Optimization Based Modeling of Multi-Service Architecture Concepts in Road Transport Telematics.

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Abstract: As a result of their high economic costs and unforeseen impacts on society, pre-implementation evaluation of telematic systems is important and can lead to time and cost savings. This article presents an optimization perspective for evaluating conceptual options of transport telematic architecture in relation to benefits to the society. These benefits are evaluated in the context of multiple services and provide one way for comparing between alternative conceptual options for telematic system architectures that can support multiple services. An optimization model is proposed and preliminary results of beneficial services for different architecture options highlighted.

Keywords-Transport; Telematic; Services; Architecture; Evaluation; Modelling; Optimization; Integer Linear Programming

I. INTRODUCTION
Transport Telematic Application Systems (TTASs) or Intelligent Transport Systems (ITS) are today considered as a suitable approach for addressing surface transportation problems e.g. reduction of road fatalities. The extent to which these problems are addressed can be considered in terms of the benefits of the resulting Transport Telematic Services (TTSs) derived from such systems. Such benefits can be influenced by the platform used for implementing the system. In Europe, the European Union (EU) action plan for ITS anticipates a future common platform for tolling, and for regulatory and commercial TTSs, all of which shall need to make use of Global Navigation Satellite System (GNSS) and Global System for Mobile communication (GSM) functionalities to facilitate interoperability between EU nations [1]. Such TTSs will have different benefits to society. Some TTSs are going to be sold as commercial services to companies and others for private use. There will also be TTSs of the type which are advocated by public authorities such as electronic fee collection service. Many of these TTSs (both advocated by authorities and the commercial sector) can be developed on common platforms sharing technology and costs. Hence society and authorities have an important influence on the future composition of TTSs by their prioritization of different TTSs. Further public authorities can choose which type of platforms to be used for a public TTS such as; Electronic Fee Collection (EFC) service, thus affecting the type of multi-service architecture for TTSs.

The purpose of this article is to develop an optimization model to support informed decisions about choices between different conceptual TTAS architectures supporting multiple services (multi-service architectures). Using estimated values for TTSs benefits to society and the cost to realize such services based on required functionalities, the choice of services to prioritize for implementation can be modeled as an optimization problem that maximizes societal benefits. For different TTAS architecture platforms, benefits derived from service values shall differ based on functionality costs. TTAS architectures are interesting because they are different from most existing architectures in many ways e.g. they consist of mobile components; makes use of advanced technology, demand a high investment cost and require different functionalities in different capacities etc. As a result of these characteristics, decisions about financing the deployment of TTAS are complex for private and public investors. Architectures consisting of many services or multi-service architectures can potentially help reduce deployment costs common use of functionalities e.g. positioning. Difficulties associated with interoperability can also be minimized if systems are developed from a multi-service architecture perspective. Societal benefits will be improved if synergies between functionalities are utilized to minimize redundancies in resource utilization.

The study provides an approach to model and evaluate different conceptual options of TTASs that can potentially host multiple services. The modeling is based on an Integer Linear Programming (ILP) optimization approach to compare multi-service architecture concepts with the objective of maximizing benefits to society. The current model is intended to determine the choice of an architecture based on the choice of services and functionalities needed to achieve those services. The functionalities provide the model the opportunity to address the technical aspects of the conceptual system architecture, while the services offer the opportunity to consider aspects about usefulness (value) from a societal perspective. Some preliminary results of beneficial services for different architecture options are highlighted. In the rest of the paper sections II, III and IV respectively, provide definitions of key terms used, motivation of study and some approaches to the evaluation of telematic systems. In sections V, VI, VII, VIII and IX are candidate architecture concepts, a proposed model, a case study that employs the proposed model, preliminary results and some conclusions, respectively.
A. Functionalities

Functionalities are the basic properties that can be implemented in a system (obtained from user requirements) and when combined together, results to the required TTS, e.g. the need for real time positioning of a vehicle. Functionalities can be achieved using different enabling technologies e.g. positioning by use of GNSS, DSRC etc. It is assumed that essential functionalities for achieving each TTS can be specified with the enabling technology. Such functionalities can be commonly used by TTSs and can be distinguished based on a cost parameter (startup and usage based costs).

B. Transport Telematic Service (TTS)

A Transport Telematic Service (TTS) consists of a product or activity targeted to a specific type of ITS user addressing a given user need. Unlike the functionalities, some services can be achieved in different ways, e.g. speed adaptation may be implemented as advisory in the car or as dynamic using roadside equipment. A service is specified by it functionalities.

C. Transport Telematic Application System (TTAS)

This is considered as the conceptual specification of transport telematic system architecture. It is assumed that this is an open system and can potentially host multiple co-existing services with different types of restrictions. There are different implications (especially benefits) for implementing a service in platforms with different design concepts e.g. EFC.

D. Transport Telematic User (TTU)

The user can be an individual, or an organization such as a commercial company or governmental agent. The user characteristic (e.g. usage or value) is a potential proxy for representing a service demand. As such, TTS demand depends on market conditions, e.g. number of users, perception of usefulness or value, etc. In road traffic evaluation, demand is usually modeled as static or dynamic over time. In the case of TTAS, limited data and models of service demand modeling compromise evaluation efforts. For this study, we assume a static demand and consider variations in architecture options.

III. MOTIVATION OF THE STUDY

The scarcity of good tools for benefits and costs evaluation of ITS systems is seen to be a hindrance for deployment of new ITS user services [7]. Unlike traditional transport systems where evaluation and assessment methods have mostly been based on analyzing historical data, such methods are faced with a limitation when applied to the evaluation of ITS systems [8]. Whereas, there is a need to evaluate TTASs, so as to understand their performance in relation to integrity, reliability, workability, and adaptability, either from a user’s perspective or from a technical perspective ([2], [4]). In the context of multiple interoperating services, quantifying the benefits of TTASs can be challenging as benefits vary between different platforms used to achieve the services.

It is generally acclaimed that the benefits of TTASs, such as the anticipated Swedish Road User charging (RUC) system, can be improved if the system is developed to support multiple TTSs. Further, the system can be highly beneficial to the commercial sector because TTSs can make use of already existing functionalities such as satellite positioning. However, in most cases, the choice of services that can be achieved depends on the type of TTAS architecture adopted e.g. thin client or thick client etc. It is difficult, yet important to quantify societal benefits as TTS value is user dependent. In relative terms, benefits can be used to compare and analyze architecture options. Since services can be specified from different functionalities, this study hypothesizes that a good multi-service system platform is one that optimizes the services based on the estimated benefits.

One basic approach for estimating such benefits is to discount the cost of all necessary functionalities for a TTS from its estimated societal value. A complexity dimension is included when considering the different options of services and architectures with the value dependency between services e.g. what is the societal value (and hence benefits) of intelligent speed adaptation service given that e-call service will be implemented. Since functionalities for TTSs can be achieved in different ways, the choice of functionality using different technologies should be based on some parameter e.g. economic cost etc. While this work may not lead to answers surrounding the challenges that face the implementation of TTASs, it can provide support for high level decision by highlighting the consequences of adopting given architectures.

IV. TRANSPORT TELEMATIC EVALUATION APPROACHES

Evaluation of TTAS architectures has been approached in different ways [3], [5], [6] to overcome various challenges [15]. High level evaluation of the cost associated with implementing the physical and functional elements of the national ITS architecture and related ITS services, is addressed in [21]. The type of evaluation approach, e.g. formative or summative depends on the goal behind the evaluation [9]. A good evaluation approach can help distinguish between different conceptual architecture options and corresponding services in terms of associated benefits to society. Therefore the task of evaluating such options in concept is concerned with how to identify, quantify and compare for all alternatives, all impacts on all people in all affected areas over all time [14]. However, in practice such an evaluation goal is optimistic due to the complexities involved (as discussed in section III) especially for multi-service conceptual system architectures. Thus it is important to abstract conceptual architecture system characteristics for evaluation [20] to help understand the potential impacts of a real system.
The use of discrete event based simulation approach abstracts and identifies interacting components and states for ITS evaluation [3]. This work does not consider the evaluation of multiple co-existing services as the tool is aimed at single service evaluation. The benefits of each TTS are evaluated on the basis of indicators such as traffic volume increase, standard deviation of speed decrease, oil-consumption reduction, emission decrease, system construction cost and vehicle equipment cost for EFC systems [5]. It remains to demonstrate that these indicators can be used for modeling and evaluating other services that can potentially be implemented on EFC platforms or identifying additional indicators and modeling approaches, e.g. optimization, to understand the potential benefits. Candidate EFC systems have been evaluated based on charging accuracy, system costs and societal benefits, flexibility and modifiability, operational aspects, and security and privacy [6]. The study in [6] considers the support for multiple services (flexibility) and provides a qualitative evaluation of architecture concepts but does not quantify such benefits. Thus [3], [5] and [6] supports identification of indicators for quantifying TTAS benefits.

While many studies on the evaluation of TTASs have not quantified benefits, approaches based on the economic and goal evaluation methods have address the question of benefits quantification [11]. In this study, [11], the authors provides a framework for benefits assessment using benefit trees and other emerging methods of analysis for benefit studies and observes the significant variation in the complexity and details in ITS evaluation methods. Such variation in evaluation approaches and choice of criteria has partly been explained by their dependency on the end user of the evaluation results [7]. As a consequence, most evaluation methods are based on very specific approaches for specific end users making it hard to compare results between services and systems on a general level. This issue has been partly addressed using ITS Option Analysis Model-(ITSOAM) for forecasting the benefits of ITS elements and estimating the deployment cost [7]. The study in [7] addresses decisions related to system benefits, in which each ITS system should be considered separately and their benefits evaluated independent of each other. Our view about benefits differs from this study since we consider such benefits to be context dependent e.g. on the given TTASs collection, on the given platform, etc. This is because systems may advocate conflicting goals (as in [20]), such as speed limit systems and emission reduction through reduced driving time.

Nearly all the above studies have proposed different criteria for various evaluation approaches (as in [5], [7] [10], [12], [20]). How and which of these approaches may be suitable for the evaluation of platforms that can potentially host multiple services remains an open question. It is unclear how to formulate or apply any of these approaches on a multi-service architecture with diverse characteristics. The use of optimization models for evaluating TTAS architecture concepts as advocated in this study has not been explored so far. This can be understood due to the difficulty of obtaining data since quantitative models, such as optimization are highly data dependent. Thus, quantitative data models should be accompanied by extensive sensitivity and break-even analysis to understand how such models are affected by underlying assumptions [11]. Yet, there exists, a great potential in the use of optimization [19] models in evaluating TTASs in order to;

- Understand advantages and disadvantages of different TTAS architecture concepts at pre-implementation.
- Predict future consequence of decisions related to multi-service TTASs.
- Study TTASs using different parameters such as economic cost, time savings etc

From all the above studies addressing evaluation of TTAS benefits based on methods such as simulation, goal-tree analysis, costs benefits analysis, multi-criteria analysis, etc, there has been limited work done on multi-service architectures and the interdependencies between the values of TTASs to society. This article attempts to fill this gap by introducing an ILP optimization model to investigate multi-service architectures with dependencies between TTASs.

V. CONCEPTS OF TRANSPORT TELEMATIC APPLICATION SYSTEM ARCHITECTURE

System architecture in ITS generally refers to three levels of system specification, reference, logical and physical architecture specifications [16]. A logical architecture defines the activities and functions necessary to provide the required TTASs. Functionalities are realized using different technologies which impact the system in different ways [18]. This article considers concepts of a logical system architecture which represents the functional specification of the system. It is necessary to evaluate these kind of conceptual architecture designs, because the incorporation of multiple services increases the system complexity and this can lead to potentially conflicting system characteristics e.g. variable speed limit may lower vehicle speed that may result to queue build up and hence congestion. Practical TTAS evaluation should be based on aspects considered important to the system such as processing, communication and their implications for cost and benefits. For the purpose of the approach considered in this study, conceptual architectures can be described based on basic characteristics (as in [2] & [6]) as shown in Table 1:

<table>
<thead>
<tr>
<th></th>
<th>Centralized communication networks</th>
<th>Distributed communication networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized data</td>
<td>Z1 (e.g. Centralized)</td>
<td>Z2 (e.g. thin client)</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distributed data</td>
<td>Z3 (e.g. thick client)</td>
<td>Z4 (e.g. Vehicle-vehicle)</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Example of multi-service architecture concepts
VI. A PROPOSED OPTIMIZATION MODELING APPROACH FOR MULTI-SERVICE ARCHITECTURE IN ROAD TRANSPORT

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 expressing the limits on possible decision choices [17]. The proposed model assumes that multiple services can be achieved in a common architecture platform. The implementation of such services needs several functionalities to be realized. It is assumed that decisions regarding the functionalities, services and architecture can be treated as discrete (yes/no). Thus there are several possibilities for combining different functionalities in an architecture that may results to a number of services. All different solutions have different economic implications on the basis of which optimization can be used to suggest economically favourable decisions about TTSs and architecture concepts.

PARAMETERS

\( C_j \geq 0 \) represent the fix cost for \( j \in F \) and
\( C_{i,j} \geq 0 \) represent the variable cost for \( i \in S \), \( j \in F \)
The variable costs \( C_{i,j} \) is usage based and hence differs for different services.
\( l_{i,j} \geq 0 \), cost of extra functionality \( j \in F \) as a result of architecture concept \( t \in A \)

\( V_i \), the estimated value of service \( i \in S \)
\( L_{i,j} \geq 0 \) is the capacity limit for \( t \in A \)
\( M_{i,j} \geq 0 \) is the capacity utilization for \( j \in F \), \( i \in S \)
\( d_{ii} \geq 0 \) is the dependency between \( i, i' \in S, i \neq i' \)

\( P_{i,j} = \begin{cases} 1, & \text{if service } i \text{ needs function } j; \forall i \in S, \forall j \in F \\ 0, & \text{Otherwise} \end{cases} \)
\( R_{i,j} = \begin{cases} 1, & \text{if architecture } t \text{ needs function } j; \forall t \in A, \forall j \in F \\ 0, & \text{Otherwise} \end{cases} \)
\( Z_t = \begin{cases} 1, & \text{if architecture } t \text{ is selected}; \forall t \in A \\ 0, & \text{Otherwise} \end{cases} \)

VARIABLES

We define variables as follows:
\( X_i = \begin{cases} 1, & i \in S \\ 0, & \text{Otherwise} \end{cases} \)
\( F_i = \begin{cases} 1, & i \in F \\ 0, & \text{Otherwise} \end{cases} \)
\( Y_{i,j} = \begin{cases} 1, & i \in S, j \in F \\ 0, & \text{Otherwise} \end{cases} \)
\( D_{ii} \geq 0, i, i' \in S, i \neq i' \)

OBJECTIVE

Maximize for \( t \in A \),
\[ Ob = \sum_{i \in S} V_i * X_i - \sum_{j \in F} C_j - \sum_{i \in S, j \in F} C_{i,j} * Y_{i,j} - l_{i,j} - \sum_{i \in S, j \in F} D_{ii} \]
Subject to the following main constraints;
\[ \sum_{i \in S} F_j * M_{i,j} \leq L_{i,j} \quad \forall j \in F \]
Discrete relation between services and functions
\[ X_i + F_j - 1 \leq Y_{i,j} \quad i \in S, j \in F \]
Functionalities for each service are chosen as specified by the requirement matrix
\[ X_i * P_{i,j} \leq F_j \quad i \in S, j \in F \]
Functionalities specific to a given architecture concept are chosen according to architecture functionality specification
\[ R_{i,j} \leq F_j \quad \forall j \in F \]
Dependencies between TTSs
\[ d_{ii}(X_i + X_{i'} - 1) \leq D_{ii} \quad \forall i, i' \in S, i \neq i' \]

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

VII. CASE STUDY OF THE ILP OPTIMIZATION MODEL

A scenario experiment employing the proposed optimization model considers the following data set (Table 2):
Set \( S \) of E-Call (EC), Navigation (Nav), Weight Indicator (WI), Intelligent Speed Adaptation (ISA), Accident Reporting (AR), Automatic Driver Logs (ADL), Staff Monitoring (SM), Transport Resource Optimization (TRO), Vehicle Follow up (VF), Remote Monitoring (RM), Dynamic Route Planning (DRP), Goods Identification (GI), Real Time Track and Trace (RTT), Goods Monitoring (GM), Traffic Information (TI), Route Guidance (RG), Theft Alarm (TA), Pay as You Drive (PYD), Transport Order Handling (TOH), Geo-Fencing (GEO).

Set \( F \) of Global Positioning (GP), Local Positioning (LP), Map Matching (MM), Real-time Two-way Communication (RTC), Occasional Two-way Communication (OTC), Temperature Monitoring (TM), Data Transfer (DT), Data Broadcast (DB), Unique Vehicle Identification (UVI), Vehicle Speed Monitoring (VSM), Time Stamping (TS), Data Processing (DP).

Set \( A \) of Centralized Processing (Z1), Thick Client (Z2), Thin Client (Z3), Vehicle-Vehicle Communication (Z4).

Table 2: Sample data set used in the model.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>0, ( \geq J_{iL} ) *10^7</th>
<th>0, ( \geq J_{iC} ) *10^2</th>
<th>0, ( \geq J_{iC} ) *9 *10^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_{ij} \geq 0 ) *10^7</td>
<td>Z1 1 2 0 1 0 1 1</td>
<td>Z1 3 1 0 4 0 1 3</td>
<td>EC 5 0 0 11 0 0 1 2</td>
</tr>
<tr>
<td></td>
<td>Z2 0 5 4 0 10 1 5</td>
<td>Z2 0 2 2 0 3 1 3</td>
<td>Nav 4 0 1 0 3 0 0 233</td>
</tr>
<tr>
<td></td>
<td>Z3 2 0 0 8 1 1 1</td>
<td>Z3 4 0 0 1 5 2 1</td>
<td>WI 0 2 0 2 1 0 0 46</td>
</tr>
<tr>
<td></td>
<td>Z4 10 5 2 0 2 1</td>
<td>Z4 3 1 3 0 1 2</td>
<td>ISA 3 2 1 4 0 0 1 546</td>
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<td></td>
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<td>AR 4 0 2 0 1 0 1 67</td>
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</table>

Table 3: Sample Data used in the proposed model (assuming 9*10^3 HGVs in Sweden and all values estimated in SEK).

We assume that the functionalities studied can be quantified in terms of data received/transmitted or processed within a static time period, e.g. one month. All functionalities, e.g. temperature monitoring are considered from a contactless monitoring perspective and hence data rates can be used as a proxy parameter from which cost values are generated. Limiting values, e.g. for positioning, are obtained by considering GNSS data transfer rate of 50 bits per second over a one month period with full network availability for a given region. Processing functionality is estimated based on the use of processing memory resources e.g. RAM etc.

VIII. RESULTS

As expected, data related to cost of functionality vary depending on the common use of functionalities between TTSs and architecture concepts. The results obtained are based on the specification of functionality cost estimates and weather such functionalities are commonly used by both TTS and architecture or not. In addition, the value estimates for TTSs are obtained from diverse sources e.g. in some cases estimates from the UK department of transport are used to deduce equivalent values for Sweden. TTSs value estimates have been within a time window of one year and the functionality costs calculated for a period of twelve months. Assuming that these values are fairly estimated in the scenario, the above model identifies beneficial TTSs (Y) for the various architecture concepts studied, as shown in Table 4 based on common use of functionalities with each architecture concept.

Table 4: Preliminary results from the proposed model without dependencies between TTSs

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Most Beneficial Services</th>
</tr>
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<tr>
<td></td>
<td>ADL AR DRP GF SM TI WI</td>
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<tr>
<td>Z1</td>
<td>Y Y Y Y Y Y Y</td>
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<tr>
<td>Z2</td>
<td>Y Y Y Y Y Y</td>
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<td>Z3</td>
<td>Y Y Y Y Y Y</td>
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<tr>
<td>Z4</td>
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Table 5: Preliminary results from the proposed model with dependencies between TTSs.

If in addition to the common use of functionalities, dependencies between TTSs are considered, the results are as shown on Table 5.

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<tr>
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From the above output, some TTSs are seen to be beneficial on all platforms (AR and SM Table 4, EC and GF, Table 5) based on the current model data. Others are platform dependent such as GF, GI in Table 5. Assuming the availability of a given TTS in the market affects the value of a newly introduced TTS positively, negatively or not at all, the model selects services such that they are less dependent resulting to the difference between Tables 3 and 5. How such dependencies have been estimated is based on the author’s
perceptions. Model sensitivity depends on the estimated capacity constraints for various functionalities implemented by different architectures as well as the common use of functionalities with TTS. Thus with a given amount of resource, e.g. communication bandwidth, TTSs are selected depending on how their utilization of such resources is estimated in the model.

IX. CONCLUSION AND FUTURE WORK

This article has proposed a model that can be used to potentially support strategic decision making related to the design of and investment in telematic systems and services. The decisions were abstracted as discrete, enabling the use of ILP optimization to address interdependencies between events. The usefulness of ILP models is seen in the capability to prescribe decisions while allowing for evaluation of if-then-else situations by varying different constraint limits. In addition to modeling how the common use of functionalities can influence benefits of a TTS, the proposed model has also considered the interdependencies effects on the value of TTSs.

The model results indicates TTSs that are beneficial for a given architecture concept, hence supporting decisions related to the implementation of such architectures. However, because architecture concepts are studied from a functionality perspective, implementation time, available technology, physical architecture layout, regional or national architecture requirement etc, are necessary to consider in addition, before embarking on developing a given architecture concept. In addition, constraints requirement by different TTAS architecture concept need to be further explored.

This article further indicates that even though TTS benefits maybe context dependent, multi-service architecture evaluation has not been widely researched but this will become an important research area because of the growing number of new TTSs. The proposed model serves as a complement to other models for ITS with main focus on other aspects e.g. service demand patterns. Since some TTSs require different time periods to generate benefits, interesting results can be obtained by incorporating dynamic time windows. Therefore, further improvement to the proposed ILP optimization model can be achieved by introducing dynamic time windows, dynamic TTS demand, etc, while expanding the data sets in Table 2. It is our intention to further work on this model to improve it sensitivity in addressing these aspects.

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