

QUANTITATIVE ASSESSMENT OF INTELLIGENT TRANSPORT SYSTEMS FOR ROAD FREIGHT TRANSPORT

Gideon Mbiydzenyuy

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"After climbing a great hill, one only finds that there are many more hills to climb"

– Nelson Mandela (2009)

Abstract

In this thesis, methods for using computer-based models as support tools for assessing Transport Telematic Services (TTSs) are studied. Such assessments provide one way to understand how TTSs can address problems caused by transportation, such as accidents, emissions, and energy consumption. TTSs are services based on telematic systems which are Intelligent Transport Systems (ITS) involving the integrated use of information and communication technologies in transport. The focus is on TTSs that are relevant for road freight transport, even though the suggested methods can easily be adapted for TTSs in other areas. We characterize TTSs, e.g., in terms of their functionalities, and apply computer-based modeling for pre-deployment assessment of various TTSs (from an ex-ante perspective). By analyzing information provided by the suggested computer-based models, it is possible to make an informed decision whether to (or not to) deploy a given TTS.

A review of previous studies reveals information about relevant TTSs for freight transport in areas such as driver support, administration, safety, traffic management, parking, and goods handling. A hierarchical clustering algorithm and a K-minimum spanning tree algorithm were employed to analyze synergies of TTSs. Synergies can enable identification of sets of TTSs that can lead to cost savings if deployed on a common platform (cf. Multi-Service Architectures). An analytical model inspired by the net present value concept is used to estimate quantified societal benefits of TTSs. An optimization model is formulated and solved using a branch and bound method to determine an optimal combination of TTSs taking into consideration societal benefits, costs, dependencies, and synergies. The optimization model also addresses possible system architectures for achieving multiple TTSs. Dominance rough set approach is used to assess and compare benefit areas for TTSs specific to truck parking. The benefit areas are suggested with the help of conceptual modeling, which describes functional models of a system in terms of states, transitions among states, and actions performed in states.

The main scientific contributions of the thesis are in suggesting new quantitative models, extending and applying existing models in the assessments of TTSs, and obtaining results that can help decision-makers select TTSs for medium-to long-term investments. Researchers can employ and build on the proposed methods when addressing different scenarios (geographic or organizational) involving similar TTSs. By studying a range of TTSs and possible Multi-Service Architecture concepts for such TTSs, the thesis contributes to achieving convergence of TTSs in a Multi-Service Architecture environment that will improve cost efficiency, minimize redundancies, and encourage the establishment of standards in the deployment of TTSs in road freight transport. TTSs implemented in such an environment can contribute to optimizing available capacity, accuracy, speed, and efficiency of road freight transport systems.

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Finally, I would like to thank the almighty GOD for my life.

Karlshamn, April 16th 2013

Gideon Mbiyzenyuy

Preface

This thesis includes the following articles:

- I. Mbiydzenyuy, G. (2009). Characterization framework for road transport telematic services. *The 9th International Conference on Transport Systems Telematics, Archives of Transport System Telematics*, 2(4):24-30, 2009, ©PSTT, ISSN 1899-8208, Katowice-Ustroń, Poland.
- II. Mbiydzenyuy, G., Persson J., Davidsson, P. , & Clemedtson, P. O. (2012). A Method for quantitative valuation of road freight transport telematic services. *IET Intell. Transp. Syst.*, 6(4):388-396, 2012, ©The Institution of Engineering and Technology 2012, ISSN 1751-956X, DOI: 10.1049/iet-its.2011.0168.
- III. Mbiydzenyuy, G., Persson J., & Davidsson, P. (2013). Exploring the relationship between telematic services and functionalities using synergy analysis. *Submitted for journal publication.*
- IV. Mbiydzenyuy, G., Persson J., & Davidsson, P. (2011). Toward cost-efficient integration of telematic systems using K-spanning tree and clustering algorithms. *14th International IEEE Conference on Intelligent Transportation Systems, Washington DC, USA. October 5-7, 2011*, pages:803-808, 978-1-4577-2197-7/11 / ©2011 IEEE, DOI: 10.1109/ITSC.2011.6082957.
- V. Mbiydzenyuy, G., Persson J., & Davidsson, P. (2012). Optimization analysis of multiservice architecture concepts in road transport telematics. *Journal of Intelligent Transportation Systems*,16(4):197-210, 2012, ©Taylor and Francis Group, LLC, ISSN:1547-2450, print/1547-2442, DOI: 10.1080/15472450.2012.710159.
- VI. Sochor, J. & Mbiydzenyuy, G. (2013). Assessing the benefits of intelligent truck parking. *International Journal of Intelligent Transportation Systems Research*. Pages:1-11, ©Springer Science +Business Media New York 2013. ISSN 1348-8503, DOI: 10.1007/s13177-012-0055-3.
- VII. Mbiydzenyuy, G., Persson J., & Davidsson, P. (2012). Problem-driven design of core services for the deployment of intelligent truck parking. *Submitted for journal publication.*

Papers II, III, V, VI & VII are respective extensions of the following conference papers:

- VIII.** Mbiydzenyuy, G., Persson J., Clemedtson P. O., & Davidsson, P. (2009). The Value of transport telematic services in heavy goods vehicle transport *2nd EasyWay Annual Forum, Vienna Austria.*
- IX.** Mbiydzenyuy, G., Persson J., & Davidsson, P. (2008). Analysis of added-value services in telematic systems and service in road-based vehicle freight transport *14th World Congress on Intelligent Transport Systems, New York, USA.*
- X.** Mbiydzenyuy, G., Persson J., & Davidsson, P. (2009). Optimization-based modeling of multiservice architecture concepts in road transport telematics. *12th IEEE Conference on Intelligent Transport Systems, St. Louis, MO, USA.*
- XI.** Sochor, J. & Mbiydzenyuy, G. (2011). Assessing the Benefits of Intelligent Truck Parking. *18th World Congress on Intelligent Transport Systems, Orlando, FL USA.*
- XII.** Mbiydzenyuy, G., Persson J., & Davidsson, P. (2012). Proposed ITP core services for the deployment of Intelligent Truck Parking. *19th World congress on Intelligent Transport Systems, Vienna, Austria.*

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Introduction

1.1 Overview

The world population and its economy have increased quite fast over the past century. As the standard of living has increased, so too has the demand for products and services. In order for these products to reach the consumers, transportation is necessary in most cases. This imposes demands on transportation systems in terms of capacity, reliability and energy efficiency. Transportation has to be sustainable and minimize negative impacts on the environment. Fortunately, computers and communication systems have developed rapidly and can support transport planning and operations. Currently, there are several Intelligent Transport Systems (ITS) on the market that are creating new capabilities by integrating information processing and wireless communication technologies. ITS provide support for road transport operations, e.g., systems for supporting navigation, traffic information, and tolling operations. Collectively, such systems can be referred to as telematic systems for road transport, hence, delivering Transport Telematic Services (TTSs). To deploy a TTS, several stakeholders need to make difficult decisions. For example, government organizations have to decide whether or not to finance a given TTS, and transport organizations have to decide whether or not to acquire a given TTS. Assessment and analysis of each TTS, for instance, their benefits to society, can help stakeholders make better decisions.

In this thesis, methods for using computer-based models as support tools for assessing TTSs are studied. We refer to these models as Decision Support System (DSS) models. The focus is on TTSs that are relevant for addressing the challenges in road freight transport, even though the suggested methods can easily be adapted for TTSs in other areas. We have chosen road transport due to its numerous challenges, e.g., emissions and accidents. In addition, road freight transport exhibits special characteristics, e.g., cross-border traffic, and connection to economic factors. The thesis has identified relevant telematic systems for road freight transport, characterized the basic concept and functionalities of the systems and applied computer-based modeling for pre-deployment assessment of various TTSs (ex-ante perspective). An important decision intended to be supported by the methods studied in the thesis concerns whether or not to deploy a given telematic system. The main scientific contributions of the thesis are in suggesting new quantitative models, and extending and applying existing models in the analysis and assessment of telematic systems. Models for designing TTSs are also suggested. Additionally, application of the models to various case studies provides new knowledge for supporting decision-making in different situations concerning the deployment of telematic systems.

1.1.1 Major Challenges Facing Road Freight Transport

One of the major impacts from advances in science and technology is undoubtedly in the ability to transport cargo and passengers from one geographic location to another. This can be seen in the increasing distances covered in the same amount of time using

different types of vehicles. In addition, large cargo volumes are being transported each day. Increasing capabilities of transport systems have coincidentally correlated with some important indicators of economic well being. For instance, Gross Domestic Product, GDP, per capita, and share of employment per sector (European Commission, 2012; Limão, 2008; Mahieu, 2009).

Advances in scientific research and technology provides improved possibilities for measuring the true effect of transport in areas such as accidents, environmental emissions, and energy consumption (Ran et al., 2012). Specific capabilities are built on the use of computer-based information processing, data collection with the help of sensors, and mobile wireless communication. Therefore new tools using these capabilities are helping to improve ways of measuring the performance of transport systems, hence, their cost and benefits, on a society-wide scale.

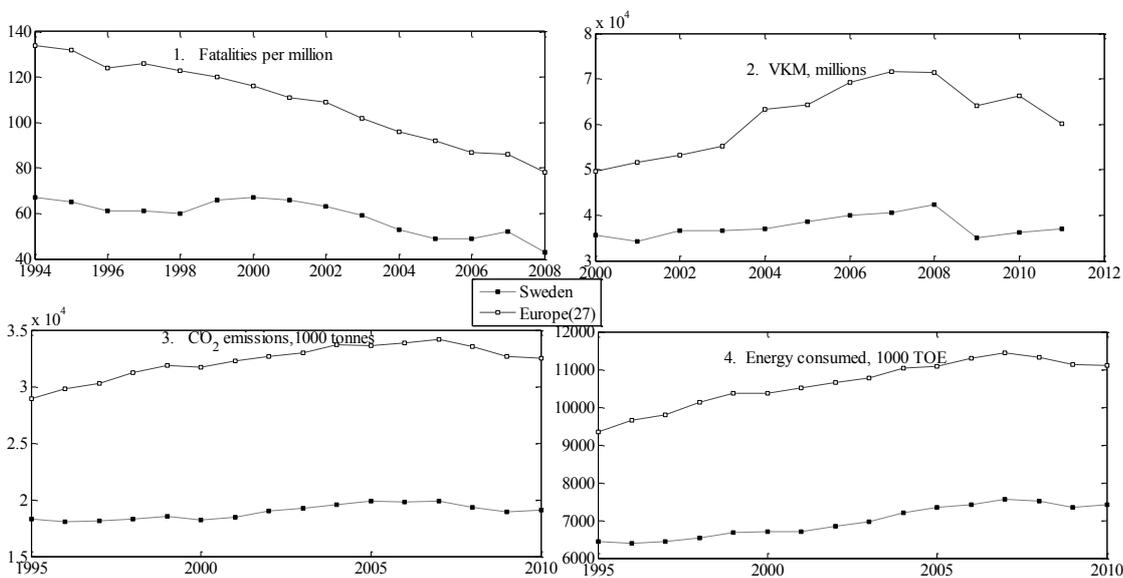


Figure 1.1: Comparing EU-27 and Sweden average road transport indicator values for fatalities per million people, vehicle kilometers, CO₂ emissions and energy consumption (source Eurostat Database (2012)).

Even-though there have been improvements in road transport performance, there are still several undesired impacts on society. For instance, the average annual vehicle kilometer (VKM) has increased significantly in the last decade, as shown in Figure 1.1 (Mahieu, 2009). One of the outcomes of increased VKM is congested road networks. The number of fatalities as a result of road transport have decreased (also shown in Figure 1.1). However, in Europe, more than 35000 lives are still being taken away each year by road transport accidents (including non-freight transport) (Eurostat Database, 2012). Figure 1.1 further shows that CO₂ emission and energy consumption as a result of road transport are high. These trends (VKM, fatalities, CO₂ emission and energy consumption) are not sustainable in the long-term future. Therefore, new approaches

are required for developing and operating road transport systems. Such approaches should enable a cost efficient and yet sustainable transport system in the medium to long term.

Many organizations are involved in efforts to improve road transport systems, e.g., local and regional governments, and road haulers. These organizations are exploring several approaches. For instance, changing old taxation schemes to new schemes that better reflect how transport systems have evolved, developing vehicles with high energy efficiency and so on. Other measures may involve facilitating co-utilization of resources in the form of co-modal and intermodal solutions, and balancing flows by providing industries with incentives to influence their location.

1.1.2 Definition of Important Terminology

Telematic system: Different researchers have offered varying definitions of a telematic system (Bekiaris and Nakanishi, 2004; Bristow et al., 1997; DfT, 2011; Jain et al., 1999; Jarašūniene, 2007). This thesis views a telematic system as any system which has as its aim to provide useful information to (or perform actions for) a person, an organization or another system, through the integrated use of information and communication technologies. Telematic systems are being applied in several areas such as health, surveillance, and transport. This thesis is concerned with telematic systems typically involving wireless communication, information processing and sensing, and its application to transport. A telematic system, as used by this thesis, provides one or more end-user service(s)-TTS(s).

Transport Telematic Service (TTS): This is a service that is provided by a telematic system and to which an end-user (person, organization, or another system) can subscribe. A TTS either provides some information or performs some actions. An example of information delivered by a TTS is instructions on the choice of road to follow in a road network. The information can be provided with the help of an on-board unit. An example of an action provided by a TTS could be forcing a vehicle to change its speed. This may, for instance, be the case when entering an area with school children. A TTS can be considered to be similar to an ITS end-user service as specified by ISO/TR-14813-1a (2007); Jarašūniene (2007). However, some ITS end-user services are limited to a local environment without the need for communication, e.g., local temperature monitoring of goods.

Multi-Service Architecture (MSA): A MSA is an architecture capable of implementing more than one service with the same set of resources (Stranner and Leihs, 2010). For instance, a simple mobile phone supporting voice communication but also Short Message Service (SMS). Ideally, outdated services can be replaced with new services in a given MSA environment. This is similar to capabilities offered by some smart-phones where a user can add or remove applications. MSA, as used in this thesis, addresses possibilities of providing several TTSs by a single telematic system through resource sharing.

Assessment: Making an assessment is the act of categorizing assets according to their value, measured (evaluated) on a given scale. In the context of telematic systems, the assessment process can take place before, during, or after a system is deployed (Bristow et al., 1997). Pre-deployment assessment is referred to as ex-ante assessment. Similarly, post-deployment assessment is referred to as ex-post assessment. Ex-post assessment can be facilitated by the availability of data and knowledge gathered during system development. However, projects could be exposed to high risk if they only are focused on ex-post assessment as the cost of experimentation with real world systems may be high. This thesis focuses on pre-deployment, or ex-ante assessments, which help to gain knowledge that can guide deployment decisions and reduce the risk associated with ex-post assessment.

Decision Support System: A decision support system (DSS) is a computer-based information system that supports decision-making activities in an organization, e.g., a transport organization. A DSS is here considered as an interactive system that helps a decision-maker to solve problems by using data and computational models. A DSS may consist of several computational models such as those proposed in this thesis. The problem domains could be structured (all states are clearly identified), unstructured, or semi-structured.

1.1.3 How ICT can Support Transportation Systems

As mentioned above, Information and Communication Technology (ICT) provides one approach that can improve transport systems. These improvements can be at the level of transport planning or operations (McHale, 2000). ICT can also provide support for decisions about investment in transport infrastructure (Salling et al., 2007). Benefits may be in the form of bringing down the number of people killed on the road each year (DfT, 2011; Kulmala, 2010). Other benefits may be in making sure that loading capacity of vehicles are utilized as much as possible (Davies et al., 2007; DfT, 2011). Such benefits will lead to reducing or possibly eliminating unprofitable transport activities, such as unnecessary waiting times (Crainic et al., 2009; Thill et al., 2004).

By gathering and storing large amounts of data over time, computer models can be used to improve our understanding of transport systems. Data gathering can successfully be achieved using sensor technologies such as Global Positioning Systems (GPS), magnetometers, lasers, cameras, and loop detectors (Bennett et al., 2007). The data can be about vehicles and vehicle operations, drivers, road infrastructure, goods, etc. With present day wireless communication technologies, this data can easily be communicated almost as soon as it is available, i.e., in real time. The data can then be fed to computer systems with advanced information processing models. Using different models, computer systems can synthesize new information such as the current traffic situation, or provide near and long term predictions of the traffic conditions (Abdulhai et al., 2002).

The integration of activities that involve collection, processing, and distribution of

information about transport systems result in end-user TTSs (Figure 1.2). By taking advantage of the information or actions provided by TTSs, transport stakeholders can improve operational and planning decision-making (Goel and Gruhn, 2005; McHale, 2000).

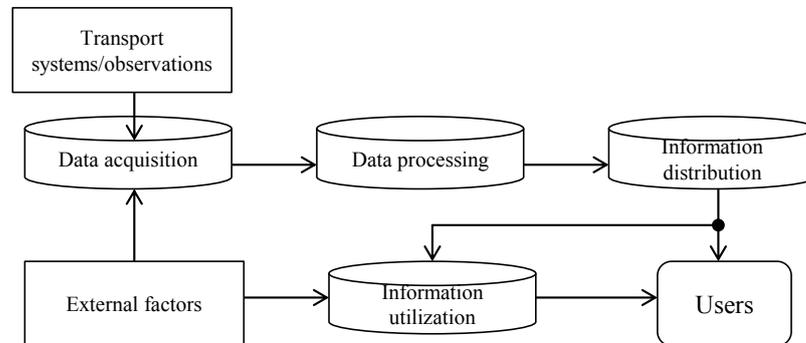


Figure 1.2: Typical information process for a telematic system that leads to delivery of a TTS, where data flow is indicated by arrows (modified from Jarašūniene (2007)).

Examples of TTSs delivered by various telematic systems include Intelligent Speed Adaptation (ISA), eCall (EC), Transport Resource Optimization (TRO), Route Guidance (RG), Road User Charging (RUC), Pay as You Drive (PYD) insurance system. Today, systems offering these services are often provided by different companies. In many cases, each system come with its own terminal installed on-board the vehicle. To address different needs, transport organizations tend to acquire and install several different telematic systems. For instance, an EC system may come with the acquisition of the vehicle from the manufacturer, and a RUC system may be installed to comply with governmental regulations. Additionally, a transport organization may have the desire to optimize its fleet operations, hence, may acquire a TRO system. If each system has to be installed on-board the vehicle to meet different transport needs, this may lead to a situation with multiple systems in the vehicle as shown in Figure 1.3.

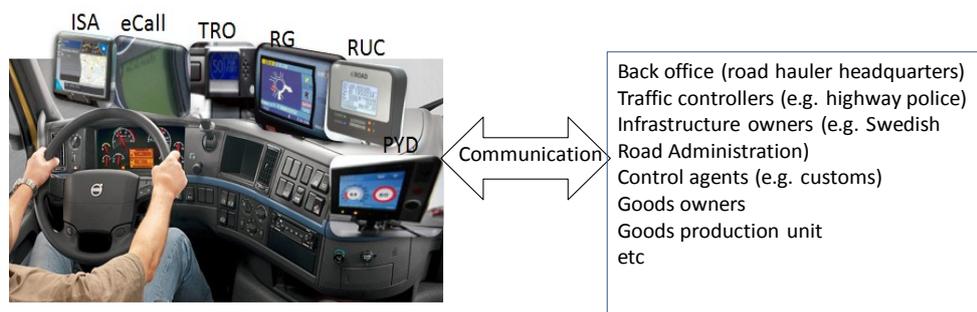


Figure 1.3: Illustration of transport telematic systems offering TTSs mounted on-board the vehicle (an extreme case), source Volvo images (2010)

1.1.4 Challenges of Road Transport Telematic System Development

Despite the possibilities offered by ICT to help manage transport challenges as earlier discussed, development and use of ICT solutions are faced with many challenges. On a general level, it is difficult to identify which TTSs will achieve the desired outcome. Different TTSs can achieve different societal effects (Bekiaris and Nakanishi, 2004; Fan et al., 2007). This creates a complex choice problem for stakeholders such as government agencies, telematic service providers, and road transport operators. Like many industrial problems involving choice, computer decision support systems may enable stakeholders to make better choices.

Telematic systems differ in their specification, i.e., the scope and depth of information about telematic systems is specified to different extents. Variations in telematic systems specification could be in the conceptual description, organizational scope as well as geographic scope (Kuschel, 2009). Given the differences in the specification of telematic systems, modeling, analyzing and comparing TTSs is a major challenge. The modeling challenge is compounded by the limited data about the benefits of TTSs or their performance. Quantification of such benefits is limited as a result. Where quantified benefits are known, lack of clear methodologies for calculating such benefits limit the usability of the results.

Telematic systems consist of advanced technological tools and techniques such as wireless data transfer, image processing, and satellite positioning. These tools and technologies demand a high cost of development. However, there are limited resources for financing telematic systems in road transport. As a result, the impacts of solutions based on TTSs need to be well demonstrated in order to effectively compete for financing with alternative transport projects. Transport organizations rely on multiple telematic systems for different needs (Figure 1.3). This situation results in additional costs for the end-user. Similar functionality is paid for multiple times due to the isolated nature of various systems. Most existing telematic systems today have been described as specialized "islands" or "silo" solutions, tailored according to the needs and requirements of individual fleet operators (TCA, 2008). There are suggestions of architectures with the ability to deliver multiple services, hence to reduce costs of duplicate functionalities, e.g., see Chu et al. (2010). The success of such solutions are still limited.

There are short-comings as a result of limited use of computational DSS models to understand different impacts of telematic systems in road transport. For instance, the legal and policy frameworks have not been developed since policy makers do not have sufficient knowledge about impacts of such systems. In addition, information security and privacy issues pose major threats to adopting telematic-based solutions in transport. Further, lack of knowledge about unknown impacts, and lack of economies of scale are considered to be some of the reasons behind limited deployment of telematic systems in transport (ECORYS, 2005; Thill et al., 2004). A number of tools have been proposed to address some of these shortcomings (2DECIDE, 2013; McHale, 2000) but several critical problems remain to be addressed, e.g., choice of TTSs and potential platforms.

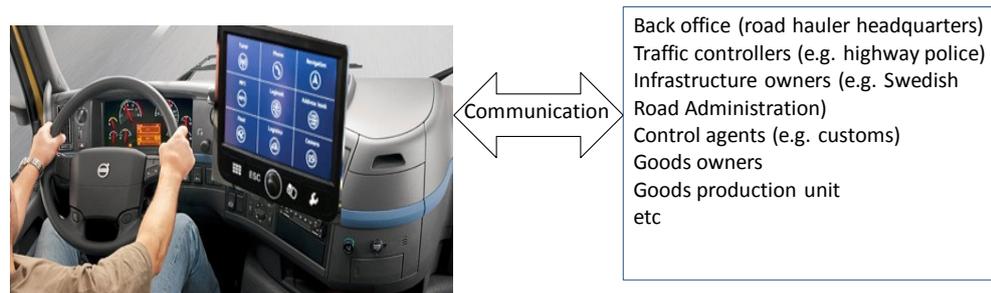


Figure 1.4: Illustration of a potential platform with multiple TTSs, source Volvo images (2010)

Multi-Service Architecture (MSA) with the potential to deliver multiple TTSs are referred to as system platforms (Talib et al., 2010). MSAs can provide both a single, unified interface to the user and an efficient resource management plan (GST, 2013; Stranner and Leihs, 2010). Functionalities offered by a MSA are adapted for easy configuration and content delivery (Stranner and Leihs, 2010) (illustrated in Figure 1.4). There are limited computational DSS models for understanding potential benefits of MSAs in road freight transport. Consequently, system designers and TTS providers may not have enough information to successfully develop MSAs. In addition, stakeholders such as auto-manufacturers, road operators, and third-party telematic service providers, differ in their traditional practices (Bunn et al., 2009). These differences are a hindrance to the cooperation required in order to develop architectures that can deliver multiple services on a single platform.

Transport stakeholders can make informed decisions with the help of computational DSS models. Such support can be achieved through assessments and analysis of the societal effects of TTSs, e.g., user group investigations, benefit modeling, and synergy assessments. As a first step toward addressing some of these critical problems in development and deployment of TTSs, it is important to model processes that influence TTS deployment decisions. Several questions need answers during planning (McHale, 2000), especially because the high costs of telematic systems do not warrant extensive experimentation. During planning, stakeholders need to make decisions that will enable them to attain their goals. Such decisions will influence the types 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. Therefore, approaches that offer new knowledge about societal effects at the pre-implementation phase can support stakeholder decisions. Thus, we have considered the decision process for the deployment of telematic systems as follows:

- **Real world system:** This is a system as it exist in the real world. A telematic system is intended to be deployed (or is already deployed) in the real world. Key components of such a real world system that have an influence on (or are influenced

by) the deployment of telematic systems are taken into account. Examples include road transport networks, satellite navigation systems, information processing technologies, wireless communication technologies, road users, and so on.

- Beliefs: This is a specification of what is known about the real world system. This could be based on established theories of transport models, the potential of TTSs, user acceptance, regulations, privacy issues, and so on.
- Goals: Desired goals in the real world system need to be considered. Decisions are driven by the goals addressed with the system and the availability of information about solution alternatives. The needs of different stakeholders are reflected in their goals. Such goals may be a reduction in transportation time delays, emissions, fatalities, or improvement in road capacity utilization and energy efficiency.
- Decision-makers: Several stakeholders are involved in the deployment of telematic systems such as local, national, or regional government, telematic service providers, and transport organizations (Bunn et al., 2009).
- DSS models: These are models that can support decisions for various stakeholders. Such models employ computational techniques to process different types of information to help decision-makers. Existing as well as new models can be applied to support this task.
- Decisions: Each stakeholder faces a number of decisions and seeks to make the best decision that will enable them to achieve their goal. Examples of decisions may be related to a specification of a TTS and its functionalities as well as the architectural choices for implementing the service. These choices may involve structured, unstructured, and semi-structured decision problems.
- Societal effects: The types of decisions made by stakeholders lead to some effects on society. Effects may be about changes in the transport system-related emission levels, fatalities, vehicle kilometers traveled, etc. The changes could be specific to a given geographic region and usually take place over a given period of time.

When a real world transport telematic system is to be implemented, two possible approaches can be followed: (1) The system can be designed and implemented directly assuming it will generate some positive effects on society. Sometimes the results are not always positive. Even though system design and implementation involve iterative steps, an undesired outcome could lead to redesigning the system, which is costly. (2) Alternatively, the real world system can be abstracted into beliefs that describe its behavior, e.g., traffic theories, regulatory frameworks and user attitudes. By studying the process through which the real world system is to be implemented, stakeholder goals and decisions can be abstracted. Computational DSS models can be employed to analyze different decisions and goals and identify better decisions to achieve desired effects. Figure 1.5 is a simplified representation of the complex decision process.

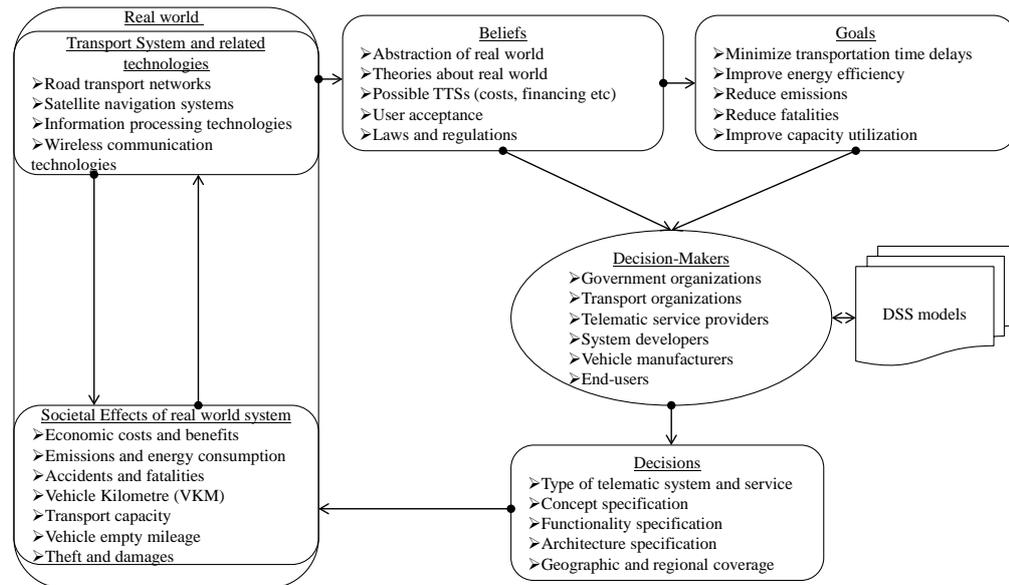


Figure 1.5: A simplified representation of the complex decision process for ITS stakeholders. The arrowhead indicates the flow direction of the activity.

1.2 Related Work

Firstly, work related to the development of TTSs is reviewed. The scope of the review focuses on TTSs relevant to road freight transport, existing and anticipated. Since a TTS is delivered by some telematic system, the concept specification for such a telematic system has to be taken into account. Different telematic system specifications are reported, i.e., within given frameworks. Hence, the literature review also considers framework studies for the specification of TTSs. Secondly, studies reporting approaches for modeling telematic systems and resulting models are presented. Efficient implementation of TTSs requires suitable architecture specifications. Thus, the final phase of the literature review explores studies related to potential Multi-Service Architectures relevant for TTSs in road transport. Each of the areas reviewed uncovers multiple research gaps, some of which are addressed by this thesis.

1.2.1 Developments of Road Transport Telematic Services

In the last decade, unsolved transport challenges, coupled with advances in ICT, has led to attempts to deploy a variety of TTSs. Many scientific articles have reported on different TTSs (Chu et al., 2010; Fan et al., 2007; Kuschel, 2009; Martínez-Torres et al., 2013). There are also Research and Development (R&D) initiatives focusing on telematic systems that will provide several TTSs for road transport (EasyWay Project, 2008; Krueger et al., 2005; Malone et al., 2008; McDonald et al., 2001; STARDUST, 2004).

Most of these TTSs are increasingly ubiquitous, spanning geographical, organizational and technical boundaries (Kuschel, 2009). Additionally, it is becoming necessary to consider the impact of transport projects on a wider societal scale (Thomopoulos and Grant-Muller, 2013). All these indicate that it is necessary to consider multiple societal consequences in order to select the right TTSs. A societal approach requires joint efforts with inputs from different stakeholders including industry (transport organizations) and the research community (ITS experts). Recent trends however show that industry and research focuses do not necessarily have to overlap (Fan et al., 2007). Industrial focus may be driven by the availability of business models, which at the moment are limited for many TTSs. Overall, many TTSs are appealing to different stakeholders according to the stakeholder goals.

The plurality of TTSs covers a scope that is inconceivable when designing telematic systems with specific focuses. Moreover, the use of terminology changes depending on the region, type of user, type of system, etc (FHA, US DOT, 2005; Ho et al., 2000; Sundberg, 2007a). For instance, Electronic Toll Collection, Electronic Fee Collection and Road User Charging are commonly used to refer to a TTS deployed to collect road charges. Despite these and many other difficulties, researchers still manage to provide an overall view of various telematic systems and how they have been applied in different areas. For example, a US-based study showed that both research and patents issued within ITS in general have focused on traffic management (Fan et al., 2007). The ITS Handbook also provides a range of different ITS user services within road transport (Chen and Miles, 2004). A Swedish-based R&D project has identified information needs and possible telematic services in a logistic chain (Mobile-Networks, 2006). There are several studies that have identified candidate TTSs for road freight transport (EasyWay Project, 2008; FHA, US DOT, 2005; Martínez-Torres et al., 2013; Sundberg, 2007a). Different approaches have been employed by different studies. For instance, concept mapping techniques (consensus building through statistical techniques) have recently been used to identify suitable TTSs, such as traffic information (Martínez-Torres et al., 2013). Their study, (Martínez-Torres et al., 2013), took into account the perspectives of different stakeholders accommodating multiple societal effects. Systematic analysis, taking into account multiple services, that will facilitate assessments of various telematic systems is currently difficult. This is because many of the TTSs in literature do not follow a common specification or terminology.

Specification of concepts for telematic systems helps to understand the operating principles of such systems. Usually such concepts are specified within a given framework (Lee et al., 2009; May, 2005). Frameworks typically provide a way to manage a system of interacting objects, suggest patterns of collaboration between components, and allow flexible channels of collaboration (Veera Ragavan et al., 2010). Unfortunately, attempt to study concept specifications for telematic systems have shown that such specifications are too broad to apply in an operational context (TSAO, 2001). However, there are some common characteristics that can be seen in many specifications of telematic systems. These are related to location referencing, data acquisition, data processing, communication, and information distribution and utilization (May, 2005).

However, such dimensions are insufficient to provide useful deployment information, e.g., motive, and domain of usage of TTS, as applied to freight transport. To address such concerns, TSAO (2001) proposed a framework in order to anticipate, recognize and organize TTS deployment issues that may limit design options for TTS operating concepts and technologies. The proposed framework (TSAO, 2001) focused on decisions and decision-makers impacting the deployment of TTSs and identified the following key dimensions: needs, solution/opportunity, decision-maker, decision-making, decision influencing, time, risk management, and synergy. Despite of all the efforts made in the specification of telematic systems, there are no approaches for studying multiple TTSs.

1.2.2 Modeling and Evaluation Experiences of Road Transport Telematic Systems

There are many studies that address the modeling of TTSs (Bonnetfoi et al., 2007; Frotveit et al., 1995; Ho et al., 2000). Other studies have focused on TTS assessment (Bekiaris and Nakanishi, 2004; Bristow et al., 1997; Lind, 1997; Peng et al., 2000). Extending traffic modeling approaches, Ho et al. (2000) proposed and argued for a hybrid modeling tool for TTSs. Their proposed tool (Ho et al., 2000) combines transportation planning models and traffic analysis/simulation models to capitalize on Measures of Effectiveness (MoEs) at different levels of details. Also, a Specification and Description Language (SDL) has been used to model architectures of telematic systems by extending software development techniques applied in telecommunication systems (Frotveit et al., 1995). Further, to address the design, modeling, and formal analysis and specification of TTSs, UML and Petri Nets approach has been proposed (Bonnetfoi et al., 2007). In modeling impacts of TTSs, multiple societal impacts are often not considered. If societal impacts are taken into consideration, then analysis of multiple TTSs and their interactions need to be addressed. Most of the models discussed by the various studies have not focused on analysis of multiple TTSs.

Modeling TTSs can help understand their societal benefits. The work by Peng et al. (2000) suggested a framework for benefits assessment using benefit trees. Their review of assessment methods (Peng et al., 2000) showed that there is a significant variation in the complexity and details of evaluation methods related to TTSs. The choice of method should depend on the target of the assessment. Even though their proposed approach is generic (Peng et al., 2000), it fails to provide possibilities for obtaining quantitative information. Quantitative assessment of benefits is crucial (though not always possible) for deployment decisions by stakeholders (Newman-Askins et al., 2003). In a review of the strategic assessment of TTSs, Lind (1997) argued that existing models are not sufficiently adapted to the assessment of ITS. Their study (Lind, 1997) suggested approaches for assessment based on Delphi studies, compilation of field trial results, micro-simulations of regions or corridors, etc. Many studies (Lind, 1997; Peng et al., 2000) show that several methods for the assessment of TTSs should take into account the target of the assessment. Newman-Askins et al. (2003) showed how different

methods are employed to study different impacts for various evaluation scenarios.

In order to assess TTSs, specific indicators have to be considered (Ho et al., 2000). Examples of some indicators or Measures of Effectiveness (MoEs) are road capacity, labor hours, number of traffic accidents, traffic flow speed, environmental pollution, and travel time (HE et al., 2010; Leviäkangas and Lähesmaa, 2002; Rämä et al., 2009). Some of the indicators can easily be quantified, hence, are suitable for developing quantitative models. Models based on quantitative indicators can help address aspects that were difficult to quantify in the past due to increased possibilities for data collection using new technologies (José et al., 2004; Leviäkangas and Lähesmaa, 2002). For example, a quantitative model has been developed and employed to estimate the benefit of incident management telematic systems with the help of a travel time indicator (Leviäkangas and Lähesmaa, 2002). Several European R&D projects have focused on cost and benefits of technologies for TTSs with the help of different models. Examples of such R&D projects includes 2DECIDE, CHAUFFEUR, DIATS, STARDUST, eIMPACT, and ICSS (Krueger et al., 2005; Malone et al., 2008; McDonald et al., 2001; STARDUST, 2004). However, estimating societal indicators in terms of monetary cost and benefits is difficult. To evaluate multiple societal impacts from the deployment of TTSs, different quantitative methods may be necessary (Hadi et al., 2010; Leviäkangas and Lähesmaa, 2002; Mikhailov and Tsvetinov, 2004; Ng et al., 2006).

Despite the advantages of quantitative models, such models rely heavily on accurate data. Even though there are several TTS data collection tools, the cost of collecting data is high and transport organizations are not always ready to release existing data. In addition, assessments of overall societal costs and benefits of TTSs are important at the planning stage (Thill et al., 2004). During such planning, quantitative data is not always available (Newman-Askins et al., 2003). The potential of quantitative models can fully be appreciated when carrying out ex-post evaluation (Fries et al., 2007; Guin et al., 2007; Odeck and Welde, 2010; Yang et al., 1999). However, in addition to data limitation, it has been shown that the lack of good tools for benefit and cost evaluation of TTS is a hindrance for the deployment of new TTSs (Bekiaris and Nakanishi, 2004; Thill et al., 2004). This is because traditional transport analysis approaches may not be appropriate in reliably assessing the economic impacts of TTSs (Bekiaris and Nakanishi, 2004; Thill et al., 2004). This thesis uses alternative quantitative approaches such as optimization in the assessment of multiple TTSs.

1.2.3 Multi-Service Architecture Development for Road TTSs

There are reference examples of efforts for developing MSAs such as OSGi (Open Service Gateway Initiative) and GST (Global System for Telematics) (GST, 2013; Hackbarth, 2003; Mobile.Infor, 2013). A cloud computing platform architecture called "Cargle" has been proposed for TTSs (Chu et al., 2010). However, their study (Chu et al., 2010) does not address how to identify relevant TTSs for the proposed platform. System platforms capable of providing multiple TTSs are shown to have several advantages

(Huschebeck et al., 2009; Talib et al., 2010; U.S. DOT, 1999). Some of these advantages are: 1) reduce system economic costs through common use of functionalities; 2) facilitate the development of new services by providing base functionalities; 3) drive interoperability, standards, and usability; 4) improve trust between public-private co-operations through sharing of information; 5) reduce the burden on the driver. Since these systems involve different stakeholders and business cultures with different goals (Kostevski, 2010), there are several complexities that need to be resolved. As a result, careful planning is vital. Such planning can be achieved with the help of computational DSS models, e.g., simulation and optimization models. Telematic systems that can support multiple services for freight transport have not been the focus for most of the studies. Freight transport deserves to be considered separately. This is because it involves transport across national and international boundaries, with varying cultures. In addition, for drivers, freight transport involves more than just work activities. The vehicle sometimes may serve the purpose of a home, which puts a high demand on security and other basic necessities. Some of these necessities can be met with the right choice of TTSs. Such services can be delivered on MSAs, e.g., by extending an existing functionality provided by vehicle systems instead of building such a functionality from the beginning.

The research work in this thesis is intended to contribute to developing methods of assessing multiple TTSs. We consider the possibility of a MSA for achieving such TTSs. In a recent study Crainic et al. (2009) showed that governments and industry have in the past prioritized the hardware aspect at the expense of the methodological aspect. Since there is limited computational DSS, a lot of data is still being processed and acted upon by human operators. Computational DSSs can facilitate the development of TTSs by supporting the decision-making process involved. Assessment methods must address modeling with focus, not only on the physical components and the associated flows of resources, but also on the adequate representation of the associated information flows and decisions involved (Crainic et al., 2009). Models that are based on proposed methods should be able to be solved with efficient solution approaches. Such models should provide the ability to address large instances of formulations, including integer-valued decision variables, nonlinear objective functions and constraints, and uncertain data. A societal perspective is important when considering the impacts of TTSs in particular and transport systems in general (Thomopoulos and Grant-Muller, 2013). For efficient implementation of multiple TTSs, MSA concepts need to be addressed.

1.3 Research Questions

1.3.1 Main Research Question

The main Research Question (RQ) addressed in this thesis can be formulated as follows:
How can telematic systems in road freight transport be assessed with the help of computer-based decision support?

To address the main research question, it is necessary to identify relevant telematic systems for road freight transport and the characteristics of concepts used to describe such systems. Computational modeling can then be employed to develop methods that can help in the assessment of various TTSs. The context in which the assessments are carried out in this thesis is mostly from a pre-deployment or ex-ante perspective. We assume the planning time to deployment to range from medium term (e.g. 1 year to 3 years) to long term (e.g., 3 years to 10 years). In this context, concepts of telematic systems will be investigated both in relation to existing TTSs as well as to newly proposed TTSs. The expected outcomes are computational DSS models. The models can help to decide whether or not to deploy a given TTS. If the concept investigated concerns a system already in existence, the outcome could be regarded as a validation of the decision to deploy the system. The final decision depends on several aspects such as societal benefits of the TTS, and the possibility to share common platforms.

1.3.2 Specific Research Questions

Some RQs are focused on the use of a TTSs and others are focused on the development and deployment of a telematic system.

- RQ1. What types of TTSs have the potential to contribute to alleviating challenges in road freight transport?

Information gathering is necessary in order to identify candidate TTSs for road freight transport. Such TTSs could be at different stages of their development, from anticipated concepts to already deployed TTSs. Identified TTSs can then be assessed on their contribution to addressing challenges in road freight transport. In this way, RQ1 will contribute to addressing the main RQ.

- RQ2. How can telematic systems for road freight transport be characterized in a way that enables them to be analyzed?

A systematic approach is necessary for characterizing telematic systems in order to facilitate modeling of such systems. Characterization is used here to refer to the dimensions of telematic system that must be provided when specifying each system and the information content for each of those dimensions. While RQ2 does not directly contribute to the main RQ, it can be seen as an important step towards modeling multiple TTSs, hence, their assessments.

- RQ3. What modeling approaches can be used to assess telematic systems for road freight transport?

Having identified and characterized telematic systems, RQ3 is intended to come up with suitable modeling approaches. Modeling here involves establishing important relationships between various dimensions of TTSs identified in RQ2. Such relationships could be described mathematically, or otherwise with the use of concepts and other formal modeling methods. By modeling telematic systems,

resulting models can be employed to assess TTSs for road freight transport, hence, contributing to addressing the main RQ.

- RQ4. To what extent can we quantify the societal benefits from employing TTSs in road freight transport?

Benefits provide important information necessary in the deployment process for telematic systems that will provide TTSs. Quantified societal benefits can be employed to motivate different deployment scenarios. The extent of the quantification of benefits is considered by the types of indicators but also in terms of the overall performance of each telematic system to address freight transport challenges. By addressing societal benefit quantification, RQ4 contributes to the assessments of TTSs in road freight transport, hence, to the main RQ.

- RQ5. How can quantitative models provide support for decisions regarding investments in telematic systems that can offer multiple TTSs?

To answer RQ5 models resulting from answering RQ3 together with benefits obtained from answering RQ4 will be employed in the assessment of telematic systems for road freight transport. Such assessments will contribute to answering the main RQ. Since the models from RQ3 focus on telematic systems identified in RQ1, it is assumed that assessments based on such models will provide reliable decision support concerning relevant TTS investment. Further, in order for the suggested quantitative models to be employed in a computational DSS, additional information is required, e.g., cost of TTSs as well as architecture specifications.

1.4 Research Method

1.4.1 Overview of Research Methods

This thesis studies telematic systems that provide TTSs for decision-makers involved in freight transport. A consistent scientific approach has been used to achieve this task. Such an approach makes it possible to systematically establish evidence and yet allow the natural environment to play its role (Sismondo, 2005). A systematic approach has been applied in several iterative phases. Each phase contributes to building computational models for supporting stakeholder decisions. This kind of a methodology is inspired by the works of several researchers such as Creswell (2008); Pervez and Kjell (2005). The diverse nature of the problem domain requires more than one specific research method. Literature reviews, mathematical modeling and conceptual modeling have all been employed to varying extents. Conceptual modeling is concerned with describing key model structures in terms of entities, relationships, and constraints (Brännström et al., 2001; Embley and Thalheim, 2011; Wild, 2007). The goal is to describe the behavior or functional models of a system in terms of states, transitions among states, and actions performed in states (Embley and Thalheim, 2011). Such actions can be described using

model inputs and outputs that control interactions with the model. The following phases were involved:

- Phase I: This involves planning and specifying sub-goals to be achieved from observing the real world. These sub-goals were connected to the research theme, i.e., assessment of telematic systems for freight transport. Examples of sub-goals could be to estimate the societal value of a TTS. Identification of sub-goals was guided by literature reviews. In some cases the sub-goals were influenced by project work such as Intelligent Truck Parking (ITP Project Website, 2013) and Mobil IT project (MOBILIT, 2013). Relevant methods were either developed or selected to address the sub-goals.
- Phase II: The focus of Phase II was to identify or develop solution approaches for executing the models in Phase I. Where appropriate, computational algorithms were chosen or developed. The solution approaches depended on the type of data available for the scenario considered. Some examples of algorithms employed included nearest neighbor Hierarchical Clustering Algorithm (HCA), K-Minimum Spanning Tree (KMST), Linear Programming with Branch and Bound (LP B&B), and Dominance Rough Set Approach (DRSA).
- Phase III: In the final Phase, focus was on executing the models with the chosen algorithms. Result analysis was performed by adjusting parameter values and data values in order to study the behavior of the model. Analysis of the output provided the basis for making recommendations related to the scenarios for which data was obtained. Non-quantitative models were also employed to carefully investigate a given idea such as in Paper I and Paper VII. In case where non-quantitative methods were involved, findings were discussed with other researchers and experts in the study domain.

The application of each specific research method helped to transform pieces of isolated data about TTSs into generalized statements (Sismondo, 2005). Such statements are intended to remain valid both for the current scenario studied but also for future similar situations.

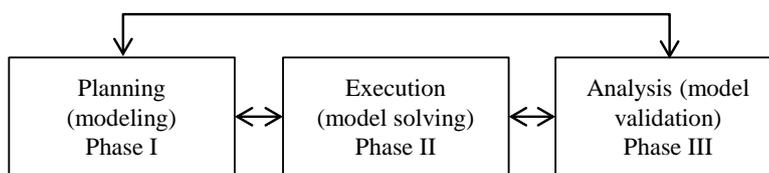


Figure 1.6: Overview of the methodological approach adopted in this thesis

The fundamental structure underlining the methodology in this thesis (Figure 1.6) can be observed from two perspectives: 1) information about telematic systems is collected,

and analyzed with respect to key transport challenges. Evidence of how resulting TTSs can address transport challenges is synthesized. Such evidence is used to motivate decisions related to deployment of telematic systems that were studied as well as similar systems, 2) beginning with key transport challenges, information concerning the capabilities of different technologies is synthesized. Knowledge about technologies and transport challenges is used to suggest what kind of telematic systems can be developed. TTSs provided by a telematic system can then be employed to address the transport challenges. Thus, on one hand we go from what we know about existing TTSs to identify what problems can be solved, and on the other hand we go from what transport challenges are there and define what TTSs are needed. If these two approaches can be generalized then they can be connected to induction and deduction respectively (Sismondo, 2005). Induction, at its very best, allows scientist to establish general claims, based on existing isolated pieces of information (e.g., about telematic systems). On the other hand, deduction can generally be seen as combining existing knowledge, e.g., about transport challenges and capabilities of today's technology, to establish new knowledge, e.g., proposing new TTSs.

While induction has been widely practiced in nearly all fields of science, skeptics have argued that the assertion that a generalization can be falsified with one counter example is not enough to dismiss the validity of such generalizations. According to Duhem Quine, theories are part of an entire web of beliefs, and as Sismondo (2005) puts it, when scientific theory or hypothesis fails to explain a given situation, the answer is in finding and adjusting which part of the web is wrong. This sort of thinking seems to resonate well with mathematical modeling. Hence, researchers versed in mathematical modeling (Lundgren et al., 2010; Rardin, 1998), have highlighted the notion of "garbage in garbage out" in reference to a mathematical model. As such, poor model results do not necessarily translate to a bad model since the problem could instead be with the data. However, because a model correctly enables us to understand different situations, it is by no means a true realistic representation. This is because there are infinitely many other possible models for explaining the same situation according to the principle of underdetermination (Sismondo, 2005).

1.4.2 Application of Research Methods

The research methodology above helped address various research questions.

Phase I: The planning phase.

Phase I involved methods (including literature reviews) and data collection.

I. Methods (Within Phase I)

For each RQ, we present the methods that were applied during Phase I and indicates which research paper it concerns.

RQ1: What types of TTSs have the potential to contribute to alleviating challenges in road

freight transport?

Literature reviews constitute the main research method used to answer RQ1. The aim has been to identify and describe TTSs. The literature review considered TTSs that have been deployed or are in the process of being deployed to address road transport challenges, e.g., accidents. The literature review included journal articles, conference articles, and project reports. Some examples of literature sources include: ARENA (2013); EasyWay Project (2008); FHA, US DOT (2005); ITS Japan (1999); Lanza et al. (2009); Mobile-Networks (2006). Surveyed articles are presented under related work (Section 1.2) and under respective papers in the thesis. In addition to literature reviews, brainstorming activities within projects such as Intelligent Truck Parking (ITP Project Website, 2013) and Mobil IT (MOBILIT, 2013) were carried out. Workshops and discussions with experts led to proposing several concepts of new TTSs.

RQ2. How can telematic systems for road freight transport be characterized in a way that enables them to be analyzed?

To characterize TTSs identified in RQ1 important dimensions of the corresponding telematic system need to be specified. This is achieved through conceptual modeling. A conceptual model of the telematic system is created, e.g., information entities, functionalities, and data sources. Relationships between these entities are also described. The transitions that occur between the entities and any constraints influencing such transitions are studied. To provide a common specification for important dimensions of each TTS, the following approaches were employed:

Framework Approaches: As mentioned earlier, frameworks typically provide a way to manage a system of interacting objects, suggest patterns of collaboration between components, and allow flexible channels of collaboration (Veera Ragavan et al., 2010). A framework was used to identify general patterns for describing TTSs. As an example, such patterns may require that for each TTS, we specify their usage, problem domain and functionalities. In Paper I some key dimensions were identified, that when employed for describing TTSs, can improve modeling and analysis. In Paper VII, similar dimensions were also suggested that could help in the analysis of alternative designs of different concepts of TTSs.

Service Design: In suggesting new TTSs for addressing key transport challenges, the main characteristics of the TTSs are described during the design process. There are several methods suggested specifically for achieving service design (Wild, 2007). The method adopted in this thesis is similar to that proposed by Brännström et al. (2001) and extended by Alonso-Rasgado and Thompson (2006). Based on their proposed method, modeling and designing a service involves the creation of a concept and identification of required subsystems. Moreover, the subsystems can be modeled, integrated, and tested so as to deliver the service. In Paper VII, our proposed method is preceded by the problem being addressed and the type of information required. The information entities, together with inputs and outputs, determine the concept specification, subsystems, and how they are modeled.

RQ3. What modeling approaches can be used to assess telematic systems for road freight transport?

In order to answer RQ2 (above), concepts of TTSs were proposed and modeling of the concepts enables the characteristics of the TTSs to be identified. However, conceptual models are difficult to employ in order to perform quantitative analysis, e.g., analyses of costs and benefits of TTSs. As such, mathematical modeling approaches were employed (RQ3). Mathematical modeling involves the task of building models using mathematical formalization. Mathematical modeling enables real-world behavior to be abstracted using mathematical formulas (variables, constants, relations, and operators). The key advantage of building and using mathematical models is the high accuracy of representation and concise manipulations (Rardin, 1998). As such, mathematical models can benefit from the use of computational processing in the search for better alternatives to support decision-making. However, mathematical models are criticized for not being able to satisfactorily quantify most of the information existing in the real world, e.g., comfort and utility (Williams, 1999). In the interpretation of results obtained from mathematical models, it is crucial to bear in mind the context of the assumptions made in developing the model. Mathematical modeling can be applied to develop different kinds of quantitative models. For instance, Multi-Criteria Decision Analysis, Clustering, and Integer Linear Optimization, which have all been employed in this thesis.

RQ4. To what extent can we quantify the societal benefits from employing TTSs in road freight transport?

The result of a modeling process in general is a model. The outcome of applying a mathematical modeling approach in RQ3 is a mathematical model. Such a model can be used to establish quantitative evidence, e.g., estimating the societal benefits of TTSs (RQ4). For stakeholders involved in decision-making, information concerning the expected benefit from deployment of TTSs is important. To answer RQ4, a review of approaches for service valuation in related areas was conducted. Following from the review, there were limited approaches for quantification of service value (Grönroos, 1993; Parasuraman et al., 1988). In some cases, the value of a service has been assessed according to the perception of the end-users (Parasuraman et al., 1988). In other cases, it has been the performance of the service that determined its value (Grönroos, 1993). We extend the view that the value of the service depends on its performance to suggest a mathematical model for valuating TTSs. In the suggested approach key categories of societal cost (performance saving indicators) are identified and quantified. The societal value of the TTS is determined by its ability to improve societal saving indicators, e.g., reducing annual cost of accidents or thefts related to freight transport. The mathematical structures used are an extension of the net present value approach. The objective with this method is to estimate the benefits of freight TTSs with focus on the Swedish hauler industry. These benefits depend on the costs of the systems, but also on the set of TTSs being considered for deployment. To address this,

optimization methods are used in order to account for multiple dimensions such as dependencies and synergies.

RQ5. How can quantitative models provide support for decisions regarding investments in telematic systems that can offer multiple TTSs?

Quantitative models provide information that enable decision-makers to take a stance. For instance, an assessment of potential benefit for a given telematic system can enable the decision of whether to finance or not to finance the system. Often, different types of quantitative information need to be considered in order to arrive at a suitable decision. As such, models may have one or more objectives and employ one or more types of data. As an example, costs, benefits, and dependencies of TTSs were all considered by some of the models proposed in this thesis. To analyze and assess telematic systems and TTSs for freight transport, several models were considered including:

Integer Linear Optimization: Optimization models represent problem choices as decision variables and seek values that maximize or minimize the objective function of the decision subject to constraints on variable values (Rardin, 1998). Constraints help to limit the values of the different variables. For an optimization model in which the objective function and constraints are all linear functions, the model is said to be linear. If in addition all decision variables are discrete (binary or integers), then the model is referred to as an integer linear program, e.g., the optimization model proposed in Paper V. Nearly all optimization models are based on some assumption justifiable enough to represent a good approximation of natural reality. The validity of the optimal solution depends on how well or to what extent the assumptions hold. Optimization-based models are employed in this thesis to help identify TTSs with high net benefits, that can be implemented in a long-term perspective. Combining costs and benefits of TTSs together with dependencies and synergies of common functionalities, Paper IV and Paper V investigate the optimal combination of TTSs that can be deployed on different platforms.

Multi-Criteria Decision Analysis: Multi-Criteria Decision Analysis (MCDA) refers to an approach for selecting, sorting, or ranking among a set of alternative courses of actions (e.g. what TTSs to deploy). The rankings are based on given criteria and the objective is to satisfy a set of goals or preferences for the decision-maker(s) (José et al., 2004; Macharis and Stevens, 2013). Supposed there are n -preference relations over a set S , MCDA can be used to determine the dominance preference relationship that represents all the other n -preference relations. There are methods of MCDA that take into account the preferences of the decision-maker. Such preferences are then employed to induce decision rules that govern the problem, e.g., Dominance-based Rough Set Approach (DRSA) is one such method. DRSA helps manage inconsistencies in the preferential information, resulting from hesitations of the decision-makers (José et al., 2004). MCDA differs from multi-objective optimization in that the performance of each alternative

course of action on multiple evaluation criteria is explicitly known, i.e., the impact matrix. MCDA has been used in this thesis to compare potential benefits from different areas generated by implementing a potential Intelligent Truck Parking system, as can be seen in Paper VI.

Clustering: Cluster analysis is the organization of a collection of patterns (usually represented as a vector of measurements, or a point in a multidimensional space) into clusters based on similarity (Jain et al., 1999). Cluster analysis methods are based on empirical procedures designed to create a classification from a data set. Results can either be a new cluster or an assignment to an existing cluster (Morey et al., 1983). There are several clustering techniques. For instance, Hierarchical Clustering Algorithm (HCA) provides one technique in which clusters are generated by iteratively dividing the entire data space into subsets until every element belongs to its own set (decomposition). Alternatively, HCA can also be employed to iteratively combine data elements until all data is in one cluster. If information is known about the categories to place the data, this is regarded as supervised learning. If information about the clusters is unknown before the classification, it is referred to as unsupervised learning as in the case of hierarchical clustering. It is necessary not only to support TTS design and analysis decisions but also to influence the business models already at the level of design decisions. One such approach is to study the combine deployment of TTSs that can lead to low costs of investment and operations. We applied clustering models (Paper III) as well as optimization models (Paper VI) to identify suitable combinations of TTSs that can be deployed together on common platforms.

II. Data Collection (Within Phase I)

Secondary data sources: Secondary data includes data that was collected for some purpose and used for a different purpose. We have used secondary data to compensate for insufficient data. Data insufficiency is a critical problem when studying concepts of TTSs that have not been implemented and tested. Even though such concepts can be implemented and primary data collected, it will lead to a high cost and may take a long time. Secondary data needs to be evaluated for its relevance, accuracy, case study considered and circumstances under which the data was collected (Giuliano et al., 2010).

Sources ranging from project reports to statistical data bases have been used in this thesis, e.g., Statistiska Centralbyrån (SCB), Statens institut för kommunikationsanalys (SIKA), Trafik Analys, and Sverige's Åkeri Företag. These databases provide official statistics about transportation in Sweden. Other sources such as Eurostat were employed to complement official data about transportation in Europe. Moreover, scientific papers, especially those reporting on results obtained from field trials, were the main secondary sources of data related to costs, performance, and value (benefits) of TTSs. Other sources such as "cost elements of ITS" provided by the US DOT within the framework of the Research and Innovative Technology Administration (RITA) (US DOT, 2013) help to provide

complementary data. In some cases where cost data was difficult to estimate, pricing data from different technology providers was used with consideration for VAT and profit margins. Benefit data was obtained from estimates of societal cost reduction, as presented in Paper II.

Primary Data Sources: Primary sources of data were mainly interviews but also data generated from estimating the value of TTSs. Inquiries directed to industrial practitioners, project managers, researchers, and research institutes were employed in several situations to verify and/or validate specific data-related questions, but also as a way to identify some of the TTSs analyzed in the thesis. Results from these inquiries are mostly reflected in Papers I, II and III. In Paper VI, joint efforts with other researchers were carried out in which structured interviews were employed to validate the perceived benefits of services related to Intelligent Truck Parking.

Phase II: The Execution Phase

In Phase II, specific algorithms were developed and applied to address the methods discussed in Phase I. Details about various algorithms can be found in the corresponding research Papers. Table 1.1 indicates which approach was used to solved the methods described above in order to address the stated research questions.

Method	Algorithm	RQ/ Paper(s)	Comment
Service valuation	Analytical algorithm	RQ4/PII, RQ5/PII	Implemented as a Microsoft Excel add-in for estimating service value.
MCDA DRSA	jRank	RQ3 /PVI	A command-line Java application, that implements DRSA based on java Rough Set (jRS) library (Szelag et al., 2013). For comparing ITP benefit areas.
Clustering	Hierarchical Clustering Algorithms (HCA)	RQ3/PIII, RQ3/PIV	Implemented as a Microsoft Excel add-in. For estimating gains in cost reduction due to combined deployment of TTSs.
	K-Minimum Spanning Tree (KMST)	RQ3/PIV	AMPL/CPLEX. AMPL provides an environment for building mathematical models. CPLEX implement a simplex algorithm with branch and bound.
Optimization	Integer Linear Programming, simplex together with Branch and Bound.	RQ3/PIV, RQ5/PIV RQ3/PV, RQ5/PV	AMPL/CPLEX. For selecting TTSs based on the platform and benefits while minimizing cost.

Table 1.1: Algorithms (execution phase) of the methods used in the thesis

Phase III: The Analysis Phase

The focus of Phase III is on the verification and validation of both the models proposed and the results obtained from applying the proposed models. When different models are employed in various scenarios, the results can help to support decision-making. The reliability of such results needs to be carefully assessed, e.g., the quality of the data used, the consistency in model behavior, and the parameter values. All this information needs to be clarified to the decision-maker. The decision-maker in some cases may require information from several other sources in order to arrive at a decision. If conclusions that are established from using the model align with expert decisions, or conclusions established by experimenting with the real world system, the model can be considered valid. The model can further be verified by checking that every stage of implementation actually performs the intended operation.

Usually, to study the behavior of a mathematical model requires that some data is fed in to 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, where the results produced by a mathematical model can be used to evaluate a system. A 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 outcomes in such a way as to validate the model. Any significant variations from the real-world situation and expectations (e.g. from an expert opinion) should be explained (Williams, 1999).

Since most of the models proposed in this thesis concerns conceptual systems, real world experimentation for model validity was limited. However, conferences, workshops and peer revieweing of articles provided valuable feedback that helped to improve the validity of the proposed models. Internal validity was strengthened by sensitivity analysis. In the future, as more data becomes available, the proposed models will be continously validated.

Figure 1.7 presents an overview of the content of research Phases I - III above.

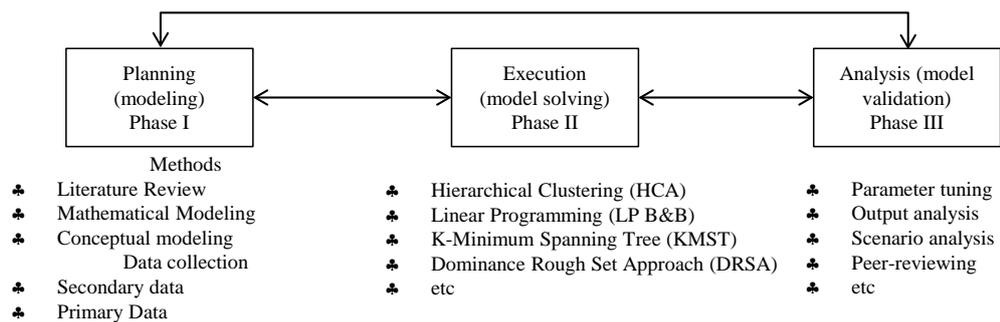


Figure 1.7: An overview of the content of each of the research phases in this thesis

1.5 Results

In this section answers to the research questions are presented. Each research question is answered across different research papers and the contributions are presented in connection to the main research question.

RQ1: What types of TTSs have the potential to contribute to alleviating challenges in road freight transport?

We summarize TTSs resulting from potential telematic systems that can contribute to alleviating transport challenges.

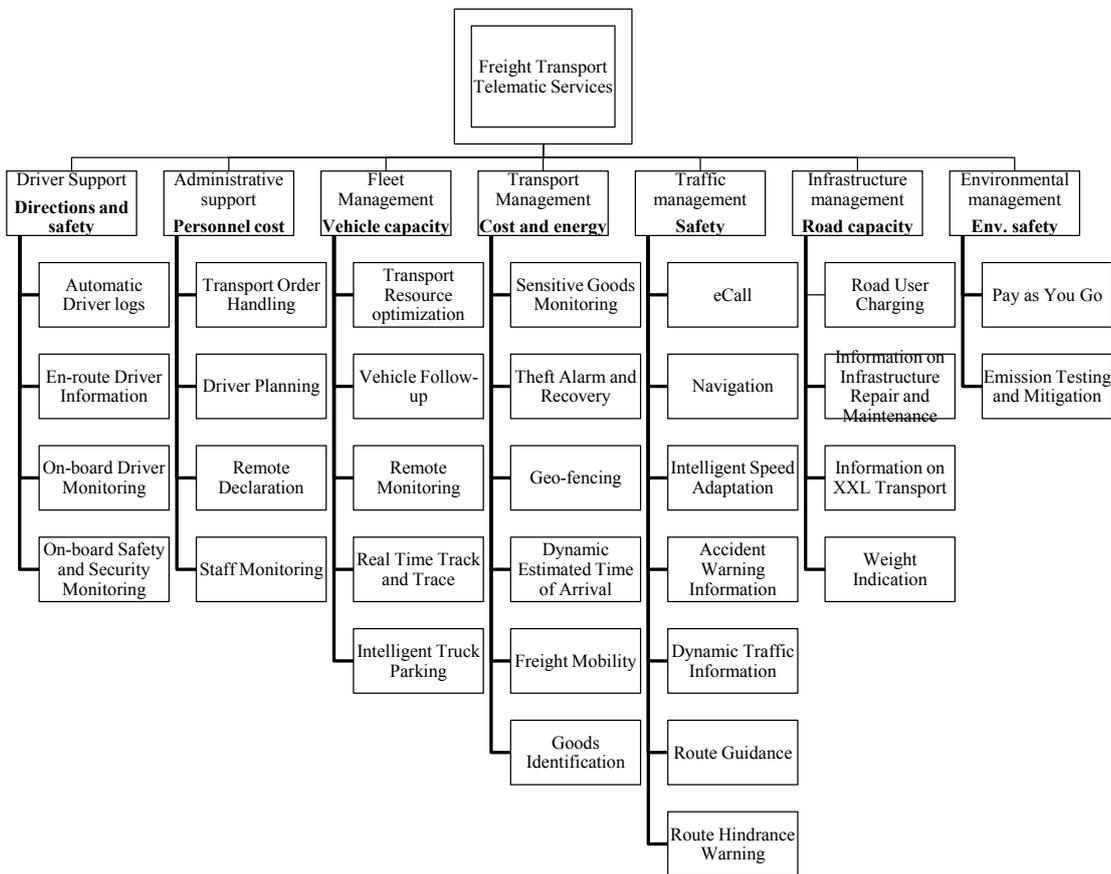


Figure 1.8: Candidate TTSs identified from different sources, Env. = Environmental

1.5.1 Conceptual Models TTSs Identified Through Literature Studies

Scanning through project reports and scientific articles, some 70 candidate TTSs were identified. A preliminary analysis of these TTSs was conducted. Two criteria for selecting TTSs included their relevance with respect to identified road freight transport challenges (Paper I and Paper VII), but also their potential positive societal value (Paper II). In total, 32 TTSs were chosen for further analysis. Each transport domain is connected to one or several challenges related to freight transport (shown in bold in Figure 1.8), e.g., driver support domain faces the challenges of navigation directions and safety risk. Specific TTSs are identified that can potentially contribute to domain challenges, e.g., Automatic Driver logs for driver support domain. It should be noted that a TTS can contribute to more than one specific domain, e.g., Automatic Driver logs is a TTS that can contribute to both administrative support and driver support even though, in Figure 1.8, it is presented under driver support.

Further analysis of TTSs were performed for specific situations, e.g., which TTSs can easily be implemented together, what choices of architecture concepts should be applied, what societal benefits will be generated, etc. The overall analysis of system concepts for TTSs in Papers III, IV, and V was to identify sets of TTSs most relevant for the different situations. Similar work has been carried out within the EasyWay research project (EasyWay Project, 2008) and the results show that E-Call, Intelligent Truck Parking, and Road User Charging were highly prioritized by European road operators; therefore these TTSs were recommended for deployment on European-wide scale. Further investigation of Intelligent Truck Parking (ITP) was performed papers VI and VII.

1.5.2 Conceptual Models of TTSs for Intelligent Truck Parking (ITP)

In Sweden, ITP has attracted interest from several transport stakeholders (Marika and Mari-Louise, 2010). In Papers VI and VII, further analysis of ITP has been carried out. In order to take into account the interests of different stakeholders connected to ITP, a set of core services have been proposed (Figure 1.9). Proposed ITP core services are based on the main problems facing truck parking operations in Europe and specifically Sweden. For an elaborate discussion of these services and the challenges of truck parking operations, see Paper VII.

In answering RQ1, we identified TTSs and corresponding systems from different sources (Papers I and II). Secondly, some of the TTSs were proposed according to previewed problems faced by different stakeholders in various domains (Paper VII). To assess TTSs, relevant TTSs had to be identified, hence, by answering RQ1, the thesis also contributed to answering the main RQ. In the course of the research reported in this thesis several new TTSs have emerged, such as those for switching off the vehicle engine when stopped by traffic lights, and more could be seen in the future.

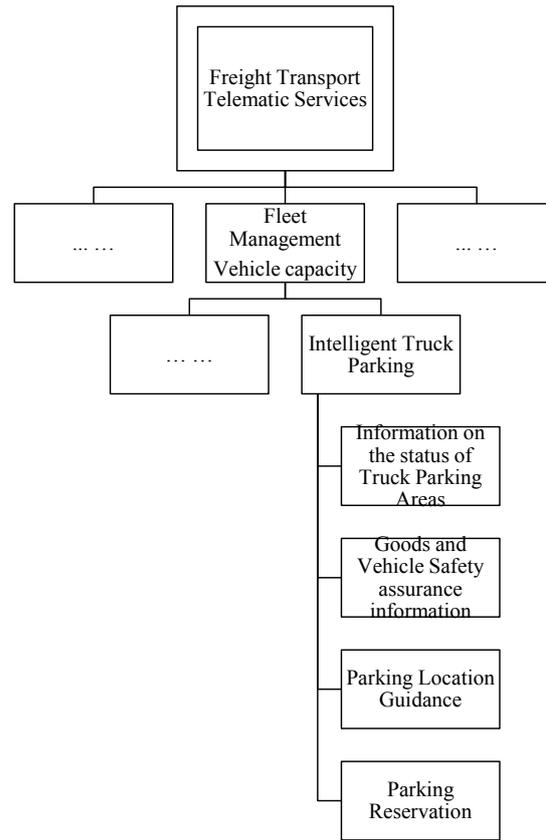


Figure 1.9: Proposed core services for Intelligent Truck Parking

RQ2. How can telematic systems for road freight transport be characterized in a way that enables them to be analyzed?

The domain of freight transport telematic systems is characterized by different types of TTSs. Each TTS may be delivered by a telematic system using different technologies. Each TTS addresses different goals along the transport chain. There is no formal or standard use of terminology for various TTSs. A uniform approach in the use of terminology, but also in the specification of information about each TTS, could help in the task of assessing TTSs. A characterization of TTSs with focus on operational structure and implementation issues and characterization of TTSs with focus on stakeholder challenges have been suggested.

1.5.3 Characterizing TTSs Focusing on Operational Structure of Transport

A holistic approach to telematic systems is employed in order to propose a framework based on the operational characteristics of freight transport (Paper I). The following dimensions are considered relevant in this framework for the purpose of assessing TTSs:

- **Unique identifier (Label or name):** A consistent but unique identification of TTSs across regions and organizations is important. Such identification may follow the domain of freight transport in which TTSs are intended to operate. For instance, "Intelligent Speed Adaption" (ISA) is an identifier that carries with it the operational activity of the TTS. In other situations the identifier may reflect the technological domain. For example, "Alcolock" and "Geo-fencing" may convey more information about the technology than about the domain of operation. A systematic approach to the identification of TTSs in particular and the use of terminology in general is important for successful assessment of TTSs.
- **Goal (motive or need):** The goal(s) of each TTS is the intended use of the TTS. The goal should clearly specify the motive of the TTS. ISA, as an example, is intended to help the vehicle maintain a speed that is appropriate in a given route segment.
- **Domain of operations:** In addition to systematically identifying TTSs, a specification of the domain of use for the TTS adds more meaning to the interpretation and analysis of the TTS. For example, if ISA is intended for driver support, it may be interpreted slightly differently than when it is intended to support speed enforcement by traffic authorities. The domain of usage is important for identifying the societal saving indicators to be addressed by a TTS, e.g., if a TTS is targeting a domain that addresses road fatalities, then the cost of road fatalities may be employed when assessing such a TTS.
- **Targeted user group:** The intended end-users of the TTSs should be specified. In some cases, such end-users could be other systems, e.g., an ISA system may provide speed information to another system controlling HGV platooning. The targeted end-users are important for assessments of benefits of TTSs.
- **Alternative options:** This is especially useful for studying potential concepts of a TTS to be implemented. Alternative options of a given TTS may target different end-user groups and domains of operation. For instance, ISA may have an option to help drivers adapt their speed along a road. Alternatively, it may also be employed to share speed information for the purpose of estimating traffic flow speed. Potential assessment of ISA implementation needs to take into account the specific telematic system that will deliver the TTS.
- **Functionalities:** Functionalities such as map matching, global positioning, and so on are the basic properties that can be implemented in a system in order to provide a TTS. TTS specifications should include necessary functionalities for implementing the TTS. Such functionalities can be specified at a high level to enable easy understanding of the components of the TTS. In order to analyze design options for TTSs, detail specifications of the functionalities need to be provided. Functionality specifications provide the possibility to assess synergy of various TTSs, and design options.

If for each TTS, all the above dimensions are specified, this could lead to facilitating the following types of assessments: 1) assessment of different implementation scenarios. This can be achieved by considering different options of the TTS and for each option the functionality specification (Paper VII). In addition, a unique identifier will help distinguish the given TTS from existing TTSs. 2) assessment of societal impacts. The goal of the TTS, domain of usage, and targeted end-users provide useful information for societal impact assessment (Paper II). The above dimensions and their contributions to assessments of TTSs are described in Figure 1.10.

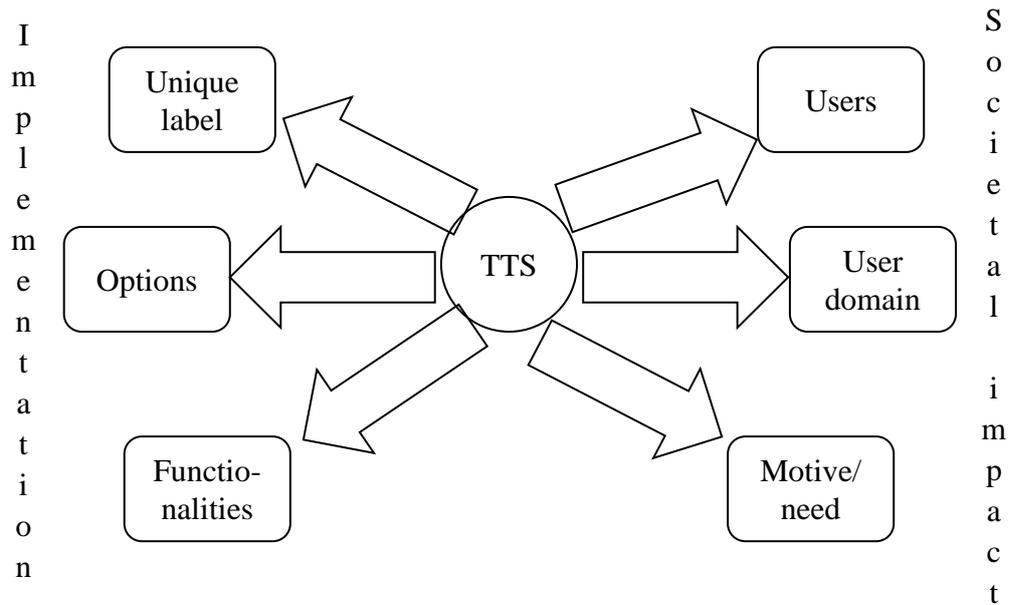


Figure 1.10: Characterization of TTSs to support different types of analyses

1.5.4 Characterizing TTSs Focusing on Stakeholder Challenges

An alternative approach to specifying a TTS that targets the analysis of design options and eventual implementation of the TTS as presented in Paper VII (Figure 1.11). In this approach, a problem-driven design process suggests a two-level specification that consists of:

Abstract service description:

- Stakeholders: These are freight transport stakeholders relevant for the TTS under consideration. They could eventually be the targeted end-users of the proposed TTS.
- Challenges: These are the problems that need to be solved in a specific freight transport domain.

- Information required or actions performed: This is the information needed to address the challenge. It could also be an action that need to be performed. The information or action has to be delivered by a TTS in order to address the given challenge.

Concrete service specification:

- Where and when the above information is generated: frequency and sources of input as well as output.
- What type of information is required by the TTS: identify main inputs necessary to generate required information.
- How the information is processed: computation of different functionalities.

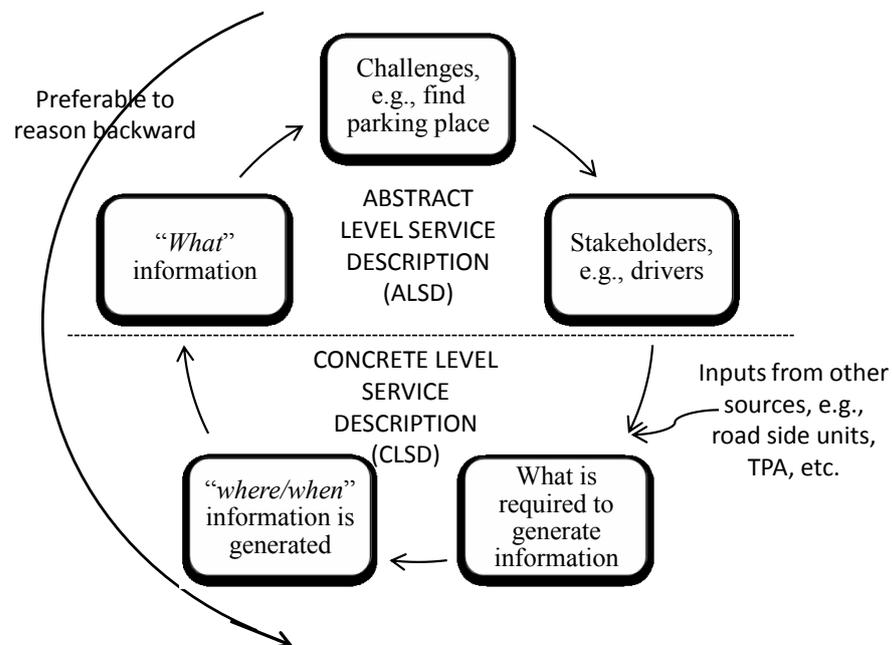


Figure 1.11: Problem-driven reasoning process for specifying TTSs

The proposed framework can be used for high-level analysis of TTSs. For instance, in supporting TTS investment decisions. This is possible because the specification directly leads to identifying the possible use of the service (challenge in question), targeted audience (stakeholders), and domain of usage (context challenge and information required). These dimensions then enable the assessments of societal impacts as a result

of the TTS. In this thesis, we employed the above approach in the specification of ITP core services. Based on the specification, a design analysis was performed. Results of the analysis lead to the identification of key platform demands for implementing ITP core services. These demands are: information dissemination, detection of vehicles at parking, accessibility to inventory of Truck Parking Areas (TPAs) and parking spaces, as well as control mechanisms in addition to positioning, communication and information processing.

RQ3. What modeling approaches can be used to assess telematic systems for road freight transport?

TTSs were modeled in the context of the framework provided above. The modeling involved abstract representation of TTSs, their relationships with functionalities and other components. Such modeling can be successfully achieved with the help of existing validated methods. Alternatively, existing methods can be extended and where necessary new methods can be suggested. In this thesis, we have in most cases, employed existing methods, e.g., as in Paper V where an optimization method was employed.

1.5.5 Mathematical Modeling Approach for Valuating TTSs

A mathematical method is proposed for modeling and valuating the societal benefits of TTSs (Paper II). The main features of the valuation method for TTSs include the following:

- Given a geographic region, identify the main indicators of freight transport challenges, i.e., Performance Saving Indicators (PSI), e.g., fuel cost.
- Quantify the societal cost for each PSI (approximations).
- Collect experimental data about the contributions of each TTS for each PSI.
- Determine under what conditions the performance results of TTSs were obtained in order to be able to estimate the performance result for a more general setting.
- Apply the generalized result to similar PSIs in a region of interest (geographic or organizational).
- Calculate the dependencies that occur when two TTSs address the same PSI.
- Determine the societal value for each TTS.

The proposed method is similar to that used today by the Swedish Transport Administration (Trafikverket) when assessing the societal impacts of various projects (EVA system (SRA, 1997)). However, in our assessments, we have considered

dependencies when two TTSs address the same PSI. Such dependencies are not taken into account by the EVA system. We employed the proposed method to estimate quantitative societal values for 32 TTSs considered relevant for freight transport in Sweden. Details of the mathematical model are presented in Paper II.

1.5.6 Clustering-based Modeling of Synergy due to Functionality Sharing

Clustering methods are extended and applied for modeling functionality cost sharing between telematic systems (Paper III). The basic information required to apply this modeling technique includes:

- Total cost of functionalities for each TTS when implemented in isolation.
- Total cost of TTSs when implemented together.
- Maximum cost of each functionality among all TTS.
- Coefficient of cost reduction for each functionality when used by at least two TTSs.

This information can be acquired from studying similar systems or from domain experts' knowledge. Once the information is obtained, the modeling technique is applied in two stages:

Firstly, the pairwise synergies are calculated from the above information for all pairs of TTSs resulting in a symmetric matrix. Different approaches are suggested in Paper III for performing these calculations. A Microsoft Excel implementation has been developed to facilitate pairwise synergy computations.

Secondly, a standard clustering algorithm, e.g., nearest neighbor hierarchical clustering, can then be applied to the pairwise matrix to estimate synergy (equivalent to cost savings) for sets of TTSs if implemented together. The procedure can be repeated for different pairwise synergy measurements to obtain different types of synergy. The synergy of different sets can be compared to determine the most interesting combination of TTSs for implementation.

Further, an analytical method is used to extend and adopt clustering and K-minimum spanning tree approaches. The model is employed in finding combinations of TTSs which maximize reductions in total system costs due to infrastructure sharing between telematic systems (Paper IV). The modeling approach is similar to the one used in synergy analysis (Paper III). The main difference is that a spanning tree algorithm, in addition, is applied to determine more accurate cost savings for different clusters.

1.5.7 A Linear Optimization Approach for Modeling Net Benefits of TTSs

Optimization-based techniques have been extended to analyze the net benefit of TTSs when implemented on different platforms (Paper V). The problem of selecting different

TTSs was modeled as a linear optimization problem with the following inputs:

- Sets of TTSs and the societal value for each TTS (from Paper II).
- The fixed cost of each functionality (Paper III).
- The variable cost of each TTS estimated from type of data employed by the TTS, e.g., text, video, or audio data.
- Specification of MSA concepts including resources and functionalities.
- Estimates of different capacity limits for different architecture resources, e.g., communication bandwidth and processing.

The outputs are the different sets of TTSs for different choices of architecture and the resulting net benefits.

1.5.8 Multi-Criteria Decision Analysis for Modeling ITP Benefit areas

MCDA has been employed to compare benefit areas for ITP as well as benefits among stakeholders (Paper VI). Different attributes are employed as different criteria and a theoretical assessment provides input to MCDA. A pseudo code algorithm (Algorithm 7.3.1 Paper VI) is presented as a guide on how to apply the modeling process.

RQ4. To what extent can we quantify the societal benefits from employing TTSs in road freight transport?

Benefits of TTSs is a subject that is mentioned in several research articles and commonly echoed within the ITS society at large (José et al., 2004). However, knowledge about the benefits derived from TTSs has remained insubstantial, and this depends on several issues. For instance, sluggish deployment and insufficient data from field operational trials are both factors that makes it hard to assess benefits of TTSs. In addition many research efforts have focused their study of benefits on specific user groups and not on society at large (José et al., 2004) . In this thesis, we attempt to study the potential benefits of TTSs by considering reductions in specific societal cost indicators referred to as Performance Saving Indicators (PSIs) (Paper II). The computations of PSIs uses statistical data obtained from freight transport in Sweden, e.g., from national data bases such as SCB and SIKA (SCB, 2012; SIKA, 2008b). In this section, results of comparing quantified societal value for different TTSs (see Paper II) are presented.

1.5.9 Quantified Benefits of TTSs From Reducing Societal Costs

Using PSIs and their dependencies, we propose a method for assessing the societal values of TTSs. Quantified estimates of the societal value for 32 TTSs are presented. The societal value for each of the 32 TTSs was estimated within a range of 0.5 million Euros

to 55 million Euros per year. The geographic scope of the TTSs was limited to Sweden and mainly concerned freight transport. The TTSs focused on different end-user groups and covered several domains of freight transport. Estimated societal values of TTSs will change with changes in performance of different TTSs, or estimates of PSIs, or both. The societal value for different TTSs are based on current estimates as presented in Paper II.

From the results of the valuation process, the following TTSs are of high benefits to society (based on Swedish freight industry): Transport Resource Optimization (TRO), Theft Alarm and Recovery (TAR), Road Hindrance Warning (RHW), Accident Warning Information (AWI), Navigation (NAV), eCall (EC), Intelligent Speed Adaptation (ISA), En-route Driver Information (EDI), Transport Order Handling (TOH), Sensitive Goods Monitoring (SGM), and Road User Charging (RUC).

The estimated societal values provide a valuable input to quantitative analysis of benefits of TTSs using methods such as optimization and Cost Benefit Analysis (CBA). Possibilities of improving the accuracy of PSI reduction values include simulation of services, gathering opinions of experts, and comparisons with similar services.

1.5.10 Quantified Benefits of TTSs due to Synergy

Benefits of TTSs can be improved by reducing costs of deployment (Papers III and IV). There are several ways to reduce deployment cost. For example, efficient use of available technology, reducing redundancies by sharing functionality, focus on low cost technology. We refer to the measure of shared functionalities as a synergy level. Synergy-based clustering is employed in this thesis to identify TTSs that can be implemented on a common MSA. The proposed synergy approach is illustrated in estimating potential reduction in total costs as a result of common use of functionalities. In a case analysis including 13 TTSs for which data was available at the time. Results indicated that as much as 2% of costs can be reduced by making use of synergy (Paper IV). These results are further indication of the potential benefits due to synergy. However, additional data is needed to fully investigate, understand, and validate the benefit due to functionality sharing among TTSs (synergy).

RQ5. How can quantitative models provide support for decisions regarding investments in telematic systems that can offer multiple TTSs?

The deployment of effective solutions in road freight transport, based on TTSs, requires long-term planning. Deployed solutions need to be monitored continuously. Where necessary, alternative measures need to be considered where TTS-based solutions may not be successful. In addition, technology evolution opens new capabilities that merit consideration. To keep up with all these changes, monitoring plays an important role. To employ quantitative models for supporting investment decisions as well as the monitoring task, different types of data need to be collected. The data could be about TTSs, transportation networks, operations, environmental effects and so on. The type

of data depends on the model under consideration. The model depends on the type of decisions being addressed. For instance, to determine TTSs that can be deployed together with a RUC system, the proposed optimization model in this thesis can be employed. Models suggested by this thesis can support different strategic decision situations.

1.5.11 Selection of TTSs Considering Benefits, Costs, and Choice of Platform

The optimization model suggested in Paper V is suitable for supporting strategic decision-making. Specifically, the model can support decisions related to the design and investment in telematic systems and services for road-based freight transport. The problem of evaluating the benefits of different TTSs in combination is formulated as an Integer Linear Programming problem. The objective of this optimization model is to select beneficial TTSs for implementation on MSAs. At the same time, the model should minimize the total costs and dependencies among TTSs. Further, functionality sharing (synergy) should be maximized among selected TTSs. By simultaneously exploiting synergies through common use of functionalities and minimizing pairwise dependencies of selected TTSs, the proposed model takes into account several dimensions. Multiple dimensions are difficult to take into account when employing models such as CBA. Moreover, the proposed model can be useful even to address questions about existing TTSs, e.g., whether TTSs are still beneficial considering available new alternatives.

Given a set of TTSs, the proposed Integer Linear Model was employed to select the most beneficial set of TTSs. The scope of all the TTSs considered was limited to Swedish freight transport. With CPLEX's branch and bound capabilities, the optimal solution to the model was generated by using a tree-based search. We show that the choice of MSA influences the selection of TTSs and the resulting total net benefit. By changing the conditions, we also illustrate that the model can be used to address "what-if" decision scenarios. We consider six different MSAs and their potential effects on possible services that can be achieved from a benefit perspective. The study provides evidence that it is possible to conduct high-level multi-service analysis using quantitative methods such as optimization. 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.

1.5.12 Selection of TTSs Considering Mandatory Deployment of one TTS

If it has been decided that a certain TTS is going to be deployed, possibilities for joint deployment may need to be investigated. The aim of investigating such joint deployment could be to identify other interesting TTSs such that the overall deployment cost can be reduced. This could be of interest to government organizations and telematic

service providers. Sometimes the decision to deploy a given TTSS can be mandated by government policy. For example, this is the case with road tolling systems in several countries.

In order to investigate such a decision, different options of the telematic system have to be considered (as specified in the framework). Each version can be evaluated to determine its support for synergy with other TTSS. In the case of the Swedish RUC, the options could be a RUC system with a thick client architecture, where most of the data is processed on an on-board unit and results send to a central control system. Alternatively, a RUC system can be implemented with a thin client architecture in which most of the data processing is accomplished by a back office system. The proposed optimization model was employed to identify beneficial TTSS for different options of the Swedish RUC system, thin client (RUC) and thick client (advanced RUC). Results 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. In general, any telematic system, beside a RUC system, can be assessed as described above.

1.5.13 Identifying and Comparing Benefit Areas of TTSS

In some cases it may be difficult to obtain absolute societal values of TTSS as anticipated in Paper II. This could be for various reasons, e.g., performance saving indicator values may be hard to estimate. One could be interested in identifying a broad range of benefit areas for comparison. Information about benefit areas, can for instance, be employed in designing business models. Alternatively, TTSS may be conceptualized and designed to address a specific goal due to potential benefits in that area. In such a case, the design of the system will be biased to suit such benefit areas.

A MCDA is used to address decisions about benefit areas related to ITP. Nine ITP Benefit Areas (BAs) are analyzed based on 28 benefit attributes. Relative differences between BAs are studied. The information gained can be used as a reference for decision-making across a variety of regions and cases related to ITP. The results indicate that the most influential areas for ITP are *parking search time* and *fatigue-related accidents*. *Perceived safety* was seen to be the least beneficial area. Theoretical results of stakeholder analysis of the identified benefits show that drivers will be the main beneficiaries of the ITP service. This group is closely followed by road haulage companies. These results are compared with complementary interview results (Paper VI). It should be pointed out that results of the MCDA are obtained based on a number of assumptions. For example, it was assumed that for each benefit attribute, we can determine the change required to generate benefits, e.g., a decrease in driving time and a decrease in number of thefts.

1.6 Discussion of Results

Road freight transport challenges such as emissions and accidents require additional measures to those provided by TTSs. Even though several telematic systems offer TTSs that can potentially contribute to addressing some of these challenges, most of the telematic systems are yet to fully developed (Psaraki et al., 2012). Several barriers still need to be overcome, e.g., standardization, interoperability, legal issues and so on (Nowacki, 2012). In this thesis, we focused on existing TTSs as well as conceptual telematic systems yet to be developed. The reason was to address the strategic assessments for different types of TTSs without a restriction on whether the TTSs exist or not.

We do not claim that all relevant TTSs were exhaustively identified and studied. This is partly due to the variation of what is considered as a TTS. Moreover, both the problems (in transportation) and solutions (types of telematic systems) are constantly evolving. Despite these shortcomings, it is also clear that neither a single TTS can solve all the main challenges in road freight transport, nor is it feasible to deploy a huge number of TTSs with the hope of addressing all transport challenges. Therefore, it is safe to say that in addressing RQ1, the thesis identified the main potential TTSs. The TTSs are motivated by their connections with important transport stakeholders and challenges faced by such stakeholders. Identified TTSs were mostly considered from the context of freight transport in Sweden. However, the approaches employed are not only limited to freight transport and certainly not only to Sweden.

To answer RQ2, the thesis investigated various concepts for specifying telematic systems. A framework was suggested for characterizing TTSs to enable analysis. There is no specific approach for developing such a framework. However, it can be observed that a possible framework will depend on the intended usage, e.g., focusing on a TTS in the context of transport operations or in the context of service design. In either situation, a framework should be regarded as providing one viewpoint, out of many, for a given set of TTSs. Many such viewpoints are required to determine different properties of TTSs. When aiming to perform an analysis of multiple TTSs, the same types of frameworks should be applied consistently to all TTSs. Without the framework it would have been difficult to model TTSs. This is due to the variation in information about TTSs.

In order to answer RQ3 modeling was accomplished by extending existing quantitative methods but also suggesting new methods. When a TTS is implemented, it is often based on some technique or model for facilitating a situation through a service delivery. The model could be basic, e.g., calculating distance from GPS coordinates. Other models can be advanced, e.g., analysis and detection of traffic bottlenecks within a network. We did not look into models of TTSs that are used in their implementation. However, understanding the underlying TTS models may facilitate new ways of modeling TTSs. We choose to focus on characteristics that were considered common to most TTSs such as functionality specification. Conceptual models were also suggested, for instance, in designing ITP core services.

Based on the modeling assumptions and data, the application of quantitative models led to quantification of several aspects, hence, addressing RQ4. Different models provided the opportunity to quantify the societal benefits of TTSs. Societal indicators were quantified in connection to freight transport. Examples of such indicators are costs related to emissions, noise, and number of fatalities. Estimates of these indicators help to assess societal values of TTSs. This kind of an approach for valuating TTSs depends on decomposing a given transport challenge into a set of indicators. It also depends on scaling up experimental results from a field operational test, or from a small scale laboratory experiment. Both scaling up and decomposition of indicators are error-prone due to changing conditions. However, from an ex-ante perspective, the approach provides information that can help in making a more informed decision at a low cost, compared to high cost alternatives such as large scale field tests. Also, since the approach depends on a set of indicators representing different transport problems, changing the priorities of the problems under consideration will lead to a different benefit outcome. This means that different organizations with different priorities could have different benefits for deploying the same set of TTSs. Consequently, one should be careful when comparing the benefits of TTSs in different organizations or regions.

To invest in TTSs as solutions for addressing challenges in road transport requires persuasive arguments especially when considering alternative approaches. The thesis offers a possibility to consider the societal value of TTSs and their costs but also the design choice for the architecture with additional dimensions, e.g., using a proposed optimization model. The outcome of applying the proposed model on a given set of TTSs and associated data will favor certain choices of TTSs and architecture designs according to perceived net benefits. Other quantitative models may also be used to provide additional information such as Cost Benefit Analysis (CBA) which is widely used for transport projects. However, care needs to be taken when considering information provided by different models. For instance, while CBA may provide information about benefits in terms of ratios, CBA is poor at capturing multi-dimensional effects when multiple TTSs are considered, e.g., synergy.

Potential benefits of isolated TTSs are not enough to fully make a decision to (or not to) deploy those TTSs. In addition, other types of information have to be considered, e.g., what other types of TTSs that have already been (or will be) deployed. Such information may show where to look for synergies and dependencies. This thesis has suggested a method for estimating both synergies and dependencies that can facilitate combined deployment on a common platform. Practically, combined deployment could be difficult to achieve, e.g., users may require time to understand various systems and the start-up costs may be too high. However, in designing new TTSs, it should be possible to take into account the potential to include additional TTSs in the future, i.e., a gradual stepwise introduction of TTSs can achieve combined deployment. In Figure 1.12, we show the overall research approach employed in this thesis.

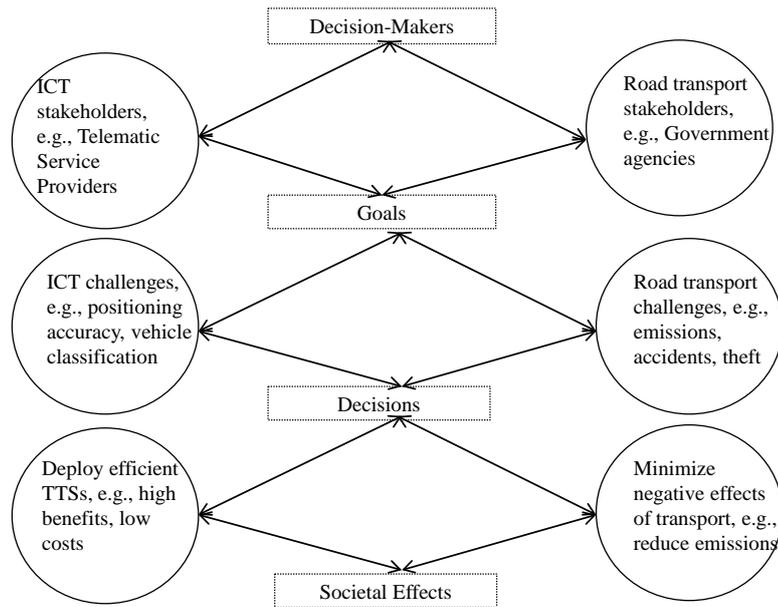


Figure 1.12: Overall research approach.

In the course of applying the thesis approach, several problems were encountered some of which include:

- Cost data about functionalities of TTSs turned out to be more difficult than was anticipated from the beginning despite several efforts aimed at collecting such data. Approximate values, and sometimes price information of similar functionality in different systems, were used to estimate costs.
- Data about the performance of different TTSs on different problem domains were difficult to uncover. Where such data was available, it was difficult to transfer, or, to scale the results, when estimating effects of TTSs on a societal scale. This was overcome partly through workshop discussions within different relevant projects, e.g., Mobil IT (MOBILIT, 2013).
- During modeling, run-time characterization, which enables modeling of system resources at run time, was difficult to achieve. This was overcome by considering snapshots of the run-time behavior in different scenarios.
- Information modeling was not straightforward due to the lack of readily measurable physical dimensions, e.g., measuring bandwidth demand. To overcome this we had to sometimes use proxy parameters such as application data type, e.g., video, text, and audio data type.

1.7 Conclusions

Road transport plays an important role in society. However there are several undesired effects as a result of road transport, e.g., emissions, accidents, and congestion. There are many approaches that can help tackle these effects, e.g., taxation schemes and policy instruments. Intelligent Transport Systems (ITS) provide one interesting approach for addressing some road transport challenges. Solutions provided by ITS can deliver efficient Transport Telematic Services (TTSs) for different transport stakeholders. However, a number of challenges needs to be overcome in order to successfully deploy TTSs. Moreover, the decisions leading to deployment of the right choices of TTSs are challenging. Some of the challenges are related to the technology while others are related to insufficient knowledge about the effects of such TTSs. Computational DSS models could help in addressing some challenges related to the deployment of TTSs. In particular, suitable DSS models can help analyze information about TTSs that will guide stakeholder decisions. In this thesis, we have identified relevant telematic systems for road freight transport, characterized the basic concept and functionalities of the systems, and applied computer-based modeling for pre-deployment assessment of various TTSs (ex-ante perspective). The decision-making process intended to be supported by the thesis concerns whether or not to deploy a given TTS.

To achieve the goal of the thesis, a systematic approach has been applied in several iterative phases. Each phase contributed to building computational models for supporting stakeholder decisions. The phases involved developing a plan, executing the plan, and investigating the outcome for a given set of TTSs. The planning phase consisted of: literature reviews, mathematical modeling, conceptual modeling, and data collection about potential systems for TTSs in road freight transport. The planning phase led to several models alongside some data required to solve the models. In the execution phase, models were then solved using different algorithms such as nearest neighbor Hierarchical Clustering Algorithm (HCA), and K-Minimum Spanning Tree (KMST). The outcomes from the models were analyzed in relation to the systems studied, e.g., by changing parameter values and by changing data values.

Results from applying the suggested approach were published in different research articles, some of which are included in this thesis. Each research article generated new knowledge concerning modeling and assessments of TTSs in road freight transport. Based on the work in this thesis, the following can be recommended for both practitioners and researchers with interest in deployment issues for TTSs:

- There are multiple TTSs for addressing road transport challenges. To take advantage of the leverage of the most beneficial TTSs, synergy between different TTSs need to be assessed and compared. Methods are proposed in this thesis that can help in such synergy assessments.
- A holistic view of TTSs is necessary in order to make deployment decisions that address transport challenges. To accomplish an assessment of multiple TTSs, a

framework is important. Different frameworks may be consistently employed since there is no one single framework approach that will address all the problems related to characterizing TTSs.

- Suitable methods for the assessment of TTSs have to model information operations. Such operations may include how information is generated, processed, communicated, and potential effect of instructions carried by such information. Most of the quantitative models that exist today are not particularly suited for modeling information. Alternative approaches are needed where the focus is on modeling and capturing how operations of TTSs are carried out with focus on information processes.
- Benefits of TTSs based solely on CBA should be interpreted carefully because CBA does not capture multiple dimensions such as dependencies, hence, may overestimate the benefits. Further, if synergies are identified and exploited, the benefits could be more than previously expected.
- The context for decision-making concerning the deployment of TTSs might be of much significance owing to dependencies, synergies, and the priorities for different transport challenges. When organizations have different priorities of transport challenges, it should be expected that their benefits will be different even when they are all considering the same set of TTSs.
- Regulations, e.g., by government, are important when considering the co-existence of multiple TTSs. This is to establish a common set of rules for operating all TTSs. However, a market-driven approach should be supported in order to establish long-term business models.
- More efforts need to be dedicated to gathering costs and benefits data for different organizations, geographic regions, and TTSs. Without quality data, the entire decision process will be difficult for stakeholders.
- There is a need to either standardize terminology or provide basic rules of terminology usage within ITS as has been done in the area of telecommunications.

The main scientific contributions of the thesis are in suggesting new quantitative models, as well as extending and applying existing models in the analysis and assessments of TTSs. Application of the models to various case studies provides new knowledge for supporting decision-making within the specific scenarios. Quantitative models are suggested for analysis of the synergy between TTSs and calculating the dependencies among TTSs. The models were illustrated by applying them to calculate synergies and dependencies in various scenarios of TTSs. The proposed models are not only limited to TTSs and can be applied in analyzing other types of services. Further, existing models such as optimization and net present value were extended and applied in the analysis of TTSs for freight transport. Analyses of other types of telematic services beside those for freight transport can apply the proposed model. Knowledge about

potential TTSs for road freight transport was synthesized, hence, providing a base for research on TTSs within freight transport. We hope that interested stakeholders can gain an overview of the potential for TTSs in freight transport through the work presented in this thesis. Case studies were conducted that led to estimating benefits, of different TTSs if implemented on different potential platforms. Design approaches were suggested that can be employed in designing services in other domains. New TTSs were also suggested that could be further analyzed, developed tested and deployed.

More generally, the work in this thesis indicates that the most significant contribution of ITS is likely to be in the area of safety. This is because traffic safety seems to be one of the areas where major stakeholders are in agreement with each other. Such stakeholders include governments, auto-manufacturers, drivers, ICT industry and so on. These stakeholders are considering TTSs such as Intelligent Speed Adaptation, Automated Driver Logs, On-board Safety Monitoring, and eCall, just to name a few. From a benefit perspective, this thesis shows that the most potential benefits could come as a result of improvements in transport operations, e.g., through TTSs such as Transport Resource Optimization. Examples of operations could be driving time, fuel use, traveled distance, empty mileage and so on. Even though such improvements will not be independent of traffic safety, stakeholders do not seem to agree in the same way as they do about safety concerns.

1.8 Future Research Directions

The research in this thesis has raised a number of issues that need further consideration. Some important issues include:

1.8.1 Improve Data Accuracy

The accuracy of data employed by the quantitative models, especially related to costs, savings potential, and performance estimated for different TTSs, needs to be continuously improved. If the accuracy of the data is improved, the results obtained from the model will be more reliable. As more experiments are conducted new data will be available.

1.8.2 Expand Synergy Analysis Between ITS and Non-ITS Systems

Most of the synergy analysis in the thesis concentrated on different scenarios of TTSs. In the future it could be interesting to look into the synergy that exist between ITS solutions and non-ITS solutions, i.e., other ICT solutions. This is possible, e.g., through the sharing of infrastructure such as communication and data transfer channels.

1.8.3 Further Explore Additional Models

In most of the analyses conducted in this thesis, TTSs were not fully diagnosed with respect to the underlying models on which they are implemented. Perhaps, by considering such models, it is possible to extend or develop new models similar to those suggested in this thesis. Additional models, particularly predictive models, need to be further explored so as to capture scenarios concerning benefits and implementation over multiple time periods, which is not currently the case.

1.8.4 Integration of Assessment Models with Transport Planning Models

One way to make use of the models proposed in this thesis is to integrate them with transport planning tools such as those used by the Swedish Transport Administration (Trafikverket), e.g., EVA. Such applications can serve an important purpose of validating the proposed models. Other research scenarios can be employed for further validation.

Paper I

Characterization Framework for Transport Telematic Services

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NOTE: This thesis contains the author proof version of the published article.

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. 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 Euro-vignette directive established common rules related to distance-based tolls and time-based user charges for goods vehicles over 3.5 tones (2006/38/EC European Commission (2006), (EC, DGB-1049, 2006)). Following these developments the Swedish Governmental Commission on road taxes proposed a distance-based charging system that covers all public roads, and all HGV with a maximum laden weight exceeding 3.5 tons (SOU:63, 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, 2007b).

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 Wills, 2003), an EFC platform has a potential for hosting coexisting TTSs (Sjöström, 2007; Sundberg, 2007a) 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-14813-1, 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 TTAs 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, 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.

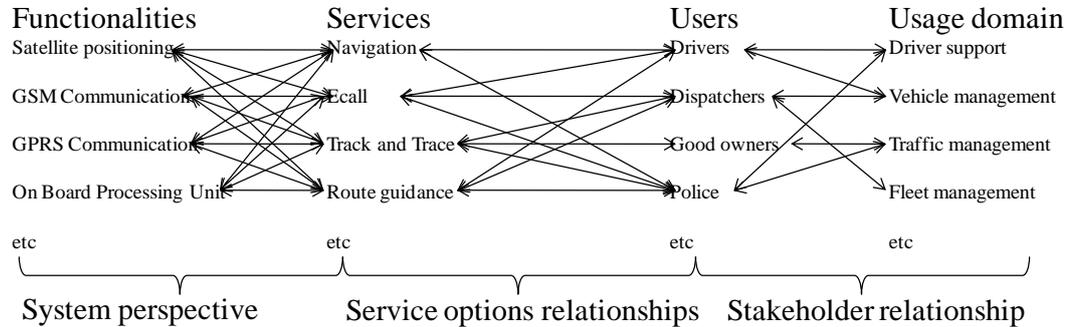


Figure 2.1: Example of functionalities, services, users and user domain choices.

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., 2000; FHA, US DOT, 2005; ISO/TR-14813-1, 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 (Wu and Turtle, 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, 2008a). 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 Wills, 2003). On the infrastructure side attention is given to route network utilization, special infrastructure utilization such as bridges (EasyWay Project, 2008) and several techniques have been developed for improving the management of infrastructure and networks, e.g., monitoring traffic and detecting incidents, network visualization (TR 1103 CODE, 1999; Wu and Turtle, 2006). 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 (EasyWay Project, 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 (EasyWay Project, 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-14813-1, 1999; ISO/TR-14813-1a, 2007). 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 includes travel and traffic management, public transportation management, electronic payment, commercial vehicle operations, emergency management, advanced vehicle safety systems, information management and, maintenance and construction management. The aim has been to develop a TTSs repository and hence the framework is less helpful from an analysis point of view. In another case TTSs have been categorized based on functional characteristics to facilitate the design of the system (Bossom et al., 2000). 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-14813-1, 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 (Chen and Miles, 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 and high infrastructure impact. 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.

D1. 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. 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, and collisions warning. Yet a number of TTSs require positioning functionality modeled externally from local vehicle systems. Services related to navigation, delays, and road information all require positioning.

D2. Administrative Support: These are supporting activities such as staff management, education, and organizational welfare. 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.

D3. 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, and improve response time to driver and staff.

D4. 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, and reducing empty mileage.

D5. 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).

D6. 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.

D7. 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., geo-fencing. 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. Such ambiguity maybe 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 it usage. Table 2.1 provides important aspects of a TTS potentially useful for analysis, e.g., benefits analysis, impact analysis, architecture design analysis.

TTS Label	Needs	Functionalities	Users	Options	User Domain (Dx)
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 proposed framework TTSs are presented with focus on user-options-user domains (Table 2.2).

Chapter 2. Characterization framework...

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)	D6
eCall	Drivers, road traffic inspectors, rescue agents, accident statistic agents, local authorities and goods owners	Ecall as network intervention report, Ecall detail report	D1, D4, D5
Navigation	Drivers	Static, Dynamic	D1, D7
Weight Indicator	Drivers, bridge infrastructure providers, goods owners	Goods only, Total weight	D1, D5
Intelligent Speed Adaptation	Drivers, traffic inspectors, police dispatchers, insurance companies	Enforcement possibility, recommendation possibility	D1, D5
Accident reporting	Drivers, traffic inspectors, police, dispatchers, accident statistic agents	Detail information, Statistically (interruption)	D1, D4, D5
Automatic Driver Logs	Drivers, police, staff or personnel managers		D1, D2
Staff Monitoring	Commercial Fleet operators		D2
Transport Resource Optimization	Commercial Fleet operators, road infrastructure providers	Fleet Scheduling, Road utilization, Driver planning	D2, D3, D6
Vehicle Follow-up	Dispatchers, HGV fleet owners and operators		D3
Remote Monitoring	Dispatchers, vehicle fleet owners	Fault prediction, Fault detection and repair	D3
Goods Identification	Customs, good owners, terminal operators		D4
Real Time Track and Trace	HGV fleet operators, police, goods owners		D3, D4, D5
Sensitive Goods Monitoring	Goods owners, Goods quality control inspectors, customs	Dangerous goods only, All goods	D4
Traffic Information	Traffic controllers, drivers, dispatchers, road and bridge infrastructure owners	Prognosis, Real time	D5
Route Guidance	Drivers, drivers in transits, intervention units, e.g., police, emergency	In transits, non-transit, sensitive segments	D5, D7
Theft Alarm	Vehicle fleet owners, drivers, goods owners, police		D1, D3, D4
GeoFencing	Vehicle fleet owners, infrastructure owners, gate operators, vehicle parking operators, loading/unloading units	Mobile, Corridors and gates	D3, D4, D6

TTS label	Users	Options	User Domain
Transport Order Handling	Dispatchers, good owners, drivers		D2, D4
Pay as You Drive	Insurance companies, vehicle fleet owners, environmental controllers		D5, D7
Variable Speed Limit Road Signs	Traffic controllers, police	Report speed violations, Determine speed limit	D5, D6
Driver Planning	Dispatchers		D2

Table 2.2: Relevant TTSs for HGV Transport (KEY: D1-Driver support, D2-Administrative support, D3-Fleet management, D4-Transport management, D5-Traffic management, D6-Infrastructure management, D7-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, and driving distance.

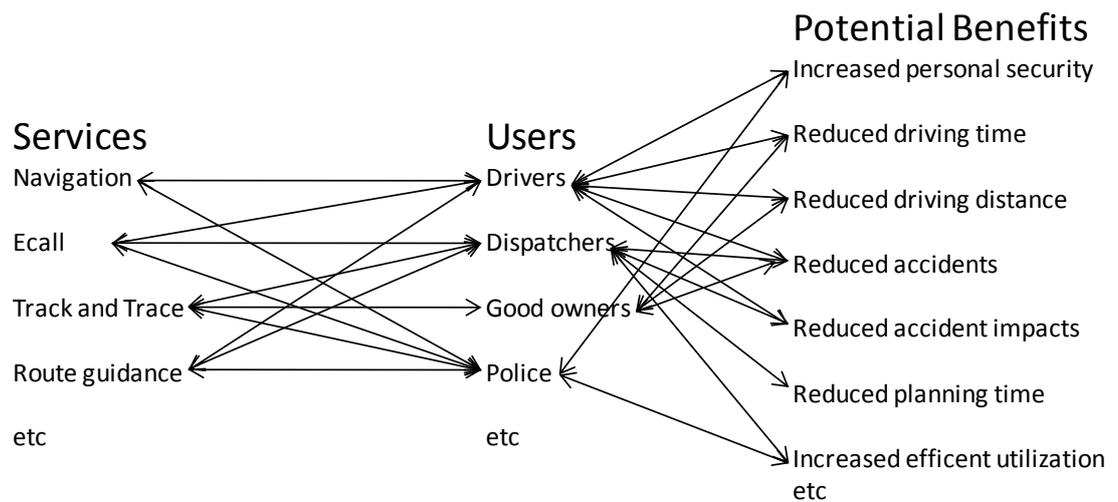


Figure 2.2: Example of analysis relating services, users and potential benefits.

2.7 Conclusions and Future Work

This article has conducted a qualitative study to point out the need for a framework in the analysis of TTSs. For organizations faced with investment decisions such as governmental agents, there is a need for a common operational view on transport

processes and how to improve such processes with the help of TTSs. A framework provides a preliminary step into supporting high level analysis of services that support investment decisions. One such framework has been proposed and illustrated, and TTSs identified and classified within the context of the Swedish HGV transport. In the future, this framework can be validated through various analysis of TTSs following suggestions presented in the framework.

Paper II

Method for Quantitative Valuation of Road Freight Transport Telematic Services

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This study describes transport telematic services (TTSs) for road-based heavy goods vehicle (HGV) transport and suggests a method for assessing the societal value of different TTSs. For decision making related to the selection of services to promote by potential investors, for example, governmental organizations and service providers, quantified service value can simplify the decision process by enabling comparison between TTSs. Moreover, these values can serve as inputs to quantitative analysis of service architectural system designs. The authors suggest a method for assessing the societal values of TTSs using potential saving indicators (PSIs), estimated in the context of Swedish HGV freight transport. To illustrate the proposed method, 32 services are analyzed, and their societal values were quantified and compared for the Swedish HGV market. Results based on estimated values of PSIs and potential percentage savings indicate the following HGV-based TTSs to be of high societal potential: transport resource optimization, dynamic traffic information, navigation, road hindrance warning, theft alarm and recovery, accident warning information, intelligent speed adaptation, eCall, en-route driver information, transport order handling, road user charging and sensitive goods monitoring.

3.1 Introduction

Although 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. Although HGVs account for less than 5% of the overall vehicle stock in Europe, they contribute to more than 20% of the mileage driven (Krueger et al., 2005). Notwithstanding the low numbers, HGV transport has high impacts on society for example, accidents. Therefore impact assessment for cars and HGVs should be performed separately (Krueger et al., 2005). Telematic systems have the potential to significantly improve road freight transport by reducing negative societal effects like emissions, congestion and accidents. This article describes transport telematic services (TTSs) for road-based HGV transport, most of which were identified in the Mobile IT project (MOBILIT, 2013). Effects of TTSs that may result in modal shift and hence effective utilization of the entire transport system have not been considered, but the method suggested can also be applied to study such effects. Also, costs associated with both the deployment and operations of TTSs (infrastructure and maintenance) are intentionally left out in order to focus on assessing their potential societal value. TTSs with a potential connection to an anticipated Swedish road user charging (RUC) system were identified in the previous study (Mbiydznyuy et al., 2008a). A framework was developed (Clemedtson et al., 2008; Mbiydznyuy, 2009) to analyze TTSs. Results of the current study can facilitate quantitative analysis of TTSs, for example, optimization and simulation.

Different TTSs address various issues associated with freight transport, such as emissions, accidents and infrastructure maintenance. We use criteria established in previous studies (Clemedtson et al., 2008; Mbiydznyuy, 2009) to characterize TTSs (Mbiydznyuy et al., 2008a). 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, that is, motivation, user domain, users, functionalities, value and quality of service (QoS) (Mbiydzennyuy, 2009). The value of a TTS is assessed by the extent to which each TTS can reduce the cost of potential saving indicators (PSIs), for example, emissions, accidents and infrastructure maintenance. In addition to providing decision support, good quantitative values can improve public acceptance of TTSs. Moreover, quantification of TTSs contributes towards assessing benefits of different telematic system design alternatives or platforms. Generic level analysis can enable comparing different TTSs and support decision making related to the selection of services to be promoted by potential investors, for example, governmental organizations and service providers.

The existing methods take into account both costs and societal value (positive benefit) of various TTSs from a cost benefit perspective with no consideration for dependencies between the positive benefits. Cost assessments are facilitated by the connection to different technologies and quantification of equipment for installation and maintenance (Malone et al., 2008). However, estimating societal value is challenging for several reasons: unknown penetration rates, lack of quantitative models, lack of operational data and so on. Researchers suggest methods of service valuation based on system performance quality (Groönroos approach) (Grönroos, 1993) and emphasize the use of a risk-oriented approach rather than human capital approach, thus suggesting that the societal value of TTSs may be seen in terms of their ability to minimize risks (Huschebeck et al., 2009). The current study identifies and assesses the full potential (assuming a 100% penetration (Huschebeck et al., 2009; Planath et al., 2003)) of TTSs based on PSIs.

To achieve the above goal, a generic quantitative method is proposed to assess the values of different TTSs. The main advantage of a generic assessment approach is for identifying efficient TTSs for deployment on system platforms based on their functional characteristics (Kanoshima and Hatakenaka, 2008; MOBILIT, 2013). The approach proposed can be seen as building on project work related to system platforms carried out in Sweden and Europe, such as the Mobile Networks (Mobile-Networks, 2006), Mobile IT (MOBILIT, 2013), HeavyRoute (HeavyRoute, 2010a), eIMPACT (Malone et al., 2008), SeISS (Krueger et al., 2005) and so on. Societal costs of nine PSIs related to HGV transport in Sweden are assessed. PSIs are then used to calculate societal values of each TTS based on the percentage estimate of how each TTS can marginally reduce the societal costs of each PSI. With this approach the potential of any mix of TTSs can be estimated when the functions are combined to address different societal issues. Section 3.2 presents a short review of work related to the valuation of services, Section 3.3 proposes assessment criteria for valuating TTS, Section 3.4 presents PSIs, Section 3.5 discusses the different services considered in the study, whereas Sections 3.6 and 3.7 present the results, conclusions and discussions, followed by acknowledgments and references.

3.2 Service Valuation: Related Approaches

Generally, services can be valued from two major perspectives, both connected to the service quality. On the one hand, value is 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 is based on what a service can achieve as a result of its functionalities and performance, the so-called Grönroos approach (Grönroos, 1993). 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), whereas customer relation services are dominated by the process of service delivery (Parasuraman et al., 1988).

Studies suggest different approaches for evaluating the impact of ITS services (Krueger et al., 2005; Leviäkangas and Lähesmaa, 2002; Mikhailov and Tsvetinov, 2004). Many EU projects focus on cost and benefits of technologies for TTSs such as CHAUFFEUR, DIATS, STARDUST, eIMPACT, ICSS (Huschebeck et al., 2009; Malone et al., 2008; McDonald et al., 2001; STARDUST, 2004) and so on. The suggested impact areas include: driver and vehicle behavior, mobility, traffic flow and efficiency, traffic safety, environment and socio-economics (Rämä et al., 2009). The current study focuses on potential impact areas for freight transport that can be quantified, for example, emissions, travel time. Empirical data from laboratory measurements (and real-world field operational tests), simulation and statistical analysis provide important approaches used for ITS socio-economic impact assessment (Krueger et al., 2005). The foremost statistical methods are cost benefit analysis and multi-criteria analysis (Rämä et al., 2009). Analytic hierarchy process models, portfolio and stakeholder analyses have also been used (Malone et al., 2008; Mikhailov and Tsvetinov, 2004). Most traditional transport evaluation methods are seen to be limited in capturing complexities involved in the evaluation of TTSs and, hence, new methods need to be developed (Grönroos, 1993; Mikhailov and Tsvetinov, 2004). From a societal perspective, a performance-based (capability to reduce PSIs) service valuation can be helpful in assessing the societal value of TTSs. Such an evaluation may reduce the subjectivity associated with user perception and concentrate on identifying and evaluating performance attributes in relation to the intended effects, hence providing a better interface between the TTS and its expected outcome, based upon which the TTS can be redesigned and improved.

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, that is, what is the gain (or loss) in relation to invested capital. We aim for an approximation of 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

$$\frac{V}{(1 + \varepsilon)^T} \quad (3.2.1)$$

where V is the estimated societal value of the TTS, ε denotes the interest rate and T the number of years it takes for the application to start producing some positive benefit. 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 investment projects (including ITS) for governments (SRA, 1997).

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. The societal value of each TTS is the sum total of its percentage reduction of all PSIs (Section 4) with the assumption that a 100% service penetration level is attained. Variation in penetration level is disregarded in order to assess and compare the full potential of each TTS. Therefore, instead of differences in penetration levels, the proposed model has considered estimates of the decrease in marginal benefits when TTSs derive their value from common PSIs. Let us consider the following notation:

- S Set of Services ($D \subseteq S$).
- P Set of PSIs, (see Section 3.4).
- $0 \leq T_i, i \in S$ Number of years to start to generate value.
- $0 \leq \varepsilon$ Discounted interest rate
- $0 \leq P_k, k \in P$ Value (societal costs) of PSI.
- $0 \leq \alpha_{ik}, i \in S, k \in P$ Potential percentage savings
- $0 \leq V_{ii}^*, i, \hat{i} \in S$ 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 equation 3.2.1 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

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

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

where $T_{i\hat{i}}$ denotes the average time for services i and \hat{i} to generate estimated value. From the above, the last term of equation 3.3.3 determines the pairwise dependency between any two services $i, \hat{i} \in S$ whose values are obtained as in 3.3.3. This is due to the expected decrease in marginal benefits of two services that address a common PSI. 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 TTSs (D) with $|D| \geq 2$, it is necessary to consider a generalized form of equation 3.3.3 as

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

where $T_D = \sum_{i \in D} T_i / D$ and $\sum_{d \subseteq D}$ denotes the summation over all subsets of S (including D). The value of T_D is an approximation since each TTS will have a different discount factor. The savings assessment for each TTS (corresponding to $0 \leq \alpha_{ik} \leq 1, i \in S, k \in P$ in the above equations) takes into account results reported from various TTSs implemented around the world. There have been many field operational tests for different applications (as in Rakha et al. (2003); SRA (2009b)), but most results are not reported in concrete terms that could directly be transferred to other studies. Most of the applications achieving these savings are implemented for road transport including both commercial vehicle transport and private cars. In addition, the degree to which each transport system is improved by the TTSs depends on the prevailing conditions of the transport system before the service was implemented.

3.4 Potential Saving Indicator (PSI) Calculations for Valuation of Transport Telematic Services

We have chosen to assess the values of services by connecting the effects of a service to a set of areas (attributes) where, potentially, resources can be saved or some costs reduced, thereby generating societal value. High-level societal attributes related to fuel, vehicles and so on contribute to different types of transport costs (SARH, 2008) and, hence, incur a loss to society. We suggest the following general PSIs in the next subsections.

3.4.1 Fuel Costs

This PSI measures the costs of fuel excluding value-added tax and constitutes a large share of the HGV operational costs (Aspholmer, 2005). According to the current fuel pricing scheme in Sweden, this cost also includes external costs of carbon dioxide (CO₂) emissions. Therefore in calculating other externalities we have exempted CO₂ emissions costs. Fuel consumption depends on factors such as weather, road topology, tire pressure, total vehicle weight, engine type and speed, making it difficult to estimate consumption per vehicle kilometer (VKM). Different studies have suggested the following values: 0.43L/VKM (Hammarström and Yahya, 2000), 0.52 L/VKM (Aspholmer, 2005) and 0.5 L/VKM (Björnfot, 2006). The Swedish Road Hauler Association estimate an average fuel cost of 0.287€/VKM (Aspholmer, 2005). Suppose that 0.287€/VKM is the average cost of fuel consumption for an average loaded HGV (which was 15.2 tons in 2008) and that 66 846 Swedish registered HGVs with a total weight of at least 3.5 tons had a total mileage of 2900 million KM on Swedish roads in 2008 (SIKA, 2008b), then total cost of fuel consumed in 2008 is $0.287 * 2900 \text{ million } \text{€} \approx 832 \text{ million } \text{€}$.

3.4.2 Distance-based Costs

This PSI is estimated based on vehicle depreciation and maintenance. A study suggests the variable costs of road transport to be 0.465€/VKM (Aspholmer, 2005). This cost includes fuel (0.287€/VKM), vehicle depreciation (0.421€/VKM), tires (0.379€/VKM) and vehicle maintenance including servicing (0.098€/VKM). The total mileage of 2900 million KM in 2008 will correspond to a KM cost (excluding fuel) $\approx (0.465 - 0.287) \text{€/VKM} = 0.1777 \text{€/VKM}$ resulting in a total distance-based cost of $2900 * 0.1777 \text{ million } \text{€} \approx 515 \text{ million } \text{€}$.

3.4.3 Time-based Costs

This involves driver and vehicle's time-based costs including activities such as loading and unloading. The main cost is the driver's salary estimated at 17.5€/h including retirement and insurance benefits (Aspholmer, 2005). Congestion also contributes to

time-based costs. In 2008, the average speed for HGVs in Sweden was estimated at 70 KM/h (SIKA, 2008b), 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, the corresponding time is = Distance/Speed = 2900 million KM/(70 KM/h) resulting in total driver costs = (2900 million KM)/(70 KM/h)*17.5 € ≈ **725 million €**.

3.4.4 Transport Administration

Transport administration has been calculated to cost 7.5€ per driver hour (Aspholmer, 2005) in Sweden. Suppose this value is an average cost for all hauler companies, the total costs resulting from this will depend on the total number of hours driven, which is given by average speed/total distance = 2900 million KM/(70 KM/h). With cost per hour =7.5 €, we have a total cost =(2900 million KM)/(70 KM/h)*7.5 ≈ **311 million €**.

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 with severe and serious injuries (Berglind, 2008). 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, 2008; SIKA, 2009). 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), that is, (69 million €)/9500, the total costs of injury (HGV only) = (69 million €)/9500 *1953 = 14 million € and cost of deaths = 2.15 * 87 million € = 187 million € resulting in a total cost of all accidents ≈ **201 million €**.

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 €/100 VKM for private cars with a depreciation period of 50 years (Thomas, 2003). We approximate cost for the HGVs to be 2.3 €/100 VKM roughly equal to the earlier proposed values (SRA, 2009a; Thomas, 2003). Hence, for total distance 2 900 million KM in 2008 and cost of maintenance per VKM = 0.023 €, we get a total cost 2 900 million*0.023 ≈ **67 million €** which is 17% of the total road maintenance cost reported by the Swedish road administration (SRA) (398 million €) in 2008 (SRA, 2009a).

3.4.7 Noise and Related External Costs

This PSI estimates the societal costs related to external effects excluding CO₂ emissions (considered to be included in fuel costs in Sweden), for example, particle emissions estimated at 0.033 and 0.110€/VKM (in urban areas and cities, respectively, (Johansson, 2007) for trucks weighing at least 3.5 tons) and noise estimated at 0.0398€/VKM (SIKA, 2003). Hence, with the total driven KM for all vehicles on city roads 5 22 000 million KM and total driven KM for all vehicles on all roads 5 52 000 million KM, we estimate the ratio of driven KM on city roads to total driven KM on all roads in 2008 = $22/52 \approx 0.42$. Using this percentage for the HGVs we get $0.42 * 2900$ million $\approx 1\,230$ million KM. Thus, HGV external environmental costs excluding CO₂ in cities = 1230 million KM * 0.110 €/VKM = 135 million €. Driven distance in areas other than city roads $\approx (2900 - 1230)$ million KM $\approx 1\,670$ million KM, resulting in emission costs of $1\,670$ million * 0.033 € ≈ 55 million €. With the total cost of noise $\approx (2\,900$ million) * (0.0398) €/VKM ≈ 115 million €, we get the total costs of noise and related external costs ≈ 135 million € + 55 million € + 115 million € ≈ 306 million €.

3.4.8 Building of New Infrastructure

This PSI is aimed at estimating the costs of infrastructure expansion and related external costs, for example, population displacement. TTSs can potentially influence the utilization of road infrastructure and hence 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 million € and 982.6 million € for 2007 and 2008, respectively (SRA, 2009a). Thus, we can approximate an annual cost of building new roads to be about 970.5 million € per year. With a utilization level for the HGV of 42% we calculate the corresponding demand on new infrastructure for the HGVs as $0.42 * 970.5$ million € ≈ 408 million €.

3.4.9 Costs of Missing and Delayed Goods

Theft cases involving HGVs reported in Sweden went down from 2377 cases in 2007 to 2140 cases in 2008 (Nilsson and Rosberg, 2008) and related costs were estimated for HGV in 2008 at 243.5 million € 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 100 million €, allocating a theft value of 47 million € and incremental costs of 53.4 million €, along with an additional 140 million € that accounted for customer aspects and marketing costs. Thus, we approximate total cost of HGV-related theft at 240 million €, noting that the study did not cover all of Sweden. Furthermore, an HGV can accumulate about 100 short delays of up to 15 min each which add costs (Lind and Lindqvist, 2007). Although most of these are associated with traffic conditions (congestion), about (20 to 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 and Lindqvist, 2007). Therefore we assess a total approximate cost associated to theft and delays \approx **244 million € (240 million € + 3.5 million €)**.

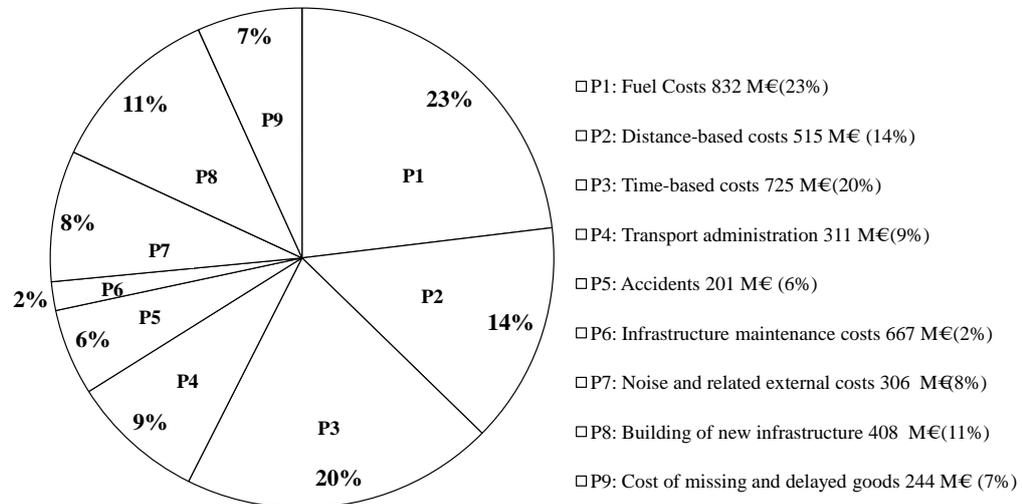


Figure 3.1: Results of cost distribution for PSIs as a relative percentage

The different PSIs calculated above can be summarized in a diagram as shown in Figure 3.1. In a related work that uses simulation to calculate HGV cost distribution for the HeavyRoute project (HeavyRoute, 2010b), we observe that there are significant differences in time-based costs of 45% for the HeavyRoute project compared with the 23% 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 missing and delayed goods, which were not separately considered in HeavyRoute. On the other hand, climate cost is considered as a separate cost function by HeavyRoute, which we considered as fuel (CO₂) costs.

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. Particular attention is given to similar existing systems tested and any results obtained. Each of the suggested TTSs given below can in turn be composed of specific sub-services.

Accident Warning Information (AWI): AWI provides accident information to nearby vehicles to enable users to reduce the effect of accidents, for example, 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% (Birst and Smadi, 2000) and fuel and delays by up to 3 and 7%, respectively (Wunderlich et al., 1999).

Advanced Driver Logs (ADL): ADL records various time-based activities for HGV drivers and helps the driver to avoid driving under the influence of external factors such as alcohol, which has been shown to account for up to 16% of driver accidents in 2008 (HeavyRoute, 2010b).

Driver Planning (DP): DP improves driver performance through planning (optimization) by considering factors such as time of day, route, vehicle, product, season and so on that suit individual driver preferences.

Dynamic Traffic Information (DTI): DTI service provides real-time traffic information that contributes to reducing costs related to delays, congestion and so on (Eliasson, 2009). If accidents do not lead to delays, then information about such accidents is obtained through AWI.

eCall (EC): EC reduces the time taken to locate and rescue victims of an accident as well as the vehicle and its contents. It reduces the total cost related to accidents by preventing deaths and reducing accident severity and waiting time because of accidents for other vehicles on the road. Trials in Stockholm suggest the accident cost reduction potential to be between 5 and 15% (SRA, 2005).

Emission Testing and Mitigation (ETM): ETM measures environmental performance to support policy making.

En-route Driver Information (EDI): EDI provides trip specific information to load/unload goods including communication with back office.

Estimated Time of Arrival (ETA): ETA monitors the current traffic situation and evaluates arrival time dynamically. Reliability inaccuracies may cost up to 2.2€ per vehicle trip (Leviäkangas and Lähesmaa, 2002).

Freight Mobility (FM): FM communicates real-time freight data between drivers, dispatchers, goods owners and so on.

Geo-fencing (GEO): GEO provides control support for areas of interest such as corridors, military areas, accident areas, parking areas, tunnels and so on without using any physical barriers.

Goods Identification (GI): GI improves goods handling (loading/unloading, declaration etc.) using contactless identification.

Infrastructure repair and maintenance (IRM): Information about IRM provides real-time information on the status and maintenance history of infrastructure, that is, similar to preventive maintenance that has been considered to potentially reduce maintenance costs by 25% (Hammarström and Yahya, 2000).

Information on Extra-Large cargo (XXL): Information on the transportation of extra-large

cargo supports drivers, public authorities and the back office in the following legal obligations for example, desired route and monitoring.

Information on Truck Parking (ITP): ITP provides parking related information in real-time to drivers and facility owners. Similar systems have been reported with about (1 to 2)% reduction in parking location time (Lindkvist et al., 2003) and 9% in travel time (SAIC, 2007).

Intelligent Speed Adaptation (ISA): ISA provides dynamic information about the current speed limit that can lead to a reduction in accidents and fuel consumption, with the trial results in Sweden showing an estimated reduction of 20 to 30%, if all cars were equipped with an ISA system (SRA, 2009b).

Navigation (NAV): NAV through a route network provides HGV-relevant information that can reduce delays. NAV has contributed to reducing queue times and delays for previously unknown destinations between 5 and 20% (Planath et al., 2003). NAV focuses on unknown destinations, DTI focuses on floating car information with no advanced navigation capabilities.

On-board Driver Monitoring (ODM): ODM monitors and reports (to the authorized agents e.g. traffic and transport managers, including rescue units) driver conditions in real time, for example, health. Accidents related to driver fatigue have been estimated at 15% in Sweden (Berglind, 2008).

On-board Safety and security Monitoring (OSM): OSM helps the driver to constantly monitor the vehicle and its contents without manual checks, for example, temperature for refrigerated products.

Pay as You Drive (PYD): PYD provides location-related information to insurance companies to help reward drivers according to risk attitudes and exposure and reinforces good driving (Azudrive-PYD, 2013). Studies show a reduction of 10% in mileage and fuel consumption and 15% in total crashes (Litman, 1997).

Real Time Track and trace of goods (RTT): RTT provides information such as speed, location and status of goods to goods owners, transport managers and so on that can enable tracking of such goods if necessary.

Remote Declaration (RED): RED enables declaration of information to be transferred electronically at gates, control stations, loading/unloading stations and so on to reduce delays.

Remote Monitoring (RM): RM minimizes costs related to vehicle breakdown through preventive maintenance.

Road Hindrance Warning (RHW): RHW provides information related to hindrances in real-time and possible suggestions to avoid queues.

Road User Charging (RUC): RUC (electronic toll collection) collects 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). Congestion control schemes in Stockholm (related to but different from RUC) 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).

Route Guidance (RG): RG provides information relevant to specific corridors related to, for instance, zebra crossings, school children and so on and also helps the 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). RG focuses on specific route information and NAV focuses on navigation in unknown networks, whereas DTI focuses on floating car information.

Sensitive Goods Monitoring (SGM): SGM provides information about sensitive goods such as perishable food products, drugs and the other goods classified as dangerous (about 0.32% of goods in Sweden (SCB, 2008)) to transport managers and government control units.

Staff Monitoring (SM): SM collects information related to health, fatigue and so on about hauler company staff for staff administration (seen as the most expensive resource) and control, for example, by police, labor unions and so on. It is different from ODM and DP in that it focuses on company-wide staff taking into account legal obligations.

Theft Alarm and Recovery (TAR): TAR provides real-time location and status information about stolen goods and vehicle to the goods owner, traffic and transport managers and so on.

Transport Order Handling (TOH): TOH provides real-time order information sharing between the goods owner, transport manager, driver and so on as well as the feedback when the orders are satisfied.

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

Vehicle follow-up (VF): VF collects and analyzes vehicle performance-related data, for example, empty mileage, fuel consumption, vehicle statutes and so on, then reports such data to different interested groups, for example, fleet owners, vehicle inspection agencies and so on.

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

PSIs	Fuel	Distance	Time	Admin.	Accid.	Maint.	Noise	Infrast.	Missing.	Value, M€
Est.	832	515	725	311	201	67	306	408	244	
ADL				0.001	0.005					1.34
AWI	0.001		0.050		0.001				0.001	38.29
DP			0.001	0.003						1.69
DTI	0.002		0.060					0.001	0.002	47.00
EC			0.001		0.150				0.001	31.79
EDI	0.001	0.015	0.030	0.001					0.001	31.49
ETA				0.020						6.34
ETM	0.001						0.004			2.10
FM				0.005					0.001	1.83
GEO				0.003					0.002	1.45
GI				0.004					0.001	1.52
IRM						0.100		0.004		8.47
ISA	0.001				0.150				0.001	31.90
ITP			0.001						0.010	3.22
NAV	0.010	0.030	0.020							39.05
ODM					0.010					2.05
OSM			0.001	0.001	0.010					3.11
PYD	0.010	0.001			0.001					9.22
RED	0.001		0.001	0.001					0.001	2.15
RG	0.001		0.001				0.001		0.001	2.15
RHW	0.001		0.050		0.003					38.45
RM			0.010	0.001	0.001				0.001	8.17
RTT			0.001	0.001					0.020	6.03
RUC	0.010	0.001	0.010			0.001		0.001		16.90
SGM				0.050	0.002				0.001	16.51
SM					0.005					1.03
TAR			0.001	0.001					0.150	38.33
TOH			0.030	0.001						22.51
TRO	0.020	0.030	0.030				0.001		0.001	55.50
VF	0.003	0.001	0.001							3.81
WI			0.001			0.050				4.14
XXL				0.001		0.001				0.39

Table 3.1: Assessment of percentage (%) savings and societal values (M€) of TTSs for HGV transport in Sweden.

Empty cell implies that we anticipate relatively insignificant savings.

Key: Fuel = fuel costs, Distance = distance-based costs, Time = time-based costs, Admin. = Transport administration, Accid. = accident costs, Maint.= infrastructure maintenance costs, Noise = noise and related external costs, Infrast. = costs of building new infrastructure, Missing. = costs of missing and delayed goods, Value = TTS value assessment, Est. = Estimated value of PSI

3.6 Results of Transport Telematic Service Valuation

The proposed model (Section 3.4) 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) the focus was on the societal effects of HGV transport only (societal effects from other road users, such as private cars, motorcycles etc, were disregarded), (c) the time period for which services were considered to start generating the calculated values was one year for all services, (d) TTS values were based on suggested percentage reductions of PSIs (in Section 3.4) according to the authors’ perceptions of TTSs in Section 3.5, (e) the dependencies between TTSs were assumed to be pairwise as in equation 3.3.2.

Based on these assumptions the results shown in Table 3.1 were obtained.

Most of the studies seen above show that for PSIs that cover a large scope, percentage reductions are usually small (in the order of 0.1%), whereas trials that cover very narrow scopes typically report high percentage impacts. Since our PSI calculations were based on aggregated values, it was necessary to consider correspondingly small percentage assessments as in Table 3.1. For small percentage estimates, $0 \leq \alpha_{ik} \leq 1, i \in S, k \in P$ equation 3.3.4 can be approximated by equation 3.3.3 (see Section 3.4) in estimating dependencies between TTSs. For example, suppose that transport administration costs about 311 million € per year in Sweden and can be reduced by EDI, GEO and GI with 0.1%, 0.3% and 0.5% respectively and the interest rate is 4%. From equation 3.3.3, the estimated total benefits will be 1.7045 million € and from equation 3.3.4, the estimated total benefits will be 1.7494 million €, which can be approximated within an error margin of less than 2.5%. Therefore if the α -values are relatively small, we can ignore higher order terms in equation 3.3.4 and hence approximate equation 3.3.4 with equation 3.3.3. The result of TTS societal valuation without dependencies is shown in Figure 3.2.

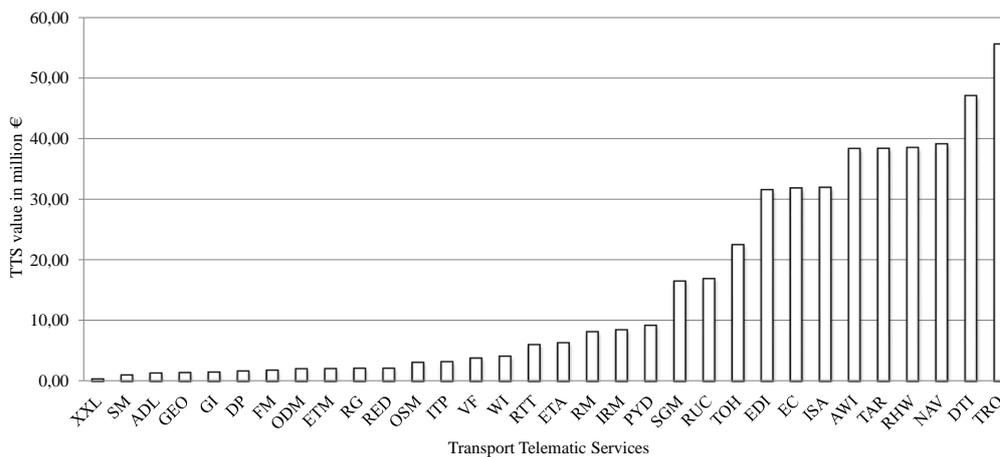


Figure 3.2: Estimated TTS societal values for HGV transport in Sweden

Where relevant in our assessment, we referred to similar experimental results obtained in assessing potential savings of similar applications (see also the descriptions of TTSs above). The assessed values of the TTSs are obtained supposing 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. For example, suppose EC and ISA are implemented, each with the potential to reduce HGV-related accident cost by 15%. The resulting potential reduction will be $15\% + (100 - 15\%) * 15\% = 0.15 + (1 - 0.15) * 0.15 \approx 0.2775$ 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. Although the proposed approach works well for pairwise dependencies, we observed that it was complex for handling combinations with more than two services. The cumulative contribution of the above TTSs in reducing the societal costs for each of the PSIs shows that there is much room for new applications targeted towards noise and external cost whereas accidents and time-based costs are most likely to experience significant impacts under the current situation (see Figure 3.3).

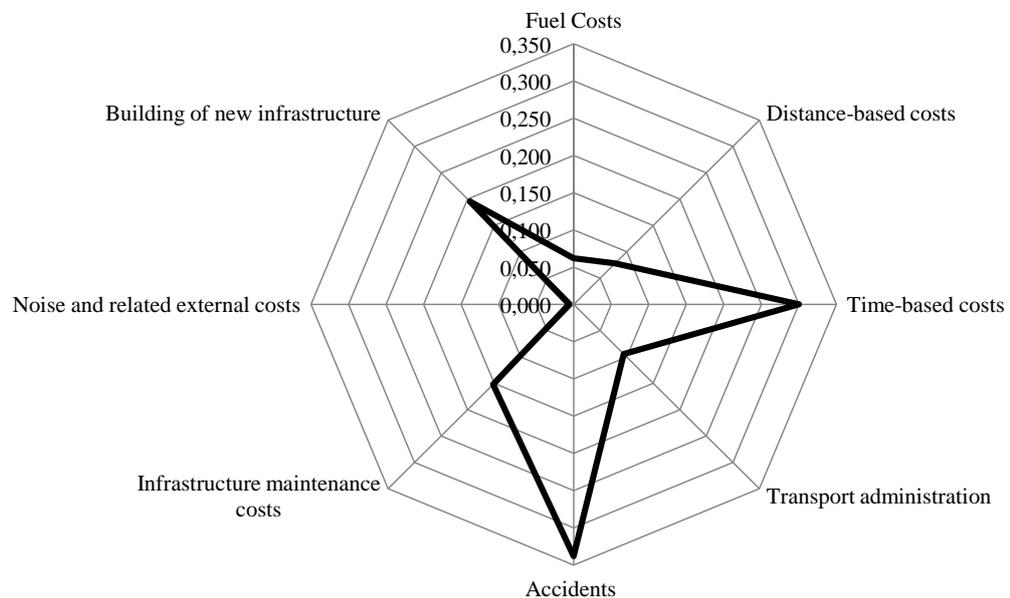


Figure 3.3: Extent of PSI reduction from the cumulative contribution of different TTSs

3.7 Conclusions and Future Work

The purpose of this study was to use the criteria established in a previous study (Mbiydznyuy, 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 calculates their societal costs. Potential percentage savings of different services for various PSIs were suggested and used to assess the value of different TTSs. We suggest that the values of PSIs and potential percentage savings are re-estimated (e.g. based on new statistics and field trials) when the proposed model is to be applied. Pairwise dependency calculations were introduced to account for redundancies that may be involved when two TTSs address a common PSI. It was shown that the pairwise dependencies could be approximated to dependencies involving more than two TTSs. The results based on estimated values of PSIs and potential percentage savings show that important TTSs with significantly high societal impacts are transport resource optimization, DTI, NAV,, TAR, AWI, ISA, EC, EDI, TOH, RUC and SGM. Efficient time management and reduced (impacts of) accidents are likely to benefit the most from TTSs as addressed in this study (Figure 3.3). The method is simple, straightforward and useful for organizations such as governments and telematic service providers. The suggested PSI values and utilized percentage effects for different services still need further validation as more experimental work becomes available and anticipated TTSs are developed. In the future, PSIs can be more specific than they are today, addressing different areas.

Paper III

Exploring the Relationship Between Telematic Services and Functionalities Using Synergy Analysis

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A method for assessing potential synergies among different sets of road Transport Telematic Services (TTSs) is suggested. Intelligent Transport Systems supports road transport by delivering different TTSs. The ability to deliver multiple TTSs, also referred to as service packaging, to address a wide range of stakeholder needs is gaining momentum not only from a marketing perspective but also from a technical perspective. The total cost of TTSs can be reduced if they share functionalities, and resulting benefits can be assessed with the help of synergy based methods. Knowledge about synergies of functionalities is useful in the (re)design and eventual deployment of TTSs especially when the underlying telematic systems are aimed at the provision of multiple TTSs. A mathematical formulation of synergy among functionalities of TTSs is provided. Results show cluster formation of TTSs according to their synergy measures, e.g., if pairwise synergies are assessed in terms of net savings as a result of common functionality utilization, then, Estimated Time of Arrival, Road Hindrance Warning and Accident Warning Information is regarded as the most beneficial cluster out of all 32 TTSs investigated.

Keywords

Transport Telematic Service; Functionalities; Synergy; Clustering; Platform; Architecture

4.1 Introduction

Road freight transport is an important part of a complex logistic chain that support production and distribution of products and raw materials. Several freight transport companies have continuously developed and improved goods handling services, warehousing services, delivery services, etc, so as to keep logistic chains resilient and efficient. Most of these services are complex, and as a result, often depends on capabilities provided by Intelligent Transport Systems (ITS). ITS provide capabilities for localization of products and vehicles, collecting and communicating real time information about activities of interest within road transport. This is realized by delivering different Transport Telematic Services (TTSs) to meet various needs of stakeholders. TTSs could be about payment for road usage (Road User Charging), controlling speeding (Intelligent Speed Adaptation) or emergency reporting (eCall). The ability to deliver, multiple TTSs, also referred to as service packaging, to address a wide range of stakeholder needs, is gaining momentum (Talib et al., 2010). For instance, commercial companies such as Scania, a manufacturer of Heavy Goods Vehicles (HGVs) in Sweden, already provides a range of telematic solutions (monitoring, analysis, and control service packages) to its clients through its fleet management system. For public authorities, one way to reduce costs and facilitate acceptance of mandated TTSs such as road user charging is to package them together with other attractive services, e.g., navigation (SRA, 2006). The success of service packages become even more interesting in areas such as mobile Smart-phone services and internet services (Talib et al., 2010). One motivation for configuring packages can be on account of their synergies so as to minimize redundant functionalities, reduce total costs, but also to attract end-users. However, there are few studies (Ghosh and Lee, 2000; Kim et al., 2007; Van der Perre, 2006; Xu, 2000) that has focused on the assessments of potential synergies in order to support design choices

based on functionality sharing.

In this paper, our objective is to develop a systematic approach for assessing the potential of synergies among different sets of road Transport Telematic Services (TTSs). A mathematical formulation is suggested which reflects the degree of common functionalities between different TTSs, i.e., their synergy. Synergy in this study will refer to a systematic estimation of the degree in which a set of TTSs use functionalities in common. A platform, or Multi-Service Architecture (MSA) will refer to a functional architecture specification of a system which can lead to realizing more than a single TTS, e.g., the functional architecture of an Electronic Fee Collection (EFC) system which can potentially offer the services of road user charging and travel time estimation. A functionality is a capability that is needed by a TTS in order to accomplish its design goal(s).

We formulate the synergy problem by considering a set of TTSs S with $n = |S|$, then defining an n -by- n symmetric matrix of all elements of S (pairwise synergies). The problem is then reduced to finding $D \subseteq S$ that has the (highest) potential savings through shared functionalities. To achieve this we apply clustering techniques (Everitt et al., 2001; Hubert, 1974; Romesburg, 2004) to estimate the synergy for all subsets of S . We choose hierarchical clustering in order to obtain an invariant solution under a monotone scaling of the data, i.e., the clustering method preserves its order if transformed from one space to another.

The work in this paper is a further refinement of previous work (Mbiydzonyuy et al., 2008b) analyzing potential synergies among TTSs. The current study has identified different ways of measuring the synergy among sets of TTSs and illustrated proposed methods on a set of 32 TTSs (Table 4.3) composed from a total of 38 functionalities (Table 4.2). The results highlight different clusters of interest based on various measures of synergies. For instance, if pairwise synergies are assessed in terms of net savings as a result of common functionality utilization, then, Estimated Time of Arrival, Road Hindrance Warning and Accident Warning Information -[ETA, RHW, AWI]- is regarded as the most beneficial cluster out of all 32 TTSs investigated. The results are particularly useful for system designers interested in studying possible reduction in costs through deployment on common platforms but also for packaging TTSs on account of technical synergies. The rest of the work is organized as follows: Section 4.2 presents the relationship between TTSs, functionalities and architectures; Section 4.3 presents some motivation for the use of synergy. A mathematical formulation of synergy is presented in Section 4.4 and a method for finding clusters based on synergy of shared functionalities is presented in Section 4.5. In Section 4.6, the proposed method is illustrated and in Section 4.7, some conclusions are discussed.

4.2 Services, Functionalities and Synergies

Functionalities are capabilities that when combined together enables a telematic system to deliver a service. Examples of functionalities are positioning a vehicle, communicating data, and identifying a driver. These are achieved through a combination of one or more hardware and software technologies involving techniques such as signal processing, geometrical analysis, and in-vehicle signage. In principle, functionalities can be physically located almost anywhere, e.g., in vehicle, road side or, accessed remotely. ITS through telematic systems such as tolling system uses one or more of these capabilities, and together with additional processing, delivers a specific piece of useful information as a TTS. In other situations, a TTS could be an action such as opening or closing a gate into a parking area. Thus a telematic system provides a TTS through the use of a number of functionalities, e.g., detecting a satellite signal with onboard antennae, calculating the coordinates of the vehicle using the signal properties. This information can then be forwarding through a wireless network to a back office system that calculate the distance covered and determine the type of road used.

A TTS often depends on basic auxiliary or key functionalities, e.g., positioning and communication. In order to facilitate that, different telematic systems can make use of different functionalities, they are sometimes implemented within a certain degree of standardization. For instance, accessibility to a given channel (GHz 599) for all services. Different sets of functionalities may conform to different standards, e.g., communication oriented and positioning oriented. Such auxiliary functionalities provide basic properties that make it easier to implement new TTSs within an environment that can be referred to as a platform or MSA.

There have been several attempts to highlight the necessity to deploy new applications on existing platforms to maximize the use of functionalities provided by such platforms (Appelt and Schwieder, 2002; Sjöström, 2007; Springer, 2007). Appelt and Schwieder (2002) discusses the opportunities of using Electronic Toll Collection systems (also known as EFC systems) as a platform for added value services and concluded that the market for telematic services can be stimulated, and the overall acceptance of EFC systems can be increased. Springer (2007) considered a specific case of the Global Navigation Satellite System (GNSS) based tolling as a platform for added value services based on available common functionalities and arrived at similar conclusions to Appelt and Schwieder (2002). Sjöström (2007) discuss different types of EFC platforms and attempts to identify suitable choices of TTSs for different implementations. Contrarily, Dimitrios and Bouloutas (2007) argued that an eCall system could provide a potential platform if such a system is embedded in the vehicle system. Ai et al. (2007); Hackbarth (2003) addresses a potential Open Service Gateway Initiative (OSGi) platform for automotive telematics which has recently been extended into an OSGi/Android platform providing a test bed for different functionalities (Chen et al., 2011). Many potential TTSs are suggested alongside the different platforms mentioned above, however no formal investigation of the relationship between functionalities and TTSs and their potential

synergies has been provided.

Emmerink and Nijkamp (1995) investigates the potential synergy effects of the joint implementation of road pricing and driver information systems and suggests an attractive alternative policy option to attain such synergies. Their study (Emmerink and Nijkamp, 1995) lacks an explicit method for synergy formulation. A method for identifying most applicable Web services and analyzing potential synergy between commercial and governmental Web services (Kungas and Matskin, 2006) is suggested but they have focused on service composition by observing input, output and information communication traces. Li et al. (2010) suggests a methodology for selecting a green technology portfolio in which the synergy coefficients are formulated based on a preference elicitation Analytic Network Process (ANP) technique that results in a rank order rather than clusters of the portfolio alternatives. Benefits from synergies are proposed as a base for designing supplier-initiated logistic service outsourcing (referred to as in-sinking) in which the synergy benefits are allocated to the participating shippers (Cruijssen et al., 2010). Most of the studies related to synergy consider synergy as a potential positive outcome expected from a combination of systems with no suggestion of how to assess such synergies and their benefits. The current study proposes an approach for estimating synergies that is based on clustering methods.

Clustering techniques comprise a range of methods for grouping multivariate data into clusters based on some similarity metric. They have been applied to several engineering and planning domains (Bacher, 2000; De Lucia et al., 2007; Everitt et al., 2001; Johnson, 1967; Romesburg, 2004). Everitt et al. (2001); Romesburg (2004) provides insight into different clustering methods most of them based on homogeneous data types. A variation of clustering that can handle nominal, ordinal and/or quantitative data based on probabilities is provided by Bacher (2000). Romesburg (2004) suggests four basic steps for applying hierarchical clustering techniques: obtain data matrix, standardize data matrix (optional), compute resemblance matrix and execute clustering method. In order to apply the steps suggested by Romesburg (2004), the current study propose a formulation for standardizing the data and computing the resemblance matrix similar to functional transformations for normalizing compromise optimization problems (Marler and Arora, 2004). In our case the result are service clusters with varying potential for minimizing redundant functionalities when implemented on a platform in a similar manner to service packages as proposed by Talib et al. (2010).

4.3 Why are Synergies Important?

Consider the following examples:

Road User Charging (RUC) System: In Sweden a RUC is proposed which makes use of satellite based global positioning (GNSS). This is to help calculate the location of the vehicle at any time, and communicate such information to a control unit when necessary or possibly in real time. Using such information it should be possible to locate the

position of the vehicle on a digital map (map matching), calculate the appropriate road fare and communicate the results to the responsible for the road system.

eCall (EC): The European Union anticipates the deployment of an eCall system which should make it possible to report information about a road accident in order to help emergency service providers make appropriate intervening measures. Therefore, the telematic system should collect information including the geographic location of the vehicle (possibly GNSS global positioning) and communicate such information in real time to the emergency unit (SRA, 2005).

Intelligent Speed Adaptation (ISA): This involves equipping vehicles with systems that will help them adapt their speed to minimize the risk of an accident. In order to receive information about position and prevailing speed limits the ISA system that was tested in Sweden either had a global positioning system (possibly based on GNSS) with digital maps or communicated with roadside transmitters in real time (Svedlund et al., 2009).

In all the above cases, real time communication, global positioning and map matching are needed. The costs of infrastructure required by each of RUC, EC and ISA systems are high. If each of the systems were implemented by itself, the costs will be much higher. Such a characteristic is not only limited to RUC, EC and ISA. There are several other TTSS (see Appendix) with several common functionality requirements. A suitable method for calculating synergies will help identify which TTSS can be implemented together on account of common functionalities that can lead to cost savings, but also the type of potential MSA platform (Figure 4.1).

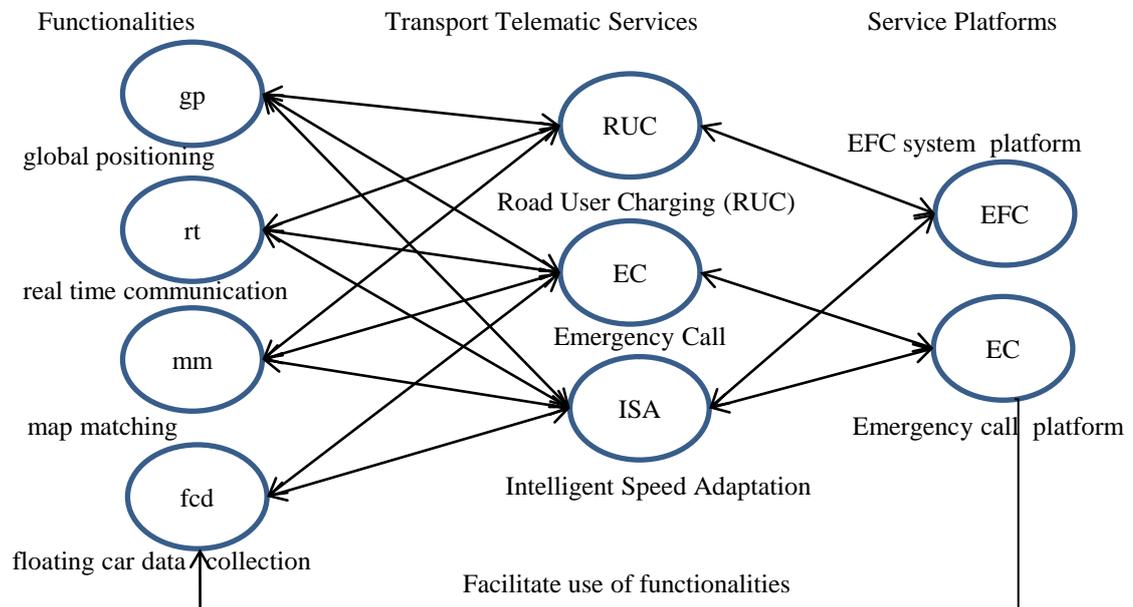


Figure 4.1: Possible interconnections between TTSS, functionalities and solution

4.4 Mathematical Formulation of Synergy

The design of any system requires that system functionalities are specified. For instance, positioning is required in order to design a distance based RUC system. The cost of the functionality depends on the type of technology used and different functionalities have different costs. As an example the United States Department Of Transport estimates the fixed costs of a Differential GPS (DGPS) to range between 500 USD and 2000 USD per vehicle, according to the 2002 cost estimates, with a life span of 10 years. We can approximate the costs of such a positioning functionality for RUC, ISA or EC by taking the average value (1250 USD), with VAT adjustments to be about 72 € per annum. For an Onboard Unit (OBU) equipment provided by Toll Collect (the German RUC system) enabling both processing and communication, the fixed costs are estimated to be 120 €, based on 2007 market price and with a life span of 10 years which approximate to 9 € per annum. The extent to which each of the functionalities is employed by each TTS is different, and we assume the difference should be reflected in the costs of developing the functionality for different TTSs. Intuitively, we can assume that if a TTS such as RUC utilizes a functionality to a lesser extent than the other TTSs, then the cost incurred should also be less than the full costs. For instance, for information processing onboard (OBU) the functionality could be 50% (≈ 5 €) for RUC, 25% (≈ 3 €) for EC and 0% for ISA (does not utilize this functionality at all). Also, the fixed costs for a map together with software for matching geographic coordinates based on the Truck Nav SP2 system can similarly be estimated at 17 € per annum following 2010 consumer price level with a life span of 10 years. In general, one can assume that cost is differentiated according to the demand for functionality and this is reflected in the retail price from commercial companies that increases with additional functionality.

TTS functionality	Estimated cost/year	RUC	EC	ISA	Maximum functionality cost
Positioning (DGPS)	72	72	72	72	72
Communication (OBU)	9	5	3	0	5
Map matching (Nav SP2)	17	17	17	17	17
Total cost	98	94	92	89	94

Table 4.1: Example of differentiated price estimates when TTS uses same functionality in €

If we assume that the functionalities in Table 4.1, are all that is needed to implement RUC, EC and ISA, then one can estimate maximum costs that can be incurred by any of the three TTSs based on the most expensive functionalities provided, i.e., $72\text{€}+5\text{€}+17\text{€}=94\text{€}$. Also it can be possible to estimate the total costs of implementing all RUC, EC and ISA, each one by itself, i.e., $94\text{€}+92\text{€}+89\text{€}=275\text{€}$. In the best case of synergy, each functionality is only implemented once and shared between TTSs, even those with the highest costs, while in the worst case, each TTS will have to pay for its own separate

functionalities. Intuitively, it can be postulated that the total costs of implementing RUC, EC and ISA, while making use of synergies, could be between the worst case and best case, i.e., $94\text{€} \leq \text{costwithsynergies} \leq 275\text{€}$. We will suggest a mathematical model that generalizes this postulate. Let's consider S to denote a set of TTSs, and F to denote a set of functionalities. Let $D \subseteq S$, be an arbitrary subset such that $|D| \geq 2$. We assume that all relevant functionalities necessary to implement each TTS in D are specified. Suppose now that $c_{ik} \geq 0$, $i \in D, k \in F$ denote the fixed cost of TTS $i \in D$ using functionality k with no synergies. Consider U_D to be the total cost of functionalities required to implement D , each one by itself, then:

$$U_D = \sum_{k \in F} U_{kD}, \quad U_{kD} = \sum_{i \in D} c_{ik} \quad \forall k \in F, \quad \forall D \subseteq S \quad (4.4.1)$$

We define the TTS cost based on the maximum costs of functionalities G_D when TTSs in D are implemented together as:

$$G_D = \sum_{k \in F} G_{kD}, \quad G_{kD} = \max_{i \in D} \{c_{ik}\} \quad \forall k \in F, \quad \forall D \subseteq S \quad (4.4.2)$$

We propose the cost for the functionalities required to implement TTSs in D with synergies, V_D , can be computed in the following way:

$$V_D = (1 - \beta_D) * (U_D - G_D) + G_D, \quad \forall D \subseteq S \quad (4.4.3)$$

where $0 \leq \beta_D \leq 1$ is a parameter for representing potential reduction in redundancies of functionality as a result of common utilization of functionalities by TTSs. We shall refer to the situation in which $\beta_D = 1$ as perfect synergy (best case scenario in our example) and $\beta_D = 0$ as no synergy (worst case scenario in our example). We suggest a formulation of the above quantities as shown Figure 4.2:

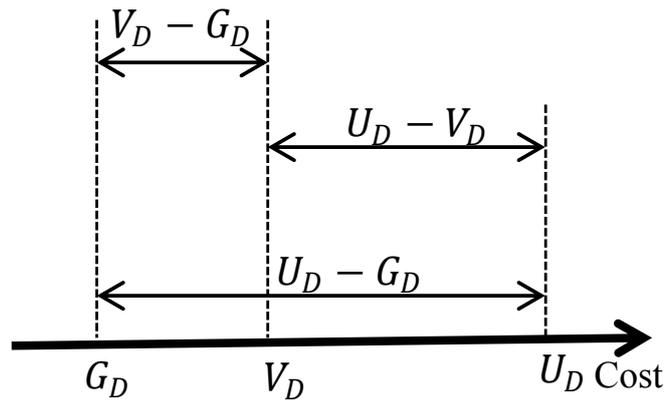


Figure 4.2: Diagram representation of the synergy components in equation 4.4.4

$$\begin{aligned}
 f^a(D) &= U_D - V_D \\
 f^b(D) &= \frac{U_D - V_D}{U_D} \\
 f^c(D) &= V_D - G_D \\
 f^d(D) &= \frac{V_D - G_D}{U_D - G_D}
 \end{aligned} \tag{4.4.4}$$

We interpret these equations as follows: (i) Absolute net savings, $f^a(D)$; This is the contribution to the net savings resulting from the difference between the total cost of functionalities with synergies and the total cost of functionalities without synergies. (ii) Relative net savings, $f^b(D)$; This measures the contribution to net savings relative to the cost of the total functionalities. (iii) Absolute net loss, $f^c(D)$; This is similar to $f^a(D)$ and measures the net loss from achieving a perfect synergy situation. (iv) Relative net loss (to total potential gain), $f^d(D)$; This is the ratio of the relative net loss ($f^c(D)$) to the total potential savings with perfect synergies. Other measures in addition to the above cases can potentially be defined. In order to assess the cost of functionalities as a result of synergy (V_D), we consider V_{kD} given by:

$$V_D = \sum_{k \in F} V_{kD} \quad \forall D \subseteq S \tag{4.4.5}$$

We introduce a synergy coefficient for each functionality as a parameter given by $\beta_k, k \in F$. This is an estimate of the relative savings due to synergies between TTSs for a given functionality. For example, a functionality providing antennae reception will have fairly the same value of $\beta_k, k \in F$ irrespective of the TTSs using functionality. In some cases the functionality cost will depend on its usage and hence the value of $\beta_k, k \in F$, e.g., communication. Thus we obtain

$$V_{kD} = (1 - \beta_k) * (U_{kD} - G_{kD}) + G_{kD} \quad \forall k \in F \quad \forall D \subseteq S \tag{4.4.6}$$

Solving for $\beta_D, D \subseteq S$ in equations 4.4.3 and 4.4.6 we obtain

$$\beta_D = \left[\frac{1}{U_D - G_D} \right] * \left[\sum_{k \in F} \beta_k (U_{kD} - G_{kD}) \right] \quad \forall D \subseteq S \tag{4.4.7}$$

This is the estimated synergy coefficient for a set of TTSs over all functionalities as a function of U_{kD}, G_{kD} , and β_k . β_D as estimated in equation 4.4.7 is continuous and

monotonically increasing in the interval $U_D - G_D$ and hence can be approximated to the rate of change of $\beta_k, k \in F$ for several measurements of U_{kD}, G_{kD} , in the interval $U_D - G_D$. Now, suppose the set $D = \{i, j\} : i \neq j, i \in S, j \in S$, i.e., consider pairs of services, then we can easily estimate V_{ijk} as follows:

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

This will result to

$$V_{ijk} = \left(1 - \beta_k\right) * \left(\min \{c_{ik}, c_{jk}\}\right) + \max \{c_{ik}, c_{jk}\} \quad \forall i, j \in D, \quad \forall k \in F \quad (4.4.8)$$

4.5 A Method for Finding Clusters Based on Synergy

Equation 4.4.4 suggests how to compute pairwise synergy measures for TTSs. The result is an n -by- n matrix where n is the number of TTSs. In order to compute the synergy for sets of TTSs, we employ a variant of hierarchical clustering to identify clusters of TTSs with high synergies. It should be noted that each part of equation 4.4.4, satisfy basic metric properties (Hubert, 1974; Johnson, 1967), i.e., symmetry, $f(i, j) = f(j, i)$, positivity, $f(i, j) \geq 0$, and nullity, $f(i, j) = 0 \leftrightarrow i = j, \forall i, j \in D$. These properties (also known as symmetric and isometric properties) can be verified with a slight twist of equation 4.4.4 to ensure that it is a monotonic (increasing or decreasing) as follows:

- $f^a(D)$ is a real valued continuous function that increases with increasing savings and hence $1/f^a(D) = 1/(U_D - V_D)$ decreases with increasing savings.
- $f^b(D)$ is a real valued continuous function that increases with increasing savings in $[0, 1]$, hence $1 - f^b(D) = V_D/U_D$ decreases with increasing savings in $[0, 1]$
- $f^c(D)$ is a real valued continuous function that decreases with increasing savings.
- $f^d(D)$ is also continuous and decreases with increasing savings.

$1/f^a(D), 1 - f^b(D), f^c(D), f^d(D)$ are all monotonic functions and continuous in a closed interval $[0, 1]$ and hence satisfy symmetric and isometric properties in $[0, 1]$. We define the situation where there are no synergies (zero) to mean 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. The function value has to be in the interval $[0, 1]$, i.e., $0 \leq f^a(D) \leq 1$ or $0 \leq f^c(D) \leq 1$, otherwise the values can always be scaled without altering the clustering solution. The solution therefore remains invariant under linear transformations of the original data. This could be a

useful property in case of noisy data due to numeric values, as focus will remain on the relative comparison rather than absolute values.

Agglomerative hierarchical clustering algorithms begins by placing each distinct data point in a cluster 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 (Everitt et al., 2001; Hubert, 1974; Johnson, 1967; Romesburg, 2004). 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 for pairs of TTSs is the level of shared functionalities as discussed in Section 4.4. The pseudo code algorithm 4.5.1 describes the basic steps involved in applying the proposed model:

```

begin
  Determine the set of TTSs S and functionalities F ;
   $n = |S|$  ;
  Initialize  $D = \{\}$ ;
  From equation 4.4.4, obtain  $n$ -by- $n$  similarity matrix M of all elements in S based on
  functionalities in F;
  Determine pair of TTSs with highest synergy  $(i, j)$  such that  $\min M[i, j], i \neq j$ ;
  Add  $i$  and  $j$  to D;
  while  $D \neq S$  do
    Select  $i$  such that  $\min M[i, j], i \neq j, i \notin D, j \in D$  ;
    Add  $i$  to D in a hierarchical order ;
  end
end

```

Algorithm 4.5.1: Pseudo-code: Basic approach for estimating synergy

The cluster formation can be achieved with the help of different metric measurements. For assessing synergies as net savings, we choose to use nearest neighbor hierarchical clustering.

4.6 Illustration: Synergy Level Estimate for Transport Telematic Services

The cost of functionalities is estimated on the basis of the technologies and most of the data used is approximated from data provided by US DOT within the RITA program (Maccubbin et al., 2008). Where necessary the data was complemented with market pricing data from commercial websites. To simplify the scenario and make up for limited data, each TTS was assumed to either incur 100%, 50% , 25%, or 0% of total costs, depending on how the TTS was defined in connection to the given functionality. Each TTS is specified by a collection of functionalities. Therefore, the data employed in the experiment includes a specification of TTSs as a collection of functionalities (see Appendix), fixed costs of different functionalities when employed by TTSs, and an estimate of the synergy coefficients derived from the variation of the changes in costs of functionalities for different TTSs. The synergy coefficients $\beta_k, k \in F$ are obtained

from the change in values across different TTSs, e.g., in the example given in Table 4.1, β_k , k =positioning (DGPS) will be $(1 + 1 + 1)/3 = 1$, and for k =communication (OBU) will be $(0.25 + 0.5)/2 = 0.375$, etc. The algorithm has been implemented in MATLAB and the cophenetic correlation coefficient is used to verify that the values used to form the clusters are indeed a reflection of the values in the raw data provided. The results are presented in Figures 4.3 and 4.4.

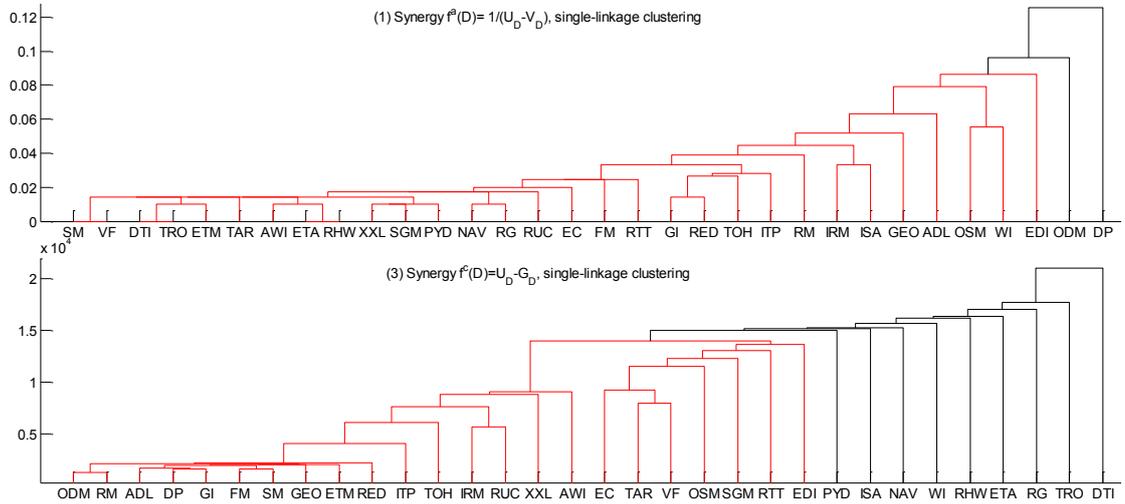


Figure 4.3: Results illustrating cluster formation: (1) Absolute net savings, (3) Absolute net loss

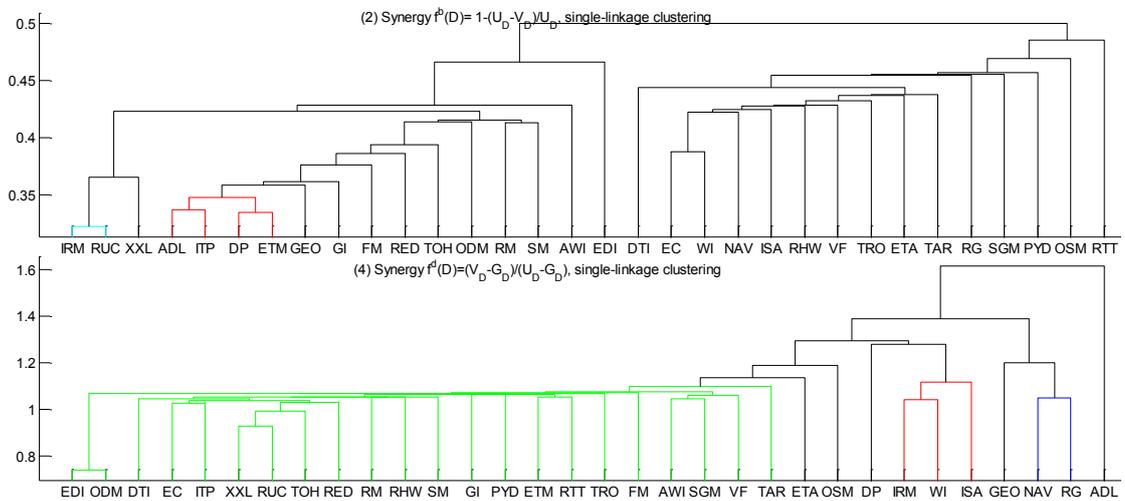


Figure 4.4: Results illustrating cluster formation: (2) Relative net savings, (4) Relative net loss

The main findings from the results in Figures 4.3 and 4.4 include the following:

- For pairwise synergies (Figure 4.3, (1)) taken as the net benefits between TTSs, some examples of clusters that can be considered interesting are: [SM VF DTI TRO ETM ETA RHW], [DTI TRO], [ETA RGW AWI], [XXL SGM PYD], and [NAV RG]. Notice here that these TTSs are clustered by taking the inverse of the net benefits due to synergies. Beneficial clusters seem to focus on traffic related operations even though the clustering is based on the similarity between functionalities.
- For pairwise synergies taken as the absolute net loss (Figure 4.3, (3)), the following clusters show relatively high synergies: [ODM RM], [ADL DP GI FM SM GEO ETM RED], [IRM RUC]. Since clustering and especially HCA is based on order, the results of this scenario do not directly mirror the previous scenario as common sense will tell us. Thus, the choice of the most beneficial clusters do not necessarily equate to the choice of the least non-beneficial clusters.
- If instead the relative benefits are considered (Figure 4.4, (2)) the following clusters appear to be interesting: [IRM RUC], [ADL ITP], [DP ETM], and [IRM RUC XXL ADL ITP DP ETMGEO GI FM RED TOH ODM RM SM]. The results are different from the net benefits as expected because of the similarity changes when the costs is taken into consideration. Benefits in this scenario are similar to percentage gains.
- If the relative loss is considered in a similar way as the relative benefits (Figure 4.4, (4)), the results are different from those obtained for net loss. The following clusters results to relatively more savings: [EDI ODM], [XXL RUC], [XXL RUC TOH], [NAV RG], [IRM WI ISA] and [EDI ODM DTI EC ITP XXL RUC TOH RED RM RHW SM GI PYD ETM RTT TRO FM AWI SGM VF TAR].

In each of the above scenarios, there are variations in the results of the choice of TTSs considered in different clusters. The main reason for this is that HCA is order dependent. When the similarity matrix change due to changes in the synergy measure used (equation 4.4.4), there is going to be a changed in the starting solution. When this happens, the clustering hierarchy changes leading to different clusters being formed. When the model is employed, e.e., by a system designer, the focus could be on a given measure of interest, e.g., to minimize losses or to maximize gains.

The results are obtained based on the specification of the TTSs in Tables 4.2 and 4.3 presented in the Appendix section. Since there are different ways that a TTS can be implemented, the results are only valid for the given specifications of TTSs. If a different set of TTSs and functionalities are specified, these will influence the computations and hence the results that can be obtained. However, the proposed method can be employed to study different scenarios when considering synergy for different choices of TTSs.

4.7 Conclusions and Future Work

This article has developed a systematic approach for assessing the degree of common functionalities (or synergy) among different sets of road Transport Telematic Services (TTSs). The method is illustrated on a case study consisting of 32 TTSs composed from a total of 38 functionalities. Figures 4.3 and 4.4 show the results obtained and highlights of different clusters of interest based on various measures of synergies. The results are particularly useful for system designers interested in studying possible reduction in costs through deployment on common platforms but also for packaging TTSs on account of technical synergy. Synergy estimates, as proposed in this study, depends on the type of functionalities specifying each TTS and the associated costs variation. The synergy is an indication of duplicated functions that maybe avoided and yet achieve the same utility in terms of TTS offers. This, presents a possibility for minimizing the cost of implementation telematic systems for ITS solutions. 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 could address multidimensional analysis in order to recommend 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. It could also be of interest to apply the proposed approach in order to assess the technical feasibility of TTSs focusing on specific domains, e.g., driver support, traffic management.

Appendix

F	Brief descriptions	β_k	G_k
as	accident sensing e.g. using sensors for detecting the occurrence of an accidents	0.61	90.00
asg	alarm signaling in vehicle for use during the occurrence of an event e.g. accidents.	0.88	162.26
at	automatic triggering for initiating events in vehicle e.g. over speeding, theft	0.66	25.62
cv	camera vision (observation) for collecting video data in or out of vehicle environment	0.85	29.04
da	data anonymity for sensitive data that require advanced encryption into and from vehicle	0.88	239.12
db	data broadcast for sending data to multiple vehicles with receivers/antennas	0.96	21.35
ds	data storage for saving data within a certain time period in a vehicle	0.72	97.20
dt	event timer in the vehicle e.g. clock, obu	0.78	290.36
dd	driver data logging for collecting data about driver such as id, health statues etc	0.75	59.78
di	driver information display e.g. LCD display	0.67	4725.00
ed	emission data logging for collecting emission data e.g. CO2 in a region/vehicle	0.83	111.02
fcd	floating car data collection e.g. using road side equipments	0.75	427.01
g p	global positioning for determining the position of a vehicle internally	0.71	720.00
gds	goods damage sensing for determining unusual changes to goods data	0.80	59.78
gd	goods data logging for collecting and storing goods data	0.79	170.10
hs	human sensing for detecting the presence of a person e.g. in accidents	1.00	45.00
ids	infrastructure damage sensing for detecting unusual changes to infrastructure	0.61	5222.98
ind	infrastructure data logging for collecting and storing infrastructure data	0.86	5.81
lp	local positioning for location determination with respect to a reference point	0.79	1110.00
mp	map positioning and updates for calculating and updating map position	0.80	55.51
mh	maintenance history gathering	0.70	170.80
m	monitoring for frequent report of small changes e.g. of a bridge, vehicle etc	0.87	179.34
no	network optimization for determining the best possible route in a network	0.63	1793.43
obu	on-board unit processing of vehicle data	0.40	102.48
odd	origin-destination data information availability of goods/vehicles	0.66	896.72
rm	ramp metering for regulating traffic flow in given road segments	0.88	569.36
rc	route congestion information for determining the average HGV density on route segment	0.76	77.72
src	short range communication for transmitting small amount of data e.g. DSRC between the vehicle and road side	0.91	17.08
sd	signal delay information for pre-empting traffic light signals	0.90	836.93
tfc	tidal flow control and traffic priority assignment for associating priority to given vehicles	0.80	75.53
ts	time stamping for logging the time an event of interest occurred	0.94	59.78
wf	weather forecasting information e.g. from weather station	0.90	2648.17
vds	vehicle damage sensing for detecting unusual changes to vehicle conditions	1.00	273.28
vd	vehicle data logging e.g. vehicle number, category etc	0.72	57.22
vs	vehicle speed information collection e.g. using odometer	0.83	8540.15
vc	voice communication for transmitting audio signals	0.71	597.81

Table 4.2: Specification of functionalities (F), their synergy coefficients, β_k , and maximum costs modified from Maccubbin et al. (2008)

TTS	Description	Functionalities
AWI	Accident Warning Information:	as, asg, db, ds, dt, di, lp, odd, rm, rc, ts, wf, vd, vs
ADL	Automated Driver Logs:	db, dd, lp, ts, vd, vc
DP	Driver Planning:	da, db, dt, dd, gd, lp, obu, odd, ts, wf, vd
DT	Dynamic Traffic Information:	as, db, du, dt, di, gp, ids, ind, mp, obu, odd, rm, rc, sd, tfc, ts, wf, vd, vs vc
EC	eCall:	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	Emission Testing and Mitigation:	db, ds, di, ed, gp, lp, mp, m, obu, rc, src, vd
ED	En-route Driver Information:	du, di, lp, mp, obu, odd, rc, src, tfc, wf, vs, vc
ETA	Estimated Time of Arrival:	db, dt, gp, gd, m, no, odd, rc, sd, ts, wf, vs
FM	Freight Monitoring:	da, ds, dt, gp, gds, gd, m, obu, odd, src, ts, vd
GEO	Geo-fensing:	asg, at, cv, db, dt, gp, m, rm, src, ts, vd
GI	Goods Identification:	at, da, db, du, dd, gp, gds, gd, mp, m, obu, odd, ts, vd, vs
IRM	Information on Infrastructure Repair and Maintenance:	gp, ids, ind, mh, mp, m, rc, src, wf
XXL	Information on the transport of extra large goods:	cv, db, dt, di, gp, gd, ids, ind, mp, m, obu, odd, rc, tfc, ts, wf, vd, vs
ITP	Intelligent Truck Parking:	at, cv, db, di, ind, lp, mp, no, obu, src, ts, vd
ISA	Intelligent Speed Adaptation:	asg, cv, db, di, gp, ids, mp, m, rm, rc, sd, tfc, wf, vs
NAV	Navigation through a route network:	di, gp, lp, mp, no, obu, odd, rm, rc, sd, wf, vd, vs
ODM	Onboard Driver Monitoring:	as, asg, db, dt, dd, gp, hs, m, obu, ts, vds, vd, vs
OSM	Onboard Safety and security Monitoring:	asg, cv, dt, di, gp, gds, gd, hs, mh, m, obu, src, vds, vd, vs
PYD	Pay as You Drive:	as, at, da, db, ds, dt, dd, gp, mh, m, obu, odd, rc, ts, wf, vds, vd, vs
RTT	Real Time Track and Trace:	db, du, dt, dd, di, gp, gd, mp, no, obu, rc, src, ts, wf, vd, vs
RED	Remote Declaration:	cv, da, db, ds, du, dd, di, gds, gd, mp, obu, odd, src, ts, vd, vc
RM	Remote Monitoring:	as, asg, at, ds, du, gp, lp, mp, m, obu, src, ts, vds, vd, vs
RHW	Road Hindrance Warning:	as, asg, db, dt, lp, mp, no, obu, odd, rm, rc, sd, tfc, ts, wf, vs
RUC	Road User Charging:	da, ds, gp, ids, ind, mp, obu, rm, rc, tfc, ts
RG	Route Guidance:	di, gp, ids, ind, mp, m, no, obu, odd, rm, rc, tfc, wf, vs
SGM	Sensitive Goods Monitoring:	da, db, ds, dt, dd, ed, gp, gd, mp, m, odd, rc, ts, wf, vd, vs
SM	Staff Monitoring:	da, db, ds, dd, gp, mp, m, odd, ts, vd, vs
TAR	Theft Alarm and Recovery:	asg, at, cv, db, ds, dt, dd, gp, gds, gd, hs, mp, rc, ts, vds, vd, vs
TOH	Transport Order Handling:	da, db, du, dd, di, gd, lp, mp, obu, odd, rc, ts, wf, vd
TRO	Transport Resource Optimization:	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	Vehicle Follow-up:	da, db, ds, du, dt, dd, di, ed, gp, mh, mp, m, obu, odd, rc, ts, vds, vd, vs
WI	Weigh Indication:	asg, at, cv, du, di, gp, gds, gd, ids, ind, mp, m, src, wf, vs

Table 4.3: Specification of TTSs in the illustrative experiment. Each TTS was assumed to either incur 100%, 50% , 25%, or 0% of functionality costs in Table 4.2. β_k was estimated from the average rate of change of the functionality cost

Paper IV

Toward Cost-Efficient Integration of Telematic Systems Using K-Spanning Tree and Clustering Algorithms

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This article uses analytical methods to assess reductions in total costs of telematic systems that can result from common infrastructure utilization. Analytical methods based on clustering and K-minimum spanning tree can be adopted for finding clusters or sets which maximize reductions in total system costs due to infrastructure sharing between telematic systems. Efficient integration of telematic systems through infrastructure sharing can positively influence telematic service interoperability while reducing costs. Results show the measure of synergy for each K-value, as well as total cost savings of up to 2%.

5.1 Introduction

Several years of experimentation and research in Information and Communication Technology (ICT) has led to systems (telematic systems e.g. Navigation) offering services with the potential to improve transport system performance on safety and the environment (Grush, 2010; Hays and Kaul, 2010; Sampson, 2010). High costs (among other reasons) make it difficult to realize the full potential of telematic systems and services that will improve transport systems (Kulmala et al., 2008). This article uses analytical methods to assess reductions in total cost of telematic systems that can result from common infrastructure utilization. The common use of functionality by telematic systems can be regarded as sharing the underlying infrastructure providing such functionality. Multiple telematic systems can share infrastructure, leading to cost synergies, and ultimately a decrease of total system costs (Malone et al., 2008). Analytical methods based on clustering and K-minimum spanning tree (K-MST) can be adopted for finding clusters or sets which maximize reductions in total system costs due to infrastructure sharing between telematic systems. The results can lead to cost-efficient integration of telematic systems in platforms that promote the sharing of system infrastructure.

Transport Telematic Services (TTSs) result from deployment of expensive infrastructure, e.g., wireless communication (e.g., based on Global System for Mobile communication -GSM) and digital map positioning infrastructure (Eurobarometer, 2006). Such TTSs are considered as an added value by consumers, who perceive the costs of such TTSs as additional costs to transport services and hence expensive (Eppstein, 1990). Subsidies, developments of low- cost technology, e.g., for communication, and efficient integrated use of telematic system infrastructure are all measures that can contribute to low-cost, affordable TTSs. Efficient integration of telematic systems through infrastructure sharing can further have a positive influence on telematic service interoperability while reducing costs. The need for efficient sharing of infrastructure resources is addressed by several research works such as Intelligent Road Infrastructure (F. op de Beek and R.Kulmala, 2010), assessment of multi-service architectures (Mbiydzennyuy, 2010), service bundling analysis (Grush, 2010), and electric vehicle service packages (Hays and Kaul, 2010). Some of these approaches are inspired by existing information system platforms like the Internet and use of APIs (Application Programming Interfaces). Hence, several attempts have aimed to benefit from potential synergies as a result of sharing infrastructure

functionalities such as GSM communication and digital map positioning.

To efficiently integrate TTSs through shared infrastructure requires that, for each TTS, we assess its functionalities and possible reduction in total cost as a result of infrastructure sharing. Such assessments should point to variation of synergy for sets (or clusters) of TTSs that share infrastructure. One major advantage of such sets of TTSs is the ability to achieve reduction in total cost, leading to improved cost efficiency regarding system integration. In addition to information on reductions in total cost, there are other aspects that need to be taken into consideration in order to achieve efficient integration of telematic systems, e.g., societal benefits. We chose to focus on the cost reduction when TTSs share infrastructure as opposed to individual implementation. We further ignore the value (benefits to society) of different TTSs so as to concentrate on the costs. In this article, we extend a previously proposed method of synergy analysis (Mbiydzennyuy, 2010) by carrying out experiments of how to maximize reductions in total system cost of multiple TTSs that can lead to cost-efficient integration of such TTSs. Given a set of TTSs, we apply an analytical method to determine the similarity between all possible pairs of TTSs. The reduction in total cost between pairs of TTSs is used as a measure of synergy between such TTSs. The result is a symmetric matrix of pair-wise similarities between TTSs. Hierarchical clustering is used for finding sets of TTSs with high synergies.

An alternative to HCA is to use a K-Minimum spanning tree. A minimum spanning tree problem (MSTP) involves finding a spanning tree ($D^* \subseteq S$) of an undirected, connected graph (G) such that the sum of the weights of the selected edges is minimum (F Bazlamaçcı and S Hindi, 2001; Greenberg, 1998). This problem has been widely studied and several variations researched, such as K-least weight spanning tree, and K-best possible spanning tree (Eppstein, 1990). TTSs can be considered as the vertices of a tree with reduction in costs between a pair of TTSs (when both are included in the set) taken as the edges. Thus, we use a K-minimum spanning tree algorithm for finding the sets of TTSs which (approximately) maximize reductions in total system costs or synergy value. K represents the maximum number of TTSs allowed in a set.

The data used includes a specification of the costs for each functionality used by each TTS and an assessment of the percentage of cost reduction factor (β_j) of the functionality (j) when shared by at least two TTSs (see Appendix). The results of applying K-MST algorithm (K-MSTA) show the measure of synergy for each K-value. The results indicate a total cost savings of up to 2%. The rest of this paper consists of the following sections (section numbers in brackets): Methodology of synergy analysis for cost-efficient integration of telematic systems (5.2), Experiment set-up (5.3), Results and analysis (5.4), Conclusion and future work (5.5). These are followed by an acknowledgment, references and an appendix.

5.2 Methodology: Synergy Analysis for Cost-efficient Integration of Telematic Systems

5.2.1 Conceptual Description

One way to specify TTSs so as to analyze the cost-efficiency of shared infrastructure utilization is by considering their functionality specification. When combined together and with appropriate input, system functionalities will result in a given system behavior. Examples of such functionalities may range from digital map positioning and GSM communication to various data collection sensors. Primary system requirements are met with a specific implementation of system functionalities. In addition to total costs of functionalities for each TTS, there are overhead costs such as labor, administration and in some cases regulation of standards may also add costs. Conceptually, the relationship

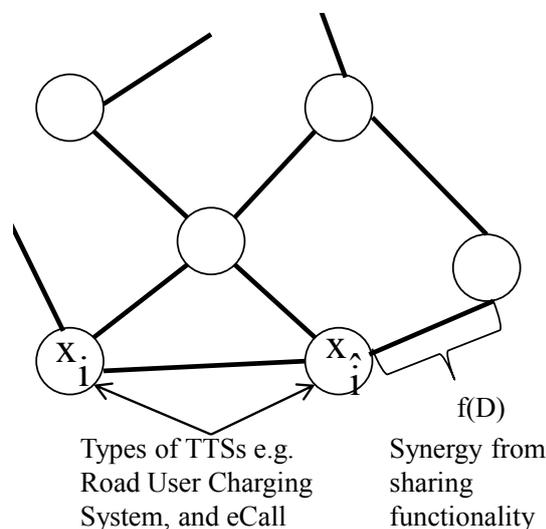


Figure 5.1: Concept of shared infrastructure between TTSs

between TTSs (e.g. x_i and x_j) can be simplified in pair-wise relations as illustrated by Figure 5.1. One basic way to relate these pairs is to estimate the percentage reduction in costs if the two TTSs share infrastructure. We refer to such a measure as synergy, following previous similar analysis (Mbiydzennyuy, 2010). By using such a synergy assessment, potential TTSs can be identified for cost-efficient integration. Sets of TTSs with high cost reduction potential can be integrated together through shared system infrastructure, hence minimizing total system costs.

In a previous study an approach is suggested for analysis of synergy between sets of TTSs (denoted by S) based on an anticipated cost reduction factor (denoted by β_j) for each functionality j (Mbiydzennyuy, 2010). In the present study, we apply a synergy measure concerning the ratio of the (net) reduction in total costs due to synergy, to the

total costs without synergy, as shown by Equation 1 (i.e. percentage reduction).

$$f(D) = \frac{U_D - V_D}{U_D} \quad (5.2.1)$$

where D is the pair-wise elements of TTSs in set S . U_D and V_D are based on the fixed costs of the functionalities as follows: U_D is total system cost (assuming independent implementation, i.e. no infrastructure sharing) and can never be zero and V_D is the reduced costs with infrastructure sharing. V_D is calculated from the assessment of reduction between TTSs (β_j) for each functionality j . Equation 5.2.1 can be seen as a synergy measure for all functionalities of a pair of TTSs. To calculate the synergy for the complete set of TTSs, Hierarchical Clustering Algorithm (HCA) and K-MST are employed. The input to the following two algorithms is the pair-wise measurements between TTSs based on Equation 5.2.1. The outputs of the algorithms are synergy measurements for sets of TTSs with varying cardinality (Section 5.4).

5.2.2 Nearest Neighbor Hierarchical Agglomeration (HCA)

Agglomerative algorithms begin by placing distinct data points in a cluster (i.e. $D_i = x_i : i = 1 \dots n$) 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 ($D = \cup D_i : i = 1 \dots n$). The similarity measure is the ratio of the (net) reduced costs due to synergy, to the total costs without synergy (Equation 5.2.1), and defines the distance between two clusters. The pseudo code is shown in Algorithm 5.2.1:

```

begin
  Determine the set of TTSs  $S$  and functionalities  $F$  ;
   $n = |S|$  ;
  Initialize  $D = \{\}$ , an arbitrary subset of  $S$ ;
  From equation 4.4.4, obtain  $n$ -by- $n$  similarity matrix  $M$  of all elements in  $S$  based on
  functionalities in  $F$ ;
  Determine pair of TTSs with highest synergy  $(i, j)$  such that  $\min M[i, j], i \neq j$ ;
  Add  $i$  and  $j$  to  $D$ ;
  while  $D \neq S$  do
    Select  $i$  such that  $\min M[i, j], i \neq j, i \notin D, j \in D$  ;
    Add  $i$  to  $D$  in a hierarchical order ;
  end
end

```

Algorithm 5.2.1: Pseudo-code: HCA applied to estimate potential savings

In this study, we use complete linkage for the similarity measure. In complete linkage, the maximum distance between any two elements in each of the clusters defines the distance between the clusters i.e. the most similar cluster is obtained by $d_{max}(D_i, D_j) = \max \|x_i - x_j\|$, where $x_i \in D_i$ and $x_j \in D_j$. x_i and x_j represent different TTSs, d_{max} is calculated by Equation 5.2.1 (above).

5.2.3 K-Minimum Spanning Tree Algorithm (K-MSTA)

Let $G=(S,E,w)$ be an undirected, edge-weighted graph with $|S| = n$ and $|E| = m$ denoting the number of nodes and edges of G . The function

$$w : E \rightarrow \mathbb{R}^+, w(E') = \sum_{e \in E'} w(e) \quad (5.2.2)$$

denotes the edge-weight function for any $E' \subset E$. Consider the following definition: a cardinality sub graph is a connected sub graph D of G : $|E(D)| = K$. The K-cardinality sub graph problem is to find a K-cardinality sub graph of minimal weight, i.e., $\min\{w(E(D)) : D \text{ is a K-cardinality sub graph}\}$. For a MSTP, $D = G$ and $K = n - 1$ and for a K-MSTP $D \subset G$ and $2 \leq K \leq n - 1$. For a given value of K (as input), the K-MSTP can be solved in polynomial time (Ehr Gott et al., 1997).

In order to study the potential total savings for a given set of TTSs (denoted by S) with cardinality n , we propose and use a variant of the K-minimum spanning tree algorithm formulated as an Integer Linear program (Ehr Gott et al., 1997). For any number of TTSs K , the aim is to determine the total savings potential (by solving the MSTP for K) due to synergies. K -value is the maximum allowed number of TTSs in the set currently considered. The result is a tree (set of TTSs) that has the maximum total synergy. The pseudo-code is shown in Algorithm 5.2.2:

```

begin
  Denote: TTS in  $D \subset S$  by  $x_i \in D, i, \hat{i} \in 1, \dots, n$ ;
  E consist of all pairs of TTSs, i.e.,  $(i, \hat{i}) \in E$ ;
  Set  $q$  to be a large positive number ;
  D is initially an empty set ;
  MinCost: From S determine  $\min\{(i, \hat{i} \in E)\{-f(x_i, x_{\hat{i}})\}$ ;
  We have the pair of TTS with maximum pairwise synergy;
  Add  $i, \hat{i}$  to D;
  Check  $K \leq |D|$  ;
  while  $D \neq S$  do
    |  $Z = \min\{-w(E(D))\}$ ;
    | D is a k-sub graph;
  end
  if  $\frac{Z}{K} \leq q$  then
    |  $q = \frac{Z}{K}$ ;
    | Criteria for inclusion;
    | go to MinCost;
  else
    | Continue;
  end
  Remove  $i, \hat{i}$  from E and add to  $D^*$ 
end

```

Algorithm 5.2.2: Pseudo-code: KMST applied to estimate potential savings

There are no cycles in the final graph and all the weights are positive. The function $f(D)$ measures the synergy (weight between a pair of TTSs) in the interval $0 \leq f(D) < 1$ and is equivalent to the percentage gain. Observe that we only consider the cases where V_D is non-zero ($V_D = 0$ means $f(D)$ is 1) because in practical situations, shared infrastructure utilization can lead to a reduction in costs ($V_D < U_D$) or no reduction at all ($U_D = V_D$), but not to zero costs, hence the interval $0 \leq f(D) < 1$. The solution consists of edges in the improving direction and hence the proposed algorithm can be seen to be greedy.

5.3 Experiment Set-up

Input data to the experiment is obtained from different sources as shown in Table 5.1.

Transport Telematic Services	Related Project	Year	Source
Automated Driver Logs (ADL)	ABECQ	(01-08)2008	(ABECQ, 2013)
Accident Warning Information (AWI)	CODIA	(01-08)2008	(Kulmala et al., 2008)
E-Call (EC)	e-IMPACT	2006-2007	(Malone et al., 2008; McClure and Graham, 2006)
Intelligent Speed Adaptation (ISA)	UK-ISA, e-IMPACT	2006-2007	(Carsten et al., 2008; Malone et al., 2008)
Navigation Through a Route Network (NAV)	Tom-Tom website	2011	(Tom-Tom, 2013)
On-Board Safety and Security Monitoring (OSM)	ECORYS	2005-2006	(ECORYS, 2006)
Real Time Track and Trace of Goods (RTT)	AVL-Transit	1998-1999	(Peng et al., 1999)
Road Hindrance Warning (RHW)	CODIA	(01-08)2008	(Kulmala et al., 2008)
Road User Charging (RUC)	ARENA	2007-present	(Sundberg, 2007b)
Route Guidance (RG)	Tom-Tom website	2011	(Tom-Tom, 2013)
Sensitive Goods Monitoring (SGM)	GOOD ROUTE	2006-2009	(Landwehr and Krietsch, 2009)
Theft Alarm and Recovery (TAR)	TM Fleet website	2011	(TM-Fleet, 2013)
Weight Indication (WI)	Thesis Project	2007	(Zhang, 2007)

Table 5.1: Input data obtained from different project sources.

In total, 13 TTSs (13 vertices, 12 edges, i.e. no cycles) are studied (Table 5.1). Each TTS is specified by a set of functionalities (26 in total). Common to all TTSs are the following functionalities: digital map (exception: ADL), wireless communication device with antenna and SIM card, graphical interface (exception: ISA, RUC), docking station and labor or installation cost. All data are converted to the cost equivalent for the year 2011 with discount rate = 5% and distributed over a time period of 10 years (life span of functionality). Using the data, we construct pair-wise synergies of TTSs. In addition to the functionalities specified for each TTS from different sources, anticipated functionalities have been included where necessary, e.g., we consider the

possibility to communicate information between vehicle and roadside equipment for a Weigh-in-motion service, which is not often the case for existing systems reported in the literature.

In some situations we use different decomposition techniques in order to estimate the fixed costs of a functionality. For instance, by studying the price variation between different versions of a telematic system (each with different functionalities), additional costs between versions can be approximated to be the cost of such new functionalities. As an example consider a basic car navigation system (NAV1) with total cost 100 €, consisting of a digital map, route suggestion estimates based on daily traffic (IQ route), a functionality for reporting map changes, SIM for communication, LCD interface and a docking station. Assume that a second version called NAV2 is then released with a total cost of 120 € with the additional functionality of advanced lane guidance and text-to-speech. From this it can be deduced within a certain degree of accuracy that the advanced lane guidance and text-to-speech functionalities will share the total additional cost of about 20 €. How such costs are distributed between the functionalities is not trivial. In the absence of any source of information, we followed an average distribution of costs between different functionalities resulting from a given component as illustrated by Figure 5.2:

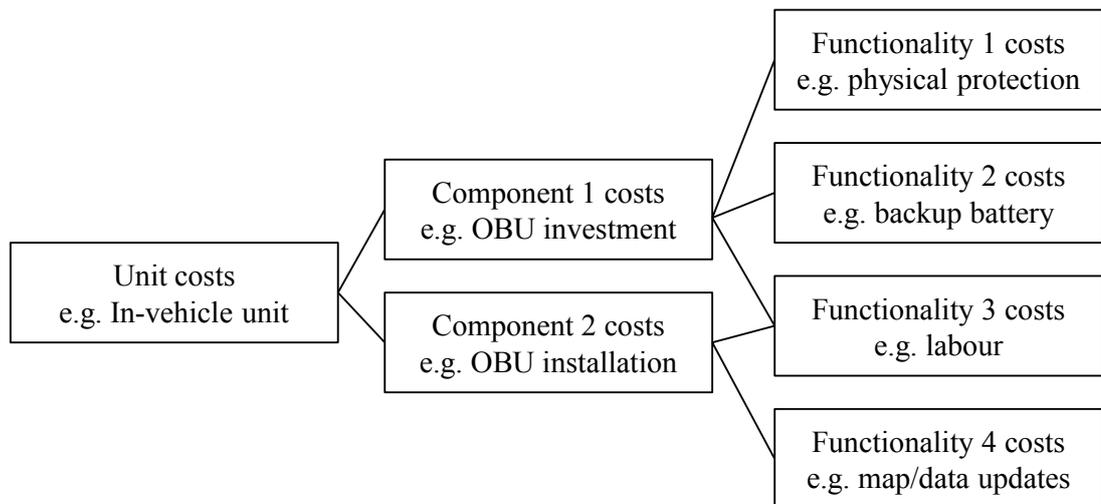


Figure 5.2: Illustration of cost distribution between functionalities.

HCA is implemented using XLMiner an Excel add-in and K-MSTA is implemented in a mathematical programming environment called AMPL.

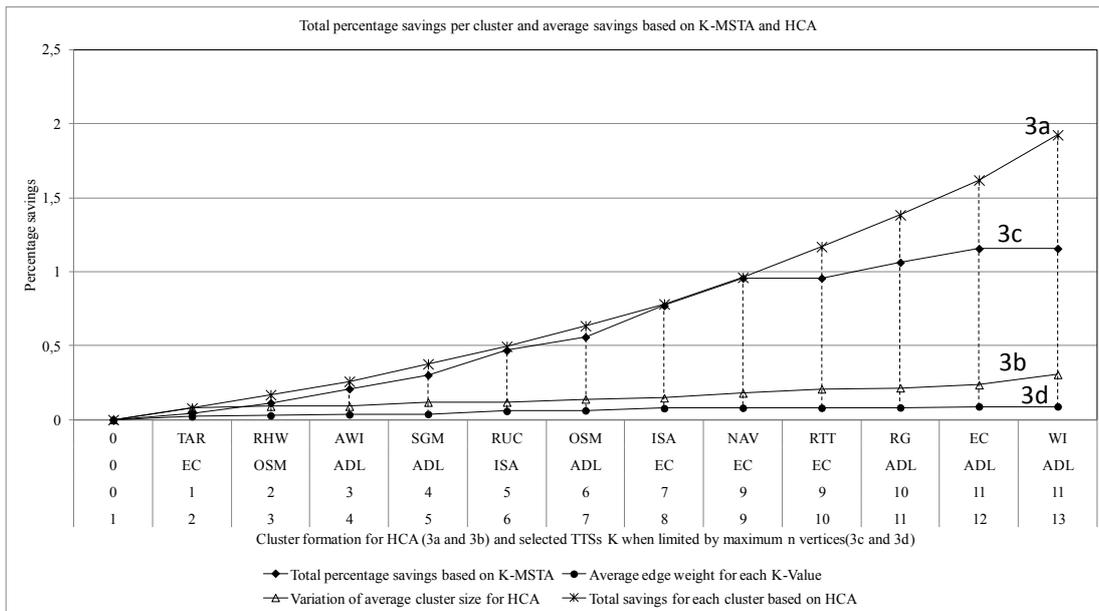


Figure 5.3: Results of complete linkage HCA (3a and 3b) and K-MST algorithms (3c and 3d) both showing total cost savings for each set of TTS (3a and 3b) and average cost savings with each additional TTS link (3c and 3d).

5.4 Results and Analysis

Results of the HCA indicate the order of final cluster formation where the TTSs TAR and EC are most likely to have the highest possible savings, and WI and ADL show the least savings. Cumulative addition of savings per link shows a steady growth as in Figure 5.3. Such cumulative additions do not show much information about the total savings associated with a cluster of a given size. While the results are true for the final cluster, the curve showing total savings maybe different if the algorithm is applied to different subsets of TTSs. For studying such variations we consider the K-MSTA.

A general tendency for HCA is the increase in total synergy with additional TTSs (3a). Since HCA is based on pair-wise synergies, there is an accuracy problem (due to double counting) estimating the synergy for a set of TTSs. This is the reason why HCA is showing larger savings compared to the K-MSTA. The results of the K-MSTA show the estimated total synergy for each K-value (3c) to be generally less when compared to HCA. The addition of each TTS in a set leads to increased synergy both in average savings (3b) per TTS and in total savings (3c) up to about 9 TTSs. This is partly due to the choices of TTS used in this experiment which turn to have similarities with each other and hence synergies.

Both approaches show a fairly similar trend, where the cumulative total savings of the final cluster formed by HCA reaches 1.9% and the final cluster for K-MSTA reaches

1.1%. The two approaches are based on different criteria for evaluating similarity where higher savings generally means higher similarity. The validity of the results above (Figure 5.3) depends on a number of factors, e.g. the total number of TTSs and functionalities considered, and the total number of users. As we studied only 13 TTSs with 26 functionalities and an individual user situation, the results of the percentage savings are low (less than 2%). The savings are likely to be higher with a large number of users, TTSs and functionalities taken into consideration. Because K-MSTA is heuristic, the question on the optimal K-Value remains open. Our focus was estimating the cost reduction rather than seeking to achieve an optimal implementation of the K-MSTA. Even though the K-MSTA may provide more accurate cost reduction estimates, the challenge is in dealing with a large set of TTSs as the power set will result in a huge search space.

5.5 Conclusions and Future work

This paper has focused on assessment of cost reduction when TTSs share infrastructure as opposed to individual implementation. The results of applying K-MSTA show the measure of synergy for each K-value that can lead to total cost savings up to 1.1%. Hierarchical clustering is used to determine variation in synergy in a given set of TTSs ($\approx 2\%$ savings). To determine the synergy measure for a given number of TTSs (K), we apply a variant of K-minimum spanning tree algorithm. Based on data from different sources (Table 5.1), the synergy variation for different collections of TTSs is a step toward cost-efficient integration of telematic systems. Such results can be useful for the analysis of system designs by influencing the choices of systems to consider. The main challenge remains information regarding absolute system cost, which is seldom available and where available is old and outdated. This information is important for research related to cost efficiency (in integration of TTSs) and even cost benefit assessments.

Key elements of this study that we consider for further improvements are: refinements of cost reduction potential (β_j), refinement of cost per functionality, consideration of the positive benefits of the TTSs, further refinement of the K-MSTA and additional data concerning TTSs. The value of the cost reduction potential (β_j) used in this study is currently based on the views of the authors. The value for some functionalities is a non-linear variation and depends on the number of applications. By monitoring results of new experiments related to implementation of TTSs and discussions with other experts more accurate estimates can be obtained.

Appendix

All cost values in Tables 5.2 and 5.3 are in €. The rows represent functionalities and columns represent the TTSs (with the exception of columns one and two that represent

functionality name and assessments of infrastructure sharing potential for at least two TTSs (β_j) respectively). An empty cell implies the TTS does not require functionality.. The following references were used for data concerning the respective TTSs: ADL (ABECQ, 2013), AWI (Kulmala et al., 2008), EC (McClure and Graham, 2006), ISA (Carsten et al., 2008), NAV (Tom-Tom, 2013), OSM (ECORYS, 2006), RTT (Peng et al., 1999), RHW (Kulmala et al., 2008), RUC (Sundberg, 2007b) RG (Tom-Tom, 2013), SGM (Landwehr and Krietsch, 2009), TAR (TM-Fleet, 2013) WI (Zhang, 2007)

Functionalities, j (Rows) and TTSs, i (Columns)	β_j	RHW	RUC	RG	SGM	TAR	WI
In-band modern licence (TBC)	0.40						
Back-up GSM antenna	0.50						
Backup battery	0.10			30.00		60.00	0.11
Hardware and software	0.70		18.23	30.00		25.00	0.20
Interface+cover protection	0.50	161.15	233.06	35.00	176.40	68.00	
Manual eCall button	0.20						
GSM antenna	0.40	893.86		50.00	176.40	100.00	
Microphone	0.30			20.00			
Wiring harness and connectors	0.10						
Embedded SIM card for communication	0.50	292.00	193.41	27.00	176.40	27.00	193.41
Vehicle manufacturer's development costs	0.20						
Processor (RAM)	0.30	955.95	18.23		176.40		0.07
Map updates	0.40	72.60	72.60	50.00	137.81		72.60
Speed limit + external roadside control e.g. cameras	0.20	1020.63	19.45		275.63		
Labor/installation costs	0.20	88.13	194.48	88.13	137.81		13.46
Compiling digital map of 1KM road length	0.30						
Back office	0.40		19.45		551.25		
Control system	0.08		27.96		8.48		
DSRC	0.33	161.15			176.40		
In-vehicle OBU	0.20		223.65	60.00	330.75		
Sensors	0.10	96.47					0.47
Data logger	0.20						0.11
In-vehicle camera	0.30						
Auto SMS capability	0.10					68.00	
Alarm system	0.30					68.00	
Docking station (connectors), Tom Tom	0.50	50.00	50.00	50.00	50.00	50.00	50.00

Table 5.2: Input data employed in the experiment (from Table 5.1).

Functionalities, j (Rows) and TTs, i (Columns)	β_j	ADL	AWI	EC	ISA	NAV	OSM	RTT
In-band modern licence (TBC)	0.40			18.23				
Back-up GSM antenna	0.50			18.23				
Backup battery	0.10	30.00		18.23		25.00		
Hardware and software	0.70	666.50		18.23		30.00		
Interface+cover protection	0.50	10.00	687.58	18.23		35.00	906.16	
Manual eCall button	0.20			12.76	112.35			
GSM antenna	0.40		2630.00	25.53	112.35	50.00		
Microphone	0.30			12.76		20.00		
Wiring harness and connectors	0.10			18.23	112.35			
Embedded SIM card for communication	0.50	27.00	739.15	38.29	193.41	27.00	193.41	193.41
Vehicle manufacturer's development costs	0.20		957.21	229.73	189.00		315.00	
Processor (RAM)	0.30				112.35			
map updates	0.40		72.60	72.60	12.60	90.00	72.60	
Speed limit + external roadside control e.g. cameras	0.20				50.40			
Labor/installation costs	0.20	88.13	88.13	88.13	94.50	88.13	88.13	0.40
Compiling digital map of 1KM road length	0.30				23.09			
Back office	0.40							0.60
Control system	0.08							
DSRC	0.33		687.58					
In-vehicle OBU	0.20					20.00		0.08
Sensors	0.10	666.50	608.48				315.00	
Data logger	0.20						127.63	
In-vehicle camera	0.30					10.00		
Auto SMS capability	0.10							
Alarm system	0.30							
Docking station (connectors), Tom Tom	0.50	50.00	50.00		50.00	50.00	50.00	50.00

Table 5.3: Input data employed in the experiment (from Table 5.1).

Paper V

Optimization Analysis of Multiservice Architecture Concepts in Road Transport Telematics

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Transport telematic systems, also known as intelligent transportation systems, can be expensive to implement but the services they provide may offer substantial benefits. However, what services the system can provide depends on the architectural choices made, which also affects the cost of the system. We propose an optimization model to support a more informed decision before investing in a multiple service transport telematic system. The model evaluates the possible choices of services and architectures, and aims to maximize the total net societal benefit. 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

Architecture; Evaluation; Integer Linear Programming; Modeling; Optimization; Transport Telematic Service

6.1 Introduction

Intelligent transport systems (ITS) are today considered a suitable approach for addressing surface transportation problems, for example, 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 coexist 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 with CBA (Bekiaris and Nakanishi, 2004; Leviäkangas and Lähesmaa, 2002; Levine and Underwood, 1996). Methods used in the assessments of transport systems are seen to be limited for the assessment of ITS (Brand, 1994) mainly because ITS are focused on soft concepts such as information accuracy, responsiveness, and so on. A platform or telematic system architecture that can deliver multiple TTSs may result in higher net benefits. Examples of anticipated platforms are the European Electronic Tolling system based on the Global Navigation Satellite System (GNSS) (Leinberger, 2008) and the emergency call platform (Serpanos and Bouloutas, 2000). These platforms have the characteristic that many TTSs can be developed through an extension of existing functionalities. The choice of architecture influences the possibility of efficiently implementing TTSs. Further, the cost of implementing and using functionalities, the benefits of TTSs, and limitation in resources, make it difficult to determine a set of beneficial TTSs for a given architectural choice. Hence we use optimization to account for these trade-offs. The purpose of this article is to develop an optimization model that can support strategic decisions about choices of telematic architectures that support multiple services (Multi-service Architectures [MSAs]). The choice of TTSs to prioritize for implementation is modeled as an optimization problem

that maximizes net societal benefit. Different TTSs utilize different types and capacities of resources as shown in Table 6.1. A case study in the sixth section illustrates the use of the optimization model.

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 6.1: Data rate requirements for communication and processing ITS data, with typical ranges of data rates for ITS applications.

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. This article proposes a model that supports the analysis of choices of MSAs, based on available TTSs, resource capacities, and functionalities needed to achieve TTSs. Different types of resources and resource capacities will lead to different costs, shown in Table 6.2, for each alternative MSA.

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

Resource utilization and costs of realizing each functionality contributes to the costs of realizing TTSs. This is somewhat similar to work done by Shaoyan et al. (1998) in evaluating the cost of data communication services, except that they focused on establishing tariffs. Results of the proposed optimization model in this article consist of a selection of various TTSs and MSAs according to perceived total net societal benefits. While this work may not lead to answers connected to the challenges that face the implementation of MSAs, it provides a method that can support 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 article, the first three sections, respectively, provide definitions of the key terms used, introduce related work, and discuss MSAs for TTSs. In the fourth and fifth sections an optimization model is proposed, which is then applied to a case study. In the sixth, seventh, and eighth sections, results and analysis, conclusions and future work, and acknowledgments are presented, respectively.

Full name of TTS abbreviations							
AWI	Accident Warning Information	FM	Freight Mobility	ODM	On-Board Driver monitoring On-Board Safety & Security Monitoring	RG	Route Guidance
ADL	Automated Driver Logs	GEO	Geo-fencing	OSM		SGM	Sensitive Goods Monitoring
DP	Driver Planning	GI	Goods Identification Information About	PYD	Pay as You Drive	SM	Staff Monitoring
DTI	Dynamic Traffic Information	IRM	Infrastructure Repair and Maintenance Information on	RTT	Real Time Track & Trace of Goods	TAR	Theft Alarm and Recovery
EC	E-Call	XXL	the transportation of XXL Cargo	RED	Remote Declaration	TOH	Transport Order Handling
ETM	Emission Testing and Mitigation	ITP	Information on Truck Parking	RM	Remote Monitoring	TRO	Transport Resource Optimization
EDI	En-Route Driver Information	ISA	Intelligent Speed Adaptation	RHW	Road Hindrance Warning Road User	VF	Vehicle Follow-up
ETA	Estimated Time of Arrival	NAV	Navigation Through a Route Network	RUC	Charging (RUCA-advanced version)	WI	Weight Indication

Table 6.3: Full names of TTSs (represented by set S).

6.1.1 Definition of Terms

- I. Functionalities: Functionalities such as map matching, global positioning, and so on (Table 6.4) are the basic properties that can be implemented in a system and, when combined together, can achieve a TTS. It is assumed that essential functionalities for achieving each TTS can be specified. Such functionalities can be used commonly by TTSs incurring different costs.
- II. Transport Telematic Service (TTS): A transport telematic service (TTS), such as navigation, road user charging, intelligent speed adaptation, and so on (Table 6.3), is a product or activity, targeted to a specific type of ITS user, addressing given

user needs (ISO/TR-14813-1a, 2007). A TTS is specified by its functionalities, and provides value to society, incurring different costs as shown in Table 6.5.

- III. Multiservice Architecture (MSA) for a Transport Telematic System (TTS): This is considered to be the conceptual specification of transport telematic system architecture. The functionalities provided can be shared by different TTSs. We connect the MSA specification to functionalities by allowing a certain set of resources. Examples are thin client (Oehry, 2003) to thick client (McKinnon, 2006) architectures, centralized, vehicle-to-vehicle based architectures (Sakata et al., 2000), and so on (Table 6.6).

Full name of functionality abbreviations							
asg	Alarm signal	gp	Global (absolute) Positioning	m	Monitoring	sd	Signal delay
at	Automatic Trigger	gds	Goods damage sensors	no	Network optimization	tfc	Tidal flow control and traffic priority
cv	Camera vision	gd	Goods data logging	obu	On-Board Unit	ts	Time Stamping
da	Data anonymity (encryption)	hs	Human sensors	odd	Origin-Destination Data	wf	Weather Forecast
db	Data Broadcast	ids	Infrastructure damage sensors	rm	Ramp Metering	vds	Vehicle damage sensors
ds	Data Storage	ind	Infrastructure data logging	rc	Route congestion	vd	Vehicle data/ID logger
du	Data updates	lp	Local (reference) Positioning	di	Driver interface	vs	Vehicle speed
dt	Digital tachographs	mh	Maintenance history data logger	ed	Emission data logger	vc	Voice communication

Table 6.4: Full names of functionalities (represented by set F).

6.1.2 Related Work

Evaluation of ITS architectures is a subject of interest that has been addressed by many studies, such as Bristow et al. (1997), Persson et al. (2007), Tai-ying (2008), and Visser et al. (2000). All these studies have been aimed at understanding benefits of ITS 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 benefit in the context of multiple TTSs. The task of evaluating architecture 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. Visser et al. (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, coexisting TTSs, as their tool was aimed at single TTS 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). Models for specific indicators have been suggested, for example, reliability model for ITS systems (Kabashkin, 2007). It remains to be demonstrated that these indicators can be used for modeling and evaluating other TTSs. The work by Persson et al. (2007) considers the support for multiple TTSs (flexibility) and provides a qualitative evaluation of architecture concepts, but does not quantify such benefits. We assess MSAs according to quantified benefits and costs of TTSs.

The use of optimization requires that the cost and benefits of TTSs be quantified. While many studies on the evaluation of TTSs have not quantified benefits, approaches based on economic and goal evaluation methods have addressed the question of benefits quantification (Peng et al., 2000). Their study (Peng et al., 2000) provides a framework for benefit assessment using benefit trees. They observe 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 the ITS Option Analysis Model (ITSOAM) for forecasting the benefits of ITS elements and estimating the deployment cost. They address decisions related to system benefits, in which each ITS application should be considered separately and their benefits evaluated independently of each other. Our view about benefits differs from their study, since we consider the context of the benefits, that is, dependencies, for example, on given TTS collection and on the given platform due to the common functionality usage. TTSs sharing functionalities existing in MSAs will result in synergies and improved net benefits. Such synergies cannot be successfully studied using CBA for an individual MSA, since the sharing of functionalities and the dependencies of benefits between TTSs are not accounted for in the case of CBA. The use of optimization models for evaluating MSAs, as advocated in this study, has not been explored so far.

TTS	Value	Variable Cost	Functionality specification
AWI	37.3	24.8	as, asg, db, ds, dt, di, lp, odd, rm, rc, ts, wf, vd, vs
ADL	1.3	0.3	db, dd, lp, ts, vd, vc
DP	1.7	0.4	da, db, dt, dd, gd, lp, obu, odd, ts, wf, vd
DTI	5.5	25.4	as, db, du, dt, di, gp, ids, ind, mp, obu, odd, rm, rc, sd, tfc, ts, wf, vd, vs vc
EC	31.2	1.5	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	1.8	24.9	db, ds, di, ed, gp, lp, mp, m, obu, rc, src, vd
EDI	30.6	24.8	du, di, lp, mp, obu, odd, rc, src, tfc, wf, vs, vc
ETA	6.2	0.8	db, dt, gp, gd, m, no, odd, rc, sd, ts, wf, vs
FM	1.8	24.8	da, ds, dt, gp, gds, gd, m, obu, odd, src, ts, vd
GEO	1.4	24.7	asg, at, cv, db, dt, gp, m, rm, src, ts, vd
GI	1.5	0.6	at, da, db, du, dd, gp, gds, gd, mp, m, obu, odd, ts, vd, vs
IRM	8.3	0.6	gp, ids, ind, mh, mp, m, rc, src, wf
XXL	0.4	24.9	cv, db, dt, di, gp, gd, ids, ind, mp, m, obu, odd, rc, tfc, ts, wf, vd, vs
ITP	3.2	49.2	at, cv, db, di, ind, lp, mp, no, obu, src, ts, vd
ISA	31.0	24.8	asg, cv, db, di, gp, ids, mp, m, rm, rc, sd, tfc, wf, vs
NAV	36.0	24.7	di, gp, lp, mp, no, obu, odd, rm, rc, sd, wf, vd, vs
ODM	2.0	0.6	as, asg, db, dt, dd, gp, hs, m, obu, ts, vds, vd, vs
OSM	3.0	25.0	asg, cv, dt, di, gp, gds, gd, hs, mh, m, obu, src, vds, vd, vs
PYD	6.8	25.3	as, at, da, db, ds, dt, dd, gp, mh, m, obu, odd, rc, ts, wf, vds, vd, vs
RTT	5.9	0.8	db, du, dt, dd, di, gp, gd, mp, no, obu, rc, src, ts, wf, vd, vs
RED	1.9	0.7	cv, da, db, ds, du, dd, di, gds, gd, mp, obu, odd, src, ts, vd, vc
RM	8.0	25.0	as, asg, at, ds, du, gp, lp, mp, m, obu, src, ts, vds, vd, vs
RHW	37.5	1.1	as, asg, db, dt, lp, mp, no, obu, odd, rm, rc, sd, tfc, ts, wf, vs
RUC	14.4	0.7	da, ds, gp, ids, ind, mp, obu, rm, rc, tfc, ts
RUCA	10.7	0.6	da, lp, ids, ind, mp, rm, rc, tfc, ts
RG	1.9	24.7	di, gp, ids, ind, mp, m, no, obu, odd, rm, rc, tfc, wf, vs
SGM	16.2	24.8	da, db, ds, dt, dd, ed, gp, gd, mp, m, odd, rc, ts, wf, vd, vs
SM	1.0	24.7	da, db, ds, dd, gp, mp, m, odd, ts, vd, vs
TAR	37.6	25.1	asg, at, cv, db, ds, dt, dd, gp, gds, gd, hs, mp, rc, ts, vds, vd, vs
TOH	22.1	24.7	da, db, du, dd, di, gd, lp, mp, obu, odd, rc, ts, wf, vd
TRO	49.9	25.7	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	3.1	25.0	da, db, ds, du, dt, dd, di, ed, gp, mh, mp, m, obu, odd, rc, ts, vds, vd, vs
WI	4.1	24.8	asg, at, cv, du, di, gp, gds, gd, ids, ind, mp, m, src, wf, vs

Table 6.5: Value (Million €), cost (Million €) and functionality data used in the study

6.2 Modeling Multiservice Architectures for Transport Telematic Services

The specific characteristic for distinguishing between two MSAs can be called MSA key features, such as communication, processing, positioning, and so on. In the proposed optimization model we interpret key features as availability of certain resources that are used by functionalities of different TTSs, as shown in Table 6.5. Key features influence

the availability of different types and levels of resources.

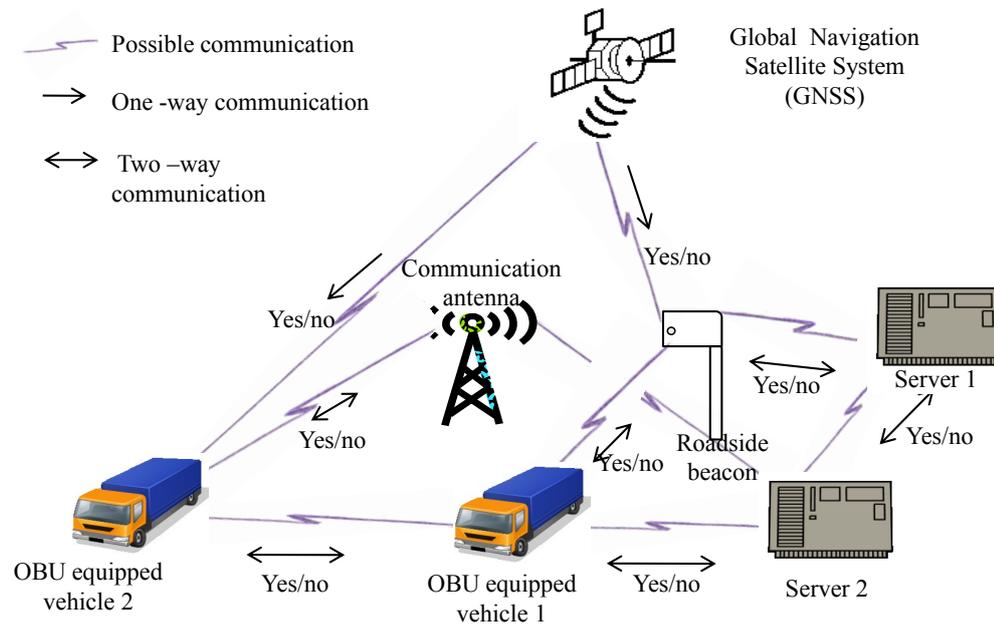


Figure 6.1: Illustration of the concept of MSA key features that provide functionality resources.

6.2.1 Multiservice Architecture Choices

Several choices of architectures (MSAs) 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 choose to interpret an MSA concept as a combination of a set of features. As stated earlier, each key 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 with an extra cost. Generally, selecting or deselecting (yes/no) a key feature means that certain resources are made available to functionalities of different TTSs as illustrated in Figure 6.1. We further illustrate specific combinations in the case study, together with the types of resources and associated capacities.

6.2.2 Resources Modeling for Transport Telematic Services

Different MSAs allow different functionalities based on two aspects: the type of resource required by the functionality and the associated capacity requirements; for example,

sensor, video, audio data may requires 0.5 Mbps, 1 Mbps, or 2 Mbps of communication band width respectively (Esteve et al., 2007).

- I. Communication: There are several ways of modeling communication. In this article, we have considered aspects related to communication capacity. For instance, one-way communication, such as data broadcasting, may require less bandwidth than two-way communication. We distinguish three types of data according to the communication capacity demand: (1) sensor data, for example, temperature, road conditions, number of vehicles; (2) audio data, for example, voice; and (3) video data, for example, road traffic cameras. For sensor data, communication bandwidth requirements are less demanding compared to video and audio data.
- II. Processing: We consider the processing capacities of MSAs to depend on the type of technique (concept) used to achieve processing as follows:
 - On-board unit (OBU) data processing: A small computer is fitted on-board the vehicle with the capability to process, display and store data (Fukang et al., 2008; Sterzbach and Halang, 1996).
 - Single central server processing: The idea is that all information is processed by one server, or possibly by multiple servers that communicate with each other and share a database. A system with multiple servers sharing tasks can also be considered as centralized processing (Serpanos and Bouloutas, 2000).
 - Multiple distributed server processing: 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 (Serpanos and Bouloutas, 2000).
- III. Positioning: One way to model positioning as a resource is to consider the possibility to achieve positioning using satellite or roadside beacons, the number of units, and the unit capacity.
 - Satellite positioning: A receiver (in the vehicle) is used to pick up a signal and the position of the vehicle is determined based on the signal properties.
 - Roadside equipment (INFORBEACON): An electronic device mounted on the roadside is used as a reference for positioning a vehicle. INFORBEACON can also be used for storing data and transmitting such data to other systems and hence can serve as a communication device.

6.2.3 Cost Modeling for Transport Telematic Services

The implementation of a functionality incurs a fixed cost. TTSs consist of functionalities utilizing different capacities of resources at a variable cost in addition to the fixed costs of implementation; for example, the transmission of sensor data may require less

communication bandwidth than the transmission of video data and hence incur different costs. Cost of resource utilization by TTSs can be modeled in several ways, for example, identifying resource requirements and estimating cost parameters. We have considered the cost of units or interfaces providing different functionalities that are available in the market for parameter cost estimates, as shown in Table 6.2.

6.2.4 Modeling Societal Values for Transport Telematic Services

In assessing the value of each TTS, it is assumed that the performance of the TTS meets the demands of its users with respect to accuracy and performance, that is, that the TTS is at its full potential. Consequently, we consider for each TTS the required functionalities for realizing its full potential. Further work on how user performance requirements may affect the quality and hence benefits of each TTS in the context of MSAs has been carried out (Mbiydzenyuy et al., 2010). The value estimate for a TTS is based on its possibility to improve a number of performance saving indicators (PSIs) such as accidents, fuel consumption, delays, and so on, all of which are addressed by a separate study (Mbiydzenyuy et al., 2012c). In this case study, we have only used societal values and cost, mainly for illustrating the use of the optimization model and for providing some indicative results.

6.3 A Proposed Optimization Model for Multiservice 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, 1998). In this article, the decision choices are the type of MSA, TTSs, and their required functionalities, illustrated in Figure 6.2.

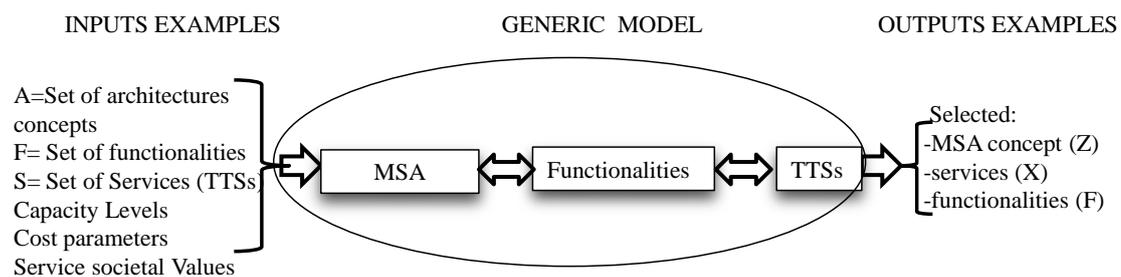


Figure 6.2: Generic model diagram illustration.

The proposed model aims to suggest the relationship between MSAs, resources,

functionalities, and TTSs. Each MSA is a specification of a set of key features. 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 generates a given amount of data. Each TTS is a specification of a set of functionalities. The positive benefits are estimated from the societal value of a TTS and the costs from the functionalities utilized by the TTSs. Later in this article, we provide a complete mathematical formulation of the preceding relationships in an optimization model. We also consider a dependency parameter $D_{i,\hat{i}} \geq 0, i, \hat{i} \in S, i \neq \hat{i}$ (S a set of TTSs) to account for the decrease in marginal benefits of two TTSs that address a related aspect.

For instance, if e-Call and intelligent speed adaptation each reduce accidents by 0.15%, the total benefit will be slightly less than 0.3% due to a decrease in marginal benefits. Dependencies are computed by calculating a pairwise matrix for all TTSs if such TTSs address a common performance indicator. Assuming that (1) if there are two TTSs that require the same type of functionality, it is possible to design a system such that the TTSs can use the same functionality without having to implement it twice, and (2) each TTS can be implemented only in a given way, we propose the following optimization model.

Sets

- S: Set of TTSs (see Table 6.3)
- F: Set of functionalities (see Table 6.4)
- A: Set of architectures (see Table 6.6)
- R: Set of resources (see Table 6.2)

Parameters

Parameters and set values indicated in parentheses are employed by the case study to illustrate the optimization model:

- $V_i, i \in S$ The value of each TTS (see Table 6.5).
- $C_j, j \in F$ The fixed cost of each functionality (see Table 6.5).
- $C_{ir}, i \in S, r \in R$ The variable cost of each functionality (see Table 6.5).
- $P \geq 0$ Cost of communicating and processing 1 megabyte of data (rough estimate of $2.9 * 10^{-3}$ € per megabyte per year).
- $D_{i\hat{i}}, \geq 0, i, \hat{i} \in S, i \neq \hat{i}$ Pairwise dependency between two TTSs (discussed earlier)
- $T_{jr}, j \in F, r \in R$ 1 if functionality requires resource, 0 otherwise.
- $M_{ij}, i \in S, j \in F$ 1 if TTS requires functionality, 0 otherwise (see Table 6.5.)
- $A_{rt}, t \in A, r \in R$ 1 if MSA allows resource usage and 0 otherwise (see Table 6.6).

$U_r \geq 0, r \in R$	Data generated per resource unit (see Table 6.1).
$Z_t, t \in A$	1 if choice of MSA 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 (see Table 6.2).
$\Phi_r \geq 0, r \in R$	Cost of each resource unit (see Table 6.2).
$E_j, \geq 0, j \in F$	Extra costs if a functionality is not supported by architecture resource ($E_j = C_j, j \in F$)
$\delta \geq 0$	Integer limiting the maximum number of functionalities (not supported by MSA) to be relaxed (2).

Variables

$x_i, i \in S$	1 if TTS 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 TTS are selected, 0 otherwise.
$\tilde{f}_{ir}, i \in S, r \in R$	1 if selected functionality is not supported by MSA resource, 0 otherwise (to be considered with E_j).
$\vartheta_{i\hat{i}} \geq 0, i, \hat{i} \in S, i \neq \hat{i}$	The dependency estimate for TTSs i and \hat{i} .
$\eta \geq 0$	Integer limiting the number of TTSs currently selected.
$\psi_r, \geq 0, r \in R$	Number of resource units required (from Table 6.2).

Objective: Maximize:

$$\begin{aligned}
 & \sum_{i \in S} V_i * x_i - \sum_{j \in F} C_j * f_j - \sum_{\substack{i \in S \\ r \in R}} P * c_{ir} * x_i \\
 & - \sum_{r \in R} \Phi_r * \psi_r - \sum_{\substack{i, \hat{i} \in S, \\ i \neq \hat{i}}} \vartheta_{i\hat{i}} - \sum_{\substack{j \in F \\ r \in R}} E_j * \tilde{f}_{jr}
 \end{aligned} \tag{6.3.1}$$

Constraints

C1: Whenever a TTS is 1, all its functionalities are also 1.

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

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 TTS is selected, the dependency 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, that is, 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 resources are used by each TTSs.

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

C7: We limit 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).

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

6.4 Case Study Illustrating the use of the Optimization Model

We illustrate one way of finding parameter values for the proposed optimization model. Here, we assume that the variable costs and resources of functionalities ($f_j, j \in F$) can be estimated in terms of data communicated or processed per TTS ($x_i, i \in S$). This allows for the use of data rates as a proxy for estimating parameter cost values. In the context of road freight transport by heavy goods vehicles in Sweden, the following assessments (estimates) provide data used in the optimization model.

6.4.1 Calculations of Resource Utilization by Transport Telematic Services

To estimate resource utilization by each TTS, we consider the total sum of the resource requirements (for all functionalities of the TTS) of type data communication, voice communication, and so on, as shown in Table 6.1. We assume a scenario where TTSs are accessing the resources simultaneously similar to a saturated network. Data utilization by different TTSs is obtained by reviewing similar existing functionalities implemented in other systems (Esteve et al., 2007; Fukang et al., 2008). An example of typical ranges of data rates for ITS applications is shown in Table 6.1. Since most of the TTSs considered are centered on communication, processing and positioning, we derive the resource estimate as in Table 6.2, including rough estimates of each unit cost.

6.4.2 Cost Calculations for Transport Telematic Services

The cost of each TTS consists of the fixed cost and the variable cost. The variable cost depends on the capacity specification (data rates) of the TTSs.

- I. Fixed Cost ($C_j, j \in F$): The fixed cost of each TTS is the total sum of the fixed cost of all its functionalities. The fixed cost is the entry cost for initial acquisition of hardware and software for providing the functionality. Fixed-cost data sources are project documents related to different TTSs, for example, European projects such as e-IMPACT, CODIA, GOOD ROUTE, ARENA, and ISA trials in the United Kingdom and Sweden (ARENA, 2013; ECORYS, 2006; Kulmala et al., 2008; Malone et al., 2008), and so on. Other sources such as Landwehr and Krietsch (2009); Peng et al. (1999); Zhang (2007) are also used, and in some cases market pricing information is used. Unit costs for each functionality are considered; for example, fixed cost for an OBU is taken as 500 € (McKinnon, 2006). All data are adjusted to the cost equivalent for the year 2011 due to inflation with discount rate = 5% as this value is typically used for ITS investment planning (Xu et al., 2004); that is, the OBU costs from 2006 will become 638.1 € (i.e., $500 * (1 + 0.05)^5$ €). In addition to the total cost of functionalities for each TTS, there are overhead costs and the cost of combining functionalities. This study focuses on the cost of functionalities.

- II. Variable Cost ($C_{ir} \geq 0, i \in S, r \in R$): The variable cost is associated with a fully functional TTS. In addition to the fixed cost, $C_j, j \in F$ associated to the resource units required, $(\Phi_r, r \in R)$, we also include a variable cost directly associated with resource usage, $C_{ir} \geq 0, i \in S, r \in R$, based on the level of utilizing a particular resource $U_r \geq 0, r \in R$. The costs of communicating or processing a megabyte of data, P , is derived from the average data rate of 2000 MB/month communicated per user in Sweden in 2009 (PTS, 2009), which gives a rough average cost estimate of 4.9/2000 €/MB from mobile operators such as tre.se. This cost includes mobile terminal and VAT and hence our estimate for unit data handled by network is $2.9 * 10^{-3}$ € per megabyte per year. Considering each TTS is to be achieved independently of all the others, the estimated total annual cost is for a fleet of 65,000 (registered heavy goods vehicle (HGV) fleet in Sweden).

6.4.3 Societal Value Calculations ($V_i, i \in S$) for Transport Telematic Services

The societal value of each TTS is calculated from the total cumulative percentage reduction of performance saving indicators (PSIs). To obtain PSI values requires aggregate estimates of the costs of accidents, fuel, time and distance, and so on, related to HGV transport for a given region. Different sources reporting statistical data in Sweden have been used to obtain these values, for example, road administration databases. The values of the TTSs are assessed per year. Details of these calculations are provided in Mbiydzenyuy et al. (2012c). The data specification of the optimization model is shown in Table 6.5. For each TTS we specify the total costs and the value calculated. The abbreviations for each TTS and functionality are defined as in Table 6.3 and Table 6.4.

6.4.4 Multiservice Architecture Specification

Following from Figure 6.1, each MSA specification is distinguished based on the type of resources provided, as shown in Table 6.6. The numbers in the resource columns indicate which MSA specification has a key feature that provides a given resource; for example, specifications Z1, Z4, and Z6, indicated by 146 under R1, have a key feature called vehicle-to-vehicle communication, which provides a resource of sensor data modems. Thus, $A_{R1Z1} = A_{R1Z4} = A_{R1Z6} = 1$. An empty cell means no architecture was considered that provides the given resource based on the key feature. We have considered six candidate MSA concepts extended from previous work (Brasche et al., 1994; Persson et al., 2007). The value of $A_{rt}, t \in A, r \in R$ corresponds to the entries in Table 6.6 for each MSA specification. Thus, the availability of resources for each MSA is determined by the key feature (rows) and the corresponding resources allowed by the key feature (columns) as shown in Table 6.6. For each MSA, where relevant, we discuss a similar example, and summarize the key features for a given MSA in Table 6.6. We provide, next, a description for each MSA considered in Table 6.6.

MSA Key Feature (H)	Resources allowed ($A_{hr}, h \in H, r \in R$)							
	R1	R2	R3	R4	R5	R6	R7	R8
Vehicle-to-vehicle communication	1,4,6							
Roadside to server communication	5							
Vehicle to server communication	3	1,2,3,5	6					
Vehicle to roadside communication		4,6	2,3,5				3,6	
Satellite to roadside communication	2							
OBU data processing			1,2,3,5,6					
Multiple server processing			4	4				
Single central server processing					3,5,6	12		
Satellite positioning							4	2,3,5
Data broadcast						2,5		

Table 6.6: MSA specification by key features and corresponding resources allowed ($A_{rt}, r \in R, t \in A$)

- I. Vehicle-to-vehicle (V2V) with centralized communication (Z1): This is similar to a proposed emergency system known as eCall+ (Madrid et al., 2009), which is a variant of the eCall architecture. The eCall architecture has been considered as a potential MSA (Dimitrios and Bouloutas, 2007). Z1 supports R1, R2, R4, and R6 but not R3, R5, and R7. This same interpretation follows for the rest of the MSAs described in the following.
- II. 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, for example, the Switzerland tolling scheme (Oehry, 2003).
- III. Thick client with decentralized data processing (Z3): This is based on using satellites to track vehicles equipped with a receiver antenna or an OBU that is capable of processing data. The results are reported to the control unit for the infrastructure owner and TTS provider, such as the German tolling scheme (McKinnon, 2006).
- IV. Vehicle-to-vehicle (V2V) with decentralized communication (Z4): This is based on a 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).
- V. 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 toll system (Biffel et al., 1996; McKinnon, 2006) based on a 5.8 GHz DSRC (CEN-DSRC) between the OBU and roadside equipment.
- VI. Vehicle-to-vehicle to infrastructure (V2V2I) Hybrid architecture (Z6): This architecture combines the advantages of the V2V and V2I options that were just

discussed. 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 13.4 kbps bandwidth transmission in both directions Miller (2008).

6.5 Results and Analysis

In the context of freight transport in Sweden, the case study is aimed at showing the potential use of the model as support for evaluating different choices of TTSs that can be implemented together and, hence, support different system design choices. Such implementations will allow for sharing expensive infrastructure and associated functionalities such as positioning, communication, and so on. Existing functionalities (e.g., provided by a potential Swedish road user charging (RUC) system) will also be well utilized if TTSs are implemented together in packages.

A scenario of the optimization model is solved with data from the case study using AMPL with CPLEX solver. AMPL provides a modeling interface and a high-level programming environment for building mathematical programming models. With a given data specification, CPLEX and AMPL will return global optimal solutions for convex optimization problems, such as the proposed optimization model.

The following analyses are illustrated:

Q1. What type of TTSs are selected, if in one case we consider a basic specification of a RUC system and in another case we use an advanced specification (RUCA)?

Q2. What is the effect of forcing a particular TTS to be implemented, for example, RUC, RUCA, and so on?

Q3. What is the effect of enforcing different MSA specifications?

The basic RUC system, according to the Swedish RUC ARENA specification (Sundberg et al., 2007), consists 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), and 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 preceding cases are discussed next.

6.5.1 Effects of Different TTS Specifications

The selection of TTSs here is independent of MSA, and hence there is no limitation on resources. The number of TTSs selected based on synergies with RUC and RUCA alternatives is shown in Figure 6.3.

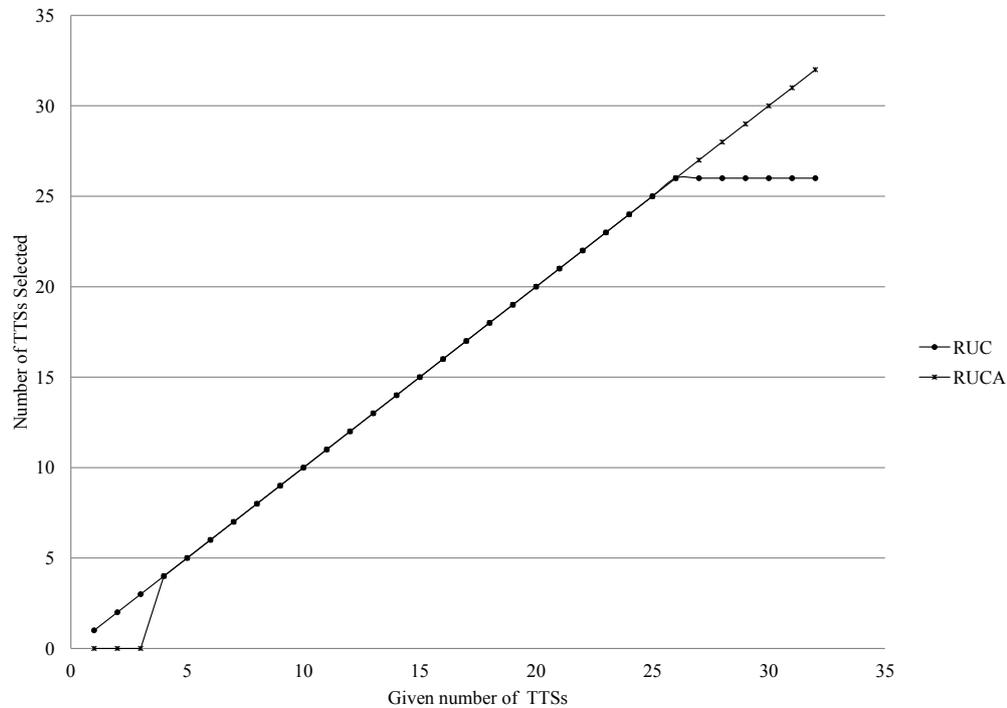


Figure 6.3: Number of TTSs selected with RUC and RUCA alternatives.

In the experiment set up for this scenario, we introduce RUC and run the model. We then introduce RUCA and run the model again. Of 32 TTSs 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, WI, and DTI that were not selected with RUC, whereas with the RUCA alternative, these applications showed positive synergies and hence were selected. In the graph, we run the optimization model with a restriction on the number of TTSs (η) from 2 to 32 (horizontal axis) and plot this against the number of applications selected by the model (vertical axis). Figure 6.3 further shows that there are potentially better synergies with RUCA than RUC, since RUCA selected more TTSs than RUC. The most significant difference is that RUCA selects more TTSs than RUC for $\eta=2$ to 32. RUC did not select DTI, XXL, IRM, ISA, RG, and WI, while RUCA did. All selected TTSs had a different selection order and hence different priorities when RUC and RUCA were considered: for example, for RUCA, the first 10 TTSs selected are EC, RHW, TAR, TRO; AWI, NAV; EDI; SGM; TOH; PYD, while with RUC we have EC, RHW, TAR; AWI, NAV, TRO; EDI; SGM;

TOH; PYD. A comma (,) separates TTSs selected simultaneously, while a semicolon (;) indicates a successive selection of TTSs.

6.5.2 Effects of Enforcing Different TTSs

In this scenario we force the selection of a given TTS by setting $x_i = 1, i \in \{RUC, RUCA\}$. From the results, the total net benefit for RUCA will be negative until more than five applications are included, as can be seen in Figure 6.4. This is in line with results from Figure 6.3, since the selection of applications for RUCA did not take place until more than three applications were included.

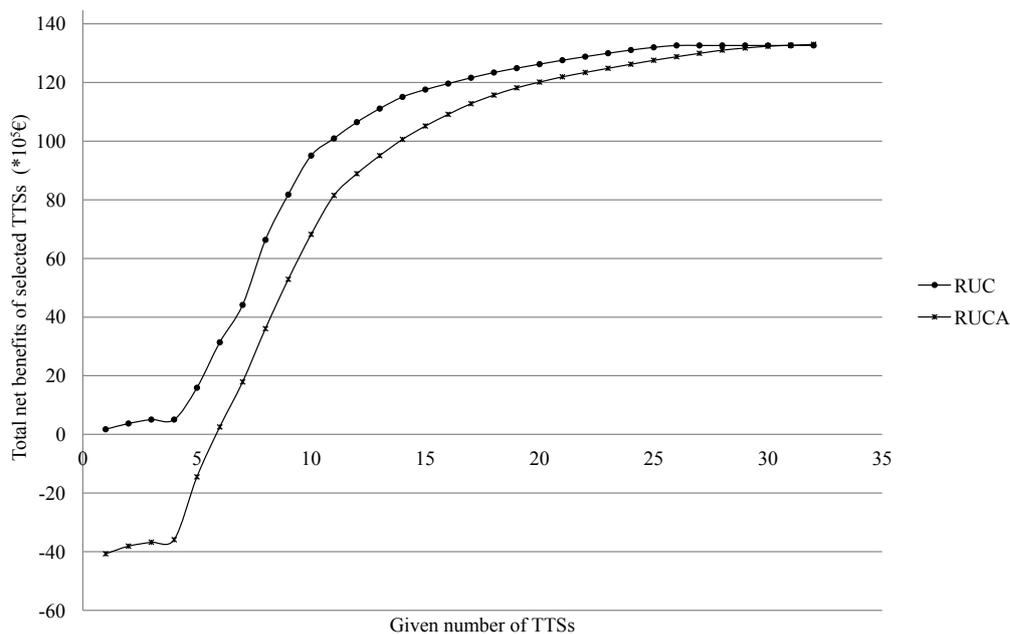


Figure 6.4: Net benefit variation with enforcement of RUC and RUCA.

From Figure 6.4, it can be seen that enforcement is likely to lead to a negative total net benefit for RUCA if only a few TTSs are allowed. The enforcement of RUCA influences the combination of AWI, EC, NAV, RHW, TAR, and TRO to be selected with a negative net profit. The functionalities of RUCA that contribute to this include global positioning (e.g., based on GNSS, GPS), secured vehicle smart card register (obu), vehicle data differentiating between vehicle class (vd), time of day (ts), road type (mp), capability to control congestion (rc) by redirecting traffic to specific roads (rm), and road infrastructure data (ind) collection. This is because the model selects TTSs based on available functionalities. The proposed 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.

6.5.3 Effects of Enforcing an MSA Specification on Selected TTSs

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 show that Z3, similar to a thick client with decentralized data processing, could support more TTSs than any of the other MSAs considered (32 of 32). Also a hybrid V2V2I architecture, Z6, can support nearly as many as Z3 (29 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. Z1 and Z4 selected the lowest number of TTSs.

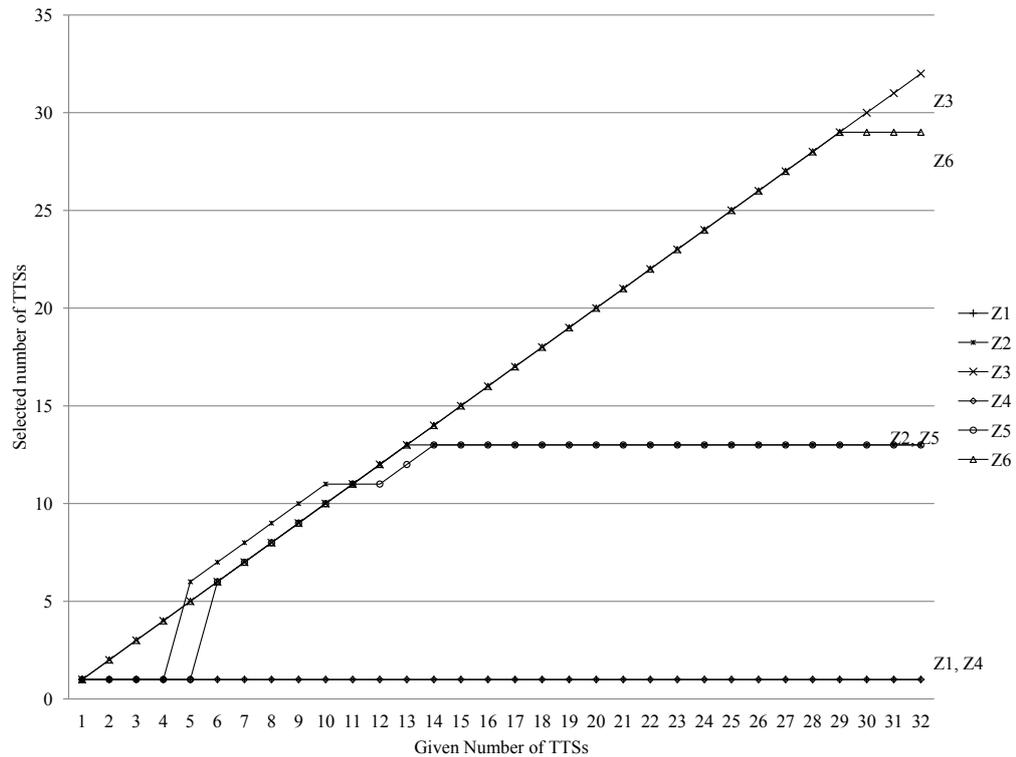


Figure 6.5: Selection of TTS for different choices of platforms.

The progressive selection of applications with given restrictions (from 2 to 32) is shown in Figure 6.5. Results of the total net benefit of selected TTSs shows that Z3 is most beneficial relative to the other MSA specifications. In order of benefits priority, the most appealing TTSs for Z3 are TRO, EC, RHW, SGM, TAR; AWI. Z6 also indicates the potential to accommodate a number of TTSs similar to Z3 except that ETA and PYD are now included instead of EC and RHW in the top selected TTSs. Z2 and Z5 can both support 13 TTSs from the list of 32. In order of benefit priority, Z2 supports similar TTSs (in top selection) as Z3 except that PYD and ADL (as in Z6) but also ETA and DP are

now included while EC, RHW, SGM are not supported at any point in the selection. Z1 and Z4 cannot be chosen as suitable architecture for the 32 TTSs considered because they support very few TTSs. One possible reason why Z3 supports the highest number of TTSs as seen in Figure 6.5 is on account of the choice of functionalities included in the Z3 architecture specification. However, at the same level of net benefit, Z6 will support more TTSs (5 of 32) than Z3 (4 out of 32) as shown in Figure 6.5.

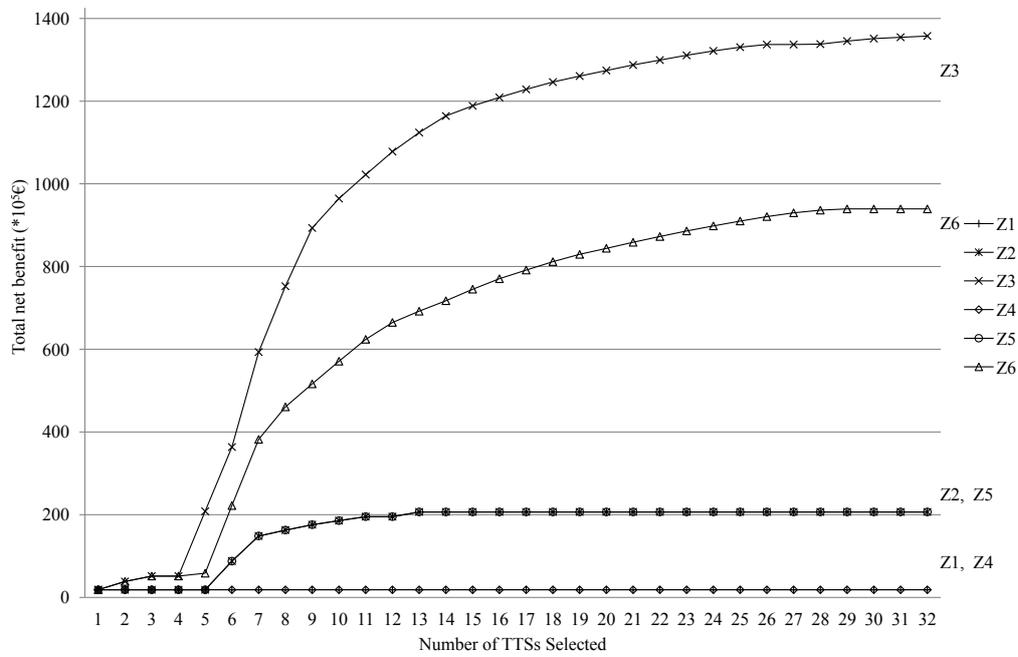


Figure 6.6: Total net benefits (objective function) of selected applications for different choices of MSA concepts.

6.5.4 Conclusions 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. Strategic decisions addressed by the model are those faced by policymakers, 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 TTSs. 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 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; for example, 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. These results differ from the suggestions in our study since the criteria used are not the same. However, most of the studies demonstrate that a common platform for multiple applications will lead to higher net benefits, though they have used different approaches for analyzing such benefits. In the future, the model can further be validated by improving the quality of data, experimenting with different case studies, incorporating quality of service factors, exploring alternative TTS implementations, and studying additional constraints on resources such as communication and processing.

Paper VI

Assessing the Benefits of Intelligent Truck Parking

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The aim of this paper is to identify and analyze important factors related to the benefits of Intelligent Truck Parking (ITP) for different stakeholders (including the end users) in the context of Heavy Goods Vehicle (HGV) transport. Previous work has neither focused on different types of ITP benefits for HGVs, nor on the end user perspective. This article identifies benefit areas and attributes as well as stakeholder groups relevant for HGV transport based on a review of previous research and projects. These benefit areas and attributes are theoretically assessed and compared for different stakeholders using multi-criteria analysis. Additionally, interview results of Swedish drivers' and companies' perceptions of ITP are presented. Comparing results of the interviews with the theoretical assessment indicates that the end users may not perceive ITP as highly beneficial although they theoretically benefit the most. Companies, particularly national haulage companies, express a low willingness to pay for ITP. Both the theoretical assessment and interviews show the potential for ITP to deliver different benefits to different actors across the transport chain.

Keywords Intelligent Truck Parking, Heavy goods vehicles, Stakeholder, User, Benefit area, Privacy, Perceived safety, Willingness to pay

7.1 Introduction

As the volume of cargo transported by road continues to increase, society is looking to new, alternative ways to deal with transportation challenges such as congestion, environmental impact, safety, and security. One such alternative is Intelligent Transportation Systems (ITS), which utilizes advances in Information and Communication Technology (ICT) to provide applications and services intended to promote a safer, more efficient use of the transportation system. In the European Union (EU), Intelligent Truck Parking (ITP) for Heavy Goods Vehicles (HGVs) is a major priority in directive 2010/40/EU (for the coordination of the implementation of interoperable and seamless ITS). As it has been estimated that over 44 % of journeys within international road freight transport require at least one rest break in order to comply with working time directives (Maunsell, 2009), parking infrastructure and information are clearly necessary to help meet the needs of different transport stakeholders, especially professional drivers.

Intelligent Truck Parking (ITP) is concerned with the management of information related to Truck Parking Area (TPA) operations for HGVs. On the parking side, ITP collects data about parking areas (space availability, services and amenities, security), processes the data (e.g. forecasted occupancy level), and communicates the information to drivers (in real time) in order to help them easily locate and make use of parking and associated facilities. Parking information aids in providing relevant options to the driver, although it also raises ethical questions related to the ability to track the position and behavior of individual trucks/drivers, which may limit the drivers' options on when and where to stop.

Progress is being made in laying the foundations for ITP. Projects such as SETPOS (SETPOS, 2013), which aimed to establish a common standard for secured TPAs and

for an ICT platform as well as develop pilot sites, and LABEL (LABEL, 2013) with the objective of establishing a certification system for secure parking areas, are some relevant examples of efforts made in Europe. From the ICT perspective, EasyWay (Kleine and Runte, 2010) has outlined deployment guidelines, and Modi et al. (2011) have developed a new, improved computer vision system to calculate occupancy rates. In Sweden, where ITP is also a priority service in the National ITS Action Plan (Marika and Mari-Louise, 2010), the project East West Transport Corridor II (Udin et al., 2011) looks to identify suitable parking areas, ICT infrastructure, and desirable services as well as develop pilot sites, while the project ITP (Smarta Lastbilsparkeringar) (ITP Project Website, 2013) investigates the need for ITP specifically in the Swedish context, e.g., TPA reservation, and guidance.

In 2011, road traffic accidents in the EU claimed some 34,000 lives and left more than 1.1 million people injured, representing an estimated cost of 140 billion Euros (Chauvin, 2012). Of these, HGVs were involved in 13% of accidents with victims, and 2% of those accidents were associated with illegally parked HGVs (Chauvin, 2012). Further, it is estimated that 27% of cargo theft occurs in non-secure TPAs. ITP is expected to contribute to a broad spectrum of general social benefits, from safety improvements to network efficiency and management (Kleine and Runte, 2010). However, there is currently a knowledge gap in the evaluation of benefits of ITP for HGVs - what specific benefits exist and for which stakeholders? Initial assessments of ITP in Sweden indicate a possible reduction in the cost of missing and delayed goods and a reduction in time-based costs for HGVs (Mbiydzennyuy, 2010; Mbiydzennyuy et al., 2012c). Potential stakeholder benefits of improved HGV parking facilities have also been addressed in the project LABEL (LABEL, 2013). But most studies evaluating advanced parking management information systems have focused on private cars in urban areas (May, 2005; Rephlo et al., 2008; SAIC, 2007; T3, 2010; Thompson et al., 2001) rather than long-distance HGV transport. A number of benefits have been reported by these studies, including load balancing for overcrowded parking areas, reduction in waiting time before parking, as well as travel times and distances (Rephlo et al., 2008). Previous work has neither focused on different types of ITP benefits for HGVs nor on the end user perspective.

The aim of this paper is to identify and analyze important factors related to the benefits of ITP for HGVs and their effects on different stakeholders in society. This study differs from earlier work in that it focuses on HGVs rather than private cars, it takes a broader approach that includes multiple benefit areas, and it identifies the stakeholders accruing the benefits. In addition, the study takes the end users' perspective of ITP into consideration. Results of interviews with Swedish professional HGV drivers and road haulage company representatives are presented and include the perceived effects of ITP on safety and privacy, the perceived benefits of ITP, and the willingness to pay for the ITP service. These empirical results are compared with the literature-based theoretical assessment and indicate that the end users may not perceive ITP as highly beneficial although they theoretically benefit the most. By using both a theoretical analysis of benefits based on information from different sources and interviews of end users, a complementary and more comprehensive approach to assessing the potential benefits of

ITP is presented.

The structure of the remainder of the paper is as follows: Section 7.2 presents the methodology, Section 7.3 describes ITP Benefit Areas (BAs), Sections 7.4 and 7.5 present the results and discussion related to the theoretical assessment and interviews, respectively, and Section 7.6 presents the conclusions and future work.

7.2 Method

7.2.1 Theoretical Assessment

Nine Benefit Areas (BAs) and seven stakeholder groups (see Table 7.2) for ITP are suggested (see Section 7.3 and Table 7.1) based on a review of previous research related to ITP (Kleine and Runte, 2010; LABEL, 2010, 2013; Mbiydzenyuy, 2010), advanced parking management systems such as Garber et al. (2004); May (2005); Rephlo et al. (2008); SAIC (2007), project reports such as BRÅ (2004); LABEL (2013); Maunsell (2009); SETPOS (2013); Udin et al. (2011), and internal project workshops. Additional BAs are identified by observing how different challenges related to TPAs are addressed among stakeholders (Mbiydzenyuy et al., 2012b).

Benefits are typically generated from reducing negative effects or improving positive effects of given attributes (summarized in Table 7.1) (Kleine and Abs, 2007). Thus, each BA is further broken down into benefit attributes or potentially measurable parameters from a rough set theory approach, i.e. BAs are considered to be a composition of attributes. Identified attributes are then assigned nominal values indicating the change required to generate benefits. In addition, some attribute changes are likely to result in higher benefits than others. We distinguish between the following:

- d or D: benefit generated by a decreasing attribute value;
- i or I: benefit generated by an increasing attribute value;
- uppercase D or I: high benefits;
- lowercase d or i: low benefits;
- no change (•): no benefits.

Benefits will be acquired by different stakeholders and are assessed by assigning the following measures:

- X: non-quantifiable benefit;
- €: quantifiable benefit, where a higher number of € symbols indicates higher benefit.

There are 28 attributes chosen to evaluate each BA (Table 7.1) and a detail assessments of various attributes can be read from Mbiydzenyuy and Persson (2012). Weights are suggested for nominal attributes to enable comparison of BAs. Then, for each attribute, one can compare and rank results of different BAs. If we change the attribute (hence the evaluation criterion), the results of the ranking will also change. To manage this, we employ a Multi-Criteria Evaluation (MCE) approach.

Benefit Attributes (expected change, P)	Benefit Area									Estimates, current Annual Status, (Sweden) Magnitude
	B1	B2	B3	B4	B5	B6	B7	B8	B9	
Driving time (0.5)	D	•	d	d	•	•	•	•	d	41 million hours (Mbiydzenyuy et al., 2012c)
Distance-based vehicle cost (0.6)	D	•	•	•	•	•	•	•	•	725 million Euros (Mbiydzenyuy et al., 2012c)
Efficient use of non-driving time (0.6)	•	•	•	i	i	i	•	I	•	Not Available (NA)
Fuel use due to search (0.6)	D	•	•	•	•	i	•	•	•	20% of total (Mbiydzenyuy et al., 2012c)
Emissions due to search (0.5)	D	•	•	•	•	•	d	•	•	NA
Goods theft at TPA (0.8)	•	D	•	•	•	•	d	•	D	100 million Euros (Dinges et al., 2005; Gustafsson et al., 2009)
Vehicle theft at TPA (0.9)	•	D	•	•	•	•	d	•	D	2140 cases (Dillén and Ekwall, 2006; Nilsson and Rosberg, 2008)
Damages (to goods and HGV) at TPA (0.7)	•	D	d	•	•	•	d	•	D	40 million Euros (Gustafsson et al., 2009)
Cost to recover stolen HGVs (0.9)	•	D	•	•	•	d	•	•	•	98 million Euros (Gustafsson et al., 2009)
Accidents from illegal parking (0.6)	•	•	D	•	•	d	d	•	D	NA
Fines from illegal parking (0.6)	•	•	D	•	•	•	•	•	D	47.3 million Euros in unpaid fines (Transportstyrelsen, 2009)
Illegal parking (0.7)	•	d	D	•	d	•	d	•	d	≥ 1.25 million fines for all vehicles (Hoffman, 2010)
Fatigue-related accidents (0.6)	d	•	•	D	d	•	d	•	d	25% of total (NORDIC, 2008)
Violation of driving regulations (0.8)	•	•	•	D	•	•	d	•	d	14.5% of drivers (SARHC Newspaper, 2006), potentially 38% of total (ABC-åkarna, 2008)
Cost of driving regulation fines (0.6)	•	•	•	D	•	•	d	•	d	11,000 Euros (only foreign HGVs) (ABC-åkarna, 2008)
TPA occupancy level (0.8)	I	i	i	•	I	i	•	i	i	14 million Euros (Hoffman, 2010)

Continued on next page

	B1	B2	B3	B4	B5	B6	B7	B8	B9	Magnitude
Search traffic on roads (0.7)	D	•	•	d	d	•	d	•	d	30% total traffic in cities (May, 2005)
Load balancing -TPA overcrowding (0.5)	•	d	•	•	D	D	d	•	•	NA
Load balancing -TPA under-use (0.9)	•	•	•	•	d	D	•	•	•	NA
Cleanliness and quality of service at TPA (0.5)	•	•	•	i	I	i	i	•	•	NA
Companies involved in ITP service provision (0.9)	•	•	•	•	i	I	•	i	•	NA
Newly created services and amenities at TPA (0.8)	•	•	•	i	i	I	•	i	i	NA
Back office administration (0.9)	d	•	•	•	•	D	•	•	•	10% of total cost (SARH, 2008)
Cost of manual control of TPA (0.9)	•	•	•	•	•	D	•	•	•	43 million Euros (HGVs, cars in cities) (Hoffman, 2010)
Accessibility of information for environmentally efficient HGVs (0.5)	•	•	•	•	i	•	•	I	•	NA
Accessibility of availability-related information (1)	•	•	i	i	i	i	I	i	•	NA
Accessibility of amenity-related information (1)	•	i	•	•	i	I	I	i	•	NA
Accessibility of security-related information (1)	•	i	•	•	•	•	I	•	I	NA

Table 7.1: Attribute assessments for each benefit area

Key: i benefit by increase, d benefit by decrease (bold high benefit, non-bold low benefit), • no change

MCE problems have been approached using fuzzy sets, rough sets and optimization-based methods. Rough set theory uses a discernibility relationship to distinguish between different elements in a set (Greco et al., 2001). If multiple criteria containing different preference rules are used (as in our 28 attributes), inconsistencies arise that are difficult to handle with rough sets (Greco et al., 2001). Thus, we turn to the Dominance-based Rough Set Approach (DRSA) proposed by Greco et al. (2001)(see also jRank Weblink (2013); jRanking (2013); Słowiński (2008); Szelag et al. (2013)) for handling such inconsistencies. DRSA therefore provides one way to perform multi-criteria ranking based on a given preference rank. The pseudo-code algorithm for assessing BAs and stakeholders as described in the current section is shown in Algorithm 7.3.1.

7.2.2 Interviews

The Swedish project -ITS and Telematics: Different Implementation Aspects- explores new, additional services, technical solutions and privacy issues in relation to a potential position- and distance-based road user charging system for HGVs in Sweden. This project identifies ITP as a core service having potentially high synergies with such a road user charging system and, thus, includes it as a scenario in the final project phase about end users' (HGV drivers and road haulage company representatives) attitudes toward ITS services.

Structured interviews via telephone were chosen to directly investigate end users' attitudes. A self-administered questionnaire was considered, but judged to be a potential deterrent to recruitment as drivers might be reluctant to dedicate work breaks to such a task. In structured interviews, a quantitative data collection method, each respondent receives the same pre-determined questions in the same order and the questions often have a limited set of predetermined responses. This consistency between individual structured interviews enables data aggregation and comparisons across respondents and time periods. Although context effects of question order cannot be completely eliminated, the nature of the structured interview holds these effects constant. Even though structured interviews traditionally only permit minimal responses, in this case the interviewer allowed respondents to elaborate if they so desired, with additional comments recorded by hand by the interviewer.

7.3 Potential Benefit Areas

ITP benefits are categorized into Benefit Areas (BAs). To enable assessment, BAs are further decomposed into specific benefit attributes.

7.3.1 B1 Parking Search Time

Currently, truck drivers stop earlier than necessary due to the risk of not finding a parking space before exceeding the regulated driving time limit. This means underutilizing the total driving time. In addition, part of the time that would have been used for driving is invested in searching for parking places. Though the drivers' search time (for parking) is unknown, estimates of up to 30 minutes for private cars composing 30% of traffic have been reported for cities such as Stockholm (May, 2005). Many benefits in this area have been reported in connection to private cars (Rephlo et al., 2008; Thompson et al., 2001; UK DfT, 2011).

7.3.2 B2 Parking-related Theft and Damage

A reduction in theft and damage of HGVs and goods will lead to economic savings. Currently, the Swedish National Council for Crime Prevention (BRÅ) reports a steady decrease in the number of vehicle-related crimes over the last decade (BRÅ, 2004), but most of the reported cases occur in or are connected to parking. The use of surveillance cameras can reduce vehicle-related crimes in parking areas up to 51% (Welsh and Farrington, 2007). Poor lighting is considered a primary cause of theft in parking areas (Dinges et al., 2005). Improved parking security contributes to a better work environment, fewer dangers, and help in informed decision-making for drivers (LABEL, 2010).

7.3.3 B3 Accidents as a Result of Illegal Parking

Among the causes of road accidents are collisions with (or obstructions due to) parked HGVs, and such accidents have increased in Europe as a result of driving time regulations (Lehmann and Kleine, 2010). Of the total number of accidents that occurred in Europe in 2011, 13% involved HGVs, and 2% of those were associated with illegally parked HGVs (Chauvin, 2012). Proper parking can reduce up to 10% of parking related accidents (Tyréns, 2010). The Swedish Enforcement Authority reports that 45% (or 47.3 million Euros) of unpaid debt cases in 2008 were related to fines for illegal parking for all vehicles (Transportstyrelsen, 2009). ITP can contribute to reducing illegal parking for those cases in which a lack of parking information negatively influenced the decision of where to park.

7.3.4 B4 Accidents as a Result of Fatigue from Excessive Driving Time

Fatigue-related accidents can be reduced with timely parking information that helps to optimize trip planning in order to ensure that driving time windows are synchronized with TPAs. Survey studies in Sweden indicate that 38% of drivers and road haulage companies have problems with, e.g., complying with driving and rest time regulations (ABC-åkarna, 2008). Random police controls of HGVs on Swedish roads found that 292 out of 2020 drivers had violated driving and rest time regulations. Fatigue-related accidents for HGVs are estimated at 57% (Bergasa et al., 2006; Flores et al., 2010; Ji and Yang, 2002) globally and 25% of all Swedish road accidents (NORDIC, 2008). ITP can aid in reducing those accidents for which a lack of parking information is a contributing factor.

7.3.5 B5 Utilization of Parking Facilities

Load balancing in the utilization of parking areas can be beneficial. Load balancing refers to a reasonable distribution of HGVs across TPAs rather than overcrowding (or

under-use) at a specific area. One aspect of load balancing is the geographic distribution of TPAs. In Sweden, most road segments have less than two hours driving time between TPAs with food services, although many TPAs become overcrowded during peak hours (Dillén and Ekwall, 2006). Advance parking information can help reduce overcrowding, which leads to shoulder damage, restriction of sight, litter, noise, etc. (Trombly, 2003). Related benefits have been reported in the United States (Lindkvist et al., 2003; Rephlo et al., 2008). An up to 30% load increase in car parking area utilization is reported in Stockholm as a result of congestion charging (Local Swedish Newspaper, 2006).

7.3.6 B6 Increased Economic Activity

During the time a vehicle is parked, other activities can be performed at the TPA, e.g. eating, which can generate some economic benefits. Rather than parking illegally or in overcrowded TPAs, efficient utilization of TPAs can improve economic activity involving services and amenities such as maintenance, wash stations, and restaurants.

7.3.7 B7 Perceived Safety

Access to information enhances perceived safety by lowering stress and uncertainty for drivers, particularly along unfamiliar routes or in unfavorable conditions.

7.3.8 B8 Potential to Support Recharging Stations for Environmentally Efficient HGVs

ITP can provide a platform for sharing information related to important infrastructure, which could facilitate the development and use of more environmentally efficient vehicles such as hybrid HGVs (Baker et al., 2010). During rest times at suitably equipped areas, vehicles can take advantage of services such as recharging. Since charging duration is an important factor, ITP information about services and space availability provides a suitable starting point (Chan and Chau, 1997).

7.3.9 B9 Insurance Premiums

As distance-based insurance schemes for HGVs are being adopted (Azudrive-PYD, 2013), the use of historic data can lead to the benefit of adjusting the insurance cost to match the estimated level of risk exposure (Grush, 2005). This should encourage the use of legal and secure parking in order to benefit from reduced premiums.

Furthermore, indirect benefits may be taken into consideration, although this is out of the scope of this paper. For example, an increase in legal, secure parking will likely lead

to fewer incidents, which may improve a road haulage company's reputation, which may lead to increased revenue through increased contract wins (UK DfT, 2010).

```

begin
  for a given context of ITP (e.g. Sweden), identify Benefit Areas (BAs) (nine benefit areas were chosen for ITP in Sweden);
  do
    for each BA do
      begin
        Identify any attributes or parameters for measuring benefits (28 attributes were selected);
        Identify stakeholders connected to ITP (7 stakeholders were selected);
        for each attribute: do
          begin
            Determine the expected level of change due to ITP (p in percent);
            Determine required change to generate benefits (decreasing(D, d), increasing(I,i), no change (●));
            Determine the current measurable impact due to ITP in the case considered;
          end
          Suggest a weight to transform normal attributes to numerical attributes in a matrix →M1 (●=0,d=i=0.5, D=I=1 was chosen to differentiate attribute values);
          Multiply level of change due to ITP by weights ( $p * d, p * D, p * I$ , etc);
          Sum the attribute scores for each BA and sort the BAs (smallest to largest) →O1;
          Apply DRSA to matrix M1 (with help of jRank), where the preference order of the BAs is as in O1 (see Figure 7.1;
          Obtain the ranking of BAs and suggested weights from jRank →W1;
        end
      end
    end
    begin
      For each stakeholder;;
      Identify BAs connected to stakeholder(should correspond to the above);
      for each BA: do
        begin
          Determine likely benefits (quantifiable(€), not quantifiable (X), no change (●));
        end
        Quantify stakeholder group in relation to ITP benefits;
        Suggest a weight to transform normal attributes to numerical attributes in a matrix →M2 (€=0.5, X=0.5, ●=0);
        Obtain the total score and ranking of all stakeholders by summing and sorting  $W2 = M2 * W1$  for all BAs;
      end
    end
    Sum the scores of BAs and sort to obtain the rankings of BAs (smallest to largest) →O2 (see Figure 7.2).
  end
end
end

```

Algorithm 7.3.1: Pseudo-code: DSRA applied to estimate relative differences between BAs

It is important to point out that the anticipated benefits of ITP discussed above are not independent of the types of services that are implemented and used together with ITP, e.g. Navigation and ITP will not lead to the same benefits as Intelligent Speed Adaptation and ITP (Mbiydzenyuy, 2010).

7.4 Theoretical Assessment Results and Discussion

A number of assumptions are necessary to perform the theoretical analysis:

- The total ITP benefit can be decomposed into BAs with each consisting of several specific attributes (taking a rough set theory approach), e.g. parking search time can be assessed with attributes such as driving time, distance-based cost, etc.;
- For each benefit attribute, we can determine the change required to generate benefits, e.g. a decrease in driving time, distance traveled, etc.;
- Since the change in attributes cannot only be linked to ITP, we can hypothetically estimate the change or potential due to ITP (given in parentheses in Table 7.1, first column), e.g., driving time is affected by many factors, but we believe that there is a 50% chance of ITP affecting driving time as accessible parking information will enable efficient planning;
- Finally, we assume there is perfect information flow between ITP systems and ITP to stakeholders.

Stakeholders	Benefit Area									Estimates, current Annual Status, (Sweden) Magnitude
	B1	B2	B3	B4	B5	B6	B7	B8	B9	
Telematic service providers €	X	•	•	•	X	€€€•	X	•	•	NA
Drivers	€€€	€€	€	€€	•	X	X	X	•	NA
Road haulage companies	€	€€	€	€	•	X	X	€	€€	11,000 companies (SARH, 2008)
Goods owners	•	€€	€	€	•	•	X	•	€	NA
Parking infrastructure owners	€	X	•	•	€€	€	•	€	X	NA
Road users	X	X	€	€	X	•	•	•	•	4,882,831 (trucks, cars, buses) (ABC-åkarna, 2008)
Traffic controllers	€	•	•	€€	•	•	•	•	•	NA

Table 7.2: Stakeholder assessments for each benefit area
 Key: € quantifiable benefit (increases with number of €),
 X non-quantifiable benefit, • no change

There are several ways to conduct assessments in order to further specify the information in Table 7.1, which summarizes the authors' perceptions of benefit attributes for each BA. For a study of absolute benefits associated with different BAs and their attributes, it is necessary to carry out field operational tests in which the performance of ITP in the different BAs can be measured via the different attributes (Garber et al., 2004). Due to practical limitations, such field test data is lacking, especially as ITP is still at an infant stage. An alternative approach is to study relative differences between BAs that can be used as a reference for decision-making across a variety of regions and cases. To study such relative differences, it is enough to have information that can help show the differences between BAs for a given attribute, e.g. using numerical weights. To achieve this, we use a weight of 1 for D, I, and €, 0.5 for d, i, and X, and 0 for •. In the case of D, I, d, I, we multiply by each attribute's expected change, p , due to ITP (given in parentheses in Table 7.1, Column 1). In this way, we apply Algorithm 7.3.1.

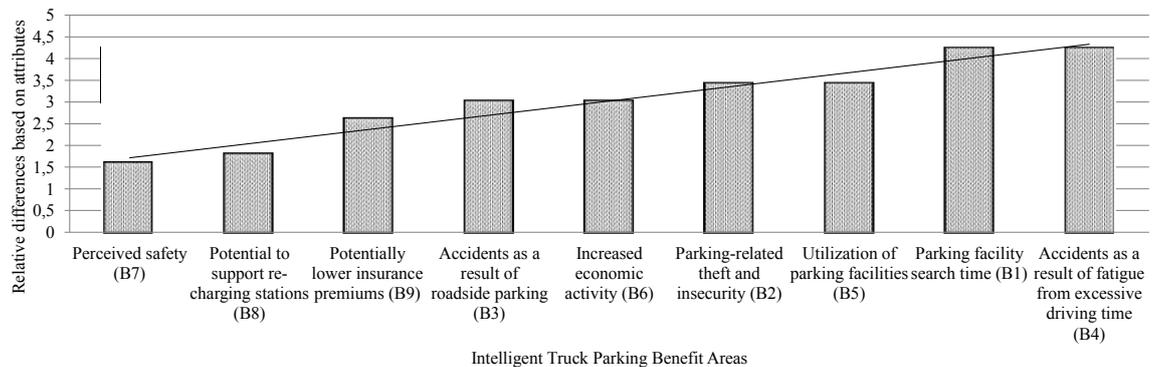


Figure 7.1: Relative differences between BAs on the basis of attribute aggregation with DSRA

The results in Figure 7.1 show that B1 is as good as B4 and B2 is as good as B5 while B3 is as good as B6. The most influential areas for ITP are B1 (parking search time) and B4 (fatigue-related accidents) and the least is B7 (perceived safety).

Applying Algorithm 7.3.1, the total benefit across all areas is assessed for each stakeholder group. The results, in Figure 7.2, indicate that the drivers will be the leading beneficiaries of the ITP service, closely followed by road haulage companies.

Since the above results depend on the nominal scores of the attributes, such results need to be interpreted with care. One way to complement such an approach is to ask the end users themselves about their perspectives on the ITP service. Do the drivers and road haulage companies see themselves as benefiting from the ITP service?

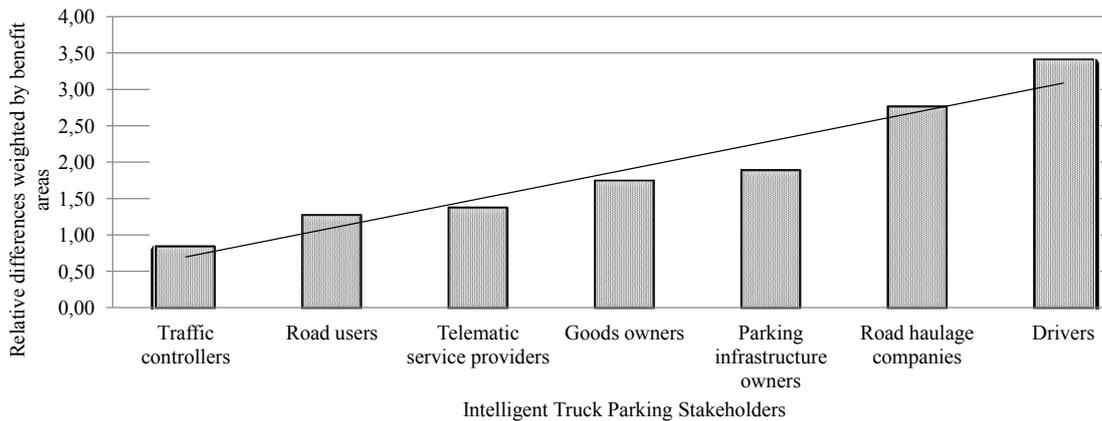


Figure 7.2: Relative differences between stakeholders' benefits on the basis of weighted BAs

7.5 Interview Results and Discussion

Participants were recruited via contact with Sveriges Åkerier (a Swedish trade organization of road haulage companies) and service providers, and Internet searches. The 19 companies who agreed to participate are spread throughout Sweden and represent many types of haulage companies, from international and national long-distance haulage companies to regional delivery and distribution. The resulting convenience sample consists of 30 drivers from 13 of the 19 participating companies and 20 company representatives (as two regional branches from one of the companies participated). Of the company representatives, 13 identified their companies as primarily national haulers and seven as international. They themselves included owners, traffic planners, project leaders, various managers, etc. Table 7.3 provides a key of symbols and overview of the socio-demographic characteristics of the participants.

Key of symbols:

\bar{x} = mean; \tilde{x} = median; s = standard deviation; $[min, max]$ = range

Demographic	Driver	Company Representative
Type of Participant (n)	30	20
Gender	29 male + 1 female	17 male + 3 female
Age (years)	\bar{x} = 44.2, [20, 66]	\bar{x} = 43.9, [20, 64], n = 17
Years of Driving Experience	\bar{x} = 20.6, [1.5, 48]	n = 12 with \bar{x} = 13.75, [2, 30] n = 8 with no experience
Years at Current Company	\bar{x} = 11.2, [0.5, 42]	\bar{x} = 9.9, [0.5, 23], n = 19

Table 7.3: Key of symbols and socio-demographic characteristics of participants

The individual, structured interviews were completed via telephone in the fall of 2010 and the data analyzed using the statistical software package SPSS. Due to the ordinal nature of the data (e.g. Likert Rating Scales of 1 to 5), nonparametric tests were used to test for significant differences ($\alpha = 5\%$) in responses. No significant effects of participant category (driver or representative), age, or driving experience on the responses to the questions about ITP were found.

The ITP scenario in the interview, adapted from the EasyWay deployment guidelines (Kleine and Runte, 2010), described ITP as follows: "The service aims to create systems for information about, management of, and booking of truck parking. It will inform the driver about current parking areas for trucks, if the parking area is monitored, the availability of additional services in the vicinity, and the possibility of booking a spot. The truck parking areas along the road as well as their occupancy levels and services will be seen on the onboard unit in the vehicle and the driver will then have the possibility to plan ahead and book a vacant place via the onboard unit. The driver can then better plan his stops in order to better utilize his time. This also means that the trucking company knows the locations of their drivers while resting, and that the owner and operator of the truck parking area know where the drivers are and what type of goods they are carrying." As this description originates from a separate, but related project (Sjöström et al., 2010), it does not encompass all the attributes listed in Table 7.1, although its contents can be linked to B7 (primarily) as well as B1, B2, B5, and B6. As ITP was just one scenario in the interviews, which focused on issues that are difficult to assess using a theoretical or quantitative approach (such as perceptions of safety and privacy) (Sjöström et al., 2010; Sochor et al., 2012), the interview results serve to complement the theoretical results presented in Section 7.4.

The ITP scenario also contained four rating questions (with one additional question for the company representatives), as illustrated in Figures 7.3, 7.4, 7.5, 7.6, 7.7:

- One question each about how the participant thought this service would affect the driver's sense of perceived safety and privacy, respectively (using a Likert Rating Scale of 1 = Very Negatively to 5 = Very Positively);
- One question each about how much the participant thought this service would benefit the drivers and company, respectively (using a Likert Rating Scale of 1 = Totally Disagree to 5 = Totally Agree);
- One question for the company representatives regarding their willingness to pay for the service (in Swedish kronor) per month and per vehicle (in order to assess the market potential for ITP).

The participants' responses to the questions in the ITP scenario are as follows:

Both drivers and company representatives think that ITP would have a positive effect on the driver's perceived safety ("trygghet" in Swedish, which encompasses the concepts of perceived safety and security as well as connotations of confidence and comfort) (see

Figure 7.3). When considering the positive and very positive ratings, a clear majority of drivers (73%) and company representatives (85%) perceive a positive effect, benefiting the driver. Despite the general agreement that ITP would have a (very) positive effect, two drivers did express concerns over becoming potential targets as criminals may assume that trucks parked at "safe" areas must be carrying valuable cargo.

When formulating the interview questions, we also wished to know if there was a perceived trade-off between safety and privacy when using various ITS services, where one accepts less of one in order to gain more of the other. In the case of ITP, there is no evidence supporting the existence of perceived trade-off of increasing safety perceptions at the expense of privacy as both the drivers and company representatives clearly feel that the ITP service will have no effects on the driver's sense of privacy (see Figure 7.4). Similar results were found in the section of the interview concerning general privacy in the workplace when asking rating questions on the effect of being able to locate a vehicle in real time on the driver's sense of privacy, and on the effect of being able to reconstruct driver behavior with the help of vehicle data on the driver's sense of privacy.

Technically, the Swedish language does not include the word "privacy". In the interview, the closest equivalent Swedish phrase "personlig integritet" was used, which directly translates to "personal integrity". This phrase has many connotations, such as honesty, justice, control, dignity, and autonomy, which may explain the few answers indicating that the ITP service would have a positive effect on drivers' privacy even though it is not a privacy-enhancing service. As some participants pointed out, having vehicle data showing locations, times, and behavior can be advantageous for drivers and companies in that it can be used to settle disputes or to make drivers aware of how to improve their driving style, e.g., staying within the speed limits, and eco-driving. In the case of ITP, being able to prove you were at a certain parking area at a certain time may enhance your "integrity" in the sense that it serves as evidence of your honesty.

Although increased perceived safety is clearly beneficial to drivers, the interview also included questions about the ITP service's general benefit to drivers and companies, respectively. On average, the perceptions of benefit to the driver were neutral (see Figure 7.5) and the perceptions of benefit to the company were slightly positive (see Figure 7.6). Although the driver's perceptions of benefits differed the most (with the company benefits higher), there was no significant difference between how each group rated the benefits to both their own group and to the other group. The slightly higher perceived benefit for the company may reflect the possibility for ITP to ensure a higher level of security for the road hauler's customers and goods carried. Multiple participants mentioned that the use of secure parking is highly influenced by the customers' demands and type of goods to be delivered.

Regarding the neutral benefit of the ITP service for the drivers, the results of this question may appear to contradict the earlier results indicating a positive effect of the ITP service on drivers' perceived safety. In this case, the positive effect on perceived safety does not directly translate to a perception of overall benefit. Why this is so is difficult to determine, but may be due to an already sufficient base level of perceived safety, in

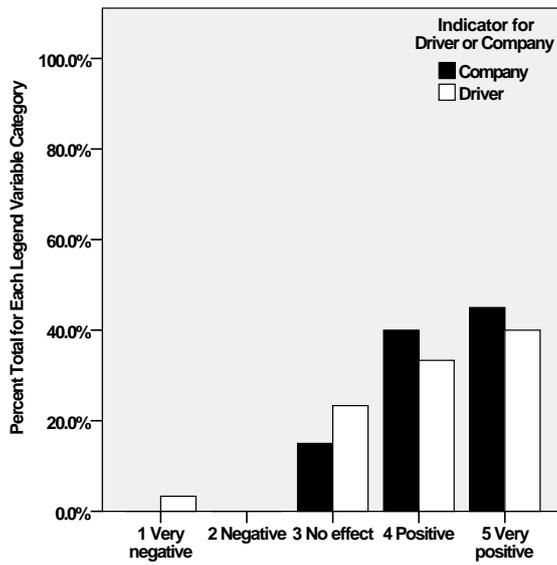


Figure 7.3: Question: How do you think the driver’s sense of perceived safety would be affected by ITP?

Overall: $\bar{x} = 4.16, s = 0.980, \tilde{x} = 4;$
 Drivers: $\bar{x} = 4.07, s = 0.179, \tilde{x} = 4;$
 Companies: $\bar{x} = 4.30, s = 0.733, \tilde{x} = 4;$

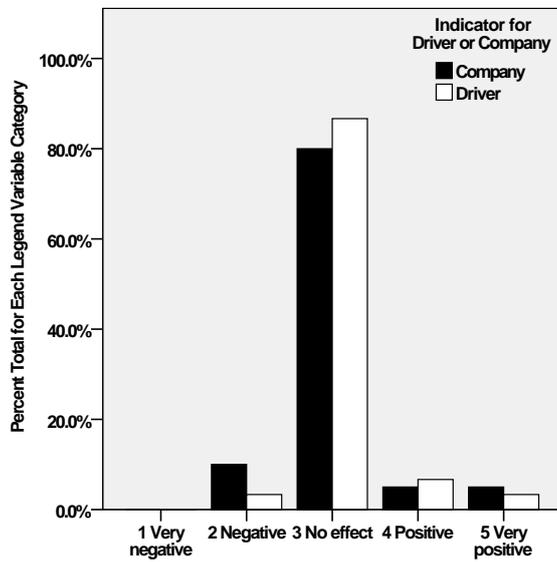


Figure 7.4: Question: How do you think the driver’s sense of privacy would be affected by ITP?

Overall: $\bar{x} = 3.08, s = 0.528, \tilde{x} = 3;$
 Drivers: $\bar{x} = 3.10, s = 0.481, \tilde{x} = 3;$
 Companies: $\bar{x} = 3.05, s = 0.605, \tilde{x} = 3;$

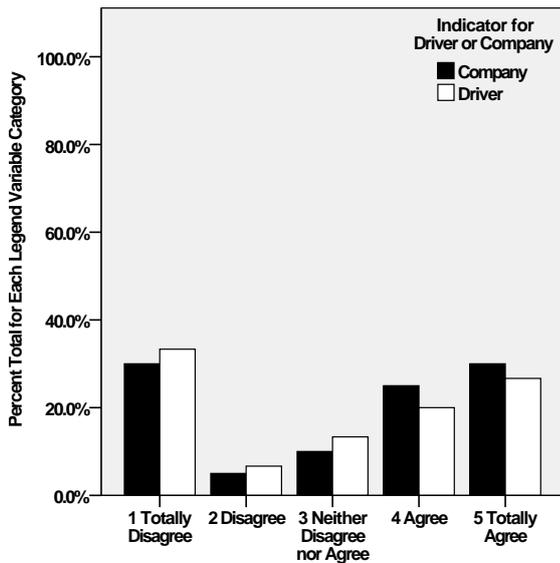


Figure 7.5: Statement: I think the drivers would benefit a lot by having ITP in their vehicles.
 Overall: $\bar{x} = 3.08, s = 1.652, \tilde{x} = 3.5$;
 Drivers: $\bar{x} = 3.00, s = 1.661, \tilde{x} = 3$;
 Companies: $\bar{x} = 3.20, s = 1.673, \tilde{x} = 4$;

which case an improvement would be more of a bonus than a necessity. Also, perceived safety is only one of the possible benefits of ITP, as discussed above, and the end users may not prioritize it as highly as other benefits, which illustrates the importance of asking complementary questions. As seen from the next question, a positive impact on perceived safety will not either translate into a high willingness to pay.

The neutral to slightly positive perceived benefits to the drivers and companies, respectively, translate into a low willingness to pay on the part of the companies. Half of the company representatives stated that they were not willing to pay anything at all (per month and vehicle) for the ITP service (see Figure 7.7). One company representative commented that there is, in general, no margin for extra costs in the haulage sector. Another commented that they would be willing to pay to park at a parking area, but they wouldn't be willing to pay for information about such an area or for booking a parking place at it, analogous to an individual finding and booking versus paying to sleep in a hotel. It should be noted, however, that 80% of those not willing to pay had identified themselves as primarily national haulers. Considering that one representative and two drivers added that the ITP service was much more relevant for international or night trips than for regular, urban, or national trips, this could partially explain the national haulers' lower willingness to pay.

Of those company representatives (half national haulers and half international) willing to pay for the ITP service, 20% stated they were willing to pay up to 50 SEK and 20% between 50 and 100 SEK (1 € is worth just over 9 SEK as of August 2011). Assuming these 50% of companies willing to pay are representative of the Swedish HGV fleet (i.e. half of the approximately 65,000 vehicles will have the service), and assuming a revenue estimate of 5 € per vehicle per month (which falls in the lowest positive category), the annual revenue amounts to 1.95 million Euros. This is far less than the cost estimate for nationwide deployment (49.2 million Euros) in Sweden (Mbiydzennyuy et al., 2012c).

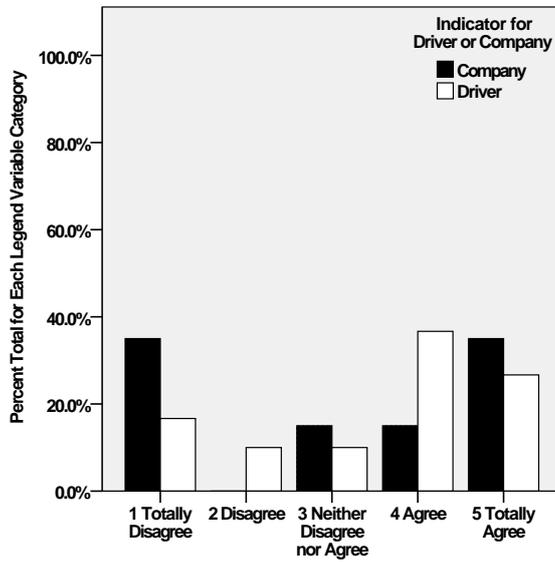


Figure 7.6: Statement: I think the company would benefit a lot by having ITP in their vehicles.
 Overall: $\bar{x} = 3.34, s = 1.560, \tilde{x} = 4$;
 Drivers: $\bar{x} = 3.47, s = 1.432, \tilde{x} = 4$;
 Companies: $\bar{x} = 3.15, s = 1.755, \tilde{x} = 3.5$;

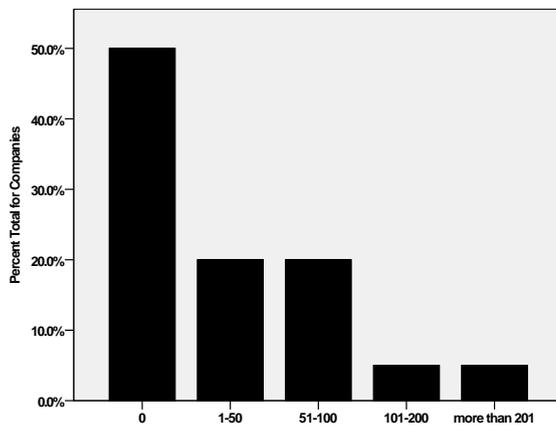


Figure 7.7: Question: How much do you think ITP is worth in Swedish kronor per month and vehicle?

7.6 Conclusions and Future Work

The aim of this paper was to identify and analyze important factors related to the benefits of Intelligent Truck Parking (ITP) for different stakeholders (including the end users) in the context of Heavy Goods Vehicle (HGV) transport. The paper compares results from a theoretical assessment with results from interviews with HGV drivers and road haulage company representatives. For the theoretical assessment, potential ITP benefits are deconstructed into Benefit Areas (BAs), measurable benefit attributes, and stakeholder groups. Using a Dominance-based Rough Set Approach (DRSA) with the identified attributes functioning as multiple criteria, the BAs are ranked with B1 (parking search time) and B4 (fatigue-related accidents) achieving the highest rank. The stakeholders' relative benefits are then estimated with the help of weights derived from the DRSA rank. Results of this theoretical assessment indicate relatively higher ITP benefits for HGV drivers and road haulage companies, followed by goods owners and parking infrastructure owners.

The interviews investigating the drivers' and road haulage company representatives' attitudes towards ITS services included a scenario about ITP. The results indicate that ITP will contribute towards the drivers' perceived safety and not invade their privacy. The benefit of ITP for the company is perceived as slightly positive and marginally higher than the benefit to the drivers, which is perceived as neutral. This also translates into a low willingness to pay on the part of the companies, especially by national haulage companies, the majority of which are not willing to pay anything for the ITP service. Based on the company representatives' estimates of the worth of the ITP service, the annual revenue is approximated at 1.95 million Euros, which is significantly lower than the initial implementation cost.

The theoretical assessment addresses benefits from the perspective of ITP's potential contribution towards alleviating transport-related challenges and concludes that the end users benefit the most. The interviews with the end users indicate that they recognize the potential for ITP to positively impact safety perceptions, which complements the positive impacts anticipated by the theoretical assessment in the areas of search time (B1) and fatigue-related accidents (B4), etc. Both the interviews and theoretical assessment illustrate the potential for ITP to deliver different types of benefits to different actors across the transport chain. There are indications that drivers and road haulage companies should welcome the ITP initiative as they theoretically stand to benefit the most, although they may not yet recognize it. Despite ITP's potential, it could be hard to deploy as a standalone service due to the potentially high start-up cost (relative to the estimated annual revenue). One way to address this is to package ITP together with other ITS services in order share infrastructure on multi-service platforms.

Further work should include gathering experimental data in order to quantify the overall benefits of ITP generated by all benefit areas and attributes in order to assess the opportunity cost, i.e., the benefits lost if ITP is not implemented. Then the opportunity cost could be compared to the market potential of ITP, i.e. the companies' willingness to

pay. Additional further work should include an in-depth stakeholder analysis specifically on the ITP service via, e.g., a Delphi study or extensive interviews in order to gather stakeholder viewpoints on all benefit areas. Also, one could quantify the suggested benefit areas for a specific case, assess the differences in benefits for HGVs versus private cars, and identify and analyze ITP subservices.

Paper VII

Problem-driven Design of Core Services for the Deployment of Intelligent Truck Parking

Mbiydenyuy, G., Persson, J. A., & Davidsson, P.

NOTE: This is an extended and revised version of:

Mbiydenyuy, G., Persson J., & Davidsson, P. (2012). Proposed ITP core services for the deployment of Intelligent Truck Parking. *19th World congress on Intelligent Transport Systems, Vienna, Austria*

A set of Transport Telematic Services (TTSs) is suggested to facilitate the realization of the Intelligent Truck Parking (ITP) concept. This concept includes the collection, processing and delivery of information about truck parking areas that may take place during the planning and execution of transports. In order to successfully implement ITP, the needs of key stakeholders, such as truck drivers and parking area operators, have to be addressed. We suggest a set of core services for handling these needs. The core services are specified based on what kind of information is exchanged among the stakeholders, as well as, when and where the information is exchanged. Hence, we suggest (i) Information on the status of truck parking areas, (ii) Goods and vehicle safety assurance information, (iii) Parking location guidance, and (iv) Parking reservation, as the ITP core services. A system design oriented approach driven by the problem(s) faced by each key stakeholder is used to identify these services. Different functionalities for composing the services are identified. Through an analysis of the core services, the basic infrastructural requirements are identified, as well as a potential platform for implementing the core services.

Keywords

Intelligent truck parking, transport telematic services, problem-driven design

8.1 Introduction

Intelligent Truck Parking (ITP) has the potential to achieve efficient information exchange related to Truck Parking Areas (TPAs). Such information can improve the overall performance of the transport system (Directive 2010/40/EU, 2010; Kleine and Runte, 2010; Marika and Mari-Louise, 2010; Schwarz, 2010). This article suggests Transport Telematic Services (TTSs) to facilitate the realization of Intelligent Truck Parking (ITP) concept. We refer to such services as ITP core services. The services are identified through a simple problem-driven backward reasoning process, i.e., from problems faced by stakeholders working with parking, to information required to solve the problems. Moreover, the functionalities necessary to compose ITP core services have been identified. Information entities required by the functionalities are also suggested. The approach used in this article for identifying and structuring ITP core services provide many advantages. For instance, requirements on a possible platform for implementing such ITP core services can be assessed. Also, various options for designing ITP core services can be explored. We illustrate how an assessment of the choice of a suitable platform for ITP core services can be performed. The work in this article can be seen as an extension of previous work (Jevinger et al., 2011; Mbiydzennyuy, 2009; Nottched et al., 2011; Udin et al., 2011) combined with techniques from structured design for software systems (DeMarco, 1979; Gooma, 1984).

The purpose of suggesting ITP core services is to address different needs of key ITP stakeholders, such as drivers, TPA operators, in relation to problems related to truck parking. Therefore we consider ITP core services as TTSs that support efficient exchange of information among TPA operators, back office operators and truck drivers, etc, with a focus on specific needs for different stakeholders. This information exchange is

already the base for achieving today's parking solutions, e.g., through phone calls, electronic road signs and so on. ITP is gaining momentum in Europe and around the world. In the EU directive 2010/40/EU, laying the framework for Intelligent Transport Systems (ITS) deployment in road transport, ITP is considered to be one key area. The emphasis in achieving ITP is to provide information and reservation services for safe and secure parking places for trucks, and to facilitate electronic data exchange between road sites, centers and vehicles (Directive 2010/40/EU, 2010; Schwarz, 2010). In the national ITS action plan for Sweden, terminal and secured parking is considered as a specific focus area under goods transport (Marika and Mari-Louise, 2010). The East West Transport corridor project (Udin et al., 2011) addresses strategies for realizing ITP in the context of a transport corridor (south Sweden) raising the need to deploy parking reservation services. The project Intelligent Truck Parking ("Smarta lastbilspareringar") investigates the needs of ITP specifically in the Swedish context, e.g., TPA reservation, and guidance (ITP Project Website, 2013).

The European project, LABEL, suggests levels of classification of the truck parking service, mainly, according to availability of facilities such as lavatories, and restaurants (LABEL, 2013). Similarly this article addresses ITP in the context of information management associated to TPAs, and then suggests the core TTSs to help address specific needs of stakeholders. If we identify "what" information is being exchanged, "when" and "where", the overall accuracy and efficiency of the information exchange can be improved with the capabilities of present day telematic systems. ITP aims to support management and operation of activities related to truck parking. To realize these tasks with the help of ITP core services, information typically available today on road signs, electronic displays about TPAs needs to be processed and channeled to stakeholders. The information can then be delivered via wireless communication networks to mobile devices such as smart phones, and on board units. Conversely, stakeholders such as drivers can communicate their parking needs to TPA operators. Information about changes during the journey, e.g., traffic flow speed, delays, and also at parking, e.g., occupancy rate, can be exchanged between stakeholders. By so doing, ITP can address the needs of various truck parking stakeholders.

The premise for achieving the proposed services is that processing of service information will be achieved within digital environments such as desktop, on-board unit or mobile phone with wireless enabled communication capabilities. In order for ITP core services to provide efficient solutions for identified truck parking problems, the right type of information has to be provided. Such information has to be provided in the appropriate moment and location required by a stakeholder. Therefore we summarize these requirements on ITP core services in terms of {what, when and where} attributes for both input/output of ITP core services. We have identified for each ITP core service, the type of information involved, when the information is needed/provided and where the information is located/delivered.

8.2 The Concept of Intelligent Truck Parking and Core Services

The concept of ITP presented here is inspired by the specification of directive 2010/40/EU and work done in the EasyWay project (Directive 2010/40/EU, 2010; Smith et al., 2005). The concept focuses on;

- Information exchange between stakeholders such as, drivers and TPA managers. Parking managers will provide information, e.g., about parking occupancy rate, and facilities, but drivers will also have to provide inputs to parking operators, such as desired parking space, anticipated time of parking and so on. The purpose of this information is to address some of the challenges facing various stakeholders.
- Gathering of information related to the current status of infrastructure such as TPAs, and interconnecting road networks from sources such as; the Swedish National Road Database (NVDB), traffic information centers, and weather information systems. The information can be relevant for a specific TPA or a larger geographic area with many TPAs. The focus is to identify other sources of information required or generated by truck parking stakeholders.
- Information processing, e.g., this could be by way of applying simple status updating, aggregation and filtration techniques, or even, advanced data mining techniques. Processing help synthesize valuable information, e.g., TPA occupancy prediction, and estimated time of arrival.
- Site monitoring of important activities within TPAs, for instance, with the help of geo-fencing to prevent unauthorized activities. Control strategies are available for enforcing ITP, e.g., ensuring that users only access the "right" facilities.
- Information concerning the identification, positioning, and communication of knowledge about HGVs, as well as locations of activities of traffic obstacles within the network, is also vital for successful realization of ITP.

Based on the above ITP concept specification, as well as the challenges faced by key stakeholders involved in truck parking, ITP core services are suggested. Figure 8.1 shows a simple problem-driven reasoning process toward identifying ITP core services. Further, the proposed approach allows for a specification of two levels of ITP core services in a way similar to structured design for software systems (DeMarco, 1979; Gomaa, 1984). First, a description that highlights the information required to address a specified task for given stakeholders. We refer to such a description as an Abstract Level Service Description (ALSD). Second, a specification that enable the internal elements of the service to be identified for further analysis. We refer to this as the Concrete Level Service Description (CLSD). The ALSD motivate an ITP core service by focusing on the information generated, the specific problem addressed and stakeholder(s) involved. The

CSLD enables a detail specification and analysis of the crucial elements that are required in the design of the ITP core service, such as computational requirements, important platform capabilities, and data requirements.

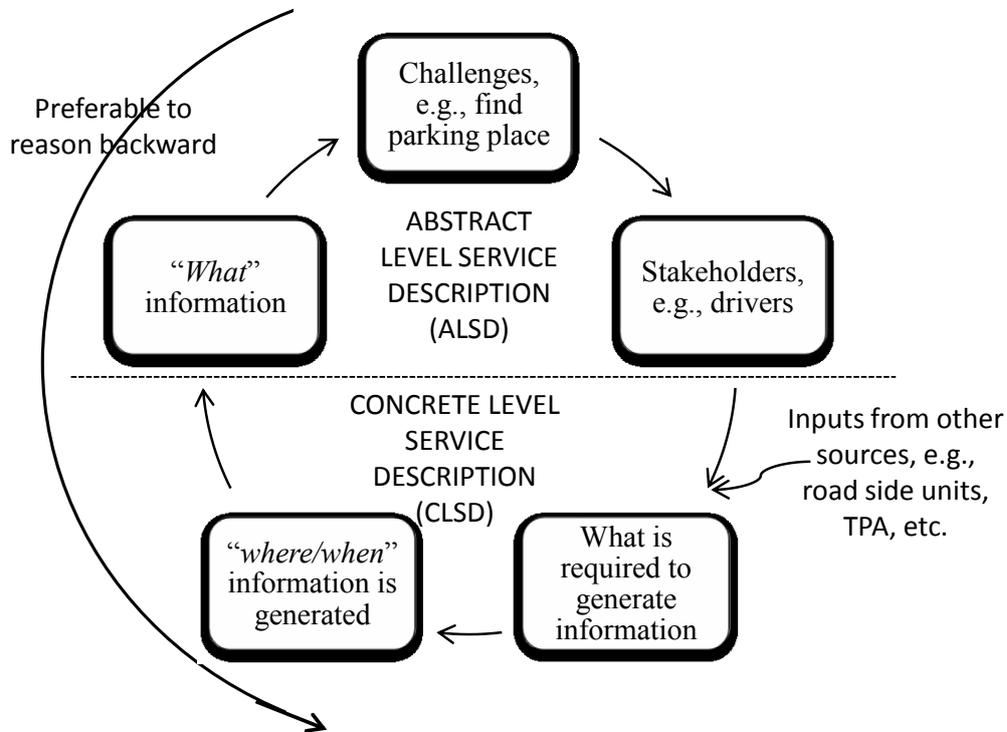


Figure 8.1: Simple problem-driven reasoning process toward identifying ITP core services.

This kind of problem-driven reasoning approach is common in engineering organizations whereby designers focus closely on the problem at hand and only use information and knowledge that is strictly needed to solve the problem with emphasis on defining the problem, and finding a solution as soon as possible (Kruger and Cross, 2006). There is empirical evidence that problem-driven design approaches are capable of producing best results in terms of the balance of both overall solution quality and creativity when compared to other approaches such as solution-driven, information-driven, technology-driven or knowledge-driven design approaches (Kruger and Cross, 2006; Marmaras and Pavard, 1999). The framework for identifying ITP core services can be described as follows:

STEP I: Identify important challenges for stakeholders that deal with truck parking. Challenges could be identified from interviews, workshops, review of documentation from other projects, but also from research articles. In the current article, literature reviews, internal workshops and seminars contributed to ideas for identifying important challenges. A summary of the main challenges related to various stakeholders is

presented in Table 8.1:

Challenge	Concerned stakeholder(s)
How to monitor the utilization of TPA.	TPA manager (infrastructure provider)
Knowledge about TPA activity status.	TPA manager, HGV Drivers
Ensuring safety of vehicle and contents when parked.	HGV Drivers, goods owners, vehicle owners (haulage company).
Difficulties in driving to parking due to lack of information about directions.	HGV Drivers, TPA manager
Uncertainty as to the availability of a parking place at a specific TPA.	HGV Drivers, TPA manager

Table 8.1: Stakeholder challenges related to truck parking activities

STEP II: Identify "what" type of information is exchanged/shared among stakeholders, when dealing with the challenges identified in STEP I, i.e., the Information Entities (IEs). Such information could be an address of a TPA, charging rates, available facilities and so on, depending on the challenge in question. We choose to show the IEs in connection to the ITP core services.

STEP III: Identify "where/when" information is generated or needed. The information could be generated from the TPA operator database system, from a driver, from one or several stakeholders, or from site-based systems at TPA, etc. This may be regularly or randomly.

STEP IV: Identify what is required to generate necessary information. For instance, the information can be generated when a vehicle enters or exit a TPA.

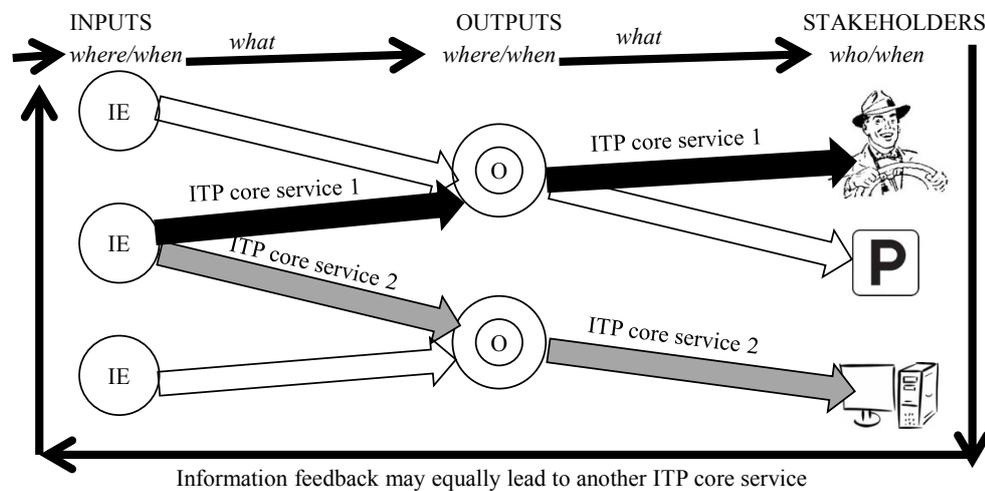


Figure 8.2: A Framework for identifying ITP core services (outputs are also IEs).

While STEPS I and II are focused on establishing the ALSD, STEPS III and IV addresses CLSD. At the end of STEP IV, depending on the possibilities for achieving "how" the required functionalities can be implemented, it may be possible to suggest a candidate

ITP core service. An ITP core service may require more than one input, produce more than one output and may be directed to more than one stakeholder or other (sub) systems. Other criteria such as affordability or costs, business model, and security, may be used to narrow down to more reasonable choices of ITP core services from possible candidates. Figure 8.2 presents the modeling process of identifying ITP core services. As an example, consider Table 8.2:

Abstract Level Service Description (ALSD)	Concrete Level Service Description (CLSD)	Stakeholders
STEP I	STEP II	STEP III
<p><i>"challenge"</i>: Uncertainty, as to the availability of a parking place at a specific TPA</p>	<p><i>"what" (Output)</i>: Parking space availability (yes/no). Initialization: booking request =TPA ID, time/date, driver or HGV ID</p>	<p><i>"where" (Input)</i>: driver on-board, e.g., vehicle; Back office system, <i>"when"</i>: user request</p>
		<p><i>"how"</i>: Compute appropriate functions and deliver to user e.g., as mobile phone message or voice; OBU, PDA, Internet</p>
		<p><i>"who"</i>: HGV Drivers, TPA manager, (hauler company if back office)</p>

Table 8.2: Modeling ITP concept for designing ITP core services

8.3 Proposed Intelligent Truck Parking Core Services

Each proposed ITP core service is presented taking into account previous suggestions for the description of ITS services (ITP Project Website, 2013; Mbiydzennyuy, 2009).

TTS Label: Unique ID of ITP core service.

Needs and Domain of usage: the challenge to be fulfilled with ITP core service.

Users: Stakeholders that are facing the challenge being addressed.

Abstract Level Service Description: A description of the operational characteristics of the ITP core services including:

- Minimum inputs {what, when, where}: this is required to initialize the service. Potentially more inputs are needed for the service to be delivered.
- Minimum outputs {what, when, where}: information required to take measures toward addressing the identified challenge. This could also be an action, e.g., physical barrier from using a reserved parking space.
- Available specific pre-conditions for implementation.

Concrete Level Service Description: These include:

- Additional Information Entities (IEs) used or generated, during the service delivery other than the final information delivered to the user.

- Implemented functions for generating information.

In the following subsections, ITP core services are proposed.

8.3.1 Core Service: Information on the Status of Truck Parking Areas - TPU

The main challenge behind this ITP core service is to enable TPA operators to monitor the utilization of facilities in TPA, and hence decide, e.g., when to deploy more or less resources. An additional challenge is to share information about occupancy level with drivers. This information will help drivers make a decision about using parking space in a TPA (Modi et al., 2011). Therefore, the aim of the TPU service is to improve the availability of occupancy information (digital information) about truck parking facilities by communicating information about the status of such facilities. Information can also be about; toilets, restaurants, truck wash, electricity, snow/ice removal equipments, bar, laundry, spare parts shop, etc. Specific information about the parking status include: occupancy status information of TPA (IE3), occupancy status estimation of TPA (IE4), and regulations specific to TPA (IE5). All data concerning parking occupancy and current vehicle location (in case of suggesting a TPA) is collected and processed to deliver information to users. If TPU is designed to provide information concerning regulations (see IE19), this can only be under the assumption that information concerning regulations about TPA is accessible from respective databases. The service is initiated either by a request for booking (IE1) or when a parking space status changes between idle/busy (IE2).

INPUTS	OUTPUTS
What \in {IE1, IE2}	What \in { IE3, IE4, IE5}
When \in {random upon request, change in parking space status}	When \in {Anytime, Upon request, Event: change of parking space status}
Where \in {back office: TPA system}	Where \in {in vehicle, roadside, back office: hauler company, TPA system}
IEs	Description
IE1	Booking request (parking)
IE2	Change in the state of TPA, busy/idle
IE3	Expected duration parking a parking space at TPA
IE4	Information about prognosis or forecast of entire TPA
IE5	Information about regulations applicable in a given TPA

Table 8.3: Basic inputs, outputs and IEs identified for the TPU service

In Table 8.3, input and output IEs are specified. Note that information concerning a specific truck parking space is different from information about the entire TPA.

Concrete Specification of Service Processes for TPU

As an example, to generate the IE36- occupancy status information of TPA, IE43- occupancy status estimation of TPA, aggregation of information (IE45) about parking spaces is required. The information can be achieved as follows:

B_{00} (initialization): a booking request is received (IE1).

B_{11} : check the occupancy level of the parking for which the request has been made. The input is the address of the TPA (IE6), aggregated status for the entire TPA (IE8) and the forecast for parking utilization (IE5). The output is the occupancy estimation (IE4). We can then represent this entire process using a function called B_{11} by $B_{11}^{IE6,IE7,IE8 \rightarrow IE4}$. If parking is 100% full end report negative, otherwise continue to B_{12} .

B_{12} (alternatively): we assume a function can be implemented called the parking space allocation function, which indicates whether there is an available free parking space. If there is, then B_{11} is not executed. The input is a signal, indicating the movement of an HGV in/out from the TPA (IE21) we represent this by $B_{12}^{IE1,IE22 \rightarrow IE4}$. If either B_{11} or B_{12} is true, then continue to B_{13} .

B_{13} : check the specific parking space and estimate if the requested duration slot is available. The input to this process is IE1-booking request (parking) with information about the parking duration. The output is IE3- duration of status (free/busy) calculated from parking system, and the process can be represented by $B_{13}^{IE1 \rightarrow IE3}$.

B_{14} : calculate aggregated status of the TPA at any given period (IE8). The input is the parking spaces that were assigned (based on IE3) within a given time compared to the static available capacity of TPA (IE9). The process can be represented by $B_{14}^{IE1,IE9 \rightarrow IE8}$. IE8 is input to B_{11} .

B_{15} : calculate forecast of TPA utilization based on historical booking information for each parking space (IE10), special event schedules (IE11), the short term occupancy estimation (IE12) and static capacity of TPA (IE9). The output for this function is IE5-parking status forecast (for each parking space), and the process can be represented by $B_{15}^{IE9,IE10,IE11,IE12 \rightarrow IE5}$. The output information may also serve as inputs to a function that determine the price of the parking space, for instance when using dynamic pricing.

B_{16} : we look up the name of the TPA obtained from the request, then we look up the same name in the digital map database (IE14) and since we know the unique geographic coordinates (IE13) for each TPA and its name (from database of TPAs, IE6), we can verify that the right TPA is being allocated. This function returns the validated parking address (IE15), i.e., $B_{16}^{IE13,IE14,IE6 \rightarrow IE15}$.

B_{17} : search available databases for regulations that are specific to the current parking address, e.g., parking service hours, dimensional restrictions, and cleaning and hygienic rules. This can be obtained based on the information provided by each TPA (IE17) and information about regulations concerning TPAs from other databases (IE18). This will return applicable regulations for a given TPA, IE19: $B_{17}^{IE17,IE18 \rightarrow IE19}$.

B_{18} : Estimate the short term occupancy of TPA (IE12), e.g., based on request (IE1) together with current location (IE10, IE11), exceeding maximum driving time (IE20) and in need of TPA. The reason for estimating the current position of the vehicle is to determine the likelihood that a parking space will be occupied in support of the forecasting information. In addition, if a vehicle which has made a reservation is close enough to the TPA and will be arriving on time, the reservation will be confirmed, otherwise, an alternative measure, such as, re-allocation of parking space is performed. $B_{18}^{IE1,IE11,IE13,IE20 \rightarrow IE12}$. A processing function is required at each step to aggregate intermediary input to final output.

Information on the status of Truck Parking Areas -TPU	
Functionality	Explanation
$B_{11}^{IE6,IE7,IE8 \rightarrow IE4}$ parking space occupancy assignment function	IE6- database of TPA addresses, IE7-Information about prognosis or forecast of entire TPA, IE8- Aggregate information about status (busy/idle) for entire TPA
$B_{12}^{IE1,IE22 \rightarrow IE4}$ parking space allocation function	This may be based on detecting entry/exit of HGVs in TPA - IE21
$B_{13}^{IE1 \rightarrow IE3}$, duration estimation function	Manage parking slot time windows
$B_{14}^{IE1,IE9 \rightarrow IE8}$ Calculate total number of free/busy parking spaces in a time interval	IE3- Information about occupancy status of TPA, e.g., number of available places, IE9- Information about static parking capacity
$B_{15}^{IE9,IE10,IE11,IE12 \rightarrow IE5}$ calculate prognosis of parking spaces from historical data	IE10- Historical booking information, IE11-special event information, IE12-short term occupancy information
$B_{16}^{IE13,IE14,IE6 \rightarrow IE15}$ Calculate forecast for use of TPA	IE13-information about geographic coordinates, IE14-digital map information in database
$B_{17}^{IE17,IE18 \rightarrow IE19}$ regulations search and update function	IE17-information provided by TPA, IE18-regulations about TPAs from other databases
$B_{18}^{IE1,IE11,IE13,IE20 \rightarrow IE12}$ current HGV position estimation function	IE20- Parking request to avoid exceeding maximum driving time

Table 8.4: TPU processes showing how IEs are generated

It is worth noting that B_{11} to B_{18} are not described in sequential order, i.e., as will occur during service execution, except for B_{11} , that initiates the service. Rather, the breakdown into steps is more for the purpose of explanation. In practice there are several steps that could occur in parallel, e.g., B_{13} and B_{14} . Others may need to be sequential, e.g., B_{12} must come before B_{13} . Finally we summarize the processes above in a Table 8.4.

8.3.2 Core Service: Goods and Vehicle Safety Assurance Information- GVS

Due to fear of insecurity in some situations, drivers, good owners or vehicle owners are worried about the status of the vehicle and its content especially when parked in a less secured TPA. The main aim of this TTS is to provide information notification (text and audio) to drivers (and relevant authorities) that assures them of the safety of the HGV and goods (IE23), i.e., minimizing risks of damage, sabotage or theft to HGV

and goods, within a Designated Area of interest (DSA). One way to achieve this is by detecting physical intrusion (such as humans) into a designated area with a given radius (IE22) containing the location HGV and goods (IE13, IE14), then communicating the information to the authorized agents for appropriate responsive measures, e.g., using a geo-fencing system. In addition detection of incidents such as fire or damage from other HGVs maneuvering to a parking place can also be reported. The TTS will reduce the time to respond to unauthorized intrusion by instantly communicating information about such intrusion. The main specific precondition is that shipments or goods can be classified in categories with associated level of sensitivity. The inputs and output IEs are defined as shown in Table 8.5.

INPUTS	OUTPUTS
What \in {E13, IE14, IE22}	What \in { IE23}
When \in {Event: movement detection, significant weather change, user request}	When \in {Anytime, Upon request, Event: change of parking space status}
Where \in {in vehicle (goods location)}	Where \in {driver: handset, back office: TPA system}
IEs	Description
IE13	Information about geographic coordinates
IE14	Digital map information in database
IE22	Radius of interest (distance)
IE23	Assurance notification of goods and vehicle safety

Table 8.5: Basic inputs, outputs and IEs identified for the TPU service

Concrete Specification of Service Processes for GVS Service

B_{20} (initialization): the geographic location of HGV and goods are provided by the user (IE13, IE14) together with the radius of interest (IE22).

B_{21} : a DSA is determined using an appropriate geometric function, e.g., a function defining a circular area based on radius (IE22) and center of the circle (IE13, IE14), here represented as: $B_{21}^{IE13,IE14,IE22 \rightarrow IE24}$

B_{22} : when there is movement within a distance from the given radius determined with the help of an electromagnetic field, a signal is generated (IE25), that initiate object processing. Potentially, this can be combined with a wide angle image camera which has rotational capability (IE26) that can redirect the angle of view toward to the specific area from which the signal is being generated. If the object processing returns a value above a threshold, a risk message is generated (IE27) otherwise the system returns to idle, hence we represent this by: $B_{22}^{IE25,IE26 \rightarrow IE27}$.

B_{23} : depending on the value of the resulting signal from B_{22} (IE27), contact is established with the security systems of the HGV and goods with specific ID (IE28, IE29) to obtain the current security status (IE30). In case of unexpected change in current security status of HGV and goods, a risk message is generated (IE23) that is communicated to the security system at TPA, if there is any, as well as to the driver and other intervention

units that have been hard-coded into the system: $B_{23}^{IE28,IE29,IE30 \rightarrow IE23}$. These processes can be summarized as shown in Table 8.6. A processing function is required at each step to aggregate intermediary input to final output.

Goods and Vehicle Safety assurance-GVS	
Functionality	Explanation
$B_{21}^{IE13,IE14,IE23 \rightarrow IE24}$ DSA calculation function	Area to set an electromagnetic field is determined.
$B_{22}^{IE25,IE26 \rightarrow IE27}$ object type processing function for object in DSA	IE25- a generated signal based on detection of an object, IE26- a camera with rotational capability to capture image of object
$B_{23}^{IE28,IE29,IE30 \rightarrow IE23}$, detect security status of vehicle and goods	IE28-goods ID, IE29-vehicle ID, IE30-change in vehicle and goods security status

Table 8.6: GVS processes showing how IEs are generated

8.3.3 Core Service: Parking location guidance - PLG

Knowledge about locating TPA may not be obvious especially for drivers performing their first route trip in an unfamiliar area. In some cases drivers may follow highway signs where as in others TPAs are not obvious to locate. Given a TPA ID from a user, the service will provide guidance information (IE31) by determining the best road leading to the TPA (IE6) from current vehicle location (IE13, IE14) and hence minimizing search time and congestion (Imatake et al., 1990). The information provided to the user should be specific about the choice of route, and any available second and third alternatives.

INPUTS	OUTPUTS
What \in {IE6, IE13, IE14}	What \in { IE31}
When \in {User request to initialize}	When \in {All time after request}
Where \in {in vehicle, road side, back office: TPA system}	Where \in {in vehicle}
IEs	Description
IE6	Information in database containing TPA addresses
IE13	Information about geographic coordinates
IE14	Digital map information in database
IE31	Guidance information to TPA

Table 8.7: Basic inputs, outputs and IEs identified for the PLG service

Primary users of the information are drivers of HGVs and gate operators. Information is updated regularly (e.g., 5 seconds) as the vehicle approach parking lot location. There are no specific pre-conditions for this service beside an up to date database of parking addresses. The basic IEs required to provide the PLG service are as defined in Table 8.7.

Concrete Specification of Service Processes for PLG Service

B_{30} (initialization): the service is initialized by a user who provides an address of a desired TPA (IE6). It is assumed that this address exist in a database accessible to the service. Such information can be obtained from a parking reservation ITP core service (see below) or based on the users’ previous knowledge.

B_{31} : The current location of the vehicle (IE13, IE14) and the TPA (IE6) are determined in a digital map in order to initiate the route search process: $B_{31}^{IE6,IE13,IE14 \rightarrow IE31}$.

B_{32} : static digital map information (IE6, IE13, IE14) is used to determine the best route (IE31) based on computation of geographic distances for different route alternatives and the expected travel time: $B_{31}^{IE6,IE13,IE14 \rightarrow IE31}$.

B_{33} : For the area containing the chosen route in B_{31} (IE31), real time information is obtained from external databases if available. In particular information concerning current traffic (IE32), current weather (IE33), accidents (IE34) and route maintenance work (IE35) are considered. A function is used to compute the new expected travel time on the chosen route by summing the expected travel times on segments that make up the route taking into account the effects of the factors for which real time information has been obtained. If the new expected travel time is higher than the one in B_{31} , then the system will return to B_{31} and choose the second best route and then proceed to B_{32} . Each time a value is obtained, it is compared with the previous best travel time estimate (IE36) and the route with the shortest expected travel time is presented to the driver: $B_{33}^{IE31,IE32,IE33,IE34,IE35,IE36 \rightarrow IE37}$. This computation runs continuously as the location of the vehicle is updated or as more real time information is obtained. Table 8.8 summarizes the processes discussed above. A processing function is required at each step to aggregate intermediary input to final output.

Parking Location Guidance (PLG)

Functionality	Explanation
$B_{31}^{IE6,IE13,IE14 \rightarrow IE31}$ location determination function	Determine current location of vehicle and TPA in digital map and search for best route
$B_{33}^{IE31,IE32,IE33,IE34,IE35,IE36 \rightarrow IE37}$ obtain external information about route choice to (re)estimate new expected travel time.	IE32-information about current traffic on chosen route, IE33-Information about current weather on chosen route, IE34-Information about accidents on chosen route, IE35-information about route works on chosen route, IE36-best historical expected travel time to TPA

Table 8.8: PLG processes showing how IEs are generated.

8.3.4 Core Service: Parking Reservation - PAR

It is not enough to know how to navigate to a TPA, e.g., by following highway signs, or relying on pre-knowledge. In addition, it is important to be able to guarantee the availability of parking prior to arrival. The focus of this service is to enable the possibility

to reserve a parking place in a given TPA and depending on whether a parking space is granted (IE38) (or not in which case an alternative is suggested IE40), payment can be made for the reservation prior to arrival (depending on the business model, there may be different mechanisms for achieving this option). Prior to making any such reservations, users shall need to have information about parking places and their status including prices and associated facilities. This information can reach users if they actively request for it or through TPU (occupancy status) suggested above. In making a request users shall need to provide sufficient information about their preferences, e.g., desired time of arrival (IE39), desired TPA (IE6), and duration at TPA (IE3). Since the reservation is made ahead of arrival, this service has some reliance on the accuracy of Estimated Time of Arrival to the TPA. Also, a mechanism to ensure that a reserved parking location is available during the time for which a reservation was made, and that such a reservation is paid for are both important pre-requisite. The flexibility of such a reservation may vary with cost (Inaba et al., 2001).

INPUTS	OUTPUTS
What \in {IE1, IE3, IE6, IE39}	What \in { IE38 or IE40}
When \in {user request}	When \in {user request}
Where \in {in vehicle, back office: TPA system}	Where \in {in vehicle, back office: TPA system}
IEs	Description
IE1	Booking request
IE3	Expected duration of parking space status at TPA
IE6	Information in database containing TPA addresses
IE28	Goods ID
IE29	Vehicle ID
IE38	Information to (or not to) grant parking request
IE39	Desired time of arrival
IE40	Alternative suggestion of available parking space

Table 8.9: Basic inputs, outputs and IEs identified for the PAR service

Concrete Specification of Service Processes for the PAR Service

B_{40} (initialization): The PAR service is initiated by a booking request (IE1).

B_{41} : The requested TPA address is verified from the TPA database (IE6), e.g., check it unique location coordinates (IE13, IE14). Depending on the ID or type of HGV and goods (IE28, IE29), a validity check of the request is performed (IE41): $B_{41}^{IE1, IE3, IE6, IE13, IE14, IE28, IE29 \rightarrow IE41}$.

B_{42} : If the request is considered valid (IE41), a search function returns a list of available parking spaces in the specified TPA, based on the user request (IE1), the address of TPA (IE6) and the duration of stay (IE3) at the requested TPA as well as the forecast of the occupancy (IE4): $B_{42}^{IE1, IE3, IE4, IE6 \rightarrow IE42}$.

B_{43} : Compare the user request preferences (IE1) with available preferences from B_{42} (IE42). Then, suggests a parking space ID and TPA address (IE38) with the highest satisfaction for the request. This is determined by whether is above a given threshold value (E43): $B_{43}^{IE1,IE42,IE43 \rightarrow IE38}$.

B_{44} : If the matching function in B_{43} returns a value (IE38) below the acceptable threshold value (IE43), continue to B_{43} and consider an alternative TPA address different from the user request but within the same neighborhood (e.g., in a radius of 10 KM) and determine the second best offer for the given user request (IE40): $B_{44}^{IE38,IE43 \rightarrow IE40}$. Table 8.10, summarizes the interacting processes for the PAR service. A processing function is required at each step to aggregate intermediary input to final output.

Parking reservation (PAR)		
Functionality		Explanation
$B_{41}^{IE1,IE3,IE6,IE13,IE14,IE28,IE29 \rightarrow IE41}$ request and determine validity	verify	Compare TPA-address with addresses from database, e.g., with help of unique geographic coordinates (IE13, IE14).
$B_{42}^{IE1,IE3,IE4,IE6 \rightarrow IE42}$ search for the list of available parking spaces in TPA		Initial search of available options
$B_{43}^{IE1,IE42,IE43 \rightarrow IE38}$ compare available options to requests and make a decision on granting parking space or not		IE43: a threshold value of matching the requested and available options must be satisfied
$B_{44}^{IE38,IE43 \rightarrow IE40}$ make an alternative suggestion in the same geographic neighborhood if threshold value was not met		Alternative parking is suggested

Table 8.10: PAR processes showing how IEs are generated.

8.4 Minimum Platform Functional Requirements for Implementing ITP Core Services

One advantage that can be derived from the proposed approach for identifying and presenting ITP core services, is to analyse the platform demands. A platform, such as those based on Multi-Service Architecture (MSA) concept (Mbiydzenyuy et al., 2012a), facilitate the implementation of the above ITP core services. Different MSA concepts will lead to different platforms that will support ITP core services to different extent. In order to find out which MSA concepts is most suitable for ITP core services we start by identifying the most essential functionalities common to all ITP core services following the problem-driven design approach presented above. The following capabilities are identified:

- A possibility to disseminate output information from ITP core services, e.g., through an OBU, mobile phone, internet, etc.

- A possibility to detect, within an acceptable error of margin, the occupancy of a parking place within a TPA, e.g., using video cameras.
- A possibility to access (or compute) the addresses of different TPAs, e.g., in the form of TPA inventories for different regions, e.g., municipality, country, etc.
- A control mechanism for access of facilities in TPA, including parking spaces.

The above capabilities shall need to be provided in addition to the basic pre-requisite mentioned above, i.e., positioning, communication and digital processing environment. Each MSA specifications offer different key features (e.g., vehicle-to-vehicle communication) and resources (e.g., data communication) (Mbiydzenyuy et al., 2012a). If we consider for each MSA, for all key features and resources allowed, the sum total of ITP capabilities that are supported we obtain the results shown below:

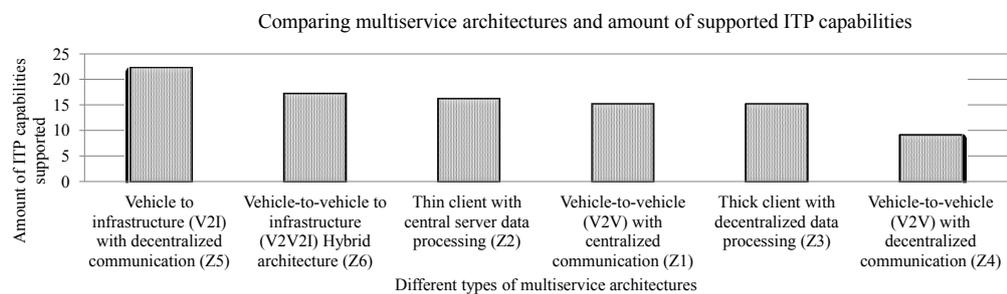


Figure 8.3: Comparing ITP capabilities supported by different MSA concepts.

Based on the comparison, vehicle to infrastructure (V2I) with decentralized communication provide the most resources and capabilities to support ITP implementation. To eventually make the choice of MSA, other candidates ITS services also have to be taken into account (Mbiydzenyuy et al., 2012a). The IEs corresponding to the minimum functional capabilities of ITP also need to be available so as to achieve ITP.

8.5 Conclusions and Future Work

The aim of this article was to suggest Transport Telematic Services (TTSs) to support the realization of Intelligent Truck Parking (ITP) concept. To achieve this aim, the article proposes a concept for ITP that focuses on the identification of relevant information about parking and associated facilities, and parking demand from road users and professional HGV drivers or representatives. Based on such information, ITP (processes and) channels information (e.g. typically provided on road signs today with the help of electronic displays) to stakeholders such as drivers, and transport companies, via communication networks to mobile devices such as smart phones, desktops and on board units. To realize this concept the paper uses a simple problem-driven reasoning

approach to identify ITP core services, by determining problems faced by stakeholders within ITP, "what" type of information is needed/provided to address such problems, "where/when" such information is needed/provided. ITP core services are therefore seen as TTSs that can support efficient exchange of information among stakeholders connected to truck parking such as TPA operators, back office operators, and truck drivers with a focus on specific needs for various stakeholders.

ITP core services proposed includes *Information on the status of Truck Parking Areas (TPU)*, *Goods and vehicle safety assurance information (GVS)*, *Parking Location Guidance (PLG)* and *Parking reservation (PAR)*. Each suggested ITP core service is presented following an ITS related framework, but, with some modifications (e.g., including problem relevant aspects as well as solution relevant aspects), inspired by structured design approach for software systems. Such modifications enable us to focus in aspects that are seen relevant for the domain of ITP related services. Thus we present an abstract service description but also a concrete service description that will enable the service to be designed, analyzed and implemented. The concrete description consists of functions relevant for computing attributes outputs based on inputs information entities. With the current presentation of the proposed ITP core services, analysis, e.g., of the service design and platform requirements to eliminate redundant inputs and functions can be performed. Information dissemination, detection of vehicles at parking, accessibility to inventory of TPAs and parking spaces, as well as control mechanisms are identified as the key ITP platform demands in addition to positioning, communication and digital processing. It is also shown that vehicle-to-infrastructure (V2I) with decentralized communication architecture concept provide the most resources and capabilities to support ITP implementation even though we argue that in order to settle on an a final choice of architecture one need to take into consideration other ITS services, security aspects and business models. In the future, different types of analysis for ITP core services will be carried out, e.g., security related analysis, business models, and prototyping.

List of Abbreviations

2DECIDE	Project to develop a decision support toolkit for Intelligent Transport Systems solutions.
ALSD	Abstract Level Service Description
AMPL	A Modeling Language for Mathematical Programming
ARENA	A Swedish project with focus on developing practical solutions for road charging systems
ARIB-STD T75	Dedicated Short Range Communication Standard
B_y^x	Function y process transformation of Information Entity x
BA	Benefit Area
BAs	Benefit Areas
Bps	Bytes per second
Cargle	Proposed cloud computing platform architecture
CBA	Cost Benefit Analysis
CHAUFFEUR	EU 4th Framework Research Project with focus on developing new electronic systems for coupling trucks at close following distances .
CLSD	Concrete Level Service Description
CO ₂	Carbon Dioxide
CODE	Co-ordinated Dissemination in Europe of Transport Telematics Achievements
CPLEX	Software Optimizer -simplex method as implemented in the C programming language,

DIATS	Project: Deployment of interurban advanced transport technology test scenarios
DRSA	Dominance Rough Set Approach
DSRC	Dedicated Short Range Communication
EasyWay	EU project focusing on the deployment of harmonized Europe-wide Intelligent Transport Systems services
EC	European Commission
EFC	Electronic Fee Collection
eIMPACT	European Specific Target Project for assessing the socio-economic effects of Intelligent Vehicle Safety Systems (IVSS), their impact on traffic safety and efficiency
EU	European Union
Eurostat	Official European Union statistics organization
EVA	Samhällsekonomiska kalkylmodell
FHA US DOT	Federal Highway Administration United State Department of Transport
GDP	Gross Domestic Product
GINA	GNSS for INnovative road Applications-GINA)
GNSS	Global Navigation Satellite Signal
GPS	Global Positioning Systems
GST	Global System for Telematics
HCA	Hierarchical Clustering Algorithm
HGV	Heavy Goods Vehicle
HGVs	Heavy Good Vehicles
ICSS	Intelligent Cargo Systems study
ICT	Communication Technology
ID	Identity
IEx	Information Entity x, e.g., x=8, Information Entity 8
ISO/TC	International Standard Organization/Technical Committee

List of Abbreviations

ISO/TR	International Standard Organization/Technical Report
ITP	Intelligent Truck Parking
ITS	Intelligent Transport Systems
jRS	java Rough Set
kbps	Kilobyte per second
KM	Kilometer
KMST	K-Minimum Spanning Tree
L/VKM	Liters per Vehicle Kilometer
LABEL	Creating a Label for (Secured) Truck Parking Areas along the Trans-European Road Network and Defining a Certification Process.
LP B&B	Linear Programming with Branch and Bound
MB	Megabyte
mbps	Megabyte per second
MCDA	Multi-Criteria Decision Analysis
Mobila Nätverk	Swedish project that identify mobile applications for freight transport
MoE	Measures of Effectiveness
MSA	Multi-service Architecture
MSAs	Multi-service Architectures
NPV	Net Present Value
NVDB	Swedish National Road Database
OBU	On-Board Unit
OSGi	Open Service Gateway Initiative
PIARC	Permanent International Association of Road Congresses
PSI	Performance Saving Indicator
PSIs	Performance Saving Indicators
Px	Paper x, e.g., x=I, Paper I

QoS	Quality of Service
R&D	Research and Development
RITA	Research and Innovative Technology Administration
RQ	Research Question
RQ _x	Research Question <i>x</i> , e.g., RQ1 = RQ1
SARH	Swedish Association of Road Haulers
SCB	Statistiska Centralbyrån
SDL	Specification and Description Language
SERVQUAL	Service Quality Framework
SIKA	Statens institut för kommunikationsanalys
SMS	Short Message Service
SRA	Swedish Road Administration
STARDUST	EU 5th Framework project with focus on assessing the extent to which ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development
TOE	Tons Equivalent Unit
TPA	Truck Parking Area
TPAs	Truck Parking Areas
TSPs	Telematic Service Providers
TSU	Telematic Service Users
TTASs	Transport Telematic Application Systems
TTS	Transport Telematic Service
TTSs	Transport Telematic Services
UK	United Kingdom
UML	Universal Modeling Language
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

List of Abbreviations

V2V2I	Vehicle to Vehicle to Infrastructure
VAT	Value Added Tax
VKM	Vehicle Kilometer

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ABSTRACT

In this thesis, methods for using computer-based models as support tools for assessing Transport Telematic Services (TTSs) are studied. Such assessments provide one way to understand how TTSs can address problems caused by transportation, such as accidents, emissions, and energy consumption. TTSs are services based on telematic systems which are Intelligent Transport Systems (ITS) involving the integrated use of information and communication technologies in transport. The focus is on TTSs that are relevant for road freight transport, even though the suggested methods can easily be adapted for TTSs in other areas. We characterize TTSs, e.g., in terms of their functionalities, and apply computer-based modeling for pre-deployment assessment of various TTSs (from an ex-ante perspective). By analyzing information provided by the suggested computer-based models, it is possible to make an informed decision whether to (or not to) deploy a given TTS.

A review of previous studies reveals information about relevant TTSs for freight transport in areas such as driver support, administration, safety, traffic management, parking, and goods handling. A hierarchical clustering algorithm and a k-minimum spanning tree algorithm were employed to analyze synergies of TTSs. Synergies can enable identification of sets of TTSs that can lead to cost savings if deployed on a common platform (cf. Multi-Service Architectures). An analytical model inspired by the net present value concept is used to estimate quantified societal benefits of

TTSs. An optimization model is formulated and solved using a branch and bound method to determine an optimal combination of TTSs taking into consideration societal benefits, costs, dependencies, and synergies. The optimization model also addresses possible system architectures for achieving multiple TTSs. Dominance rough set approach is used to assess and compare benefit areas for TTSs specific to truck parking. The benefit areas are suggested with the help of conceptual modeling, which describes functional models of a system in terms of states, transitions among states, and actions performed in states.

The main scientific contributions of the thesis are in suggesting new quantitative models, extending and applying existing models in the assessments of TTSs, and obtaining results that can help decision-makers select TTSs for medium-to long-term investments. Researchers can employ and build on the proposed methods when addressing different scenarios (geographic or organizational) involving similar TTSs. By studying a range of TTSs and possible Multi-Service Architecture concepts for such TTSs, the thesis contributes to achieving convergence of TTSs in a Multi-Service Architecture environment that will improve cost efficiency, minimize redundancies, and encourage the establishment of standards in the deployment of TTSs in road freight transport. TTSs implemented in such an environment can contribute to optimizing available capacity, accuracy, speed, and efficiency of road freight transport systems.

