs. These key features are considered important because of their high costs and also because they influence most system functionalities especially communication and processing. Therefore the underlying aspects in a MSA will be the amount of data that can be processed, communicated. How each MSA achieves communication, processing, positioning and road side equipments can be considered as a key feature of the given MSA since a particular approach affects resource utilization i.e. data processed or communicated. The implementation of TTSs requires several functionalities which are sometimes similar or same for certain TTSs and hence resulting to unnecessary duplications when multiple TTSs are implemented.

5.3.1 Multi-Service Architectures Choices

Several choices of architectures (MSA) can be used to achieve different types of TTSs depending on the types of functionalities allowed or not allowed by such architectures (Xu et al., 2004). In this study we chose to interpret a MSA concept as a combination of a set of features. As stated earlier, each MSA feature allows for a given resource or set of resources and capacities that are used by functionalities. Different types of resources and resource capacities are used by TTSs through their functionalities. If such resources are not available then the functionality cannot be achieved or it is achieved an extra cost. As an example, a MSA key feature such as vehicle-vehicle communication means that we can support sensor data and voice data communication but not video data communication. Hence any TTSs with a functionality that requires the

communication of voice and sensor data can be achieved with a MSA that has a vehicle-to-vehicle feature. Vehicle to infrastructure communication means that we can achieve sensor data, audio data and video data communication and so on. A number of such MSA features are considered. Generally selecting or deselecting (yes/no) means that certain resources are made available to functionalities of different TTSs. Selecting or deselecting a feature depends on the choice of MSA. This concept can better be illustrated with a diagram (Figure 5.1). We will further illustrate specific combinations in the case study, together with the type of resources and associated capacities.

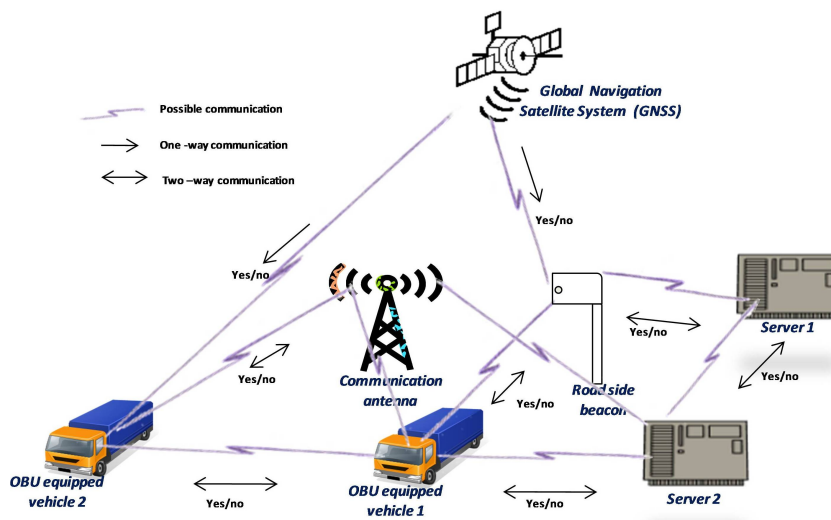


Figure 5.1: Illustration of the concept of MSA key features that provide functionality resources

5.3.2 Resources for Transport Telematic Services

Different MSAs allow different functionalities based on two aspects: the type of resource required by the functionality and the associated resource capacity e.g. sensor, video, audio data with capacities 0.5Mbps, 1 Mbps or 2Mbps of communication band width.

I. Communication

There are several ways of modeling communication. In this paper, we have considered aspects related to communication capacity. For instance, one-way communication (only in one direction), e.g. data broadcasting, may

require less bandwidth than two-way communication. . Data broadcasting involves the transmission of data to multiple users simultaneously. Both one-way and two-way communication can be influenced by the choice of architecture e.g. allowing for vehicle to road side or server to vehicle etc. We consider communication to be limited by data capacity and hence such data capacities can be used as a distinguishing factor between different MSA choices. We distinguish three types of data according to the communication capacity demand; 1) sensor data e.g. temperature, road conditions, number of vehicles etc, 2) audio data e.g. voice and, 3) video data e.g. from road side cameras. For simple sensor data communication 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 video data generated per traffic camera can reach up to 16GB in one day (Esteve et al., 2006).

II. Processing

We consider the processing capacities of MSA to depend on the type of technique (concept) used to achieve processing as follows:

- On-Board Unit (OBU) data processing: The main idea is that data is processed on moving vehicles. A small computer is fitted on-board the vehicle with the capability to process, display and store data.
- Single Central 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.
- Multiple distributed server processing: We consider here that two or more servers processing data do not need to communicate in order to accomplish their task, i.e. working in parallel. Though distributed processing can also be used to refer to a situation where tasks are shared between different computers, we consider that each server will completely execute its task without having to interact in real time with the other servers.

III. Positioning

One way to model positioning as a resource is to consider the possibility to achieve positioning using satellite or road side beacons.

- Satellite positioning: A receiver (in the vehicle) is used to pick up a signal and position of the vehicle determined based on the signal properties.

- Road side equipment (INFORBEACON): An electronic device mounted on the road side is used to reference the position of a vehicle. INFORBEACON can also be used for storing data and transmitting such data to other systems and hence as a communication device.

5.3.3 Cost Modeling for Transport Telematic Services

Different functionalities for implementing TTSs utilize architecture resources e.g. communication infrastructure. The implementation of a functionality incurs a fixed cost. TTS resulting from functionalities utilize different capacities of resources incurring a variable costs in addition to the fixed costs of functionalities e.g. the transmission of sensor data may require less communication bandwidth than the transmission of video data and hence different levels of costs. Cost of resource utilization by TTSs can be modeled in different ways. One way is to consider the costs and capacities of each of the resources according to the units or interfaces that are available in the market. Consequently, we choose for this study to consider the costs structure to depend on the interfaces or units for achieving each of the types of resources discussed above i.e. communication, processing and positioning.

Resource	Type of Resource Supported
Communication	Sensor data modem Audio data modem Video data modem
Processing	OBU equipment Distributed computer networks Centralized computer network
Positioning	INFORBEACON based on DSRC 1000 Satellite e.g. GNSS

Table 5.1: Example of resources and types that can be used to model resource cost.

5.4 A proposed Optimization Model 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 realizing the services, as illustrated in Figure 5.2 below:

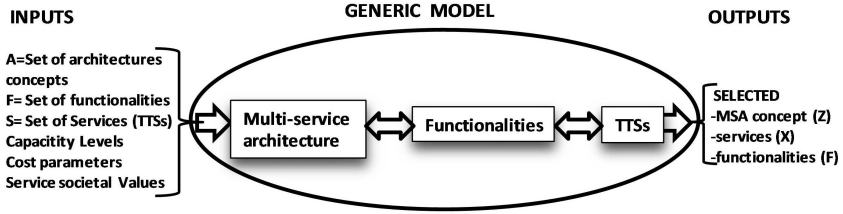


Figure 5.2: Generic Model Diagram illustration

The proposed model is aimed at suggesting the relationship between MSAs, resources (from key features), functionalities and TTSs. Each MSA is a specification of a set of key features. We have not explicitly considered key features in the model; rather we have concentrated on the resources for achieving key features. Hence each key feature involves either a single resource or a specification of a set of resource types and capacities. Each TTS functionality requires one or more resources. Once a functionality uses a certain type of resource the result is that it generate a given amount of data. Each TTSs is a specification of a set of functionalities. The positive benefits are estimated from the societal value of a TTS and the costs are from the functionalities utilized by the TTSs. Later on, we will provide a complete mathematical formulation of the above relationships in an optimization model. We also consider a dependency parameter $D_{\hat{i}\hat{i}} \geq 0, \hat{i}, \hat{i} \in S, \hat{i} \neq \hat{i}$ (S a set of TTSs) to account for the decrease in marginal benefits of two TTSs that address a related aspect e.g. accident reduction, fuel consumption etc. For instance if E-Call and Intelligent Speed Adaptation both improve accidents by 2% and 3% respectively, the total improvement or benefit will be slightly less than 5% due to decrease in marginal benefits. We compute the value of such dependencies by calculating a pairwise matrix for all TTSs depending on whether such services address a common performance indicator. We showed in an earlier study (Mbiydenyuy et al., 2009) how these computations can be obtained including the data used in the model in this article. The following assumptions are considered:

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.
- 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.** The societal value created by implementing a TTS can be quantified in money terms.
- A4.** The total societal value of two TTS addressing a common societal aspect, such as accidents, is reduced compared to the sum of the independent benefits when such services are implemented together.
- A5.** We assume there is only one best way of implementing a service.

Sets

- S: Set of TTSs (shown in Paper II)
F: Set of functionalities (shown in Paper III)
A: Set of architectures (shown in Table 4 below)
R: Set of resources (Table 3 below)

Parameters

Parameters and set values indicated in parenthesis are those used in the case study. Generally, other parameter values can be studied with the model depending on how such values represent the particular scenario of interest.

- $V_i, i \in S$ The value of each TTS (from paper II).
 $C_j, j \in F$ The fixed cost of each functionality (shown in Appendix B).
 $P \geq 0$ Cost of communicating and processing 1 megabyte of data ($2.9 * 10^{-10}$ €).
 $D_{\hat{i}\hat{i}}, \geq 0, \hat{i}, \hat{i} \in S, \hat{i} \neq \hat{i}$ Pairwise dependency between two services (discussed above and in Paper II)
 $T_{jr}, j \in F, r \in R$ 1 if functionality requires resource, 0 otherwise (shown in Appendix B).
 $M_{ij}, i \in S, j \in F$ 1 if service requires functionality, 0 otherwise (shown in Appendix B).

$A_{rt}, t \in A, r \in R$	1 whenever a key feature allows resource usage and 0 otherwise (shown in Table 5.4).
$U_r \geq 0, r \in R$	Data generated per resource unit (shown in Table 5.2).
$Z_t, t \in A$	1 if choice of architecture is considered, 0 otherwise (model solves each scenario at a time).
$\tilde{U}_r \geq 0, r \in R$	Capacity per unit of resource e.g. OBU (shown in Table 5.3).
$\Phi_r \geq 0, r \in R$	Cost of each resource unit (shown in Table 5.3).
$E_j, \geq 0, j \in F$	Extra costs if a functionality is not supported by architecture resource ($E_j = C_j, j \in F$)
$\delta \geq 0$	Integer used to relax the requirement on the architecture to allow for some functionalities that are not supported (2)

Variables

$x_i, i \in S$	1 if service is selected, 0 otherwise.
$f_j, j \in F$	1 if functionality is selected, 0 otherwise.
$y_{ij}, i \in S, j \in F$	1 if both functionality and service are selected, 0 otherwise.
$\tilde{f}_{ir}, i \in S, r \in R$	1 if TTS selects a functionality and resource is not supported by architecture, 0 otherwise.
$c_{ir} \geq 0, i \in S, r \in R$	The variable cost of each TTS for a given resource
$\vartheta_{\hat{i}\hat{i}} \geq 0, i, \hat{i} \in S, i \neq \hat{i}$	1 when services i and \hat{i} are selected, 0 otherwise.
$\eta \geq 0$	Integers limiting the number of TTSs currently considered.
$\psi_r, \geq 0, r \in R$	Number of units of resource (depends on unit capacity in Table 5.3).

Objective

Maximize:

$$\sum_{i \in S} V_i * x_i - \sum_{j \in F} C_j * f_j - \sum_{\substack{i \in S \\ r \in R}} P * c_{ir} - \sum_{r \in R} \Phi_r * \psi_r - \sum_{\substack{i, \hat{i} \in S, \\ i \neq \hat{i}}} \vartheta_{\hat{i}\hat{i}} - \sum_{j \in F} E_j * \tilde{f}_j \quad (5.4.1)$$

Constraints

C1: Whenever a service is 1, all its functionalities are also 1. This is in line with assumption A5.

$$x_i * M_{ij} \leq f_j, \quad i \in S, \quad j \in F$$

C2: Whenever a MSA choice is 1, associated resources can be used by functionalities

$$T_{jr} * f_j \leq A_{rt} * Z_t + \tilde{f}_{jr}, \quad j \in F, t \in A, r \in R$$

C3: Whenever a pair of services is selected, the value of the dependency D is considered.

$$D_{i\hat{i}} * (x_i + x_{\hat{i}} - 1) \leq \vartheta_{i\hat{i}} \quad i, \hat{i} \in S, \quad i \neq \hat{i}$$

C4: In order to estimate how much data is being generated we will like to know when both a TTS and a functionality are selected.

$$(x_i + f_j - 1) \leq y_{ij} \quad i \in S, j \in F$$

C5: Whenever a TTS is selected (all its functionalities) we estimate the cost of managing the data generated by the TTSs i.e. processing and communicating.

$$c_{ir} \geq \sum_{j \in F} U_r * T_{jr} * y_{ij} \quad i \in S, r \in R$$

C6: To estimate the variable costs we need to know how many units of each MSA resource are used up by different TTSs. This is because we consider the utilization of resources to have an effect on the fixed costs e.g. if one server can process $2GB$ of data in real time and the amount of data that need to be processed (depending on the selected TTSs) is $2.1GB$, then it requires a second processor.

$$\sum_{i \in S} c_{ir} \leq \tilde{U}_r * \psi_r \quad r \in R$$

C7: We set a limit on the number of functionalities that are not supported by MSA resources.

$$\sum_{j \in F, r \in R} \tilde{f}_{jr} \leq \delta$$

C8: Finally we set a limit to the number of TTS currently considered to study the sensitivity of the model (running from 2 to 32).

$$\sum_{i \in S} x_i \leq \eta$$

5.5 Case Study

In this case study we assume that the costs and resources of functionalities, $f_j, j \in F$, studied can be quantified in terms of data received/transmitted or processed per service ($x_j, i \in S$) within a static time period and hence data rates can be used as a proxy parameter for most parameters from which cost values are calculated. Capacity of each resource unit $\tilde{U}_r, r \in R$, e.g. for communication, are obtained by considering average data transfer rates, and values for processing by considering the data capacity of dynamic memory etc. We assume a scenario where TTSs are accessing the communication bandwidth simultaneously similar to a saturated network. The functionality fixed costs $C_j, j \in F$ are essentially the entry costs necessary to acquire hardware/software for providing the functionality, and distributed according to the life span of such products (typically 10 years). Fixed cost data was mostly obtained from market prices set by manufacturing companies. Since we considered MSA key feature resources in terms of what is available in the market today e.g. modems, OBU etc the cost of each such unit $\Phi_r, r \in R$ from their market prices e.g. OBU unit at 500€(Mckinnon, 2006). In addition to the costs associated to resource units required, $\Phi_r, r \in R$, we also include a cost directly associated with resource usage, $c_{ir} \geq 0, i \in S, r \in R$, based on resource utilization by each functionality $U_r \geq 0, r \in R$. The values for these were estimated by reviewing similar existing functionalities implemented in other systems. An example of typical ranges of data rates for ITS applications are shown in Table 5.2.

Type of Resource Supported	Parameter Value Interval	Usage ($U_r, r \in R$) in Mbps
Data communication	0.5Kbps to 11Mbps	0.0015
Voice communication	4.8Kbps to 32Kbps	0.002
Video/Picture communication	3Mbps to 6 Mbps	0.004
OBU data transfer rate	250Kbps (up-link), 500Kbps (down-link)	0.005
OBU data processing/storage	6.4Kbps	0.005
Distributed server processing	500Mbps (4GHz)	0.2
Centralized Server Processing	2000Mbps (8GHz)	0.05
INFORBEACON ARIB-STD T75	Transmission (1024 kbps) position frequency 1/10 KM	0.01
Satellite positioning	250Bps (down-link)	0.005

Table 5.2: Data rate requirements for communication and processing ITS data.

The cost per megabytes of data communicated, processed or stored in one second (Mbps) is obtained by generalizing the telecommunication pricing scheme in Sweden. Most telecommunication companies have pricing schemes that target maximum capacity usage by clients. For instance, in Sweden, data communication service companies such as tre.se charge 4.9€/month for unlimited data transfer. Statistical data shows that in Sweden an average of 2000MB/month was communicated per user in 2009 (PTS, 2009), which gives an average cost of 4.9/2000 €/MB. Since this value is a market price, it includes other costs such as mobile terminal (phone) which in 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. 0.000245€/MB. In other words for TTSs investigated in this study, the range in monthly cost per user will be from 31.5€/month to 122.7€/month which we think is reasonable compared to today's price levels. 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 value estimate for a service is based on its possibility to improve some performance saving indicators such as accidents, fuel consumption, delays etc all of which are addressed by a separate study (Mbiydzennyuy et al., 2009). The values of the services are assessed per year with a discount rate of 5% as

these values are typically used for ITS investment planning (Xu et al., 2004). We indicate resources, capacity and unit cost considered in Table 5.3.

Resource	Type of Resource Supported	Capacity $\tilde{U}_r, r \in R$	Unit cost $(\Phi_r, r \in R)$
Communication	Sensor data modems (R1)	36Kbps	150
	Audio data modems (R2)	3Mbps	250
	Video data modems (R3)	4Mbps	400
Processing	OBU equipments (R4)	6.4Kbps	500
	Distributed computer network (R5)	500Mbps	2000
	Centralized computer network (R6)	2000Mbps	5000
Positioning	INFORBEACON based on DSRC (R7)	10Mbps	1000
	Satellite e.g. GNSS (R8)	0.25Mbps	500

Table 5.3: Resources (R), capacities($\tilde{U}_r, r \in R$) and unit costs($\Phi_r \geq 0, r \in R$) used in the case study

Using the resources in Table 5.3, we specify the resources for each MSA shown in the concept diagram (figure 1) in Table 5.4 below.

H	Resources allowed								MSAs					
	R1	R2	R3	R4	R5	R6	R7	R8	Z1	Z2	Z3	Z4	Z5	Z6
H1	1	0	0	1	0	0	1	0	1	0	0	1	0	1
H2	1	1	0	0	0	1	1	1	0	1	1	1	1	1
H3	1	1	1	1	1	0	0	0	1	1	1	0	0	0
H4	1	1	1	1	0	1	1	1	0	1	1	1	1	1
H5	1	0	0	0	1	0	1	1	0	0	0	0	1	1
H6	1	0	0	1	0	0	1	0	1	0	1	1	1	1
H7	1	1	1	1	0	1	1	0	0	1	1	1	0	1
H8	1	1	1	0	1	0	0	0	1	1	0	0	0	0
H9	1	1	1	1	0	0	1	0	1	1	1	1	1	1
H10	1	1	1	0	1	0	0	0	1	0	0	0	0	0

Table 5.4: Key features (H), resources allowed (R) and MSA specification (Z) with notation explained in Table 5.5

MSA key features denoted by H1...H8 in Table 5.4 are explained in Table 5.5

Notation	Explanation
H1	Vehicle-to-vehicle communication
H2	Roadside to server communication
H3	Vehicle to server communication
H4	Vehicle to roadside communication
H5	Satellite to roadside communication
H6	OBU data processing
H7	Multiple server processing
H8	Single central server processing
H9	Satellite positioning
H10	Data broadcast

Table 5.5: Explanation of notation in Table 5.4 below

MSAs are specified in Table 5.4. We have considered six candidate MSA concepts, extended from previous work (Brasche et al., 1994; Persson et al., 2007). For each MSA, where relevant, we discuss a similar example, and summarize the key features for a given MSA in Table 5.4. We interpret a 1 as allowing resources corresponding to the MSA feature (in Table 5.4), otherwise the resources are not available if it is a zero. The choice of MSA influence the choice of resources and the choice of resources influence which functionalities can be achieved and hence the choice of TTSS. We provide, below, a description for each MSA considered in Table 5.4.

- 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 a receiver antenna or 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 (Biffel 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).

5.6 Results and Analysis

A scenario of the above model is solved using AMPL/CPLEX. AMPL provides a modeling 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. 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 consider a basic specification of a Road User Charging (RUC) system within the set of services and in another case, we use an advanced specification (RUCA)?
- Q2 What is the effect of forcing a particular TTS to be implemented? e.g. RUC, RUCA etc
- 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.

5.6.1 Effects of Selecting Different Types of TTSs .

The selection of TTSs here is independent of MSA resources.

- (a) Selected number of TTSs based on synergies with RUC and RUCA alternatives.

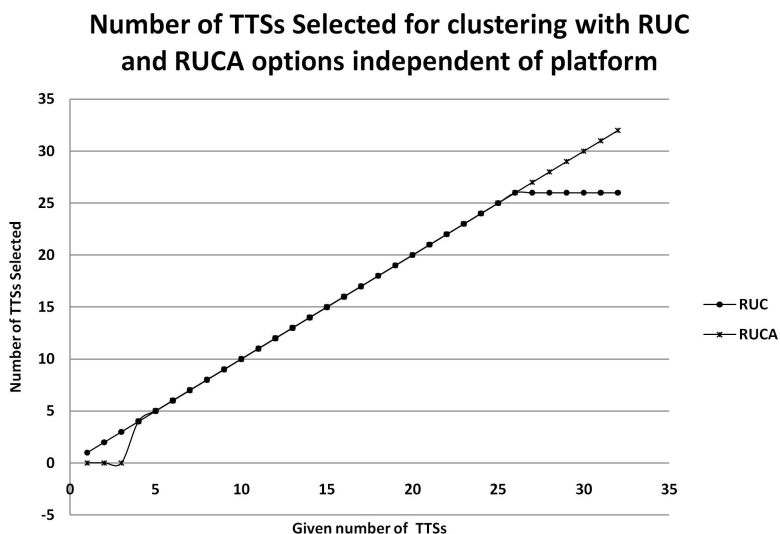


Figure 5.3: Number of TTSs selected with RUC and RUCA alternatives

In the experiment set up for this scenario, we introduce RUC and run the model, then we introduce RUCA and run the model again. 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 5.3). In the graph, we run the optimization model with a restriction of the selection of number of services η from 2 to 32 (horizontal-axis) and plot this against the number of applications selected by the model (vertical-axis). The RUC service was not selected until the model was allowed to consider at least 20 TTSS i.e. $\eta \geq 20$. 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. Figure 5.3 further shows that there are potentially better synergies with a RUCA than RUC since RUCA selected more TTSS than RUC. 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

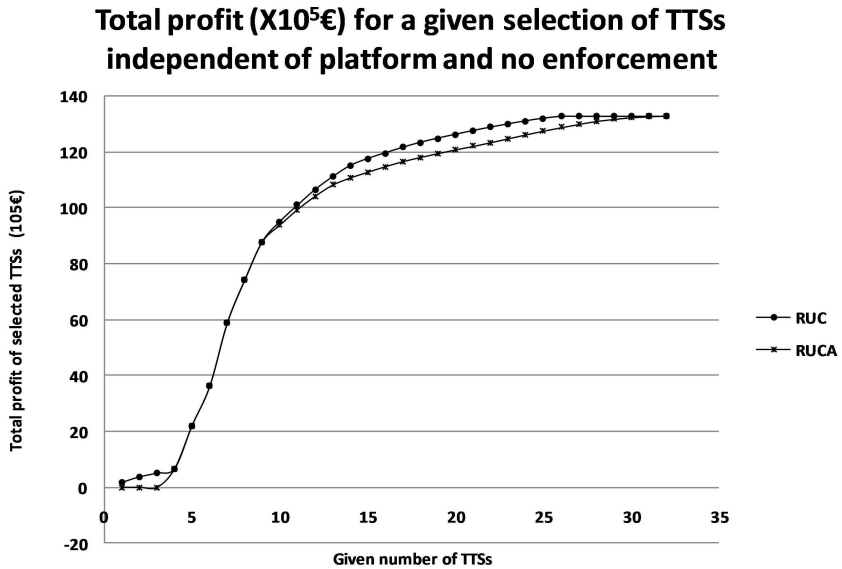


Figure 5.4: Total profit (net benefit or objective function) for applications TTSS selected with RUC and RUCA.

We use the same experiment as above instead we study the net total net

benefit variation with the selection of TTSs. 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 5.4 shows that even though RUC may only select a few applications, the net benefit is likely to be more than RUCA despite many applications selected (Figure 5.3). From Figure 5.4, it can be seen that 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.

5.6.2 Effects, on Profit, of Enforcing Different Types of TTSs

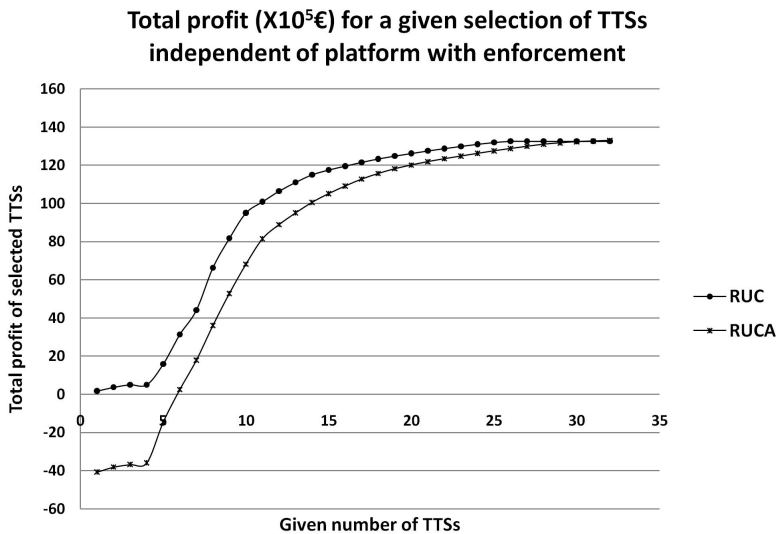


Figure 5.5: Net benefit variation with enforcement for RUC and RUCA.

In this second scenario we force the selection of a given TTSs by setting where i in this case could be RUC or RUCA. From the results, the total net benefit for RUCA will be negative until at least five applications are included as can be

seen in figure 5.5. This is in line with results from figure 5.3 since the selection of applications for RUCA did not take place until at least three applications are included. From Figure 5.5, it can be seen that the total net benefit of RUC is not affected by enforcement, while enforcement is likely to lead to a negative total net benefit for RUCA if only TTSs are allowed. 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 5.6 we show the priority of selection of TTSs when studying the RUC and RUCA alternatives in Figures 5.3, and 5.4 above. TTSs with small priority number in Table 5.6 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).

TTSs	**	*	TTSs	**	*	TTSs	**	*	TTSs	**	*
AWI	3	6	FM	15	19	ODM	27	21	RG	22	0
ADL	28	25	GEO	26	24	OSM	21	16	SGM	5	8
DP	25	23	GI	24	22	PYD	7	11	SM	29	26
DTI	19	0	IRM	19	0	RTT	10	14	TAR	1	4
EC	1	4	XXL	30	0	RED	23	20	TOH	6	9
ETM	14	18	ITP	13	17	RM	9	13	TRO	1	4
EDI	4	7	ISA	19	0	RHW	1	4	VF	11	15
ETA	8	12	NAV	3	6	RUC	20	10	WI	20	0

Table 5.6: Order of selection of different applications for RUC and RUCA alternatives (**=RUCA, & *=RUC)

5.6.3 Effects of Including MSA Specification on Selected TTSs

- (a) Selected number of TTSs based on MSA specification.

First we consider the number of TTSs selected when different MSA 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 Z3 similar to a thick client with decentralized data processing could support more TTSs than any of the MSAs considered (32). Also a hybrid V2V2I architecture, Z6, can also support nearly as much as Z3 (29 out of 32). Coincidentally, Z2 and Z5 selected the same number of TTSs (13 out of 32) even though they are specified with different resources.

This may have resulted from the level of detail of resource modeling. The current model does not provide detail resource modeling. According to the current model, Z1 and Z4 are the least MSA choices to consider when it comes to supporting additional TTSs. The progressive selection of applications with given restrictions (from 2 to 32) is shown in Figure 5.6 below:

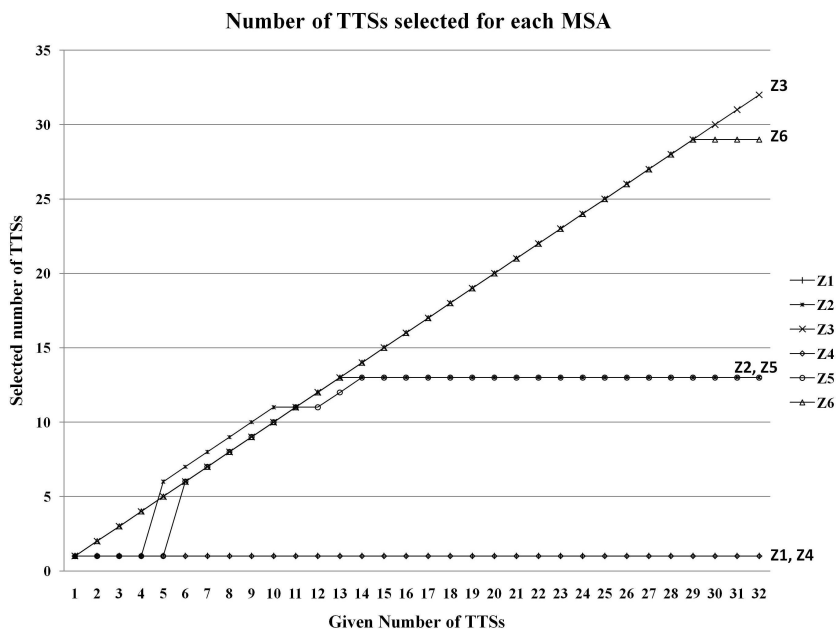


Figure 5.6: Selection of TTS for different choices of platforms

- (b) Total net benefit for selected TTS on different MSA platforms
 As before, we consider the total net benefit of selected TTSs. The results (as seen earlier in Figure 5.4) shows that Z3 will produce the highest net benefits. This is not surprising considering that Z3 can potentially support the highest number of TTSs as seen in figure 6. However, Z6 will support more TTSs(5 out of 32) achieving the same net benefit as Z3 with fewer TTSs (4 out of 32) as shown in Figure 5.7 net benefit for Z6 is greater than Z6 are the same for the first five TTSs selected. The trend for Z1, Z2, Z4 and Z4 is the same as in Figure 5.6. The results for this scenario are summarized in Figure 5.7.

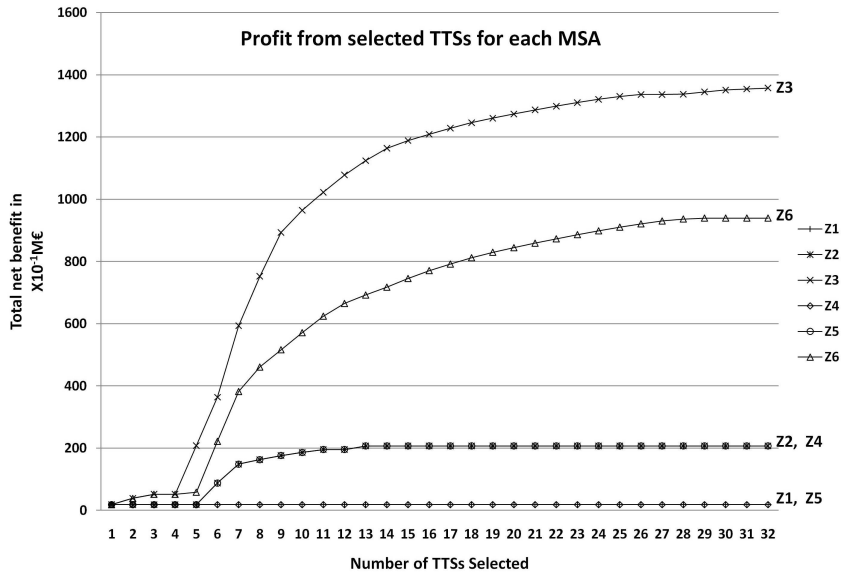


Figure 5.7: Total net benefits (objective function) of selected applications for different choices of MSA concepts.

- (c) Total dependency of selected TTSs for different MSA platforms
- The net benefit increase for different selections of TTSs on different MSAs may be partly due to the dependencies between the TTSs i.e. reduced marginal benefits when two or more TTSs target a common goal. TTSs addressing common issues, such as accidents, will lead to reduced marginal benefits when all are implemented compared to implementing only one such TTSs i.e. if the TTSs are not orthogonal in the space of targeted goals. The total dependency $\vartheta_{\hat{i}, \hat{i}}$ $i, \hat{i} \in S, i \neq \hat{i}$ (summation) of selected TTSs for various MSAs indicate that the main difference between Z3 and Z6 is a set of 5 TTSs with a high dependency as shown in Figure 5.8. For Z6 high dependencies exist up to 6 TTSs compared to Z3. Total dependency variation is summarized in Figure 5.8.

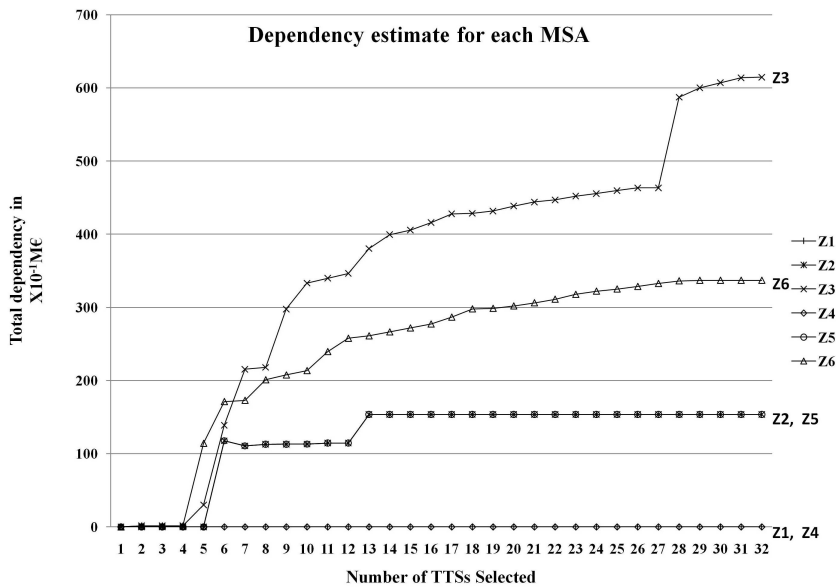


Figure 5.8: Total dependency variation (sum of $\vartheta_{\hat{i}, \hat{i}}$) of selected TTSs for different MSAs

We next present the priorities of selected TTSs in Tables 5.7, 5.8, & 5.9 indicating the order in which each application was selected for a given architecture.

Z	AWI	ADL	DP	DTI	EC	ETM	EDI	ETA	FM	GEO	GI
Z1	0	0	0	0	0	0	0	0	0	0	0
Z2	6	9	8	0	0	0	6	7	0	0	11
Z3	6	25	23	27	5	18	7	12	19	24	22
Z4	0	0	0	0	0	0	0	0	0	0	0
Z5	6	9	8	0	0	0	6	7	0	13	11
Z6	4	27	24	0	0	19	5	9	20	26	25

Table 5.7: Order of selection, for each TTS application on different platforms part I

Z	IRM	XXL	ITP	ISA	NAV	ODM	OSM	PYD	RTT	RED	RM
Z1	0	0	0	0	0	0	0	0	0	0	0
Z2	0	0	13	0	6	0	0	0	13	13	0
Z3	28	28	17	28	8	28	16	11	14	21	13
Z4	0	0	0	0	0	3	0	0	0	0	2
Z5	0	0	13	0	6	0	0	0	13	13	0
Z6	15	29	18	15	5	17	13	10	12	22	11

Table 5.8: Order of selection, for each TTS application on different platforms part II

Z	RHWRUC	RG	SGM	SM	TAR	TOH	TRO	VF	WI
Z1	0	1	0	0	0	0	0	0	0
Z2	0	1	0	0	10	6	6	7	0
Z3	5	10	28	5	26	5	9	5	15
Z4	0	1	0	0	0	0	0	0	0
Z5	2	1	0	0	10	6	6	7	0
Z6	0	8	21	7	28	5	6	5	14

Table 5.9: Order of selection, for each TTS application on different platforms part III

In Tables 5.7, 5.8, & 5.9, 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 TTSSs. Results obtained are dependent on the costs of the functionalities and the benefits of different TTSSs using different MSAs as well as on the common use of functionalities with TTSSs.

5.7 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 and designers facing long term decisions related to the implementation of telematic systems with multiple services. 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 net 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 traveler 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 5.7). 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 net 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, alternative TTSs implementations 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.

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Appendix A

Description of Transport Telematic Services

This section provides a discussion of all Transport Telematic Services (TTSs) that are analyzed in papers II, III and IV. These TTSs are considered in the context of vehicles, goods, drivers, owners, infrastructure and other stakeholders such as traffic controllers and customs that in one way or another have a contribution to road transport operations. In describing the services we take into consideration what information it provides, users of such information, data used to realize the information and how often the information is provided. In addition we consider the domain of usage of the service, the functionalities required to achieve the service and any reported experimental results of a similar service where available. 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. Road User Charging, Navigation 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. TTS descriptions provided in this section are simplified. The analysis of TTSs may need further study than what is presented in this section e.g. a TTS can be implemented in several different ways whereas we assume only one possible implementation in most of the descriptions below.

6.1 Accident Warning Information -AWI

AWI provides information about accidents (location, type of accident etc) in real time to subscribed road users who are within a certain distance from the accident scene. AWI also warn users about the potential of an accident depending on driving style, weather conditions etc. The source of information about the accidents is from accident sensors (in the vehicle), broadcasted data etc. The purpose of AWI is to help users to take decisions that will minimize the consequences of such accidents for the user, e.g. change of route. (AWI is similar to road hindrance warning, and on-board safety and security monitoring service except that AWI is focused faster dissemination of accident information whereas road hindrance warning considers all possible hindrances and focuses on minimizing the effect of the hindrance by providing alternative solutions). 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. 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 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 traveling time, 5%.

6.2 Automated Driver Logs -ADL

ADL collects driver data e.g. driver work hours, overtime, sick leave, vacation, allowances, driver condition etc during driving tasks. The information is processed by detecting patterns in this information that can be used to support the driver

e.g. automatic adjustment of seat each time the driver logs in to begin driving. Further, this information can be used to check any violations (e.g. change in alcohol level) that can indicate risks, and communicate such information to different interest groups e.g. back office, control agents etc. 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. For instance out 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

DP collects driver preferences, expected workload and together with transport orders, suggest a driver management plan to the personnel manager for driver planning. Such a plan is based on data about individual driver preferences and work load collected over a period of time and updated continuously as new data becomes available. As any of the input data (orders) changes new plans are suggested and communicated to the hauler company so as to improve driver planning and hence performance. DP will maximize driver convenience by attempting to maximize their desired preferences. Different HGV drivers have different preferences and experiences that maybe difficult to realize 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%) and time based costs (0.1%).

6.4 Dynamic Traffic Information -DTI

DTI collects process and disseminates real time traffic information to individual drivers, traffic control agents, dispatchers, environmental agents, and infrastructure operators in real time to help them avoid negative traffic situations including queue build up. The information about traffic conditions is based on dynamic events such as accidents, weather, repairs and maintenance etc that result to changes in traffic conditions. Devices such as sensors are used to collect this data in real time which is then used to estimate the current traffic conditions. 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 11.5€/vehicle in Petersson (2007) for passenger transport) 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

EC provides real time information about an accident to drivers, emergency units, traffic controllers, and goods owners. This is based on data about accidents e.g. position coordinate, vehicle contents, vehicle type etc. EC is intended to facilitate accident intervention e.g. by emergency unit and can be manually activated by a driver. 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 provides 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, 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, 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

This is a telematic service that supports both road users and environmental agents to understand the effects of driving behavior on the environment and thereby make appropriate decisions for reducing emissions and other environmental damages related to traffic in an area e.g. road segment or network, hospital areas, day care schools etc. The service collects data about emissions from the vehicle with a given driving approach (and possibly emission ratings for different areas) process the information by showing possible damages resulting from current emission (short and long term) and display the results in real time to drivers, emission

control agents etc. 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 behavior 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 support 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

EDI provides route-specific information to drivers and back office to facilitate their use of such routes, based on route specific data such as traffic, transit, road conditions, weather conditions, traffic controls, cameras and road traffic intervention. It is similar to navigation and route guidance except that it focuses on a specific route and relay this with back office. 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

This service continuously provides short time prediction of arrival time for a given destination to goods owners and dispatchers based on data collected in real time about current traffic conditions. 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 less 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

FM provides information about freight to infrastructure investment agencies, transport planners, and infrastructure owner as well as researchers. The information is based on capacity, type, location, origin-destination etc. This service will collect, process and share anonymous information about commercial vehicles that can be used for transport administration, goods control and research. This service will support 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 infrastructure investment agencies, transport planners, and infrastructure owner as well as researchers. Functionalities are data en-

ryption, 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

Geo-fence is a telematic service that provides information about access to an area or infrastructure to infrastructure owners, dispatchers, and good owners. GEO enables contact-less control of an area of interest by collecting, processing and sending real time information indicating unauthorized access and potential implications. The area could range from gate, parking spot with a truck and its content, accident scene etc to a transport corridor, bridge, tunnels, military areas etc. There is a need to control access to such areas 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 geo-fence will potentially lead to a small reduction in total time and administration (0.03%) 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

GI provides accurate real time information to goods owners, gate controllers, terminal operators, goods inspectors, custom officers and emergency units, for identification and handling of goods. GI helps in identifying goods without the need for physical maneuver e.g. at gates or loading and unloading stations. GI data is based on goods documentation e.g. waybill and sensors for collecting goods data. This is closely related to freight mobility service except that goods identification is focus on goods only. 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 goods owners, 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. Functionalities includes 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. 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

IRM provides information to infrastructure owners, infrastructure repair and maintenance units etc. The information is about predicting the need for maintenance (preventive maintenance) based on historical data collected from usage and maintenance history of such infrastructure. The frequency of communicating information will depend on changes in infrastructure data such as expansion and contraction coefficients, vibration properties etc that could imply the need for maintenance but the information can also be communicated on request. 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 Malmö 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 Extra Large Cargo -XXL

This service will provide both historical and real time information obtained from processing road data and also from road management data bases to drivers, infrastructure owners, traffic controllers and related interested parties about what measures they should take in order to successfully transport XXL cargo e.g. route restrictions. The information will be based on data provided by route infrastructure owners or government agents overseeing the transportation of XXL cargo. In Sweden it is required that the transport of XXL cargo is granted special permit according to a regulation called vägtrafikförordningen, 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 inquiries 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

maintenance costs.

6.14 Information on Truck Parking -ITP

ITP provides information about parking facility availability to drivers and parking infrastructure providers. ITP collect data about the availability of parking facility, process the data e.g. estimate parking duration, best entry and exit points etc and communicating the information to drivers (in real time) in order to help them easily access such a facility. ITP will enable efficient management of parking space and minimize wrong parking. 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

This service recommends driving speed to road users based on information obtained from data about current road conditions. 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 14023.8M€ while Police enforcement will create an additional value of 318.13 M€(Eliasson, 2006). Trials of ISA in Sweden show that if every car was equipped with an ISA system, injuries could be reduced by 20% to 30%, and each vehicle will experience 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 did not 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

This service helps a driver by providing information about a road choice in a network based on real time information about road conditions e.g. traffic flow speed, weather etc. Using data about route conditions and origin-destination of the vehicle, NAV service determines the most appropriate route (shortest time, path etc) to arrive at destination. It is similar to en-route driver information and route guidance except that it focuses on route network and does not relay information with back office. As route networks 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 minimize 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 indicate 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 -ODM

ODM provides real time information about the drivers conditions to traffic inspectors (e.g. police), goods owners, vehicle owners, company personnel unit, and dispatchers. This service watches the drivers back by collecting data that can be used to assess the health statues of a driver and sharing the resulting information with authorized agents in real time to facilitate intervention and ensure driver safety if necessary. This information is used with the drivers consent. 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 or her 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, vehicle 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 fatalities in Sweden (Berglind, 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

OSM provides information to individual drivers, vehicle inspectors and telematic service providers making use of vehicle OBU about the safety statues of a vehicle and it content i.e. goods. The information is communicated as soon as changes in the statues of the vehicle and goods are detected that can lead to a potential safety risk. The information is based on patterns in goods and vehicle data (including OBU) that are considered to be of significant effects e.g. 15% change in temperature of a certain product, compromised security of OBU etc. The driver and other interested parties (e.g. goods owners) can then be warned ahead of any potential risks in order to take appropriate decisions and actions. The driver has to constantly ensure that the vehicle (also monitored

through remote monitoring service) and its 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 status of the goods. This is not only strenuous but results in delays. In addition, the vehicle's OBU that will be used for other telematic applications will need to be monitored to ensure its status is correct. All these make it necessary for on-board safety and security monitoring. The service will contribute to driver support and transport management. 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 damage 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 impact 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 status of the goods that can be relayed to the good owner.

6.19 Pay as You Drive -PYD

PYD provides information to insurance companies, drivers and environmental management agents about driving history including driving speed, location, time, vehicle conditions, emissions etc that can be used for risk evaluation (e.g. by insurance companies), in order to support accurate insurance premium charging or for the purpose of designing environmental control policies. This information is communicated in real time or as batched information after fixed time intervals. 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. PYD is expected to have an impact on drivers behavior in traffic and with respect to the environment, and help in forging environmental control policies thus contributing to traffic management and environmental management. Users of the service are insurance companies, drivers and environmental management agents. Accident sensors, automatic trigger, data encryption, data broadcasting, data storage, driver data global positioning, maintenance history, monitoring, OBU, OD data logger, route congestion sensors, time stamping, 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 minimize 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 (Litman, 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

RTT provides information to goods owner, dispatchers, and traffic controllers or interested agents. The information can be used to track a specific vehicle at any point and time for a specific purpose extending the usual scanning at gates to cover the entire road network. This is done by collecting vehicle data e.g. identification, position coordinates, origin and destination etc processing the data and communicating the information to the RTT service subscriber. 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 today's solution in which goods are scanned at terminals. With real time information, associated supply chain activities like production planning or distribution can be adjusted to meet the current status 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 supports activities of transport management, fleet management and traffic management. Users of the service include goods owner, dispatchers, and traffic controllers. Functionalities 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 to a reduction 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

This service will provide information to goods owners, gate agents, loading and unloading terminal agents, tax agents, customs and police about goods type, vehicle identification etc in real time so as to reduce the time spent at such gates. This information will depend on the origin and destination of goods, type of goods and associated information etc. 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 minimize 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 agents, loading and unloading terminal agents, tax agents, customs and police. 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 by RED will be small and which we assess at 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

Unlike OSM & ODM, RM is concerned with the mechanical system of the vehicle. RM provides information for vehicle diagnostics and preventive maintenance to vehicle maintenance workshops, drivers and dispatchers. The information is based on archived historical and current data about vehicle performance. The information is communicated by request (in case of diagnostics) or as soon as there are indications of bad performance that can be associated to mechanical malfunctioning. Vehicle breakdowns result to cost, delays and in some cases accidents. Vehicle maintenance accounts for a significant cost to hauler companies and such faults constituted as much as 45% of all inspected HGVs in 2009 by the Swedish Vehicle Inspection Agency, bilprovning (Kågeson and Dings, 2000). The cost of maintenance can be minimized 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

RHW provides information to individual drivers and fleet operators about potential hindrance along a route and suggest possible solutions so as to minimize the effect of the hindrance. This information is based on current and expected traffic conditions and available route choices. Accident warning information is a special case of RHW that focuses specifically on accidents. Road hindrance can potentially lead to queue build up, delays in deliveries, increased emissions or even disrupt the entire supply chain processes etc. While many services already provide information related to road hindrance in different ways, it is important that this information is used to suggest potential solutions in the different scenarios that may obscure traffic flow e.g. alternative roads, recommended driving speed, estimated duration of hindrance 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

RUC provides information to infrastructure owners or authorized agents about infrastructure utilization. The information is based on the data about use of infrastructure by each vehicle such as distance traveled in a road network, re-

gion, time of use, weight of vehicle etc. Information is communicated in real time or in batches. RUC enables accurate charging of the use of road infrastructure and minimizes the time delays spent at toll booths today. 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 internalize the external costs of road transport. In particular RUC system as anticipated in Sweden can provide the possibility to avoid congested roads and balance traffic on different 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 minimizing delays at toll booths. The main users are road infrastructure operators such as government agents responsible for road operations, other agents overseeing the task of collecting charges for road usage and road users such as hauler companies etc. Important functionalities required to achieve RUC 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

RG provides real time information to drivers related to specific route choices especially if the driver uses such routes for their first time. RG also provide information to infrastructure owners about the use of a specific route, enabling infrastructure owners to influence such usage. This information is based on collecting route specific data such as zebra crossings, school children, special occasions, traffic volume etc. It is similar to navigation and en-route driver information

except that it focuses on route specific information and does not relay with back office. While a navigation service addresses problems of driving through road networks, there is a need for more specialized information for HGV drivers on a given road. To provide details such as zebra crossing, lane change, school children etc real time information is needed when a driver has settled down to drive on a given route. In addition, there is a need for infrastructure owners and traffic controllers to be able to influence the use of a given road. Thus RG will support drivers, infrastructure management, and traffic management. Primary users are drivers, infrastructure operators, and traffic control agents. Functionalities are LCD interface, global positioning, infrastructure damage sensors, infrastructure data, map position and updates, monitoring, network optimization, 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

SGM provides real time information to authorized agents such as customs, local and regional authorities etc in charge of sensitive goods about the location of such goods, type of goods and relevant data for assessing the level of risks associated with the current statuses of goods. In addition to controlling what facilities are accessible to vehicles carrying sensitive goods, the information can also be used to facilitate intervention and minimize the damage that would otherwise have been caused by sensitive goods in case of an incident. 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

SM provides real time information to administrators based on the available staff capacity and required workload, behavioral patterns etc in order to help them make the best use of company staff including driving and non-driving staff. Through efficient management of company staff it is expected that work related risk such as fatigue as well as mischievous behavior will be minimized and staff throughput maximized. 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 staff may underestimate the risks associated to fatigue. SM service is similar to on-board driver monitoring service except that SM focuses on all company staff, collecting data to facilitate administration and traffic management, whereas on-board driver monitoring is focused on security and safety of the driver. In case of the driver SM can support administration by providing accurate information on driver alertness and behavior e.g. reaction time, mischievous behavior in fuel stations etc. This will enable the road hauler administrators to monitor advice and assign task according to the capabilities of their staff and minimize 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

TAR provides information to the drivers, good owners, dispatchers and police, about the current situation of the vehicle and location in the absence of the vehicles authorized driver. The information is based on use of automatic triggers, alarms and other sensors that are activated in an event of unauthorized access. This information is provided on request or as soon as the vehicle and content are considered to be of high risk resulting from unauthorized access or theft to either the vehicle or it content. The service can also provide continuous

information about a stolen vehicle in order to facilitate recovery. 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, 2008) of a 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, dispatchers and police. 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 will subscribe to TAR, a great reduction of up to 15% can be achieved in the number of thefts Reported per year i.e. 321 theft cases can be eliminated. 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

TOH provides real time information to drivers and transport planners about incoming orders and fulfilled orders based on data collected from customer ordering systems, vehicle location, goods location etc. This information support scheduling of driver trips, reduce the time used in handling orders and improve the accuracy of handling such orders. As orders are received continuously by a transport planner, locations (origins and destinations) 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 fulfillment, 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 such as data encryption, data broadcasts, data updates, driver data and LCD display, local positioning, goods data communication, OBU, location (of goods and vehicle), inter-system 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

TRO provides information to infrastructure owners about utilization or operational strategies for combined use of infrastructure such as roads, vehicles, bridges, tunnels etc in a bit to achieve overall improved performance for all involved actors e.g. vehicle owners, road administration etc. The information is based on collecting data related to infrastructure capacity, utilization schedules etc. Limited resources are deployed in order to execute a transport operation whereby unpredictable traffic conditions make it necessary to improve overall resource utilization 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 traveled 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 NO_2 .

6.31 Vehicle Follow Up -VF

VF provides real time information to vehicle owners (dispatchers) about vehicle performance based on data related to vehicle usage such as capacity utilization, fuel consumption, idling, breaking, empty mileage etc. 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. minimize empty

mileage or maximize carriage capacity. A lot of data about HGVs, drivers and goods made available to back office in real time will combine to help in fleet planning processes. Vehicle follow up service is focused on collecting and analyzing vehicle performance related data e.g. empty mileage, fuel consumption, capacity utilization 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 concerned with fleet scheduling. 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 achieve 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 reduce time used to manually collect and analyze such data assessed at 0.1%.

6.32 Weight Indication -WI

WI provides real time information related to road infrastructure restrictions and vehicle total weight to drivers and inspection agents. The information is based on collecting and processing data related to infrastructure restrictions such as maximum height, vehicles total weight, and other relevant limitations recommended or required for use of such infrastructure. In addition changing traffic conditions may lead different recommendations of total maximum weight in a given road segment. 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 while information about road infrastructure is communicated to the driver on-board the vehicle. 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 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

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Appendix B

Additional Data Used in the Optimization Model

Additional data used in the optimization model is presented in this section.

7.1 Value, Total Costs and Functionalities Specification of each TTS

TTS	V	$C_{ir} + C_j$	M_{ij}
AWI	37.3067	24.8277	as, asg, db, ds, dt, di, lp, odd, rm, rc, ts, wf, vd, vs
ADL	1.3169	0.3453	db, dd, lp, ts, vd, vc
DP	1.6571	0.4139	da, db, dt, dd, gd, lp, obu, odd, ts, wf, vd
DTI	5.5001	25.3611	as, db, du, dt, di, gp, ids, ind, mp, obu, odd, rm, rc, sd, tfc, ts, wf, vd, vs vc
EC	31.1537	1.5493	as, asg, at, cv, db, du, dt, dd, di, gp, gds, gd, hs, lp, mh, mp, no, obu, rm, rc, src, sd, tfc, ts, vds, vd, vs, vc
ETM	1.8353	24.8955	db, ds, di, ed, gp, lp, mp, m, obu, rc, src, vd
EDI	30.6157	24.8381	du, di, lp, mp, obu, odd, rc, src, tfc, wf, vs, vc
ETA	6.214	0.7605	db, dt, gp, gd, m, no, odd, rc, sd, ts, wf, vs
FM	1.797	24.7867	da, ds, dt, gp, gds, gd, m, obu, odd, src, ts, vd
GEO	1.4191	24.7086	asg, at, cv, db, dt, gp, m, rm, src, ts, vd

TTS	V	$C_{ir} + C_j$	M_{ij}
GI	1.4863	0.5912	at, da, db, du, dd, gp, gds, gd, mp, m, obu, odd, ts, vd, vs
IRM	8.3006	0.6415	gp, ids, ind, mh, mp, m, rc, src, wf
XXL	0.3774	24.9141	cv, db, dt, di, gp, gd, ids, ind, mp, m, obu, odd, rc, tfc, ts, wf, vd, vs
ITP	3.16	49.1601	at, cv, db, di, ind, lp, mp, no, obu, src, ts, vd
ISA	31.0407	24.7883	asg, cv, db, di, gp, ids, mp, m, rm, rc, sd, tfc, wf, vs
NAV	36.019	24.7291	di, gp, lp, mp, no, obu, odd, rm, rc, sd, wf, vd, vs
ODM	2.0123	0.5817	as, asg, db, dt, dd, gp, hs, m, obu, ts, vds, vd, vs
OSM	3.048	25.0144	asg, cv, dt, di, gp, gds, gd, hs, mh, m, obu, src, vds, vd, vs
PYD	6.8345	25.2703	as, at, da, db, ds, dt, dd, gp, mh, m, obu, odd, rc, ts, wf, vds, vd, vs
RTT	5.9057	0.7506	db, du, dt, dd, di, gp, gd, mp, no, obu, rc, src, ts, wf, vd, vs
RED	1.8912	0.6906	cv, da, db, ds, du, dd, di, gds, gd, mp, obu, odd, src, ts, vd, vc
RM	8.0054	25.0136	as, asg, at, ds, du, gp, lp, mp, m, obu, src, ts, vds, vd, vs
RHW	37.4657	1.1057	as, asg, db, dt, lp, mp, no, obu, odd, rm, rc, sd, tfc, ts, wf, vs
RUC	14.3576	0.6509	da, ds, gp, ids, ind, mp, obu, rm, rc, tfc, ts
RUCA	10.67	0.645	da, lp, ids, ind, mp, rm, rc, tfc, ts
RG	1.8863	24.7392	di, gp, ids, ind, mp, m, no, obu, odd, rm, rc, tfc, wf, vs
SGM	16.181	24.797	da, db, ds, dt, dd, ed, gp, gd, mp, m, odd, rc, ts, wf, vd, vs
SM	1.0062	24.7276	da, db, ds, dd, gp, mp, m, odd, ts, vd, vs
TAR	37.5607	25.0735	asg, at, cv, db, ds, dt, dd, gp, gds, gd, hs, mp, rc, ts, vds, vd, vs
TOH	22.0607	24.6785	da, db, du, dd, di, gd, lp, mp, obu, odd, rc, ts, wf, vd
TRO	49.9383	25.6558	da, db, ds, du, dt, dd, di, ed, gp, gd, ind, mp, m, no, obu, odd, rc, sd, tfc, ts, wf, vd, vs, vc

TTS	V	$C_{ir} + C_j$	M_{ij}
VF	3.0743	24.9649	da, db, ds, du, dt, dd, di, ed, gp, mh, mp, m, obu, odd, rc, ts, vds, vd, vs
WI	4.06	24.8381	asg, at, cv, du, di, gp, gds, gd, ids, ind, mp, m, src, wf, vs

Table 7.1: Value, total costs and functionalities specification of each Transport Telematic Service

7.2 Resource Requirements for Each Functionality

Notation	Explanation
$T_{jr}, j \in F, r \in R$	is used to represent the functionality resource matrix
R1	Sensor data modems
R2	Audio data modem
R3	Video data modem
R4	OBU equipment
R5	Distributed computer network
R6	Centralized computer network
R7	INFORBEACON based on DSRC
R8	Satellite e.g. GNSS

Table 7.2: Key to table 7.3 below

The following matrix is used in the case study in Paper IV.

T_{jr}	R1	R2	R3	R4	R5	R6	R7	R8
as	1	0	0	1	1	0	0	0
asg	0	1	0	0	0	0	0	0
at	1	0	0	1	0	0	0	0
cv	1	0	1	0	0	0	1	0
da	1	0	0	1	0	0	0	0
db	1	1	0	1	0	0	1	0
ds	1	1	1	1	0	0	0	0
dt	1	0	0	0	0	0	0	0
dd	1	0	0	1	0	0	0	0

T_{jr}	R1	R2	R3	R4	R5	R6	R7	R8
di	1	1	1	1	0	0	0	0
ed	1	0	0	0	1	0	1	1
fcd	1	1	0	0	0	0	0	1
gp	1	0	0	0	1	0	0	1
gds	1	0	0	1	0	0	0	0
gd	1	0	0	1	0	0	0	0
hs	1	0	0	1	0	0	0	0
ids	1	0	0	0	0	0	1	0
ind	1	0	0	0	1	0	1	0
lp	1	0	0	1	0	0	1	0
mh	0	0	0	1	1	0	0	0
mp	0	0	0	1	1	0	0	0
m	1	0	1	0	1	0	1	0
no	0	0	0	1	0	0	0	0
obu	1	0	0	1	0	0	0	0
odd	0	0	0	1	0	0	0	0
rm	1	0	0	0	0	1	1	0
rc	1	0	0	0	0	1	1	0
src	1	1	0	0	1	0	1	0
sd	0	0	0	1	0	0	0	0
tfc	0	0	0	1	0	0	0	0
ts	1	0	0	0	0	0	0	0
wf	1	0	0	1	0	0	1	0
vds	1	0	0	0	0	0	0	0
vd	1	0	0	0	0	0	0	0
vs	1	0	0	1	0	0	1	0
vc	0	1	0	1	0	0	0	0

Table 7.3: Specification of functionalities and resource requirements

ABSTRACT

The focus of this thesis is the assessment of telematic systems for road freight transport from a planning perspective. The aim is to support strategic decisions related to architectural choices for such systems, with the possibility to achieve synergies by supporting multiple telematic services. The past decade has witnessed enormous growth in cargo volumes resulting in increasing demand for transport capacity. To match this increasing demand only with expansion of infrastructure, e.g. road and vehicles, does not seem to be a sustainable strategy. One of the few approaches with the potential to improve the use of current transport capacity is the integrated use of modern information and communication technology, otherwise known as telematic systems for road transport, an important component within Intelligent Transport Systems (ITS). This type of systems can deliver multiple services that can be used to improve the efficiency and safety of road freight transport. However, attempts to unleash the potential of telematic systems and make maximum possible use of the available transport capacity have been hindered by several challenges ranging from planning and design to development and deployment.

Considering the large scope of possible telematic services that can potentially be deployed in road freight transport, this thesis suggests a framework in order to enable structured assessment of telematic systems. Based on the suggested

framework, a set of potential transport telematic services are identified and a method for quantifying the value of the services to society is developed. The suggested method takes into account the expected impact on different transportation challenges, such as accidents, fuel consumption, and infrastructure maintenance. Quantitative methods are provided for studying the value of services sharing a common infrastructure. Using quantified benefits of services and costs of various functionalities required by telematic services, the concept of a multi-service architecture is investigated using optimization methods, which handles the multi-dimensional relations between different services that are otherwise difficult to analyze with traditional cost-benefit analysis. The analyses show which telematic services can be achieved with different approaches, such as vehicle-to-vehicle communication, vehicle-to-infrastructure communication, etc.

Although multi-service architectures are promising, several challenges need to be overcome, including security, service quality, privacy, and business models. The knowledge gained from the work presented in this thesis can be valuable for different stakeholders, such as governments, service providers, and transport service users, in fostering the planning, design, development, and deployment of telematic systems in transport.

