## DELIVERABLE

### D1.1 - State-of-the-art Report

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<td>The objective of D1.1 “State-of-the-art Report” is to provide a systematic overview of the current research in the key ICT and transport related thematic areas that will enable us to fulfil our vision by serving as the basis to achieve OPTIMUM objectives.</td>
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## Deliverable Resubmission

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<td>There is in-depth state of the art analysis of the different domains. Unfortunately, some concrete project decisions are missing and not well explained, such as:</td>
<td>The analysis of the research gaps in the various state-of-the-art areas was revised by better explaining why the identified gaps are important, as well as why and how they are tackled by OPTIMUM. As far as the area of tolling is concerned, the approach chosen for further investigation is explicitly mentioned.</td>
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<td>• For some domains like tolling, no clear statement is given, which approach will be chosen or further investigated.</td>
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<td>• The gap analysis made are rather “limited”. It is not clear why the identified gaps are of importance and if and why OPTIMUM will tackle these gaps.</td>
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# Definitions, Acronyms and Abbreviations

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<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
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<tr>
<td>CO2</td>
<td>Carbon dioxide</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<td>OODA</td>
<td>Observe, Orient, Decide and Act</td>
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<tr>
<td>Dx</td>
<td>Deliverable (where x defines the deliverable identification number e.g. D1.1.1)</td>
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<tr>
<td>ICT</td>
<td>Information and Communications Technology</td>
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<td>TIS</td>
<td>Traveller Information Services</td>
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<tr>
<td>ETL</td>
<td>Extract-Transform-Load</td>
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<tr>
<td>BI</td>
<td>Business Intelligence</td>
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<td>MDM</td>
<td>Multi-Dimensional Data Modelling</td>
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<td>CRISP-DM</td>
<td>CRoss Industry Standard Process for Data Mining</td>
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<td>KDD</td>
<td>Knowledge Discovery Databases</td>
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<td>SEMMA</td>
<td>Sample, Explore, Modify, Model, Assess</td>
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<tr>
<td>PAM</td>
<td>Partitioning Around Medoids</td>
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<td>FAMES</td>
<td>FAst MEdoid Selection</td>
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<td>ARIMA</td>
<td>Autoregressive Integrated Moving Average</td>
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<td>SARIMA</td>
<td>Seasonal ARIMA</td>
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<td>ANNs</td>
<td>Artificial Neural Networks</td>
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<tr>
<td>SVR</td>
<td>Support Vector Regression</td>
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<tr>
<td>CCZ</td>
<td>Congestion Charging Zone</td>
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<tr>
<td>ANPR</td>
<td>Automatic Number Plate Recognition</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>OBU</td>
<td>On-Board Unit</td>
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<tr>
<td>TrEPP</td>
<td>Traffic Estimation and Prediction tool</td>
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<tr>
<td>ERP</td>
<td>Electronic Road Pricing</td>
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<tr>
<td>IUSS</td>
<td>In-vehicle Units</td>
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<tr>
<td>MOT</td>
<td>Mode Of Transportation</td>
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<td>TERN</td>
<td>Trans-European Road Network</td>
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Executive Summary

The objective of D1.1 “State-of-the-art Report” is to provide a systematic overview of the current research in the key ICT and transport related thematic areas that will enable us to fulfil our vision by serving as the basis to achieve OPTIMUM objectives. The thematic areas analysed in the context of deliverable D1.1 reinforce further development of the OPTIMUM architecture on the basis of the OODA approach. As the project consortium is multi-disciplinary, with the aim to cover a wide spectrum of competences and skills required for the successful implementation of the innovative project vision, D1.1 enables OPTIMUM partners to set a common ground, by providing access to a common glossary and facilitating mutual understanding of important concepts of the various research areas. To this end, the basis for a fruitful collaboration among people of different backgrounds and disciplines is provided.

The following ICT and transport related knowledge domains, are examined in this deliverable and in the context of the OODA approach, providing the basis for the identification of the main research gaps for each domain:

- fusion and harmonization of big transportation data (observe)
- real-time big data processing for transportation, including big-data architectures and complex event processing, theories and latest developments on transport forecasting, including socio-econometric models and traveller behaviour forecasting, as well as technologies such as real-time sensing and stream analytics of transport data, which include machine learning for social media applications and online stream analytics (Orient)
- dynamic crediting and charging models, system aware optimization and multimodal routing (Decide)
- persuasive technologies and information personalization (Act).

In addition, since ITS technologies will form the technological spine of the proposed platform, ITS-related directives, action plans, regional strategic plans and deployment strategies are reviewed, while the outcomes of ITS projects in the area of Traveller Information Services (TIS) for multi-modal transportation are indexed.
Introduction

The transportation sector is undergoing a considerable transformation as it enters a new landscape where connectivity is seamless and mobility options as well as related business models are increasing. Besides technological advancements, which have revolutionized transportation supply with services such as, real-time traveller information, collective travelling, provision of way findings and navigation services regarding multi-modality of trips, the need for more efficient transportation systems emerges due to the current vast development in urbanization. Indeed, the number of people living in big cities is constantly increasing - by 2030 it is estimated that 60% of the global population will live in urban areas\(^1\).

Intelligent Transportation Systems (ITS) are the means to mitigate problems emerging from the large and even-increasing urbanization including excessive CO2 emissions, high levels of congestion, increased accident risks and reduced quality of life. The emerging area of ‘digital-age transportation systems’ aims at tackling the needs of different individuals while building on massively networked systems and applying user centred approaches masking the underlying complexity. In addition, the technological developments that underpin the operation of current transportation services, leads to the generation of huge amount of available data with short update rates. This growth in data production is being driven by individuals and their increased use of media, novel types of in-vehicle and infrastructure sensors with enhanced communication capabilities, application of modern information and communication technologies with the proliferation of internet connected devices and systems. Data sets grow in size because they are being gathered increasingly by ubiquitous information sensing mobile devices, aerial sensory technologies (remote sensing), software logs, cameras, microphones, radio-frequency identification readers, and wireless sensor networks, together with machine-generated and unstructured data (e.g. photos, videos, social media feeds). This means that ITS applications have to sense huge amounts of data, process them, infer and communicate usable information in such way to allow efficient decisions and actions to be made. But for true and real change in our life, novel transport systems have to be able to foresee situations in near real time, and provide the means for proactive decisions which in turn will deter problems before they even emerge. Our vision is to provide the required interoperability, adaptability and dynamicity in systems and services for a proactive and problem-free transportation system.

OPTIMUM operates in an environment of ubiquitous connectivity throughout the transportation systems and its surroundings that continuously provides data on the present state and emerging situations. Examples include traffic and in-vehicle sensors, positioning information (e.g. Global Navigation Satellite System (GNSS) data), occupancy of public

\(^1\) UN Department of Economic and Social Affairs/Population Division, “World Urbanization Prospects”, 2012.
transportation, crowd data sourcing through social networks and availability of modalities such as shared bicycles and cars. Sensors for vehicle-to-vehicle and vehicle-to-infrastructure information exchange offer context-aware pervasive configurations that can infer situations on transport networks. Environmental and weather sensors may provide insights on the status of the ambient environment and its impact on the utilization of the transport networks. Another important source of information refers to social sensors, i.e. citizens interacting in social media (e.g. twitter and Facebook) openly offering opinions and observations. On the other hand, user centred transportation information needs to be able to accommodate the individual. It needs to provide choices for the user in a personalized and understandable manner.

OPTIMUM aims to establish a largely scalable, distributed architecture for the management and processing of multisource big-data, enabling continuous monitoring of the transportation systems needs and providing data-driven mobility services based on proactive decisions and actions in an (semi-) automatic way. In order to achieve OPTIMUM’s aim, we follow a cognitive approach based on the Observe, Orient, Decide and Act (OODA) loop of situational awareness\(^2\) that has been recognized as one of the main models for the big data supply chain - the key for continuous situational awareness. This model recognizes decision-making occurring in a recurring cycle of unfolding interactions with the environment, guided by cues inherent in tradition, experience and analysis. These cues inform hypotheses about the current and emerging situation that, in turn, drive actions which test hypotheses. Based on the OODA approach, the project’s goal will be accomplished through the following set of scientific and technical objectives:

1. To capitalize on the benefits and potentials of big data fusion and proactive behaviour in the diverse and multi-modal transportation context by designing a distributed and scalable architecture
2. To enable comprehensive observations of the transport ecosystem, by designing and developing a smart sensing system able to cope with a huge amount of heterogeneous data in real-time (Observe)
3. To enable semantic understanding of acquired data and predict the status of transport networks for short and medium term horizons by designing and developing an efficient management framework for dynamic (proactive) and context-aware forecasting and detection of the situations of interest on the basis of complex and predictive data analysis algorithms and event-detection (Orient)
4. To realize sustainable transportation behaviours through system aware optimization mechanisms that integrate adaptive charging and crediting models and real time multimodal routing and navigation algorithms (Decide)

5. To support proactive decisions and sustainable transportation behaviours through proactive information provisioning and personalization, persuasive mechanisms (Act)

1.1 Objectives of the Deliverable
The objective of D1.1 “State-of-the-art Report” is to provide a systematic overview of the current research in the key ICT and transport related thematic areas that will enable us to fulfil our vision by serving as the basis to achieve our objectives. The thematic areas analysed in the context of D1.1 underpin further development of the OPTIMUM architecture on the basis of the OODA approach. As the project consortium is multi-disciplinary, with the aim to cover a wide spectrum of competences and skills required for the successful implementation of the innovative project vision, D1.1 enables OPTIMUM partners to set a common working ground by providing access to a common glossary, as well as by facilitating mutual understanding of important concepts of the various research areas. To this end, the basis for a fruitful collaboration among people of different backgrounds and disciplines is provided.

The following ICT and transport related knowledge domains, are examined in this deliverable and in the context of the OODA approach: fusion and harmonization of big transportation data (observe); real-time big data processing for transportation, including big-data architectures and complex event processing, theories and latest developments on transport forecasting, including socio-econometric models and traveller behaviour forecasting, as well as technologies such as real-time sensing and stream analytics of transport data, which include machine learning for social media applications and online stream analytics (Orient); dynamic crediting and charging models, system aware optimization and multimodal routing (Decide); persuasive technologies and information personalization (Act). In addition, since ITS technologies will form the technological spine of the proposed platform, ITS-related directives, action plans, regional strategic plans and deployment strategies are reviewed, while the outcomes of ITS projects in the area of Traveller Information Services (TIS) for multi-modal transportation are indexed.

1.2 Structure of the Deliverable
In order to achieve the aforementioned goals, the following methodology was defined and applied for each research area:
- the most relevant related research work was analysed
- for ICT related research areas, emphasis was given on existing applications in the transportation domain
- related applications were identified, where relevant
- the main research gaps and limitations of the existing state-of-the-art in the area were analysed, as the basis for enabling OPTIMUM to build upon existing research practices and go beyond the current state-of-the-art
Moreover EU Strategies, Directives, Action Plans, Regional Strategic Plans and Deployment Strategies related to multi-modal travellers’ information services, as well as ITS projects were identified and analysed.

The rest of the report is structured as follows. Sections 2-7 present the state-of-the-art analysis of all the fields related to the OPTIMUM project starting with fusion and harmonization of big transportation data (Section 2), real-time big data processing for transportation (Section 3), transport forecasting and stream analytics of transport data (Section 4), continuing with dynamic crediting and charging models (Section 5), system aware optimization and multimodal routing (Section 6) and concluding with persuasive technologies and information personalization (Section 7). Each one of these Chapters consists of an analysis of the related work in the relevant area and the identification of research gaps of the current state-of-the-art. In Section 8, ITS-related projects, directives, action plans, regional strategic plans and deployment strategies are presented, while finally Section 9 concludes the deliverable.
2 Fusion and harmonization of big transportation data

Big Data is a broad terminology for extremely large and complex data sets, which cannot be adequately handled by traditional data processing tools and mechanisms. Most common definitions for Big Data are Gartner’s 3Vs definition for Big Data and De Mauro’s variant for the 3Vs:

- Big data is high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making (Gartner, Inc., 2013).
- Big Data represents the Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value (De Mauro, Greco, & Grimaldi, 2014).

In both definitions, **Volume** represents the ever augmenting amount of data collected, **Velocity** corresponds to the exponential growth on data acquisition, and **Variety** stands for the growing heterogeneity of data formats and communication protocols that exist to share and spread data.

From all data-gathering areas and contexts, transportation data must be one of those types of data in which all of these Big Data characteristics are present, from large quantities of data, captured every day in intervals ranging from hours to seconds, varying from real-time or simulated traffic data, floating-car and GPS data, weather and traffic forecasting and history data among several others.

Big transportation data is also highly variable, since it still presents lots of inconsistencies, such as intermittent sensor data (traffic, parking spots, etc.) or outdated data from transportation providers (schedules, stops, etc.). These inconsistencies lead to a low veracity ratio, since the quality of data is always changing, even in the same provider. Finally, complexity refers to Volume-to-Variety ratio, and to the difficulties to fuse large amounts of data coming from several different sources.

Taking into account all of the peculiarities of Big Data, its collection, treatment and harmonization for future use has to be so that the extrapolation of valuable information and knowledge from Big Data surpasses, or at least minimizes the problems raised by Big Data characteristics.
Formally, the lifecycle of Big Data, from its collection to its usage as valuable information is comprised by several stages, as shown in Figure 1 (OECD/ITF, 2015).

Beyond data collection, acquisition and recording tasks, data has to be fit for analysis, meaning that, once the data is parsed into relevant fields a series of operations can be performed to clean, transform and model the data in order to retrieve meaningful value from it. Data analytics represents all the ways in which information can be extracted from a given data set (OECD/ITF, 2015).

OPTIMUM, will utilise various data sources, including traffic loop sensors on highways and urban networks, data from traffic simulations, real time GPS data from the trucks, motor homes and the city busses, traffic events data, weather, social media, points of interest data and also some internal states of the trucks and motor-homes.

### 2.1 Related Work

#### 2.1.1 ETL Methodologies and Tools

ETL stands for Extract-Transform-Load, representing the process in which data is loaded from one or more source systems to a unified data repository. ETL is a concept introduced in the context of a Data Warehouse, i.e. a central repository for all or significant parts of the data that an enterprise's various business systems collect. However, it is now being adapted to all kinds of data-interacting areas, such as Business Intelligence & Analytics or Data Mining. The steps for a generic ETL process are described below:

- **Extract**: This step entails data extraction from source systems, making it accessible for further processing. The idea is to extract all the required data from source systems with as little resources as possible.
- **Clean**: ETL encompasses a cleaning step as a separate step. The cleaning process is one of the most important steps, as it ensures the quality of data, by making identifiers...
unique, converting null values into a standardized Not Available value or converting numbers such as phone numbers and ZIP codes to a standardized form.

- **Transform**: The transform step applies a set of rules to transform the data from the source to the target. This includes converting any measured data to the same dimension (i.e. conformed dimension) using the same units so that they can later be joined.

- **Load**: During the load step, it is necessary to ensure that the load is performed correctly and with as little resources as possible. The target of the Load process is often a database.

ETL is evolving to support integration across much more than traditional data warehouses. ETL has become the next component of analytic architecture poised for major evolution. Much new data is semi-structured or even non-structured, and constantly evolving data models are making the accepted tools for structured data processing almost useless. ETL can support integration across transactional systems, operational data stores, BI (Business Intelligence) platforms, MDM (Multi-Dimensional Data Modelling) hubs, the cloud, and other Big Data platforms, such as Hadoop. ETL software vendors are extending their solutions to provide big data extraction, transformation, and loading between Big Data platforms and traditional data management platforms. Hence, like the conceptual tipping point that brought to life the term “big data,” the same scale of evolution with ETL has been reached. The term “Big ETL” describes the new era of ETL processing, defining it as having the majority of the following properties (Caserta & Cordo, 2015):

- The need to process “really big data” – the data volume is measured in multiple Terabytes or greater.
- The data includes semi-structured or unstructured types – JSON, Avro, etc.
- Interaction with non-traditional data storage platforms – NoSQL, Hadoop, and other distributed file systems (S3, Gluster, etc).

Let us now look what methodologies and technologies are often used for ETL, and how these are evolving into Big Data ETL tools.

### 2.1.1.1 Methodologies

There are several methodologies for managing the lifecycle of ETL, from the ones most widely spread, to the ones created and used within a single company or entity, going through new findings and novel methodologies. Some of the better known, and the ones highlighted here, are the CRoss Industry Standard Process for Data Mining (CRISP-DM), the Knowledge Discovery Databases (KDD) and Sample, Explore, Modify, Model, Assess (SEMMA) methodologies or models.
2.1.1.1 KDD

The KDD model is an iterative and interactive model (Brachman & Anand, 1996; Fayyad, Piatetsky-Shapiro, & Smyth, 1996). It refers to finding knowledge in data and emphasizes the high level of specific data mining method. It consists on the extraction of hidden knowledge according to databases. KDD requires relevant prior knowledge and brief understanding of application domain and goals. There are nine different steps in the KDD methodology (Shafique & Qaiser, 2014):

- **Domain Understanding**: KDD goals are defined from the customer’s point of view and used to develop an understanding about the application domain and its prior knowledge.
- **Data Selection**: The data is partitioned in subsets of data samples in order to ease the mining processes, both in terms of complexity and performance. This is an important stage because knowledge discovery is performed on all these data subsets.
- **Pre-processing**: Data cleaning and pre-processing processes to enable completeness and consistency, producing data without any noise and inconsistencies. In this stage strategies are developed for handling noisy and inconsistent data.
- **Transformation**: This step focuses on transformation of data from one form to another so that data mining algorithms can be easily implemented. For this purpose different data reduction and transformation methods are implemented on target data.
- **Data Mining**: The Data Mining step actually encapsulates three distinct steps: Choosing a suitable data mining task, choosing a suitable data mining algorithm and employing the data mining algorithm.
- **Interpretation/Evaluation**: Interpretation and evaluation of resulting mining patterns. This step may involve extracted patterns’ visualization.
- **Knowledge Usage**: This is the last and final step of KDD process in which the discovered knowledge is used for different purposes. The discovered knowledge can also be used by interested parties or can be integrated with other systems for further usage.

2.1.1.2 CRISP-DM

CRISP-DM (Chapman, et al., 2000) was launched in late 1996 by Daimler Chrysler (then Daimler-Benz), SPSS (then ISL) and NCR. This model has been refined over the years. CRISP-DM 1.0 version was published in 1999 and is complete and documented. It provides a uniform framework and guidelines for data miners. It consists of six phases or stages which are well structured and defined (Shearer, 2000):

- **Business Understanding**: This step uncovers important factors including success criteria, business and data mining objectives and requirements as well as business terminologies and technical terms.
- **Data Understanding**: This step focuses on data collection, checking quality and exploring of data to get insight of data to form hypotheses for hidden information.
- **Data Preparation**: selection and preparation of final the data set. This phase may include many tasks, such as records, tables and attributes selection as well as cleaning and transformation of data.
- **Modelling**: Selection and application of various modelling techniques. Different parameters are set and different models are built for same data mining problem.
- **Evaluation**: Evaluation of obtained models and decision on how to use the results. Interpretation of the model depends upon the algorithm and models can be evaluated to review whether it achieves the objectives properly or not.
- **Deployment**: Determining possible uses for obtained knowledge and results. This phase also focuses on organizing, reporting and presenting the discovered knowledge when needed.

![Figure 2. CRISP-DM Process Diagram](image)

### 2.1.1.3 SEMMA

SEMMA (SAS Institute, 2014) model was developed by SAS institute. It has five different phases. It offers and allows understanding, organization, development and maintenance of data mining projects. It helps in providing the solutions for business problems and goals. SEMMA is linked to SAS enterprise miner and basically a logical organization of the functional tools for them.
Sample: Sampling of data. A portion from a large data set is taken that big enough to extract significant information and small enough to manipulate quickly.

Explore: Exploration of data. This can help in gaining the understanding and ideas as well as refining the discovery process by searching for trends and anomalies.

Modify: Modification of data by creating, selecting and transformation of variables to focus model selection process. This stage may also looks for outliers and reducing the number of variables.

Model: Modelling of data. The software for this automatically searches for combination of data. There are different modelling techniques are present and each type of model has its own strength and is appropriate for specific situation on the data for data mining.

Access: Evaluation of the reliability and usefulness of findings and estimates the performance.

2.1.1.1.4 Comparative Analysis of KDD, CRISP-DM and SEMMA

By examining all three data mining process models, it clearly shows that they are somehow equivalent to each other. Even SEMMA is directly linked to the SAS enterpriser miner software and CRISP-DM Daimler Chrysler (then Daimler-Benz), SPSS (then ISL) and NCR (Shafique & Qaiser, 2014). The KDD process model is more complete and accurate than its counterparts, with CRISP-DM being more complete as compared to SEMMA. CRISP-DM remains the top methodology for data mining projects, with essentially the same percentage as in 2007 (43% versus 42%). However, it is reported to be used by less than 50% (Piatetsky, 2014).

CRISP-DM does not seem to be maintained and adapted to the challenges of Big Data and modern data science. One response to this lack of modern methodology is the significant increase in people using their own methodology and other methodologies (together 35.5%, up from 23% in 2007). There is also a big decline in SAS SEMMA methodology (from 13 to 8.5%).

2.1.1.2 Big Data ETL Tools

Unlike traditional ETL platforms that are largely proprietary commercial products, the majority of Big ETL platforms are powered by open source. These include Hadoop (MapReduce), Spark, and Storm, which will be presented below. The fact that Big ETL is largely powered by open source is interesting for several reasons: First, open-source projects are driven by developers from a large number of diverse organizations. Second, one of the most important features of ETL platforms is the ability to connect to a range of data platforms. Instead of waiting for a vendor to develop a new component, new integrations are developed by the community. Third, and perhaps most important, the fact that these engines are open source (free) removes barriers to innovation. Organizations that have a great use case for processing big data are no longer constrained by expensive proprietary enterprise solutions.
Because of the inability of NoSQL and Hadoop to perform ad-hoc joins and data aggregation, more ETL is required to pre-compute data in the form of new data sets or materialized views needed to support end-user query patterns. In the NoSQL world, it is common to see the same event appear in several rows and/or collections, each aggregated by different dimensions and levels of granularity (Caserta & Cordo, 2015).

2.1.1.2.1 Big Data Integrated Environment Tools
ETL and data integration software is primarily meant to perform the extraction, transformation and loading of data. Once the data is available for example in a data warehouse or OLAP cube, Business Intelligence software is commonly used to analyse and visualize the data. This type of software also provides reporting, data discovery, data mining and dashboarding functionality. Some of the most successful open-source integrated environments with ETL and BI capabilities are listed below:

- **Talend Open Studio**: Talend Open Studio (Talend, 2014) is a versatile set of open source products for developing, testing, deploying and administrating data management and application integration projects. For ETL projects, Talend Open Studio for Data Integration delivers a rich feature set including a graphical integrated development environment with an intuitive Eclipse-based interface. The advanced ETL functionality including string manipulations, automatic lookup handling, and management of slowly changing dimensions and support for ELT (extract, load, and transform) as well as ETL, even within a single job.

- **RapidMiner**: RapidMiner (RapidMiner Inc., 2015) is one of the leading data mining software suites. RapidMiner supports all steps of the data mining process from data loading, pre-processing, visualization, interactive data mining process design and inspection, automated modelling, automated parameter and process optimization, automated feature construction and feature selection, evaluation, and deployment. RapidMiner can be used as stand-alone program on the desktop with its graphical user interface (GUI), on a server via its command line version.

- **GeoKettle ETL**: GeoKettle (Open Source GeoBI, 2015) is a powerful, metadata-driven spatial ETL tool dedicated to the integration of different data sources for building and updating geospatial databases, data warehouses and services. GeoKettle enables the Extraction of data from data sources, the Transformation of data in order to correct errors, make some data cleansing, change the data structure, make them compliant to defined standards, and the Loading of transformed data into a target DataBase Management System (DBMS) in OLTP or OLAP/SOLAP mode, GIS file or Geospatial Web Service.
2.1.1.2.2 Distributed Processing Tools

Distributed computing is a field of computer science that studies distributed systems. A distributed system is a software system in which components located on networked computers communicate and coordinate their actions by passing messages. The components interact with each other in order to achieve a common goal. Three significant characteristics of distributed systems are: concurrency of components, lack of a global clock, and independent failure of components (Coulouris, Dollimore, Kindberg, & Blair, 2013). There are two main types of distributed computing systems: batch (off-line) and stream (on-line) computing. When the term Big Data became a buzzword, it applied mainly to batch processing, because companies had lots of historical data already on their databases to process. But soon, companies realized that using distributed computing to process real-time streams of data was a necessity (Chen & Zhang, 2014). Below, we present three of the trendy distributed processing technologies available today:

- Apache Hadoop\(^3\) (batch processing): The Apache Hadoop (The Apache Software Foundation, 2014) software library is a framework that allows for the distributed processing of large data sets across clusters of computers using simple programming models. It is designed to scale up from single servers to thousands of machines, each offering local computation and storage. Rather than rely on hardware to deliver high-availability, the library itself is designed to detect and handle failures at the application layer, so delivering a highly-available service on top of a cluster of computers, each of which may be prone to failures.

- Apache Spark\(^4\) (online-stream processing): Apache Spark (The Apache Software Foundation, 2014) is a fast and general-purpose cluster computing system. It provides high-level APIs in Java, Scala, Python and R, and an optimized engine that supports general execution graphs. It also supports a rich set of higher-level tools including Spark SQL for SQL and structured data processing, MLLib for machine learning, GraphX for graph processing, and Spark Streaming.

- Apache Storm\(^5\) (online-stream processing): Apache Storm (The Apache Software Foundation, 2014) is a free and open source distributed real-time computation system. Storm makes it easy to reliably process unbounded streams of data, doing for real-time processing what Hadoop did for batch processing. Storm is used for real-time analytics, online machine learning, continuous computation, distributed RPC, ETL, and more. Storm is fast: a benchmark clocked it at over a million tuples processed per second per node. It is scalable, fault-tolerant, guarantees your data will be processed, and is easy to set up and operate.

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4. [https://spark.apache.org](https://spark.apache.org)
5. [https://storm.apache.org/](https://storm.apache.org/)
2.1.1.2.3 BIG DATA STORAGE TECHNOLOGIES

Regular SQL Engines and databases are not built to support, manage and process today's Big Data. Big Data refers to petabytes of information, and to interact with this amount of data through regular SQL solutions is difficult. The first solution for this issue was the creation of the NoSQL (Not Only SQL) concept (Schmid, Galicz, & Reinhardt, 2015): A NoSQL database provides a mechanism for storage and retrieval of data that is modelled in means other than the tabular relations used in relational databases. Motivations for this approach include simplicity of design, presumed better "horizontal" scaling to clusters of machine, which is a problem for relational databases. NoSQL databases are increasingly used in big data and real-time web applications.

Lately, a number of solutions based on SQL but called SQL-on-Hadoop engines (Bertran, 2014) are coming to the spotlight. With SQL-on-Hadoop technologies, it's possible to access big data stored in Hadoop by using the familiar SQL language. Users can plug in almost any reporting or analytical tool to analyse and study the data. Here are some examples of the latest NoSQL and SQL-on-Hadoop solutions:

- Apache Hive\(^6\) (SQL-on-Hadoop): The Apache Hive (The Apache Software Foundation, 2011) data warehouse software facilitates querying and managing large datasets residing in distributed storage. Hive provides a mechanism to project structure onto this data and query the data using a SQL-like language called HiveQL. At the same time this language also allows traditional map/reduce programmers to plug in their custom mappers and reducers when it is inconvenient or inefficient to express this logic in HiveQL.

- Cloudera Impala (SQL-on-Hadoop): Impala (Cloudera, Inc., 2015) is a fully integrated, state-of-the-art analytic database architected specifically to leverage the flexibility and scalability strengths of Hadoop - combining the familiar SQL support and multi-user performance of a traditional analytic database with the rock-solid foundation of open source Apache Hadoop and the production-grade security and management extensions of Cloudera Enterprise.

- Apache Cassandra\(^7\) (NoSQL): Apache Cassandra (The Apache Software Foundation, 2015) is an open source distributed database management system designed to handle large amounts of data across many commodity servers, providing high availability with no single point of failure. Cassandra offers robust support for clusters spanning multiple datacenters, with asynchronous masterless replication allowing low latency operations for all clients. Cassandra also places a high value on performance.

\(^6\) https://hive.apache.org/
\(^7\) http://cassandra.apache.org/
MongoDB\(^8\) (NoSQL): MongoDB (MongoDB, Inc., 2015) (from humongous) is a cross-platform document-oriented database. Classified as a NoSQL database, MongoDB eschews the traditional table-based relational database structure in favor of JSON-like documents with dynamic schemas (MongoDB calls the format BSON), making the integration of data in certain types of applications easier and faster.

2.2 Big Data Technologies Adapted to ITS

Some works refer to the above technologies so as to cope with the huge amount of data coming from the Transportation sector. Most of the research works tackle the issue of Big Data in transportation, in terms of algorithm optimization for big data processing and preparation in transportation planning (Huang & Levinson, 2015), (Toole, et al., 2015), traffic operations & forecast (Li, et al., 2015) and safety (Carrel, Lau, Mishalani, Sengupta, & Walker, 2015).

According to our best knowledge, only a minority of scientific literature related to Big Data in the Transportation sector actually tackle the adoption of existing Big Data technologies to handle, process, fuse and harmonize huge amounts of data coming from a panoply of sources, such as car-floating, traffic operator, weather, GIS and road network, in-car sensor, road sensor or fleet operator data, just to name a few.

The authors in (Zhu, Yu, & Du, 2012), present a cloud computing platform for historical data mining of Traffic Information, based on the Hadoop platform, the Hadoop Distributed File System (HDFS) and the MapReduce paradigm. (Gavali, Mane, & Patil, 2014) also uses the Hadoop system to perform traffic forecasting and learning models in a distributed system, using Gaussian Mixture Models and Bayesian networks. A drawback of these works is that they do not cope with real-time, online streamed data. On the other hand, (Zygouras, et al., 2015) (Zygouras, Zacheilas, Kalogeraki, Kinane, & Gunopoulos, 2015) are two works coming from the same authors, which allow both real-time streaming and also offline batch processing Big Data. The systems are based also on Hadoop for batch data processing tasks, and rely on Storm for real-time stream processing tasks. The first one, presents the architecture, from data collection to its harmonization and fusion, and adopting Complex Event Processing approach on Big Data. The later, describes the detection of faulty traffic sensors in real-time. One major drawback relates to the fact that MapReduce is not ready (yet) to cope with the incremental nature of Transportation data. Transportation data is highly dynamic in its nature, from floating-car data to traffic sensor data, and MapReduce implies that, each time the data changes, the Map and Reduce tasks have to be rerun, in order to cope with new data. Fortunately, there are already several MapReduce-deriving paradigms, such as InCoop (Bhatotia, Wieder, Rodrigues, Acar, & Pasquin, 2011), that already tackle this incremental data problem.

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\(^8\) [https://www.mongodb.org/](https://www.mongodb.org/)
There are several companies, European and worldwide, that work with Big Data in the Transportation area, towards a more efficient ITS. A relevant case study which excels in this area is Google, with its integration between Google Maps and Waze data, and INRIX, which is collaborating with several of world class companies to transform how people and commerce move across the world’s transportation networks. In Europe, several companies and endeavours are already established to harmonize and fuse European countries’ transportation data (Sandgren & Ottoson, 2002):

- Western European Road Directors (WERD) is an organization that represents the national road administrations among the member states of the European Union and, via their subgroup 5 “Road Databases” has worked for many years in this field. They have produced a specification for a road data exchange format (RADEF).
- ERTICO is a Europe-wide, non-profit, public/private partnership for the implementation of Intelligent Transport Systems and Services (ITS). Members in ERTICO come from both the public and private sector and are constituted of national road administrations, automobile manufacturers, electronics industries etc. ERTICO has shown a great interest in road data. They are interested in road-informatic applications, which in turn are dependent on accessibility to up-to-date and quality-assured road data.

EuroGeographics is the association of European National Mapping Agencies (NMAs), and is deeply engaged in the development of the European Spatial Data Infrastructure. One important aim is to achieve interoperability of the National Mapping Agencies reference databases. EuroGeographics members have established seamless Administrative Boundaries of Europe (SABE) and are now in the process to build up EuroRegionalMap (topographical reference data at a scale of around 1:250 000) and EuroGlobalMap (reference data at approximately 1:1 million). EuroGeographics has also carried out studies and arranged workshops aiming to prepare a project on harmonisation of European road data, involving the participation of representatives from road administrations and from the private sector, including SMEs.

2.3 Research Gaps of State-Of-The-Art

The big challenge in ITS is not on how to collect, but how to process and model large volumes of unstructured data for posterior analytics, which cannot be handled effectively by traditional approaches. There is a need for developing innovative services and applications capable of processing and inferring information in real-time for better support of decision making, but also in order to predict complex traffic related situations before they occur and take proactive actions.

Other aspects that must be considered are the challenges driven by a big data context, such as inconsistencies on the data itself (e.g. highway counters are susceptible to several anomalies),
outdated data, the bandwidth of the connection. Such inconsistencies lead to the lack of quality on the data sets and, adding to that, the challenge in fusing and harmonizing large volumes of data from many sources at the same time (volume to variety ratio). These aspects bring particular importance to ETL (Extract-Transform-Load) processes, when traffic data need to be loaded from sources into a harmonized data repository. ETL software houses have been extending their solutions to provide big data extraction, transformation and loading between big data platforms and traditional data management platforms, describing ETL now as “Big ETL” (Caserta & Cordo, 2015).

Existing surveys and Roadmaps talk about the need for harmonization of Big Data within the Transportation sector, but they still do not present any concrete, practical solutions. Examples of such surveys are (Council for the Environment and Infrastructure of Netherlands, 2015) and (Thompson, 2015). On the other hand, most research works on the matter are still light-years away from fulfilling the potential of Big Data on Intelligent Transportation Systems, due to the fact that most of them do not use any kind of the above described Big Data technologies, and the ones that use them do not entirely solve the issue concerning the incremental nature of transportation data.

Hence, an ETL-based approach is proposed, able to process and model large volumes of raw traffic data efficiently. The proposed architecture should be able to: (i) take into account the data quality; (ii) the ability to cope with already existing data standards under the ITS domain, such as DATEX-II, to guarantee harmonization among data; (iii) provide a robust and scalable storage system.

The proposed architecture adopts “big data technologies”, such as Apache Spark for data processing, and MongoDB for data storage. This approach follows the principles of parallel, in-memory processing by Big Data technologies with all the advantages showed in studies (Luckow, et al., 2015) and (Ma & Liang, 2015).

In OPTIMUM, we will compute, store, and analyse high volumes of transportation and traffic related data through ETL processes, adopting CRISP-DM methodology. We will also use Storm/Spark approaches to parallelize and process the data, and use incremental versions of MapReduce to handle the incremental nature of Transportation-related data. Adopting a NoSQL and a distributed processing approach, will allow us to process up to hundreds of Terabytes of transportation and traffic data much faster than with conventional methods. In this sense, the OPTIMUM project aims to adapt these Big Data-based ETL paradigms and technologies to the Transportation sector, in order to pave the way for true Big Data ITS.
3 Real-time big data processing for transportation

3.1 Related Work

3.1.1 Introduction: the role of real-time big data processing

Every second, vehicle telematics devices produce data, such as date, time, speed, position, acceleration, fuel consumption, etc. A major challenge is to make sense of such data in real time. For example, providing fleet operators the ability to process vehicle information can lead to informed real time decisions (traffic jam, wrong driving way, etc.). This not only results in cost savings, optimised driver behaviour and effective route planning but also allows dynamic, life-saving accident management.

Telematics can produce a lot of data in real time. Additional data can be gathered at different levels: on the local level (level of the object), from the object surroundings or even from the other open data platforms (city, region, news, etc.). Traffic light systems, for example, can share information on their phase times allowing a driver support system to highlight the optimal driving speed for catching all the lights on green.

In the following we describe shortly the most important cases for exploiting big data processing in the transportation domain, we found in the recent literature (https://datafloq.com/read/big-data-create-smarter-transportation-industry/119).

3.1.1.1 Optimization of freight movements and routing

Consolidating shipments and optimizing freight movement for large logistics can enable same day regional delivery. Knowing exactly which products are where in which warehouses can help companies like Amazon to deliver the right product at the right time to the right customer within 24 hours or even on the same day. Removing supply chain waste and analysing transaction-level product details will ensure efficient and smarter transportation of freight.

Using satellite navigation and sensors, trucks, airplanes or ships can be tracked in real-time. The routing different trucks, airplanes or ships need to take can be optimized using a lot of public data such as road conditions, traffic jams, weather conditions, delivery addresses, location of gas stations (in the cases of trucks) etc. Whenever a change in address comes in from head office, it can be pushed to the driver or captain in real-time. The system automatically calculates and optimizes the ideal and cheapest new routing to the new destination.

Sensors in trucks, ships or airplanes can also give real-time information about how the truck, ship or airplane is performing, how fast it is going, how long it is on the go, how long it is standing still etc. With all this data, combined with sensors that monitor the health of the engine and equipment, errors can be predicted and maintenance can be prepared without
losing to much time. It is even possible to automatically book maintenance at the location that requires the least downtime for the transportation company, while the engineer instantly knows what the problem is and how it can be solved.

In case of large logistic organizations with hundreds or thousands of trucks, sensor data is used to known where all trucks are at any moment in time, what their inventory is as well as their destination. This information can help the transportation company to optimize their fleet and increase efficiency.

3.1.1.2 Determining Inventory on Hand
Stock that is in-transit is still part of the inventory of an organization, although it physically left a warehouse. It is important to know the exact inventory at all times, especially if last minute changes need to be made. When all products contain sensors they can be tracked in real time and adjustments and/or inventory counting becomes very simple.

Inventory management analytics can be used to create a centralized platform that offers organizations a detailed overview of departure and arrival times, order cuts as well as the possibility to provide customers with detailed information on their freight.

3.1.1.3 Improving the End-to-End Customer Experience
Customers want to know exactly where in the process their freight is and where it is located as well as when the expected time of arrival is. With a smarter transportation system, freight shippers and customers are given the information and tools to decide for themselves the best way to get their product from origin to destination, across different modes of transport, considering cost, time and convenience. A package can use several modes of transport and within a smart transportation system customers can determine how their freight goes from A to B. This will enable the customer to better manage their supply chain as well as costs.

3.1.1.4 Reducing Environmental Impact and Increase Safety
Fuel consumption can be reduced via several ways. First of all, sensors can monitor the engine and optimize fuel input based on the need of the engine and what the truck, ship or airplane is doing. Combined with the best optimized routing, created by taking into account weather conditions, driving behaviour, road conditions, location etc., a lot of fuel can be saved.

Sensors can also monitor how fast the driver is driving where and whether the driver is sticking to the rules on the road. It can be monitored if the driver is behind the wheel too long or if the breaks are too long. It can keep the driver awake and as such prevent accidents, while keeping the drive accountable.

More and more cities around the world are experimenting with smart transportation systems that will reduce pollution and increase road safety. The city of Brisbane has developed a complete, real-time overview of the city’s transport network, which provides a platform to
develop and test new strategies in a stable and real-time virtual environment. This platform enables the city to predict and improve traffic congestions, resulting in happier commuters and shippers, while reducing emissions. They also use variable speed limits and roadway queue management algorithms to improve highway safety. With the increasing demands of customers to have their freight delivered as fast as possible, as cheap as possible, transportation companies face a challenge that luckily can be tackled with big data.

3.1.1.5 Unusuality detection
Modern telematics systems are already capable of analysing driving style and providing comprehensive feedback to both managers and drivers in real time. Drivers have the power to correct their behaviour in real time, but maps which provide metre-by-metre, hour-by-hour, day-by-day accuracy would allow behavioural monitoring systems to become even more intuitive, to point where the braking system could react automatically if it detects a driver is going too fast on a given section of road. E.g. the telematics system would automatically know if a 90-degree corner was approaching in 200 metres and could adjust the speed if a driver had failed to properly judge the severity of the bend. Similarly, if a vehicle’s data highlighted heavy rain up ahead, brakes and wheel sensitivity could be adjusted to suit the conditions automatically.

However, in most of these situations it is difficult to calculate exact thresholds when and how to react on these real-time situations. In other words, the human-defined rules can be imprecise and not covering all situations. This is why we aim to automate the processing of the situations of interest by applying novel Big data processing techniques. In OPTIMUM we will focus on anomaly (unusuality) detection which is explained below.

3.1.2 Anomaly detection: processing unusuality in real-time data
Anomaly detection refers to the problem of finding patterns in data that do not conform to expected behaviour\(^9\). Anomalies are the set of data points that are considerably different than the remainder of the data. This is the topic of an active area of research which draws on concepts and techniques from fields such as machine learning, data mining, statistics, information theory, etc. Examples of such techniques include clustering, support vector machines, neural networks, rule-based approaches, etc.

Various approaches to anomaly detection have been proposed, depending on the type of anomaly, type of data, underlying technique, and intended application domain.

3.1.2.1 Type of anomaly
As shown in Figures 3, 4, 5 several types of anomalies may be distinguished (Chandola, Banerjee & Kumar, 2009). Point anomalies are anomalies where an individual data point is considered an

\(^9\) http://cucis.ece.northwestern.edu/projects/DMS/publications/AnomalyDetection.pdf
anomaly by itself. By contextual or conditional anomalies a data point may be anomalous only within a certain context but not in a different context. This requires a notion of context. In the case of group or collective anomalies, an individual data point are not considered anomalous but having a sufficient number of such data points is considered to be an anomaly. This requires a relationship among data instances such as sequential data, spatial data, etc.

**Figure 3:** An individual data instance is anomalous w.r.t. the data (point anomalies)

**Figure 4:** An individual data instance is anomalous within a context (contextual anomalies)

**Figure 5:** A collection of related data instances is anomalous (collective anomalies)
3.1.2.2 Type of data
A key aspect of any anomaly detection technique is the nature of the input data. Each data instance can be described using a set of attributes. The attributes can be of different types such as binary, categorical or continuous. Each data instance might consist of only one attribute (univariate) or multiple attributes (multivariate).

Depending on data labels, we distinguish between supervised, semi-supervised and unsupervised anomaly detection. Supervised approaches assume that labelled training data (both normal data and anomalies) is available, from which a predictive model can be build that distinguishes anomalous from normal data points. Semi-supervised approaches usually assume that only labelled normal data is available, but not labelled anomalous data. Such approaches work by trying to build a model of normal behaviour, against which new data points can be matched. In the case of unsupervised approaches, no labels are assumed and the anomaly detection is based on the assumption that anomalies are very rare compared to normal data. It means that unsupervised approaches work with the assumption that most of this data is normal, and anomalies can be detected based on their rarity (e.g. by being away from the main clusters, or by being in a low-probability region of the space).

3.1.2.3 Underlying technique
To detect anomalies, two steps have to be applied: (1) build a model of the “normal” behaviour, whereas a model can contain patterns or summary statistics for the overall population; (2) use this “normal” profile to detect anomalies, i.e. observations whose characteristics differ significantly from the normal model. To build a model, different methods can be used such as statistical-based, distance-based, model-based, etc. A survey of anomaly detection methodologies and their applications is given in (Niu, Shi, Sun & He, 2011).

Several clustering based anomaly detection techniques have been developed. Clustering algorithms tend to identify groups of similar objects and produce partitions for the given dataset. A number of clustering algorithms exist, from partitioning algorithms such as K-means\textsuperscript{10}, over hierarchical algorithms that form a tree of clusters (dendogram) by performing clustering on different levels, to density based algorithms such as DBSCAN that group objects based on the neighbourhood of each object. All of these algorithms have their own purpose, advantages and weaknesses, so a great caution is need while choosing the appropriate clustering method.

K-medoids\textsuperscript{11} is a partitioning algorithm, similar to K-means, that uses medoids to represent clusters. Unlike the K-means algorithm where centroids are used to represent clusters, in case of K-medoids, medoid is one of the objects from the dataset that is the best representative of

\textsuperscript{10}https://en.wikipedia.org/wiki/K-means_clustering
\textsuperscript{11}https://en.wikipedia.org/wiki/K-medoids
the cluster. PAM (Partitioning Around Medoids) is the most common realization. The basic steps of K-medoids algorithm are initialization, assignment of objects to closest medoid and new medoid selection for each of the clusters. Medoid selection is the most expensive procedure of the algorithm. FAMES is a medoid selection algorithm that tries to overcome this problem.

K-medoid algorithms try to find optimal medoids in the dataset, while finding a single medoids requires $O(n^2)$ distance calculations. This makes this algorithm practically unusable for bigger datasets. FAMES (FAst MEdoid Selection)\(^\text{12}\) represents an improvement of K-medoids algorithm by offering a fast selection of good representatives.

In (Muenz & Carle, 2007) the authors presented a novel flow-based anomaly detection algorithm based on the K-mean clustering algorithm. Training data contained unlabeled flow records that were separated into clusters of normal and anomalous traffic. The corresponding cluster centroids are used as patterns for computationally efficient distance-based detection of anomalies in new monitoring data.

The main target of (Callegari, Giordano, Pagano, Pepe, 2012) was to develop efficient algorithms able to detect abrupt changes in the data, with the smallest detection delay. The authors presented a novel method for network anomaly detection, based on the idea of discovering heavy change in the distribution of the Heavy Hitters by applying several forecasting algorithms. To assess the validity of the proposed method, an experimental evaluation phase has been performed.

In (Hayes & Capretz, 2015), the authors proposed a contextual anomaly detection framework. It is composed of two distinct steps: content detection and context detection. The content detector is used to determine anomalies in real-time, while possibly, and likely, identifying false positives. The context detector is used to prune the output of the content detector, identifying those anomalies which are considered both content and contextually anomalous. The context detector utilizes the concept of profiles, which are groups of similarly grouped data points generated by a multivariate clustering algorithm.

Two approaches to monitoring the behaviour of deployed sensors are described in (Hughes & Du & Hallstrom, 2015). The static approach is based on user configuration data that captures the expected reporting period of each sensor. The adaptive approach relies on an online time-series analysis of reporting times. The ability to automatically identify reporting patterns enables the determination of whether a sensor is more likely to be damaged, versus exhibiting normal variation in reporting behaviour.

In (Häussermann, Zweigle & Levi, 2015), the authors introduced a novel anomaly detection framework based on spatial-temporal models which is generally applicable for e.g., plan execution monitoring. The introduced framework combines the methodology of Kohonen's Self-organizing Maps and Probabilistic Graphical Models exploiting all advantages of both concepts. The detailed description of the data-driven training of the spatial-temporal model and the reasoning process are given.

In (Aggarwal, Han, Wang & Yu, 2003), the clustering problem for data stream applications was studied. An effective and efficient method, called CluStream, for clustering large evolving data streams has been proposed. The CluStream model provides a wide variety of functionality in characterizing data stream clusters over different time horizons in an evolving environment.

The continuous cluster model validation, monitoring, trend and change detection, and summarization of the cluster mining output is discussed in (Hawwash & Olfa Nasraoui, 2012). The authors proposed a complete framework to mine, track and validate the clusters in a data stream. The proposed framework keeps track of each discovered cluster model of the stream through time, while quantifying, modelling and summarizing the cluster evolution trends, and storing a summary of the cluster models and the evolution trends only at milestones corresponding to the occurrence of significant changes. The experiments demonstrated the accuracy of the proposed framework in tracking cluster evolution over time. Additionally, a concise summary of the evolution trends over the lifetime of the stream is generated.

In order to deal with big data, in (Hadian & Shahrivari, 2014) the authors proposed an algorithm that combines parallel clustering with single-pass, stream-clustering algorithms. The proposed clustering algorithm utilizes maximum capabilities of a regular multi-core PC to cluster the dataset as fast as possible while resulting in acceptable quality of clusters. The data is split into chunks and each chunk is clustered in a separate thread. Then, the clusters extracted from chunks are aggregated at the final stage using re-clustering. Parameters of the algorithm can be adjusted according to hardware limitations.

### 3.1.2.4 Application domain

Anomaly detection is used in numerous application domains, including security (intrusion detection), finance (fraud detection), medicine and public health, manufacturing (fault detection), science (astronomy, ecology), etc. In the transportation domain, e.g. real-time road traffic anomaly detection based on short-term variation of traffic flow characteristics can be applied for road accident detection.

### 3.2 Research Gaps of State-Of-The-Art

Anomaly detection has many challenges. In the context of OPTIMUM, where most of the available data is numerical, multivariate and unlabelled, we will deal with many of these challenges. For example, defining a representative normal region or the boundary between
normal and outlying behaviour is a challenge, as there are no precise approaches. Additionally, normal behaviour keeps evolving and the exact notion of an outlier is different for different application scenarios. One of very important issues is the limited availability of labelled data that can be used for training and for validation.

As we have to deal with time-series data, we will consider the contextual anomalies where the contextual data will include the longitude and latitude of a location, the time of an instance on the entire sequence, etc. For example, speed of 180 km/h might be normal during the summer (at time t1) at that place (e.g. in Germany), but the same value during winter (at time t2) and/or in another place (e.g. in Serbia) would be an anomaly. We will also consider the collective anomalies, as e.g. weather conditions over a long period of time are more important than the atmospheric conditions at a given hour/date.

We will work on a new methods and tools for unsupervised anomaly detection based on clustering methods. Our idea is to develop a combination of scalable K-means|| (K-means parallel) initialization and K-medoids like algorithm that relies on FAMES for medoid selection. K-means|| represents an improvement of K-means++ algorithm. The major downside of the K-means++ is its inherent sequential nature, which makes it difficult to use in case of big data because it requires k passes over the data to find good initial set of centres.

Another important aspect that is missing in the literature is an efficient detection of complex real-time situations in the transportation domain. Indeed, most of the approaches are focused on relatively simple situations where several parameters are compared against thresholds, the process which is supported by traditional CEP engines (like Esper, www.espertech.com/esper/). Although the event processing languages (EPL) can support different operators (usually from event algebra), the main issue is that the situations that should be discovered are complex from the point of view of the parameters in their temporal context. As a general rule, if more parameters are available, the corresponding patterns are more complex. However, in the transportation domain there is a huge need for a combination of the spatial and temporal conditions, due to the nature of the transportation use cases. The real problem with the spatial patterns is that they require more complex calculations than pure temporal ones. For example, the detection of congestion on a highway is not only related to a temporal sequence of lowering the speed (breaking event) of one car, but rather to a set of breaking events in a spatial context. The problem is not trivial since the spatial context should be properly selected in order to reflect the nature/characteristics of the highway.

Another critical issue in this kind of patterns is the generation of false positive alarms (too many of them). The cause is often in an inappropriate combination of the time and the spatial constraints so that there is a mismatch that leads to false positive alarms. Indeed, the time context should be properly shared within a larger spatial context in order to avoid the generation of the false positive alarms.
Additionally, the situations in the transportation domain are data-reach, which means that a huge amount of data should be processed in a very short period of time, e.g. in order to detect a traffic accident as soon as it appears or even better to predict that such a situation will appear (proactivity). Current approaches are mainly related to the volume of data, whereas the use cases are even more going toward the real-time processing with a minimal latency which requires dealing with velocity in big data. In order to resolve this issue, different types of the parallelization of the processing should be done and one of the most successful methods is based on the Storm architecture (storm.apache.org/).

Recently, the processing that is done as close as possible to the data source, i.e. the so-called edge processing, has become increasingly important for the transportation domain. Indeed, the sensors used in modern vehicles (cars, trucks) generate lots of data that should be processed in the vehicle in order to increase the reactivity on emerging situations (or even enabling proactivity). Since edge processing assumes usage of small, resources constrained devices, the complex event processing should be specially designed for this computation infrastructure. Most of the current CEP engines cannot scale down to the level of small, embedded systems and this process (development) has become very important.

Our approach in OPTIMUM project takes into account all these issues in the realization of a modern complex event processing system.
4 Transport Forecasting and stream analytics

Transport forecasting focuses on the development of models and techniques which allow the prediction of the state of transport networks in short, or long term time horizons, and the identification of demand requirements for future travelling. Since the early research attempts in the mid-70s, the application domain of early forecasting models included travel demand planning (Hiesz, 1974), short-term traffic forecasting (Ahmed & Cook, 1979) and long-term traffic forecasting (Lingras & Adamo, 1996). Since these early efforts, numerous forecasting models have been developed, using different input/output parameters, data sources, transport network types and time horizons. Despite the above stated variability of the characteristics of forecasting, the overall goal of all models was the analysis of static and dynamic data for generating information that could support planning and traffic management strategies, decision making for individual travellers and operational services for commercial, or public transport fleets. The availability of large amount of traffic related data, collected from a variety of sources and emerging field of sophisticated machine learning algorithms has led to significant leap from analytical modelling to data driven modelling approaches. The traffic prediction models have become a main component of most Intelligent Transportation Systems (ITS). In more specific, different types of ITS applications that can be supported by effective forecasting approaches are:

- Dynamic route-guidance
- Congestion management
- Automatic incident detection
- Advanced traveller information systems
- Commercial vehicle operations
- Dynamic traffic control
- Travel demand management

The following sections aim to present a review of real-time sensing and stream analytics for transport forecasting applications. This includes a range of transport forecasting models, their functional characteristics and issues related to their implementation as well as demand analysis and traveller behaviour models. The latter are essential for the development of information services related to multimodal transport.

The section concludes with how OPTIMUM will build upon existing research for developing the necessary tools, which will constitute the “Orient” layer of its architecture.
4.1 Traffic Forecasting Models

Traffic forecasting models can be categorised into different groups based on the nature of the modelling approach (e.g. parametric, non-parametric, hybrid), input type (e.g. univariate, multivariate), input and output ranges (e.g. flow, speed, travel time, occupancy, weather data, social data, etc.), forecasting horizons (e.g. short-term, long-term), forecasting application (e.g. motorway, rural, urban networks, etc.) and algorithmic requirements (e.g. statistical, machine learning, etc.). A summarisation of different traffic forecasting models together with their key functional characteristics can be found in Appendix 1. For the purposes of this state-of-the-art, literature findings will be sectioned according to the underlying theories that underpin the operation of each model.

4.1.1 Naïve Methods

Naïve methods are considered as unsophisticated forecast approach where no forecast model is actually built. In the field of traffic prediction, they are widely used in practice because of their low computation complexity and fast response, although their accuracy is very poor. Usually any parametric or non-parametric methods give better results and naïve methods are used as baseline comparisons for other more sophisticated methods. Because of their undemanding properties, these methods are also widely used for data pre-processing such as filling missing data and smoothing (Bellemans, Schutter, & Moor, 2000). Three simple (usually used) naïve methods are presented in the next part.

Main naïve hypothesis in these methods is that current traffic state (parameters) will remain a constant. No modelling or actual computing is included in such method therefore it is very fast, but usually also very inaccurate (especially in urban environments). But nevertheless, instantaneous predictions will sometimes result in relatively reasonable results, where traffic is very homogeneous over longer period (for example free flow state in highways and motorways). This method is still widely used in practical applications for most en-route travel time information panels (Van Lint & Van Hinsbergen, 2012). In the scientific literature of short-term traffic prediction, it is usually used as baseline.

Historical averages is also known as easy to be implemented and fast working model. It relies only on historical data and it is usually the best choice for long-term traffic predictions, where current traffic status is not that important, since it doesn’t have a lot of influence on the long term. Lack of current data consideration and consequently, its inability to respond to unexpected events and incidents, this method is not so much suitable for short-term predictions. Also widely used as baseline for comparison (Smith, Williams, & Keith Oswald, 2002).

Combining current data (instantaneous predictions method) with historical data (historical averages method) provides better results, than any of those methods alone. One common
approach that combines both methods derives from assumption that ratio of current data to historic conditions is good enough indicator of how the traffic conditions in the next interval will deviate from historic conditions (Smith, Williams, & Keith Oswald, 2002).

Other common approaches include different smoothing techniques, such as moving average techniques, where prediction of the next step is made from n number of historical data and their averages. More sophisticated smoothing models are based on exponential adjustment methods (Chrobok, Kaumann, Wahle, & Schreckenberg, 2004).

Also popular naïve methods are varieties of clustering methods, where real time data is clustered based on similarity with historical values. This approach is commonly used in combination with other methods to increase their accuracy of prediction (Van Hinsenberg, Lint, & Sanders, 2007).

4.1.2 Time Series Analysis

Time-series models were firstly introduced in the middle 70s (Box & Jenkins, 1976) as an effective approach for accurate traffic forecasting. The family of models known as Autoregressive Integrated Moving Average (ARIMA) includes common statistical time series techniques used for prediction. They involve modelling a (traffic) variable as a parameterized (weighted) linear function of past observation of that variable (AR) and past error terms (MA). In a way, they are a special case of regression models, where input parameters are series of past samples. Early versions of auto-regressive integrated moving average (ARIMA) models were used for single spot forecasting based on historic patterns of traffic data (Brockwell and Davis, 1991; Hamed, Al-Masaeid and Bani Said, 1995). Experimentation results revealed as a deficiency of ARIMA models their tendency to concentrate on the means and miss the extremes. Such extremes may arise when nonrecurring events disrupt the flow on a network, and traffic states shift abruptly (for example, from free-flow speed to congested conditions). To address the aforementioned limitation, Yu and Zhang (2004), developed four ARIMA models that, using a switching algorithm, were utilised at different times based on the underlying traffic patterns. Moorthy and Ratcliffe (1988), proposed a long-term forecasting multivariate Box-Jenkins time series model, which demonstrated potential for more accurate predictions. Other enhancements to ARIMA included the introduction of Seasonal ARIMA (SARIMA) by Hoel and Williams (2003), which aimed to capture the seasonality of peak and off-peak traffic as part of the model. Despite of the enhanced responsiveness of SARIMA on seasonal data variations, Hong (2011) disputed the effectiveness of the technique due to its assumption of linearity between current and historic values. A recent study by Kumar and Vanajakshi (2015), targeted the issue of large data requirements for a SARIMA model by compressing the required input to consist of data from the previous three days.
Smith, Williams and Oswald (2002), developed a nonparametric time-series model, which employed heuristics for describing the relationship between dependent and independent variables without previous assumptions on such relationships. However, the performance of the model was inferior to that of ARIMA. As part of their comparative analysis, the authors highlighted the significant computational requirements of ARIMA. A 10-minute data series, of 3-month historical data required six days of analysis for the derivations of the necessary parameters of the model. In contrast, Smith and Demetsky (1997), compared nonparametric and ARIMA based models, with the former producing more accurate results due to its ability to react better in unexpected changes of traffic states. Clark (2003) developed a nonparametric regression model using the k Nearest Neighbour (k-NN) paradigm, in which a group of recent ‘neighbour’ observations are compared with historic ones in order to provide a forecast. Optimised k-NN models were developed by Zheng and Su (2014) who integrated k-NN with principal component analysis to improve the forecasting potential of their model over multiple discrete steps, and Guo, Krishnan and Polak (2012) who employed Singular Spectrum Analysis (SSA) for data pre-processing. Turochy (2006), ascertained that the inclusion of mechanisms and input variables that can infer current state conditions can improve the performance of nonparametric regression models. Wang, Shang and Zhao (2010) used pattern recognition to optimise the performance of a nonparametric regression model. Their analysis of the proposed hybrid model, using traffic data from an urban network, demonstrated better results from traditional regression predictors, but similar performance to that of a SARIMA model. Furthermore, Kamarianakis, Shen and Wynter (2012) proposed a regime-switching space-time model using an adaptive absolute shrinkage and selection operator (LASSO) for the interchanging use of different regression models.

Stathopoulos and Karlaftis (2003), used Kalman Filtering (KF) for incorporating an extra dimension (spatial) as part of a time-series model. Flow input from spatially successive sensors formed a multivariate time series state space model with enhance performance compared to that of a univariate ARIMA model. Kalman filter estimates the future state from only the estimated state in the previous time step and the current measurement therefore requires no memory and makes them ideal for real time predictions or systems with low computable power. Another important fact is that state space model is a multivariate approach, which makes KF suitable for network wide predictions (Whittaker, Garside, & Lindveld, 1997). Kamarianakis and Prastacos (2005), also enhanced time-series analysis by integrating spatial characteristics and data as part of an ARIMA model. Using a multivariate time series model for multiple intersections not necessarily belonging on the same physical path, Ghosh, Basu and O’Mahony (2009), argued the importance that the spatial arrangement of the sensors that provide the traffic data has on improving the accuracy of the predictions. To remove the noise from erroneous, or missing data, Xie, Zhang and Ye (2007) used discrete Wavelet decomposition as part of a Kalman filtering forecasting model. The authors highlighted the
negative performance implications that noisy data have in identifying traffic states, by verifying the superiority of their model against direct Kalman filtering.

4.1.3 Artificial Neural Networks

Artificial Neural Networks (ANNs) are machine learning techniques that aim to mimic the behaviour of biological neural networks. ANNs are constructed as a layered architecture of “neurons”, which are connected together using weighted links. Each neuron is fired based on an activation function and this allows information to be propagated, through the connections, within the network. Training allows the estimation of the weights that can produced optimal outputs based on a finite set of inputs. For transport related applications, Florio and Mussone (1996) investigated the suitability of ANNs for the evaluation of flow-density relationships for motorway traffic. Furthermore, Ledoux (1997) and Nam and Schaefer (1995) used ANNs to model traffic flow as part of an integrated traffic management system, and as a forecasting tool for air passenger traffic respectively.

ANNs have been utilised considerably for the development of traffic forecasting models and are considered a competitive alternative to time-series models. Early attempts of using ANN for traffic forecasting were made by Faghri and Hua (1995) and Lingras and Adamo (1996) who developed models for predicting Annual Average Daily Traffic (AADT). Dougherty and Cobbett (1997) and Dia (2001) proposed various structures of ANNs for the short-term prediction of different traffic parameters, such as flow, speed and occupancy. The authors noted that larger ANNs produced more accurate results, but were computationally expensive. Li and Rose (2011), developed an ANN for the prediction of mean travel times on motorways.

A number of researchers have adopted different deterministic, statistical, or stochastic techniques in order to improve the performance of ANN in traffic forecasting applications. Using wavelet analysis, Jiang and Adeli (2005) designed a time-delay recurrent neural network, which provided better accuracy than a conventional one. Vlahogianni, Karlaftis and Golias (2005) and Khosravi, Mazloumi, Nahavandi, Creighton and Van Lint, (2011) used a Genetic Algorithm (GA) for optimising the structure and hyperparameters of an ANN for predicting flows and travel times in urban networks, while Li, Xu and Wen (2010), encoded the weights and thresholds of an ANN as chromosomes of a GA and used Simulated Annealing (SA) to deter the GA for converging to local extremes. In a similar manner He, Lu and Wang (2013) used Chaos Optimisation instead of SA to optimise the performance of a GA supported ANN. Zhu and Zhang (2009), constructed a layered forecasting algorithm using ANN and Self-Organising Maps (SOM), while Chen, Grant-Muller, Mussone and Montgomery (2001) adopted SOM to classify traffic data as input to an ANN. In the former study, the layered structure was used to effectively support the forecasting task in situations where external events (e.g. incidents, social events, etc.) affected greatly recurrent traffic patterns. Other optimisation techniques for
ANN included Bayesian regularisation (Yeh & Chang, 2012), Graphical Lasso (Sun, Huang & Gao, 2012) and wavelet transform (Yang, Yang, Zhao & Gong, 2012).

Fuzzy logic has also been employed to support the operation of neural forecasting models. Yin, Hong, Xu and Wong (2002) developed a fuzzy neural model which classified input data using fuzzy rules and mapped input to output data using an ANN, while Stathopoulos, Dimitriou and Tsekeris (2008) designed a fuzzy rule base system that combined ANN and Kalman filtering as part of a short-term forecasting model. Lu, Sun, Qu & Wang (2015) devised a deep-learning-based coefficients optimization algorithm based on fuzzy ANN and integrated as part of the forecasting model spatial and temporal correlations. Finally, Chai, Pasquier and Lim (2006) designed a fuzzy neural network, which successfully extracted fuzzy rules from training data and revealed better forecasting capabilities than those of a conventional ANN.

### 4.1.4 Additional Forecasting Models

Despite the fact that most literature findings focused on the application of time-series, ANNs and their hybrid alternatives, a number of other machine learning and reasoning approaches have demonstrated effectiveness in the solution of traffic forecasting problems.

A machine learning approach that has gain popularity as part of traffic forecasting is Support Vector Regression (SVR). SVR is based on Support Vector Machines (SVM), which are supervised learning models that can be used for classification problems. Hong, Dong, Zheng and Wei (2011), devised a SVR model that was coupled with GA-SA for the optimisation of its parameters. Another optimisation approach utilised chaos theory and wavelet analysis to define the input space and kernel function of a SVR model (Wang and Shi, 2013). In a similar manner, both Li, Hong and Kang (2013) and He and Xiong (2011), optimised the performance of a SVR model using chaotic particle swarm optimisation.

Hou, Edara & Sun (2015), used two types of decision tress, namely random forest and regression trees, as part of a forecasting model that aimed to predict flows in urban areas where construction works were under progress. The experimental analysis of the authors revealed that the random forest model performed better than its ANN and nonparametric regression counterparts. In addition, researchers have integrated (in forecasting models) decision trees as mechanisms of selecting appropriate algorithms based on the state of the transport network (Coric, Wang & Vucetic, 2011; Prasad & Ramakrishna, 2014).

Innovative linear predictors were used by Zhang & Rice (2003) and Fei, Lu and Liu (2011) to predict travel times for motorway trips. In the first study, the coefficients of the model varied according to the departure time and the authors reported that segmentation of the forecasting process for different sections of the same trip improved the model’s accuracy. On the other hand, Bayesian theory was used on the latter model to develop a dynamic system that was updating past knowledge based on real-time information. In general, linear regression
approaches are characterised as simple models, but in some literature they show surprising good results (Rice & van Zwet, 2004), as well as very fast prediction, since time consuming parts may be done offline. This makes linear regression approach very suitable for online real time predictions. Gaussian maximum likelihood is another classical statistical method, which is based on two assumptions (Van Hinsenberg, Lint, & Sanders, 2007): (1) the prediction deviates as little as possible from the historical average, and (2) the prediction increment deviates as little as possible from the historical increment. Predictive results are usually strikingly good comparing to other methods (Lin, 2001).

Locally Weighted Regression (LWS) uses local regression models to fit a flexible curve predicting desired input variable, using the training data-set by weighting proportionally to its proximity to the current measurement. The difference from classical linear regression, besides the more flexible functional form, is that this approach can easily be extended with additional explanatory variables, something that is not easy (if at all possible) using the typical speed-density relationship (Antoniou, Koutsopoulos, & Yannis, 2013). Very good results are shown in prediction accuracy, as well as computational time (Nikovski, Nishiuma, Goto, & Kumazawa, 2005).

Huang and Sadek (2009) proposed a spinning network model based on the operation of human memory, which despite its low computational complexity produced more accurate forecasting outputs than that of an ANN and a k-NN model. Lee, Tseng and Tsai (2009) and Li, Liu, Liu, Liu and Zhang (2012) applied rule-based reasoning coupled with data mining techniques for traffic forecasting in urban intersections.

Bayesian networks are most widely used as a data mining technique for traffic prediction on a network scale basis, where predictions are made for all roads in an entire network based on measurements on some of the links (Sun, Zhang, & Yu, 2006). This is one of the rare non-parametric techniques that is used for network wide predictions (Van Hinsenberg, Lint, & Sanders, 2007). It is also very appropriate method for a spatial-temporal approach, where the models use all the spatial and temporal information from the traffic network (Sun, Zhang, & Zhang, 2005). Because of its multivariate abilities it is therefore very suitable for predicting traffic conditions in urban area, where there is usually lack of data for other classical data mining techniques (Sun, Zhang, & Yu, 2006). Well known commercial product from Microsoft spinoff, called INRIX is based on this approach (Horvitz & Liao).

The vast majority of the model reviewed so far are using input from ITS as part of their operation. Schadschneider, Knospe, Santen and Schreckenberg (2005), investigated the utilisation of cellular automata based simulation for traffic predictions using statistical analysis. Furthermore, Zhang and He (2007) simulated traffic flow for an urban intersection and employed an ANN as part of a forecasting system. In microscopic simulations, every vehicle is considered as an individual in the network. Dynamic variables of the models represent
microscopic properties like the position and velocity of single vehicles. One approach for microscopic modelling involves multi-agent systems in which each vehicle is modelled as an agent with his own ‘mind’ and road task that has to perform (De Oliveira & Camponogara, 2010); while other popular approaches use car-following models (Doniec, Mandiau, Piechowiak, & Espié, 2008). Another simulation approach involved macroscopic modelling, which frames the relationship among traffic characteristics such as flow rate, density, velocity, mean speed of traffic stream, etc. (Hoogendoorn & Bovy, 2001). In contrast of microscopic models, macroscopic models focus on the whole traffic system and therefore it is more appropriate for network wide simulations. It is computationally less demanding than microscopic modelling and this is also one of the reasons why, several authors also conclude macroscopic model is more appropriate for short-term traffic prediction in real time, comparing to microscopic simulation (Bolshinsky & Freidman, 2012).

Many researchers have focused on integrating different techniques as part of the forecasting task. Wong (2009) created 3 different models (moving average, exponential smoothing and SARIMA) for three different data sets (ds1-daily similarity, ds2-weekly similarity, ds3-hourly time series). Models were chosen by the data set type which suits them best. The prediction of different models, were then used as an input in NN model which produced the final prediction. The suggested combination of models produced better results than individual models alone.

![Figure 6](image)

**Figure 6:** Description of combining results from different models (Wong, 2009)

Combination of particle filter approach and well-known first order macroscopic traffic model has provided very good results in network wide traffic predictions (Sau, Faouzi, Aissa, &
Mouzon, 2007). A macroscopic approach is based on hydrodynamic analogy describing the behaviour of the traffic flow, and particle filters (or sequential Monte-Carlo approach) were chose due to high non linearity of traffic model (Kalman filter can hardly be used). Predictions are coming from Bayesian Monte Carlo state vector reconstruction from multivariate independent measurements (traffic detectors, tool collection system data, and probe vehicles).

4.1.5 Social Networks and Forecasting
In the last few years, several authors have attempted to investigate the suitability of data from Twitter as part of predicting applications. Asur and Huberman (2010), developed a model about the rate at which tweets can help make better market predictions. As an example, they used Twitter to forecast box office revenues for movies and discovered that such predictions are better than those produced by information markets. In addition, Sakaki et al. (2010) proposed a real time event detection framework based on social sensors. They integrated semantic analysis with real-time streaming of tweets to create an algorithm that can detect specific events and tested their work for earthquake prediction.

In an attempt to include social dynamic as part of traffic forecasting models, researchers have investigated the mining of information from social sites and services. Pathania and Karlapalem (2015), claimed that social network sites are a source of human travel information that can be useful for predicting traffic flow. The developed an agent-based architecture to detect the movement of general public and in doing so, the authors investigated a number of variables that may affect human-to-human interaction. These included, age similarity, physical distance, type of event and others. He, Shen, Divakaruni, Wynter and Lawrence (2013), reported significant negative correlation between traffic intensity and tweet counts. They incorporated semantics from tweets as part of a regression model for traffic prediction and proved that their integrated model provided better forecasting outputs compared to a regression model with only traffic related variables. Finally, Wibisono et al., (2012), developed an intelligent system architecture capable of extracting traffic information data from the twitter account of the police department. Using an ANN the information was then used to predict travel times and these were disseminated to the users in their handheld mobile devices.

4.1.6 Traffic Forecasting Discussion
Vlahogianni, Golas and Karlaftis (2004) highlighted the different elements that forecasting models should encompass and categorised them into three layers. Two of these layers are related to the properties of the model (data input, output, quality and algorithmic types) and to the services that would be provided to the end-user as a result of the model’s application. For the latter, Mele (2007) categorised the services as real-time, where sensory input is used to provide instantaneous services (e.g. provision of traffic messages, or variable speed limits through Variable Message Signs); short-term, where sensory, or simulated input is analysed in order to predict traffic conditions in the near future (e.g. dynamic route guidance taking into
account live traffic conditions); and long-term, or historical predictive, where historical data are used for planning related services (e.g. route planning for a fleet of freight vehicles based on recurring traffic patterns). Figure 7 below, illustrates the different considerations that need to be taken into account when designing a traffic forecasting model. These are discussed in more detail in the following sections.

Figure 7: Traffic Forecasting Considerations (Adapted from Vlahogianni et. al. 2004)

4.1.6.1 Modelling

4.1.6.1.1 Data Heterogeneity

Despite the advances on traffic forecasting, existing work has a number of limitations. In most cases the input of the models is limited to flows, speeds and occupancy levels as read from sensors on the road network. Nevertheless, there isn’t a clear consensus regarding which input parameters can provide the best forecasting outputs (Vlahogianni, et. al. 2004). Taylor, Bonsall and Young (2000) identified a number of parameters that can be used as part of traffic engineering modelling. These parameters extended beyond primary traffic engineering information and included environmental and energy related variables. Therefore, the impact in forecasting of other transport, or non-transport related variables (i.e., weather conditions Li and Rose (2011), users’ reactions on information received through ITS, spatial interactions between adjacent local networks Vlahogianni (2009) and others) needs to be investigated further. Although the use of multiple parameters can improve the accuracy of a model (Stathopoulos & Karlaftis, 2003; Dia, 2001) and has been recommended by Hong (2001), it also
raises the issues of increased computational cost (Vlahogianni, et. al. 2005) and the real-time application of a model. Furthermore, inclusion of multiple parameters may require the deployment of a variety of intelligent ITS applications which could be proved costly. For example, vehicle identification and location technologies (ANPR, RFID, GPS etc.) are required for generation of travel times, but their deployment is more expensive than that of inductive loop detectors.

4.1.6.1.2 Dynamicity and uncertainty in data relationships
The temporal and spatial dynamicity of the relationships between traffic engineering parameters can also affect the performance of the forecasting task. Hou et al., 2015, highlighted the importance that combining temporal and spatial data has in the accuracy of the predictions, while Ghosh et al., (2009) showed that modelling interdependencies between spatial data can also enhance model accuracy. Furthermore, understanding data relationships can help in the reduction of their dimensionality. Specifically, Dougherty and Cobbett (1997), concluded that when data measurement sites are in sequence spatially, some sites have less importance for the prediction task than others. Parametric forecasting models have a good potential in identifying relationships between variables (Kamarianakis et al., 2012), but a number of machine learning models operate as black-boxes and thus such relationships are difficult to be understood (Stathopoulos, et. al. 2008).

4.1.6.1.3 Data noise and unavailability
The quality of the data is another factor that one needs to consider in the design of traffic forecasting models. This can be affected by noise in the data (e.g. incorrect readings), or data unavailability (e.g. off-line sensors, area not covered by data collection equipment). Wang and Shi (2013) and Zhu & Zhang (2009), highlighted the importance of de-nosing data before they are used as input to a model. Although a number of techniques (as noted in previous sections) can be used to compensate for inaccurate data, the substitutes are approximations and therefore need to be fused accordingly with actual data from working sensors (Xie et al., 2007). The potential for minimising prediction errors due to erroneous, or unavailable data by the integration of meso, or micro traffic simulations hasn’t been fully investigated. Last but not least, responsive applications of forecasting models require the integration of large datasets, a task which poses certain challenges. As Khan (2012) reports, such data can be used in real-time for offering responsive mobility services, or they can be archived and used as historical input for future predictions.

4.1.6.1.4 Relevance of output to intended applications
The ITS applications that a forecasting model can support depend greatly on the output type and the forecasting step and horizon. Although the majority of the investigated models produce traffic flows as their main output, travel times are more applicable for applications related to driver information systems, or multimodal travelling advice. Nevertheless, accurate travel time
prediction is a more complex problem due to the various uncertainties. These include the existence of different types of vehicles with different kinematics characteristics, individuality in driver behaviours, traffic and public transport strategies (ie. high-occupancy lanes) and other exogenous factors. To eliminate the impact that these uncertainties have on the quality of the information that is presented to the travellers, a Prediction Interval (PI) (e.g. arrival time in the next 5 - 9 mins) is considered a better alternative to a single mean travel time value (Khosravi et. al., 2011).

The forecasting horizon of a model also affects the range of the applications that can support. Short-term prediction models operate within a range of 5-min to 1-hour into the future (Coric, et. al. 2011) and are suitable for traffic management systems and real-time driver and traveller information systems. On the other hand, long-term forecasting may extend from hourly to monthly forecasts and are more applicable for planning related services (Dia 2001).

4.1.6.1.5 Considerations for modelling methodologies
In terms of the modelling methodologies, Moorthy and Ratcliffe (1988) argued that the context of forecasts, the availability of data, the degree of accuracy, the cost of evaluation and the forecasting horizon need to be considered. Stathopoulos et al., (2008) and Huang and Sadek (2009), expanded these requirements with computational plausibility, short-term adaptability and transferability. However, a number of trade-offs need to be analysed between the aforementioned qualities of a model. Turochy (2006), stated that transferability of a model into a different environmental requires additional data collection, while Lippi, Bertini and Frasconi (2013), pointed out the trade-off between computational intensity and accuracy by explaining the characteristic of machine learning techniques to integrate data coming from multiple sources. Due to these trade-offs, it is evident from the research findings in Van Arem, Kirby, Van Der Vlist and Whittaker (1997); Smith, Williams and Oswald (2002); Vlahogianni, et. al. (2004); Vlahogianni, et al., (2014) that the debate regarding ‘the best traffic forecasting model’ is timeless.

4.1.6.2 Determination of Scope

4.1.6.2.1 Complexity of transport networks
It has been suggested that the majority of research efforts have been concentrated on forecasting for motorways, or highways with limited emphasis on urban networks Vlahogianni, Karlaftis and Golas (2014). The latter are of great importance as a supportive mechanism for offering next generation mobility services Mai, Ghosh and Wilson (2013). Due to their complexity, urban networks present far more challenges than those presented when single link forecasts on motorways are pursued. Lee et al., (2009) contributed the complexity of urban environments to interrupted traffic flows at intersections, multiple possible paths, low resolution of real-time sensory data and higher probability of event occurrence. Additionally,
Schadschneider (2006) observed that when detectors are not equally spaced, non-uniformity on available spatial information may add an extra layer of uncertainty. This spatial disuniformity in the spatial arrangement of sensory technologies is more common in urban networks. Due to the above, for urban environments, it is believed that multi-link forecasting can outperform single-link models (Sun, et. al. 2012).

4.1.6.2.2 Unpredictability of events
As He, Lu and Wang (2013) suggest, limited work has been done to relate traffic features (e.g. queue dissipation rates, queue/intersection spill overs, etc.) with traffic conditions (e.g. traffic flow) and this would be an interesting feature for newly developed models. In the same context, prediction, or detection of events that may affect the status of a traffic network is important due to the impact it has on the accuracy of models that depend heavily on historic data (Takagi 2014). Embedding of such event-based information as part of a forecasting algorithms has been proposed by Wang, Shang and Zhao (2010).

4.2 Related Work in Traveller Behaviour Forecasting
The field of transportation involves everyday decision-making processes (Duarte, Garcia, Giannarakis, Limão, Polydoropoulou & Litinas, 2008). Current research focuses on understanding the growing complexity of decision-making processes, combined with the increasing number of alternatives presented to individuals under various economic, social, and human, safety and environmental dimensions. All of the above must be taken into account when providing information and guidance to travellers (Tsirimpa, Polydoropoulou & Antoniou, 2010; Benjamin, Kurauchi, Morikawa, Polydoropoulou, Sasaki & Ben-Akiva, 1999). Random Utility theory based discrete choice models are the de facto tool for modelling transport related individual behaviour (such as activity set, departure time, destination, mode (including car-pooling), route choice, etc.) (Antonini, Bierlaire & Weber, 2006; Benjamin et al., 1998; Bierlaire & Frejinger, 2008; Polydoropoulou & Ben-Akiva 2001; Bierlaire, Bolduc & McFadden, 2008). These models aim to quantify factors influencing transport choices (such as attributes of the alternative choices i.e. travel time, travel cost and socioeconomic characteristics, attitudes and perceptions of decision-makers) and the capability of forecasting individual’s behaviour under different scenarios. These studies focus mainly in the estimation of the parameters’ weights for the variables composing the utility function, the calculation of the value of times and the forecast of market shares for the alternative transport modes (Polydoropoulou & Ben-Akiva, 2001). More advanced modelling techniques incorporate the attitudes and perceptions (such as risk, stress, or happiness) of travellers as explanatory variables of the choice behaviour (Ben-Akiva, Benjamin, Laubrete & Polydoropoulou, 1996; Ben-Akiva, Bottom, Gao, Koutsopoulos & Wen, 2007; Ben-Akiva, McFadden, Gärbling, Gopinath, Walker, Bolduc, Börsch-Supan, Delquié, Larichev, Morikawa, Polydoropoulou & Rao,1999; Tsirimpa et. al., 2010). Personalised information taking into account the decision maker’s attitudes and perceptions seem to have
great potential in helping travellers achieve their objectives and capturing and forecasting the individuals’ decision making (Lambrou, Polydoropoulou, Nikitakos & Litinas, 2005).

Further steps include the creation of a platform for developing, analysing, and deploying transportation and energy innovations aimed at enhancing sustainability and well-being. This would require integrated modelling of transportation, environmental impacts, and energy use for the evaluation of a range of “green” policies and projects (Duarte et. al., 2008). This modelling effort is linked with a range of information and communication technology (ICT)-enabled innovations, ITS, and with decision models, to analyse the impact on system performance impacts of various novel transportation concepts (Tsirimpa & Polydoropoulou, 2009, Tsirimpa et. al., 2010).

4.3 Research Gaps of State-Of-The-Art

OPTIMUM will develop forecasting models that would predict travel demand in a continuous changing environment accounting for the opportunities provided by: (a) the availability of information via social media and crowdsourcing on trips, locations, and activities, as well as sources providing real-time, multimodal travel information; (b) the availability of innovative “green” transport alternatives and sharing systems; (c) the behavioural adaptation through knowledge acquired from feedback on the impact of individual decision making on a regular basis.

Integration of traffic simulation modelling

The existing limitations due to uncertainties under highly variable traffic conditions will be addressed with the integration of off-line and real-time simulations as part of the forecasting engine. Simulation modelling can allow the production of scenarios of events that haven’t occurred in the past and subsequently generation of data not previously available from sensors. This in effect allows the training of models and estimation of the necessary parameters for different states that can be put in effect when a similar event occurs in real life. Furthermore, micro-simulations can estimate successfully traffic engineering parameters using models that replicate vehicle dynamics and a range of behavioural attitudes.

As discussed in preceding sections, travel times cannot be directly estimated without the deployment of vehicle identification systems, for example Automatic Number Plate Recognition (ANPR), Radio Frequency Identification (RFID), at specific locations on the road network. Indirectly, travel times can be estimated using average speeds but this methodology can only be realised when detection sites with speed recording capabilities are available. Well calibrated micro-simulation models can be used to calculate travel times of single vehicles and this opportunity will be explored as part of the OPTIMUM project. In addition to flow, speed and travel times, micro-simulation models can provide outputs related to air quality data, delay
times, capacity utilization and others. Furthermore, simulation models can be used for generating traffic data in areas where sensory information is not available.

OPTIMUM will explore the facilitation of such simulations in real-time by the introduction of customized automated urban layout generation and evolutionary placement mechanisms (Syed, Georgakis and Nwagboso, 2009; Syed, Georgakis and Nwagboso, 2011), adoption of cellular automata related techniques, and exploration of Spatial Data Mining (SDM) (Li & Wang, 2005). The overall aim will be to divide complex urban networks into several sub-networks and thus reduce the computational cost of holistic network status forecasting models.

**Big-data approach**

OPTIMUM will introduce additional variables as part of the computational elements of the existing models. The big-data framework will allow fusion of historical and real-time information from multiple sources that will enrich the existing conventional parameters with the view to improve the forecasts generated by the platform. Techniques capable of generating knowledge about latent (hidden) variables, such as factor analysis (Georgakis, Booth and Mehmood, 2014), Principal Component Analysis (PCA) and Hidden Markov Models will be employed. This will allow the identification of unknown correlations between observable and latent variables that, when used, can potentially improve further multi-point forecasts in complex urban environments. Predictive analytics will be used when stable linear correlations are established, while fuzzy-based techniques can be used to model a stochastic system, when the correlations display non-linear behaviours. Besides using the default features, which are available in the sensor and other data feeds, the feature set in OPTIMUM will be enriched using contextual enrichment and feature engineering.

OPTIMUM will tackle the data obsolescence issue, identified in the literature, with the integration of stream analytics mechanisms that will feed real-time data into the different components of the engine based on the priority of the computations needed to produce an optimum forecast. It is believed that the big-data approach supported by online stream analytics will make forecasting models more resilient in error built up resulting from wider prediction horizons. This existing limitation has been reported in studies that have shown that the accuracy of a forecasting model deteriorates as the number of prediction steps grows (Coric, et. al. 2011; Dia 2001). This approach will enable the evaluation of the impact that an action that is taken based on the forecasting outputs has on the transport network. This is a limitation of existing models which neglect to feed data related to the expected forecasting impact back in the model. For example, Li and Rose (2011) commented that the provision of travel time ranges allows the dispersion of departure time and therefore reduces the probability of creating highly congested networks. How such an output can affect the forecasting in subsequent steps needs to be investigated.
As more and more multi-source traffic related data is available in large numbers, OPTIMUM will attempt to define a workflow for successful pre-processing and fusion of general multivariate data sources to improve predictions. For example, one of the major problems for traffic prediction in urban areas, is the lack of sensor measurements in cities, where there are a lot of intersections and traffic signalizations. With new data collection opportunities (e.g. GPS data from mobile phones, probe vehicles, etc.) lack of measurement in urban areas could be substantially reduced (interpolating non-measured links).

These research gaps are all the consequence of usual lack of good quality data (amount of data regarding the number of records, regarding number of modalities, fusion problems and missing data). This is especially prevalent in Academia and research institutions not directly linked to big players in this field (Google, Here.com, Microsoft-Inrix, Be-Mobile). For this reason it was very rare for the research institution to be able to collect a big enough data-set to tackle the problems directly related to traffic big-data and make use of the vast quantity of otherwise available data to make big improvements on the algorithms and approaches. In OPTIMUM, we have a unique opportunity to make use of the consortium partners and continue the data collection and harmonization that started already as part of Mobis project. Our aim is that OPTIMUM will really become a big-data project that actually has the big-data, which is already starting to show. Being able to train algorithms on more than a year, across multiple domains and even in real-time will allow us to tackle the aforementioned gaps and thus greatly improve current state of the art.

Understanding interdependencies in heterogeneous data

From the reviewed literature it can be seen, that most researches have been focused on predicting traffic on a single location or fixed routes on freeway. Very small number of data driven models have been developed on network wide scale (Van Lint & Van Hinsbergen, 2012) (Sau, Faouzi, Aissa, & Mouzon, 2007). In real traffic conditions neighbour roadway sections have an inherent interdependency, which in some extend depends highly on the conditions and state of the node (for example ramps in motorways; roundabouts, cross junctions, etc. in rural and urban areas) that links them together. Apart from the complex interactions in urban areas, another difficulty in network wide forecasting is the covering of a sufficient part of the road network with sensors. Research on network level prediction is still at an early stage and therefore the forecasting models that will be developed as part of the OPTIMUM project need to explore and model complex interdependencies.

This research gap prevents the development of forecasting models, where interdependencies among data from different sensors are holistically taken into account. OPTIMUM's approach will exploit such interdependencies for addressing the following two issues related to traffic forecasting:
- **Computational cost for training models for large number of sensors.** Most studies presented in this chapter dealt with models that were trained and tested based on data from a limited number of sensors. In large metropolitan areas, and moreover for inter-urban forecasting applications, the number of sensors involved could be in the thousands. In OPTIMUM we will explore the application of clustering approaches where sensors are grouped together based on a number of features (e.g. time series profiles, location on the network, etc.), and devise methods that allow the use of models, for each cluster, that have been trained using only a subset of sensors from that particular cluster. Thus minimising the system-wide computational cost and allowing real-time forecasting on large geographical areas.

- **Combination of data from heterogeneous types of traffic sensors.** Existing forecasting models are predominately focussing on point, or corridor predictions and although tempo-spatial parameterisation is embedded this is limited to small geographical areas. The OPTIMUM big-data architecture will allow the digestion and processing of data from different types of sensors (e.g. loop detectors, ANPR schemes, CCTVs, GPS traces, OBUs) in different geospatial settings (urban and inter-urban) and explore the usage of correlation attributes as features in the relevant machine learning models used for prediction.

**Use of social networks**

The project will investigate the integration of data from social media networks as part of the forecasting models. Early research studies (Lin, et.al., 2014; Tejaswin, et.al., 2015; Steur, 2015; Ni, et.al., 2014; Abidin, et.al., 2015) in this field has demonstrated promising results and these will be explored further. Interestingly the sources of the information include public users, or accounts of authorities (e.g. police department), which raise the issue of different levels of information reliability. Therefore, mechanisms that can evaluate the reliability of information packets coming from social networks need to be investigated. OPTIMUM will aim to use such data sources for evaluating conditions in areas that are not covered by conventional traffic detection technologies. In doing so, OPTIMUM will extend existing work in the above listed studies and previous EU Framework Programme actions, such as MOBIS, by enhancing the features of a tweet with attributes related to sentiment and stress.

The generalisation of the existing short-term forecasting models (approx. 15 min forecasts) for prediction of the network’s state for longer forecasting horizons (approx. 1 hour) is potentially problematic (He, Shen, Divakaruni, Wynter & Lawrence, 2013) due to external factors (e.g. events). It is envisaged that the integration of data from social feeds will allow OPTIMUM to offer early event detection and thus address such restrictions.

**Travel demand forecasting**
Existing travel demand models do not take into consideration the interaction between travellers (Traveller2Traveller T2T, or crowdsourcing behavioural impacts), which will be necessary for imparting joint travelling behaviour. The integration of an information layer from social media applications will allow OPTIMUM to define such behavioural interactions and incorporate them as part of the forecasting and travel advice models. Real-time interaction with the OPTIMUM platform will facilitate behavioural data collection from travellers to enable development of robust methodologies and models for demand analysis of multi-modal travel.

OPTIMUM’s travel forecasting mechanisms will be based on the profiling of individual travellers, using theories of individual choice behaviour analysis. Discrete choice analysis will be used to model individuals’ choices from a set of mutually exclusive and collectively exhaustive alternatives. A decision maker will forecast the probability of an alternative to be chosen based on the ranking of different utilities available at the time the choice is to be made. An operational model consisting of parameterised utility functions in terms of observable independent variables and unknown parameters will be used. The values of such unknown parameters are estimated from a sample of observed choices made by decision makers when confronted with a choice situation. The model involves the estimation of a preference function and forecasts the choice that an individual will make, based on a number of attributes, which are correlated to stated preferences data. Such data are collected through the expressed responses to hypothetical scenarios presented to the travellers. With regards to the development of the OPTIMUM services it is important to estimate models in a relatively short time frame in order to deliver real-time recommendations and proactive decision making.

From the reviewed literature, we can conclude that field of short term traffic prediction is very suitable for many different predictive analytics algorithms. With large set of multivariate data available and short resampling intervals, it is suitable for both classical statistical algorithms as well as novel data driven algorithms. The bottom line is that none of these methods clearly outperforms others. Different approaches have their own advantages and disadvantages as described in this chapter. Therefore, combination of using the advantages from different model types has to be found. Special attention should be considered in developing hybrid methods between genetic and neural networks and classical statistical methods (Karlaftis & Vlahogianni, 2011).
5 Dynamic crediting and charging models

The main objective of this section is to present existing approaches for dynamic charging and crediting models as a framework for incorporating them in the OPTIMUM system.

5.1 Related Work

5.1.1 Urban Schemes in the EU

Congestion pricing has been advocated by transport economists and traffic planners for a long time as an efficient means to reduce road congestion. Despite growing problems with urban congestion and urban air quality, and despite a consensus that investments in roads or public transit will not be sufficient to tackle these problems, congestion pricing has not been widely adopted. In recent years, however, several cities in the EU have implemented different forms of charging or permit systems to combat congestion and/or environmental problems. These cities include Rome (implementation year 2001), Durham (implementation year 2002), London (implementation year 2003), Stockholm (implementation year 2006) (Eliasson, 2014), Valletta (implementation year 2007), Milano (implementation year 2008/2013) and Gothenburg (implementation year 2013) (Christiaens, 2014). Several other EU cities are considering it including Manchester, Copenhagen and Edinburgh (Christiaens, 2014). In the following sections we present some of the above mentioned cases.

5.1.1.1 London Congestion Charge

London was the world’s first major city to introduce a Congestion Charge schemes to reduce the flow of traffic into and around the city centre. It was introduced on 17 February 2003 and remains one of the largest congestion charge zones in the world despite the cancellation of the Western Extension which operated between February 2007 and January 2011. The charge aims at reducing high traffic flow in the central area and at raising investment funds for London’s transport system\(^\text{13}\). It consists of a daily charge for driving a motor-vehicle within the Congestion Charging Zone (CCZ) between 07:00 and 18:00, Monday to Friday. Weekends, public holidays or between Christmas Day and New Year’s Day (inclusive) are free of charge. There are a range of exemptions and discounts available to certain vehicles and individuals (TfL, 2014). The easiest way to pay the charge is by registering for Congestion Charge Auto Pay.

The standard charge is £11.50 for each day, for each non-exempt vehicle that travels within the zone, with a penalty of between £65 and £195 levied for non-payment. Enforcement is primarily based on automatic number plate recognition (ANPR). Transport for London (TfL) is responsible for the charge which has been operated by IBM since 1 November 2009. During the first ten years since the introduction of the scheme, gross revenue reached about £2.6 billion through December 2013. From 2003 to 2013, about £1.2 billion (46%) of net revenue has been

\(^{13}\) [https://tfl.gov.uk/modes/driving/congestion-charge](https://tfl.gov.uk/modes/driving/congestion-charge)
invested in public transport, road and bridge improvement and walking and cycling schemes. Of these, a total of £960 million was invested on improvements to the bus network\(^{14}\).

After ten years since its implementation in 2003, TfL reported that the congestion charging scheme resulted in a 10% reduction in traffic volumes from baseline conditions, and an overall reduction of 11% in vehicle kilometres in London between 2000 and 2012. Despite these gains, traffic speeds have also been getting progressively slower over the past decade, particularly in central London. TfL explains that the historic decline in traffic speeds is most likely due to interventions that have reduced the effective capacity of the road network in order to improve the urban environment, increase road safety and prioritise public transport, pedestrian and cycle traffic, as well as an increase in road works by utilities and general development activity since 2006. TfL concludes that while levels of congestion in central London are close to pre-charging levels, the effectiveness of the congestion charge in reducing traffic volumes means that conditions would be worse without the Congestion Charging scheme\(^{15}\).

5.1.1.2 Stockholm Congestion Charge

The Stockholm congestion charge is a congestion pricing system implemented as a tax levied on most vehicles entering and exiting central Stockholm, Sweden. The primary purposes of the congestion tax are to reduce traffic congestion and to improve the environmental situation in central Stockholm. The funds collected are used for new road constructions in and around Stockholm. A referendum was held in 2006 a couple months after the end of a seven-month trial period. In the referendum the residents of Stockholm municipality voted yes but in 14 other municipalities voted no. The congestion tax was approved and implemented on a permanent basis on 2007. The congestion tax area encompasses essentially the entire Stockholm City Centre. There are unmanned electronic control points at all entrances to this area. The congestion tax is applied on both entry and exit of the affected area\(^{16}\).

The amount of tax payable varies with the time of the day a motorist enters or exits the congestion tax area. There is no charge on Saturdays, Sundays, public holidays or the day before public holidays, nor during nights, nor during the month of July. The maximum amount of tax per vehicle per day is 60 SEK (7.23 EUR, 9.47 USD).

Payment of the congestion tax cannot be made at the control points — they merely register which vehicles have passed them. A bill is sent to the vehicle owner at the end of each month, with the tax decisions for the preceding month's control point passages. The bill must be paid before the end of the next month. The vehicle owner is responsible for the payment of the tax,


\(^{15}\) Transport for London (2014). Public and stakeholder consultation on a Variation Order to modify the Congestion Charging scheme Impact Assessment.

even if the bill does not arrive. The bill can be delivered in three different ways. By default delivery by mail to the vehicle owner's registered address, or opting for electronic delivery to the vehicle owner's Internet bank, or opting for a direct debit arrangement called Autogiro that allows the tax to be automatically deducted from the vehicle owner's bank account when the bill is due. Failure to pay the tax within the allotted time results in additional fees and the vehicle owner is noted in the Enforcement Register unless payment is made.

Exemptions from the congestion tax are implemented for some classes of vehicles such as emergency services vehicles, buses with a total weight of at least 14 tonnes, diplomatic corps registered vehicles, motorcycles and military vehicles. Until 2014, foreign-registered vehicles were exempt, but not anymore. They are included because of objections from companies about unfair taxation, and because the "Eurovignette" EU directive (1999/62/EC article 7 and 2006/38/EC) requires that user charges may not discriminate on the grounds of the nationality of the haulier or the origin of the vehicle. The former exception was mainly for practical reasons, hard to get access to foreign car registers, and to claim payment from foreigners. Some geographic exemptions also apply for the island Lidingö and the Essingeleden motorway which is part of European route E4.

The vehicles passing the control points are identified through automatic number plate recognition. The equipment, consisting of cameras, laser detectors, antennas, and information signs are mounted on a set of gantries at each control point.

There is some criticism to the measure due to double-charging for the case of Essingeleden–Bromma where vehicles have to pass through two separate control points. Also due to the automatic number plate recognition the system can't see the difference in number plates from Finland and Lithuania. Therefore all vehicles are photographed so people who notice false charging can be freed.

A study of 5 years of operation (Eliasson, 2014) showed a decrease in congestion, with some motorists turning to public transport. More specifically, traffic across the cordon was reduced by around 20%, leading to substantial congestion reductions in and around the city. Also public attitude had changed from opposed to in favour, eventually gaining support by more than 2/3 of the population.

5.1.1.3 Gothenburg Congestion Charge
The Gothenburg congestion charge is a congestion pricing system implemented as a tax levied on most vehicles entering and exiting central Gothenburg, Sweden, including some main roads passing by the city. The congestion tax was introduced on January 2013, with the Stockholm congestion charge as a model. The primary purpose of this congestion tax is to reduce traffic congestion and improve the environmental situation in central Gothenburg, and to get
financing for large road and rail construction projects in and around the city. The largest such project is Västlänken.

The congestion tax area encompasses essentially the entire Gothenburg City Centre and the E6 main road passing the city. Cars passing the city are also taxed. To avoid making cars that pass the city to go other routes also congested or unsuitable for such traffic, some more places are charged with tax. There are unmanned electronic control points at all entrances to this area. The congestion charge is applied when passing stations in both directions.

The amount of charge payable varies with the time of the day a motorist enters or exits the congestion tax area. There is no charge on Saturdays, Sundays, public holidays or the day before public holidays, nor during nights, nor during the month of July.

The maximum amount of tax per vehicle per day is 60 SEK (6.40 Euro). If a vehicle passes two stations within one hour, only the higher tax is paid, as a vehicle simply passing through the city must necessarily pass multiple payment stations. Some vehicles are exempt from tax, notably environmentally friendly vehicles (mainly electric or natural gas or ethanol fuelled).

Foreign registered vehicles were exempt until 2014 mainly for practical reasons, hard to get access to foreign car registers, and to claim payment from foreigners. But they are included now because of objections from companies about unfair taxation, and because the "Eurovignette" EU directive (1999/62/EC article 7 and 2006/38/EC).

The case of Gothenburg is considered Europe’s newest experience with congestion charging. It has reduced traffic significantly, but it may soon face a citizens’ referendum. The congestion charge introduced reduced peak hour traffic by 20% in the first year of implementation, closely matching forecasts, according to official reports. Reduced congestion has sped up travel times. Punctuality of public transport has also improved with the help of an increase in priority bus lanes. The number of passengers on express buses increased by 18% and patronage on the commuter train rose by 13%. The charge is bringing in revenue. During the first month of the implementation it raised 62 million Swedish crowns (7 million euros) (Christiaens, 2014).

5.1.1.4 Manchester Congestion Charge

The Greater Manchester, England congestion charge scheme (proposed in 2008) consisted of two cordons: the “greater” circumvented by the M60 orbital motorway, and the “inner” by the Manchester Inner Ring Road\(^\text{17}\).

Vehicles entering the greater cordon would have been charged £2.00 in the morning peak, with a further £1.00 for those entering the inner cordon. In the evening, a further £1.00 would have been charged on exit of each cordon. The figures are at 2007 prices. By 2013 the Association of

\(^{17}\) [https://en.wikipedia.org/wiki/Greater_Manchester_congestion_charge](https://en.wikipedia.org/wiki/Greater_Manchester_congestion_charge)
Greater Manchester Authorities (AGMA) estimated that the cost of crossing both cordons at charging times would be £6. The area covered by the charge would have covered about 210 km2. Payment of the charge would be via a pre-pay "tag and beacon" system. Credit would automatically be deducted from a driver's account as they passed each of the cordons. Occasional visitors to Manchester without a pre-pay tag would have been able to pay via call centre or internet, although there would have been a surcharge. The scheme was planned to be up and running by mid-2013, by which time it was anticipated that 80% of the public transport improvements would have been completed. Motorcycles, black taxis and private hire cars would not have had to pay the charge.

The proposed charge was to help pay for improvements in public transport, in particular for the Manchester Metrolink expansion, and to reduce congestion in Greater Manchester. This scheme did not get to the implementation phase as funding for it via a £3-billion package of transport funding as part of the Government’s Transport Innovation Fund was rejected by a referendum on 12 December 2008.

5.1.1.5 Milan Area C

Milan has one of the highest European rates of car ownership, as more than half of Milan citizens use private cars and motorcycles, ranking second only after Rome, and among the highest in the world. The city also has the third-highest concentration of airborne particulate matter among large European cities. Area C is a congestion charge scheme introduced in Milan, Italy, on January 16, 2012, replacing the previous pollution charge Ecopass and based on the same designated traffic restricted zone or ZTL (Italian: Zona a Traffico Limitato), corresponding to the central Cerchia dei Bastioni area. The ZTL encompasses about 8.2 km2 and 77,000 residents (4.5% and 6% of the city total, respectively). The area is accessible through 43 gates, monitored by video cameras. Area C started as an 18-month pilot program based on the partial implementation of the results of a referendum that took place on June 2011. The objectives of the program were to drastically reduce the chronic traffic jams that take place in the city of Milan, to promote sustainable mobility and public transport, and to decrease the existing levels of smog that have become unsustainable from the point of view of public health. Area C was definitively approved as a permanent program in 2013.

The charge applies to every vehicle entering the city centre on weekdays (except Saturday) from 7:30 am to 7:30 pm, on Thursdays the operation is limited to 6 pm. Every vehicle entering the charging zone must pay €5 regardless of its pollution level. Residents inside the restricted area must also pay to reach their houses but they have 40 free accesses per year and a discounted fare of €2. Access to the area is forbidden for diesel Euro 3 or below, gasoline Euro

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0, and private vehicles over 7m long. Electric vehicles, motorcycles and scooters, public utilities' vehicles, police and emergency vehicles, buses and taxis are exempt from the charge. Hybrid electric and bi-fuel natural gas vehicles (CNG and LPG) are exempt until the end of 2016.

In the first month of the Milan C scheme implementation, cars entering the city center decreased by 33%, with a total of about 700,000 vehicles less during the month or about 40,000 per day. A substantial decrease in traffic congestion in the restricted area was also reported, while traffic outside the area remained unchanged. The congestion charge did not appreciably affect pollution levels, with the exception of black carbon level, which decreased by about 30% in the ZTL\textsuperscript{20}. Data from the first two months showed a decrease in traffic also outside the restricted zone. There was a reduction of about 6% of vehicles outside the ZTL compared to the same months of 2011. The reduced congestion in the city centre resulted in increased average speed for public transport, especially for buses and during peak hours. While there has been an increase of only about 3% in the whole day, the average speed in the morning peak hour (8-9 am) for surface public transport was about 10% higher than pre-Area C levels.

All net earnings from the scheme are used to promote sustainable mobility and policies to reduce air pollution, including the redevelopment, protection and development of public transport, "soft mobility" (pedestrians, cycling, Zone 30) and systems to rationalize the distribution of goods. In 2012, the program had a total revenue of about €20.3 million and net earnings after expenses of over €13 million. These resources were used to increase service on the Milan Metro, on surface public transportation network and to finance the extension of the BikeMi bike sharing scheme.

Area C, as its predecessor Ecopass, came with much criticism until its final enforcement in 2013.

5.1.2 Interurban Schemes in the EU

5.1.2.1 Eurovignette in Belgium, Netherlands, Luxembourg, Denmark and Sweden

Eurovignette is a common toll collection system in Belgium, the Netherlands, Luxembourg, Denmark, and Sweden. When using the motorways and motor vehicle roads in these countries, payment for Eurovignette fee is necessary – also in case a vehicle only transits in any of these countries.

Since October 2008 the Eurovignette system has been electronic – for time required, the vehicle is registered in the system database. Receipt received on point of sale or printed from website payment transaction may not be retained as a proof of payment. The toll payments apply only to vehicles over weight of 12 tons. Time validity of the vignette is restricted – for one day, week, month or year.

\textsuperscript{20} https://en.wikipedia.org/wiki/Milan_Area_C
5.1.2.2 Vignette in Slovenia and Austria

Vignette - Toll Stickers in Slovenia

From 1 July 2008, motor cycles, private cars and vans whose maximum permitted weight does not exceed 3.5 tons must carry a vignette in order to drive on all Slovenian motorways and expressways managed by DARS d.d., regardless of their length. Annual vignettes for the current year are valid from 1 December of the previous year to 31 January of the coming year (total of 14 months). Half-year vignettes are valid for six months from the day of purchase, or until the end of the last day of the sixth month, if there is no such day in the sixth month. Monthly vignettes are valid from the moment of purchase up until the end of the day with the same number one month after the day of purchase, or up until the end of the last day in the month, if the next month has no such day. Weekly vignettes are valid for seven consecutive calendar days from and including the day determined by the user upon purchase of the vignette. Vignettes are sold at petrol stations in Slovenia and neighbouring countries and at branches of the national and foreign automobile clubs, at post offices in Slovenia and at some magazine stands. For more information a list of sales points is available.

Table 1: Vignette Cost 2015 in Slovenia\textsuperscript{21}

<table>
<thead>
<tr>
<th></th>
<th>Toll class 1 (one-track motor vehicles)</th>
<th>Toll class 2a (caravans and two-track vehicles &lt;3,5t)</th>
<th>Toll class 2b (two-track vehicles &gt;3,5t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly vignette</td>
<td>55 EUR</td>
<td>110 EUR</td>
<td>220 EUR</td>
</tr>
<tr>
<td>Half-year vignette</td>
<td>30 EUR</td>
<td>30 EUR</td>
<td>60 EUR</td>
</tr>
<tr>
<td>Weekly vignette</td>
<td>7,5 EUR</td>
<td>15 EUR</td>
<td>30 EUR</td>
</tr>
</tbody>
</table>

For driving on a motorway without a valid vignette sticker or without paying the road toll, a fine of 300 to 800 euros is envisaged. For motorway journeys coming from Austria up to the Hrušica exit towards the interior of Slovenia and in the reverse direction, use of a vignette is not required. The road toll for the Karavanke tunnel is valid between the first motorway exits on either side of the national border (in Slovenia the Hrušica exit, in Austria the Podrožca – Rosenbach exit).

For vehicles whose maximum permitted weight exceeds 3.5 tons such as buses, mobile homes and lorries, there are several ways of paying for road use. These possibilities include i) Pay per use: Every time you pass a toll station by paying on the spot and ii) Prepayment and later payment.

\textsuperscript{21} [www.slovenia.info](http://www.slovenia.info), the Official Travel Guide by Slovenian Tourist Board
payment: Intended for users of electronic media - DARS card, DARS Transporter card and ABC plates.

**Vignette - Toll Stickers in Austria**

A vignette is compulsory in Austria for all motor vehicles up to and including 3.5 t. Vehicles with a maximum gross weight of more than 3.5t need a GO Box (lorries, busses and heavy motorhomes) which is available at so-called GO Stations. The obligation to pay tolls in Austria begins immediately at the state border. Vignettes are compulsory on all motorways and expressways in Austria.

Toll Sticker Prices 2015:

- A twelve-month sticker for private cars and motorhomes up to 3.5t is EURO 84.40 and for motorcycles EURO 33.60
- A two-month sticker for private cars and motorhomes up to 3.5t is EURO 25.30 and for motorcycles EURO 12.70
- A 10-day sticker for private cars and motorhomes up to 3.5t is EURO 8.70 and for motorcycles EURO 5.00

For vehicles exceeding 3.5 t the toll tariff system is based on emission categories and applies on all Austrian motorways and expressways. These vehicles are required to attach a small adjustment - named the GO-Box - to their windscreen. This includes larger private vehicles such as motor caravans that are above the weight limit.

### 5.1.2.3 Toll Collect system in Germany

Truck drivers are required to pay toll on all German motorways and selected federal trunk roads. Thousands of heavy goods vehicles from throughout Europe pass through Germany every day, particularly on motorways. In order to ensure that the burden of cost is borne equitably by road users in relation to the distance driven, the German government introduced a distance-based toll in 2005 for all German and non-German trucks with a gross vehicle weight of 12 tonnes or more. In the scope of a public-private partnership on behalf of the Federal Republic of Germany, Toll Collect developed and established the world’s first toll system that combines satellite positioning and modern mobile communication technology in a single system. In contrast to vignette solutions, the toll charges are based on the distance travelled on the toll route, the number of axles on the vehicle and the emission class. Users pay only for the actual distance travelled on toll routes – a fair and equitable system.  

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[22](https://www.toll-collect.de/en/)
Toll Collect has created a system that operates without disrupting traffic flow. Unlike conventional toll systems, this innovative technology does not require vehicles to slow down, stop, or use specific lanes. The result is an advanced, flexible system for the German and European transport industry. Toll Collect technology is designed to support other tolling systems. The TOLL2GO service implemented in cooperation with the Austrian toll operator ASFINAG was introduced in September 2011. With TOLL2GO, the toll for trucks weighing 12 tonnes or more can be paid in Austria using the Toll Collect On-Board Unit.

The Toll Collect system offers users three different log-on options:

- Automatically, using a Toll Collect On-Board Unit (OBU) installed in the vehicle
- Manually, at a toll-station terminal
- Manually, via Internet

Automatic log-on is the mainstay of the Toll Collect system. An On-Board Unit installed in the vehicle uses satellite signals (Global Positioning System – GPS) and other positioning sensors to automatically determine which toll route segments a truck is driving on. The OBU pinpoints the location of the vehicle and identifies its position on any of the route segments (both directions) in Germany’s 30,000-kilometre toll road network. The On-Board Unit then calculates the toll charge based on details provided by the user, including vehicle emission class and number of axles. This information is then transmitted to the Toll Collect computer centre via mobile communication signals. Alternatively, vehicles can be logged-on manually. The user can log-on to a toll route at a toll-station terminal or on the Internet. This information is also transmitted to the Toll Collect computer centre. In Figure 88 is presented schematically the automatic log-on system applied in the Toll Collect scheme for German roads.
To be able to log-on with an OBU or via Internet, vehicles and users must be registered with Toll Collect. Road usage charges for registered users can be paid by credit card with or without a credit account, settlement by credit account through Toll Collect, fuel card account or LogPay plan. The option to log-on at a toll-station terminal is available to all users. Non-registered users can choose to pay by cash, fuel card or credit card. In addition to these methods, registered users can pay using the vehicle card. The log-on will then appear on the monthly toll statement and the account is not charged until after the toll route is used. The customer service team is available to answer any questions users may have on payment methods and on the whole toll system.

To ensure compliance with toll requirements, Toll Collect has made available a comprehensive enforcement system the Federal Office for Goods Transport (BAG). In the course of enforcement, the Toll Collect computer centre checks to determine whether monitored toll liable vehicles are logged on to the toll system. The enforcement system consists of automatic enforcements performed by enforcement gantries and portable enforcement devices, as well as stationary and mobile enforcements using appropriate enforcement equipment and onsite enforcement. The combined effect of these methods ensures adequate continuous enforcement of the toll requirements. At the same time, it offers options to adapt the toll enforcement system to changing conditions, while ensuring compliance with data protection regulations.23

23 Toll collect in Germany, User Information brochure, Bundesamt für Güterverkehr (German Federal Office for Goods Transport), 2014
5.1.3 Dynamic Toll Schemes in Non EU Countries

5.1.3.1 Dynamic Toll between Jerusalem and Tel Aviv in Israel

The dynamic Jerusalem-Tel Aviv toll scheme aims at smoothing flowing traffic between these two cities. It is based on an algorithm developed by Siemens that adjusts the toll charge to the current traffic situation and is currently applied in a dedicated highway lane known as the “fast lane” on the highway connecting Jerusalem and Tel Aviv in Israel.

The scheme aims at setting the fees at a level that will ensure the dedicated lane’s capacity is sufficiently utilised while preventing traffic jams. The system uses induction loops in the road surface to register the speed and numbers of vehicles on the free driving lanes and the fast lane. The algorithm uses the measured data to calculate the toll fees down to the minute. When traffic is light, the toll fee drops, giving drivers an incentive to use the lane. When traffic gets heavier, the fee increases, which deters some drivers and thus prevents congestion.

The updated toll fee is displayed on electronic traffic signs at entrances to the fast lane. For applying the toll fee, a video system films the vehicle’s license plate number when it enters the lane. The fee can be debited from the bank accounts of drivers who have registered for this option in advance; otherwise they receive a bill. Buses and fully occupied vehicles are exempt from the toll. The fast lane is 12 kilometers long and makes it possible to cover the distance in about 12 minutes — compared to the 30 to 60 minutes the trip can take during peak hours.²⁴

5.1.3.2 Singapore Area Licensing Scheme- world’s first digital congestion charging system

Already in 1975, Singapore implemented its first congestion charging system in the form of an Area license System (ALS) that charged drivers a flat rate for unlimited entries into Singapore's central area. The system improved during the years, to a high tech digital system. In 1998 it was upgraded to electronic toll collection in the form of Electronic Road Pricing (ERP). In an effort to improve the pricing mechanism and to introduce real-time variable pricing. Singapore's Land Transport Authority, together with IBM, ran a pilot in 2007, with a traffic estimation and prediction tool (TrEPS), which uses historical traffic data and real-time feeds with flow conditions from several sources, to predict the levels of congestion up to an hour in advance. This new system integrates with the various LTA's traffic management existing systems, such as the Green Link Determining System (GLIDE), TrafficScan, Expressway Monitoring Advisory System (EMAS), Junction Electronic Eyes (J-Eyes) and the Electronic Road Pricing system. LTA is also considering Global Navigation Satellite System as a technological option for a second generation ERP.²⁵

The ERP scheme consists of gantries located at all roads linking into Singapore's central business district – areas within the Central Area such as the Downtown Core. They are also located along the expressways and arterial roads with heavy traffic to discourage usage during peak hours. The gantry system is actually a system of sensors on 2 gantries, one in front of the other. Cameras are also attached to the gantries to capture the rear license plate numbers of vehicles. Currently, there are 80 ERP gantries in Singapore while new gantries are implemented where congestion is severe. A device known as an In-vehicle Unit (IU) is affixed on the lower right corner of the front windscreen within sight of the driver, in which a stored-value card, the CashCard, is inserted for payment of the road usage charges. The second generation IU accepts Contactless NETS CashCard and EZ-Link. The charge for passing through a gantry depends on the location and time, the peak hour being the most expensive. The ERP system uses a dedicated short-range radio communication system to deduct ERP charges from CashCards. These are inserted in the In-vehicle Units (IUs) of vehicles before each journey. Each time vehicles pass through a gantry when the system is in operation, the ERP charges will be automatically deducted.  

The pay-as-you-use principle of ERP makes motorists more aware of the true cost of driving. This way, road usage can be optimised. Charges are levied on a per-pass basis and rates are set based on traffic conditions at the pricing points. The system has curbed traffic demand and managed road space for highest productive capacity, cutting congestion, pollution, emissions, and fuel use. As a result, today 65% of the commuters in Singapore use public transport.

A lightweight version of this same technology is implemented for use on parking, known as the Electronic Parking System (EPS). It has since been adopted in favour by several carpark operators, superseding the use of autopay tickets or parking coupons. These systems have also typically switched to charging by the minute.

Another similar system in metropolitan areas of Asia is the case of Dubai, at the United Arab Emirates, which in 2007 implemented a corridor congestion pricing scheme called Salik. While in other Asian cities such as Hong Kong, the implementation of similar systems were cancelled due to public opposition.

5.1.3.3 High Occupancy Toll (Hot) Lanes in the USA

The idea behind High Occupancy Toll (HOT) lanes is to allow paying drivers onto dedicated HOV lanes in addition to High Occupancy Vehicles, and in this way "fill up" the available capacity (McDonald and Noland, 2001).

26 [https://en.wikipedia.org/wiki/Singapore_Area_Licensing_Scheme](https://en.wikipedia.org/wiki/Singapore_Area_Licensing_Scheme)
This generates a source of revenue and enables drivers to buy themselves a shorter journey time. The basic requirement is for the quality of traffic flow on the HOT lane not to fall below a specific level, as otherwise its use would not entail any added value. HOT lanes are mainly operated in the United States. Various systems are in operation or under construction or in the planning (Leonhardt et al., 2012).

![Map of HOT lanes projects in the United States by 2012](image)

**Figure 9: Map of HOT lanes projects in the United States by 2012**

### 5.1.3.4 Emerging Trends of Congestion Dynamic Charging in the US

Congestion problems are now being tackled through pricing measures in the US and discussions are made on the ubiquitous “value pricing” roads in the whole country. State, regional and local governments are engaged in a host of pricing initiatives with potential to reduce congestion, reduce environmental problems and support the growing trend toward livable city and suburban centres. The initiatives span the full gamut of pricing categories and strategies including road, parking, mileage, rideshare and other pricing initiatives.

More specifically the six categories of pricing strategies below represent a summary of the most important recent trends and developments:

- Managed lane networks
- Pricing of existing facilities

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Parking pricing
- Priced vehicle sharing and dynamic ridesharing
- Pay as you drive pricing
- Integrating pricing into long range planning

5.1.4 Tolling with Mobile applications
With the proliferation of mobile devices smartphone-only tolling being trialled in Spain by Cintra, aiming at a future when road charging is integrated into a general mobility pricing policy\(^{29}\). (Almeida M., 2014)\(^{30}\)

5.2 Credit-Based Congestion Pricing Concept
Kockelman and Kalmanje (2005) proposed another version of congestion pricing, called credit-based congestion pricing (CBCP), to counter CP’s adverse effects. CBCP provides eligible travellers with travel budgets that can then be used to travel on priced roads.

Proposed Strategy: CBCP
- Road users are held responsible for the marginal social cost of their trip, as it impacts others.
- Bankable credits permit a basic amount of travel – & an opportunity to make money (by avoiding congested roadways during peak periods).

CBCP: A Scenario and toll collection scheme
- Every month licensed drivers receive allowance of “driving credits” to drive on congested roads using an EZ-Pass/ FastTrak credit-card account (or debit card) linked to his/her name.
- Some drivers would spend much more than others & travel under uncongested conditions, deriving benefits from reduced delays & less variable travel times.
- Some drivers would spend much less & receive cash (or tax credits) – &/or may donate credits to special groups.
- Total credit updates would be based on total revenues collected in prior month, so policy is revenue-neutral.
- Bus use & local shopping increase, emissions fall, roads busier at off-peak periods...
- Each network link, at each time of day, priced distinctly, based on current demand.
- Electronic technology uses card-like transponders mounted on cars windshields.
- Tolls automatically deducted from user’s account (or debit card) when vehicle passes toll collecting point, with no delay.
- Electronic displays upstream of collection points (& on-line) indicate exact tolls.

\(^{30}\) Almeida M. (2014). Mobile Tolling – A Geotracking Capable Mobile Application for Toll Fee Collection
- Maximum tolls & variability may be set (e.g., 50¢/mile, 1¢/mile/minute), to minimize uncertainty.
- Possible exceptions for HOVs, taxis, &/or others.

Individuals who exhaust their monthly travel budgets must pay out of pocket to keep driving. The budgets are determined by the previous month’s net revenues. Kockelman and Kalmanje (2005) polled the Austin, TX public and found that CBCP may compete reasonably well with transportation policy alternatives, particularly once users become more familiar with such policies – and experience tolling first hand. Kalmanje and Kockelman (2005) predicted Austin trip-based welfare impacts and land value changes under CBCP (travel budgets were assumed to be provided to all the residents with a valid driver’s license in this case) and found that this policy benefited most residents, whereas standard CP (without revenue redistribution) benefited relatively few.

However, the above analysis does not consider benefits from CP revenue for the standard CP scenario. Gulipalli et al. (2008) interviewed transport economists, toll technology experts, administrators, policy-makers, and commercial users to gauge their opinions and concerns about CBCP. Expert opinion suggested that CBCP is technologically feasible. Based on expert feedback, Gulipalli et al. (2008) concluded that CBCP may be politically viable and provided recommendations for its implementation.

All previously discussed road pricing schemes aim at obtaining a desirable flow distribution over the network by charging a toll on all or a selective set of links, hence increasing the travel costs of all or some of the travellers. Tolling schemes for managing traffic could be paralleled to a penalty while credit based schemes could be paralleled to a reward. This is an attempt to twist the way of making trip choices for road users. Credit based strategies could encourage road users towards system optimum mobility choices, rather than punish them for polluting (polluter pays principle) via tolls.

Both schemes can change travellers’ route choices but the effects on the traveller’s surplus are opposite. Inspired by this thought, we propose a novel carrot-and-stick strategy, via Credit Based systems, to change the flow distribution over a network. Instead of paying money to use the toll road, under the Credit Based systems, travellers can consume or earn credits when they traverse a road segment. Such a strategy requires all or part of the links in the network be associated with a credit rate. The credit rate can be positive, which stands for a traditional toll, or negative, which is equivalent to a subsidy.

Compared with traditional congestion tolls, the credit based system has several advantages (Xiao et al., 2012): 1) the scheme can face less public resistance because everyone might benefit from it; 2) it adds additional degree of freedom to achieve simultaneously different planning goals, such as equity, efficiency and self-sustainability; and 3) it functions also as a
revenue redistribution scheme. It is well known that allocating the revenue collected by the toll could be a controversial issue. To road users, the congestion toll is merely a variant of a lump-sum tax. In contrast, the ABC scheme is able to directly return the revenue to road users. The scheme itself can break even, which means the total credits given out to the road users could all be covered by the credits collected from the road users.

5.3 Research Gaps of State-Of-The-Art

The presence of road pricing in the literature is neither new, nor under-studied. Research about road pricing goes back as far as 1961 (Walters, 1961), where it is observed that “efficient prices” are higher than the existing level of prices in US highways. The literature has been focusing on various aspects of road pricing, including mathematical formulations, policy-wise analysis, economic and environmental impacts (the external cost of transportation), future projections, study of new infrastructure. However, the literature has limited research on the behavioral aspect of road pricing, the way road users perceive toll prices and react to the adjustment of the price. The rest of the literature review will be concerned with studies examining this aspect of road pricing.

Burris and Pendyala, (2002) aiming to examine the user behavior on a dynamic (“variable”) toll system, focus on the Lee County variable pricing project in Florida, US, which was one of the first variable tolling systems in the world. They developed disaggregate discrete choice models which resulted in the observations that flexibility in the work schedule or being retired are positive factors influencing the change of an individual’s daily habits in order to obtain a toll discount. On the other hand, having a strict schedule, being in a commute trip or having a bigger household income are negative factors in the change of the daily routine in order to obtain the reduced price.

Ozbay and Yanmaz-Tuzel, (2008) conduct their research in another part of the US which had a dynamic, variable pricing system in place, the New Jersey Turnpike (NJTPK) time-of-day pricing program. Using departure/arrival time choice models to estimate Values of Time for the users of the NJTPK program. Results indicate that VOTs range between $15 to $20 per hour, and that most users that commute during the peak hours are willing to pay $0.32/minute for work trips and at most $0.25 for leisure trips. These high values are commented by the authors to be the reason of the low-level response that the time-of-day variability of the tolls introduced by the road operator had among commuters.

Holguín-Veras and Allen, (2013) also conduct research based on the New Jersey Turnpike. The authors use discrete choice modelling in order to explore variables that affect user choices. Results of the model indicate that very few users are willing to switch to other modes, such as public transport, to avoid peak hour pricing. Most of the users are willing to adjust their schedule and to travel in non-peak hours or to switch to an alternate route that may not
contain tolls. Toll price, travel time and scheduled delays are the variables that affect most the choices of time-of-day travel and route choice. The paper also provides useful insight into payment methods and the interconnection between it and route choice/time-of-day choice. The authors also state that including socio-economic variables into the models showed that there is more to road pricing modelling than toll price and travel time.

Considerations related to areas of further research in dynamic crediting and charging models include:

- Social, political and institutional considerations play a significant role in the potential implementation of road pricing schemes, in addition to technological and design options related to network performance and economic efficiency (Kockelman and Kalmanje, 2005).
- Dynamic credit-based or tradable rights-based charging schemes for congestion pricing in cities with serious problems of traffic congestion and air pollution have been unsuccessfully proposed (Raux and Souche, 2004; Ieromonachou et al., 2006; Ieromonachou et al., 2007). Further research on their introduction as feasible schemes is necessary.
- Further market segmentation and understanding of the users behavioural aspects is needed.  

The integration between road charging into a general mobility pricing policy (Czako, 2015)

The overall literature review points out that the behavioral aspect of dynamic toll pricing is crucial to the optimal application of a toll scheme and is helpful in discovering additional incentives towards road shift or hour-of-day shift for commuters. It also may lead to better responses to dynamic toll pricing, especially if focused on special groups of road users and their distinct behavior and heterogeneity in decision-making. Regarding OPTIMUM project, dynamic toll pricing is studied in the context of behavioral modelling in order to examine, pinpoint and exploit the relevant aspects of decision making process that will lead to better, dynamic toll pricing schemes and an optimal balance between supply and demand.

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6 System aware optimization and multimodal routing

6.1 Related Work
In OPTIMUM an optimisation approach is followed which is – instead of current state of the art approaches – not focusing on the optimisation of single user requests but on the optimisation of the system as a whole. In fact, this has to be understood in the sense that the influence of one decision on other decisions to be made is incorporated into the optimisation approach. Obviously, this means that isolated decisions must not be taken. Furthermore, this implies that complete data on the requests is necessary as in other cases not all effects can be estimated and therefore respected during the optimisation approach. In order to demonstrate system aware optimisation approaches the multi-modal routing application was chosen to be of great interest. On the one hand, mobility – and especially public transportation – is a topic which is highly relevant to urban areas as a lot negative effects are pinned to the use of suboptimal mobility (e.g. greenhouse gas emissions, (road) safety issues, noise pollution, harm to the national economy due to congestion, etc.). On the other hand, mobility is a sector where a multitude of participants is currently uncoordinatedly moving in a system where appropriate data is – theoretically – available. E.g., current road traffic information or public transport availability is in most cities provided via more or less generic interfaces.

6.1.1 Multi-Modal Routing
The core application – or so to say the starting point – for multi-modal routing is routing. The term routing itself is occupied by two closely related applications: On the one hand, with routing the pathfinding of data packages in (virtual digital) networks is meant. So, the best-known – although not recognized – application with respect to this is the TCP/IP protocol (Comer, 2001) which is responsible for the communication in the (digital) internet. All messages – which are building the fundamental building parts – are formatted according to this protocol and are then transported through the network via communication hubs (often referred to as routers).

On the other hand, routing denotes the path finding within a (street) transportation network. Obviously, other transportation networks such as rail networks are included therein as well. Although there are analogies between these two applications, there are also significant differences. E.g., in digital networks it is very easy to duplicate parts of messages and drop them again whenever the duplicates are not needed anymore (or impasses are reached). Before, it is even possible to decompose a message into small data junks of appropriate size which are then recombined at the destination point. Obviously, both approaches are only very limited possible in a physical network with physical objects to be transported.
However, since elementary routing algorithms are working on single data junk basis (even for the digital internet application) research for both areas is relevant in our context. Nevertheless, the most popular algorithm in this context (Dijkstra, 1959) was developed on a pure mathematical model of a network. In this work a label setting algorithm is proposed which finds in networks with non-negative edge weights minimum weight path. In this context, a network is represented by a graph consisting of nodes (vertices) and edges (in the directed case referred to as arcs). In addition, a weighting function is defined which assigns to each edge in the network a non-negative value (referred to as weight). As in graph theory a path is defined as an alternating sequence of nodes and edges (starting and ending with a node) where none of the nodes occurs twice, the result of the algorithm proposed by Dijkstra returns a path (from a provided start node towards a defined end point) with the property that there exists no other path (from start to end) which has less weight than the returned one. The weight of the path is defined as the sum of the weights occurring along the edges of the path. It is proven that this algorithm is optimal in term of runtime and result quality (i.e. the algorithm always returns the correct solution and there exists no asymptotically faster algorithm with the same property).

As in typical applications within the transportation sector only non-negative edge weights occur (e.g. travel time or distance) the algorithm proposed by Dijkstra is optimal. However, there are implementations which are faster on average but identical (or slower) in the worst case. Among others, Highway Hierarchies (Sanders and Schultes, 2005, and Sanders and Schultes, 2006) as well as Contraction Hierarchies (Geisberger, 2008, and Geisberger et al., 2008b) should be mentioned. Although the request-to-answer time for routing requests can be dramatically reduced by these approaches, it has to be highlighted that a majority of this computation time decrease is achieved via additional pre-computations and annotations of the underlying routing network with (partially) painful computation times. In addition, flexibility is lost by this approach meaning that changes in the underlying network induce a rerun of the pre-computations (which are for large networks in the magnitude of several minutes).

If the case occurs that negative edge weight may be given then the algorithm of Dijkstra is not applicable anymore as the result may be wrong, i.e. the path returned might not be that one with the minimum costs. Furthermore, and more important, in case of negative weights negative cost cycles might occur in the network – i.e., a closed path (a path where the first and last node are identical) with a negative sum of weights. In such a case, the finding of a minimum weight path is NP-hard, i.e., there is yet no algorithm known which finds a shortest path in polynomial, frankly spoken in acceptable, time. Moreover, algorithms providing an optimal path in case of negative cost cycles may have astronomically high computational time. However, employing the algorithm by Bellman and Ford (Bellman, 1958, and Ford, 1956) it is possible to detect negative cost cycles (in polynomial time) and in the case of absence of negative cost cycles to find the optimal cost-efficient path. Obviously, this algorithm could also be applied to the case with non-negative costs. However, the (asymptotically) runtime is in this case a...
polynomial of third order while for Dijkstra’s algorithm the runtime is in $O(n \log n)$, with $n$ denoting the number of nodes within the network. It should be mentioned that the algorithm of Bellman and Ford is a label correcting algorithm while Dijkstra’s algorithm is part in the class of label setting algorithms.

Finally, a further “class of algorithms” should be mentioned: so-called A* search (Hard, Nilsson & Raphael, 1968). In fact, A* is not a class of algorithm but an extension of Dijkstra’s algorithm via the use of guiding heuristics. A* is, however, often used for referring to algorithms using the same principle (extending an existing algorithm by heuristics for speeding up the solution finding process). While the main idea of Dijkstra is in each iteration to label among all directly reachable nodes that one which can be reached with minimum costs, A* includes a heuristic in that step leading selecting that node for which the path to that node plus the estimated path to the target is minimal. While the path to the node can be exactly determined, the estimated path to the target is heuristically computed (e.g. via beeline). In worst case, this algorithm has the same performance as Dijkstra but in general it is way faster.

So far, only routing in uni-modal networks where considered. I.e., along one route only one mode of transportation (MOT) is used. In case of multi-modal networks, i.e. networks which incorporate more than one MOT, different approaches can be used to find the optimal route. As multi-modality just means that one or more MOTs are incorporated in the network, the first and most straightforward approach is to apply a uni-modal routing algorithm for each MOT individually. The resulted routes are then compared and the cheapest one, i.e. that one with the lowest weight, is returned as the final result.

In case of intermodal routing, i.e. providing one route incorporating more than one mode of transport, a similar approach can be applied which basically routes from each node to each other nodes for each MOT. The final route is then pieced together accordingly. Obviously, using a smart way of doing these computations a competitive performance can be obtained. In fact, it is possible to simply apply Dijsktra’s algorithm when appropriately building up the underlying graph (Prandtsstetter, Straub & Puchinger, 2013). Additional characteristics of street networks can also be easily incorporated (e.g. turning restrictions or living areas).

### 6.1.2 System Aware Optimisation

System aware optimisation is a term widely used in many contexts which are all differing and not relevant for OPTIMUM. In transportation science the work of Wardrop and Whitehead (Wardrop & Whitehead, 1952) builds the basic in system aware optimisation. In fact, two equilibria are defined within their work (noted as Wardrop’s first and second principle): While the first principle states that in a transportation network the routes are chosen by the individuals such that no user can decrease her travel time by choosing another route. In fact, this means that each user minimises her travel time without respecting the impact on other users. Therefore, the resulting state is also referred to as user equilibrium.
The second principle states that at equilibrium the average journey time is minimal meaning that whenever one user chooses to take another route the overall travel time (or average travel time) is increased (although the travel time for the changing user might be decreased). Also referred to system optimum in this equilibrium each user chooses her route under considering the social impact, i.e. the impact on the travel times of all other users.

As the first principle seems to mirror typical user behaviour it got accepted to describe the “real” world and builds the basis for the prediction of traffic patterns. In their work, Köhler et al. (Köhler, Möhring & Skutella, 2009) investigate different algorithms for finding a system optimum in transportation networks. Although these approaches are rather promising, it has to be highlighted that only traffic flows are optimised, i.e. only shares are computed for where traffic flows should occur. However, as soon as routes should be provided to users an assignment of individual cars (and not aggregated flows) to roads needs to be done. The resulting problem is NP-hard. That is, it can be expected that no exact algorithm is existing providing optimal solutions in polynomial time.

6.2 Research Gaps of State-Of-The-Art

With respect to system aware optimisation, we have to highlight that the efficient use of (today’s) transportation infrastructure is of crucial importance: Based on the numbers presented in various resources (among others the EU White Paper on Transport 2011, European Commission 2011), we can expect that the transportation volume is further increasing while we aim at the same time to cut down the emissions originating from transport towards zero. However, to achieve this goal, it is essential to come up with methods and approaches for an efficient and sustainable use of existing transportation infrastructure. Among others, system aware optimisation is one of these approaches.

Unfortunately, there are virtually no works focusing on multi-modal routing under system consideration. Even uni-modal routing under system consideration is currently not (or only conceptually) addressed in (academic) literature. Especially when focusing on the computation of (multi-modal) routes of individuals. I.e., instead of optimising traffic flows, the main topic (and research gap) is how to compute individual routes assigning to each traveller exactly one route. (Mathematically speaking: For the former problem it is sufficient to provide floating point solutions (e.g. 4.3 cars on the left road and 7.7 cars on the right road) while for the latter, integer solutions are required (e.g. 4 cars on the left road and 8 cars on the right road).)

Within OPTIMUM we are now addressing three open points: First, it is necessary to exactly formulate the problem statement using a formal notation. The goal is, among others, to introduce this novel problem formulation in the scientific community. Second, we need to provide first exact algorithms, in order to assess the practical complexity of the problem (i.e. how many routes can be computed in parallel while still providing optimal decisions). Third, as
we expect that the scalability of the exact approaches is limited, we are aiming at developing heuristic solution methods which are providing good solutions in short computation times as one of the practical constraints is real-time capability.

A final step addressed in OPTIMUM as well, is the consideration of non-OPTIMUM users while planning system aware routes as it is (very) unlikely that all users (e.g. in a city) will use the OPTIMUM app for planning their trips. Therefore, we will provide algorithms incorporating traffic demand estimations into the computation of (multi-modal) routes.
7 Persuasive technologies and information personalization

7.1 Related Work

As the envisaged OPTIMUM approach for the (Pro-) Act phase includes the design and development of smart personalized and persuasive services, in this chapter we describe research practices, approaches, methods and applications in the underlying research areas of persuasive technologies and information personalization. Figure 12 depicts the two research areas of interest as circles, along with another circle representing the application domain of transportation/mobility. Obviously, different intersections exist among the two research areas and the application domain of interest.

![Figure 10: Methodology for state-of-the-art analysis](image)

The methodology followed for analysing the state-of-the-art in the aforementioned research areas and for identifying the need for personalized persuasive services in the transportation/mobility domain is the following:

- First, each one of the two aforementioned research areas was analysed. The analysis concerns the top-left (1a) and top-right (1b) parts of the information personalization and persuasive technologies circles, respectively, of Figure 10 and covers the underlying theory, terms and concepts that are most relevant for our work in OPTIMUM.
- Then, related work and applications of each one of the two research areas in the transportation domain were examined. For both information personalization and persuasive technologies, this concerns areas 2a and 2b of Figure 10, respectively, i.e. the intersection of the relevant circle of Figure 10 with that of transportation/mobility.
excluding the common intersection of all circles. Transportation-related applications of information personalization and persuasive technologies are reported in sections 7.1.1.2 and 7.1.2.2, respectively.

Finally, the research gaps in the literature were investigated, revealing the need for personalized and persuasive technologies in the transportation domain (area 3 of Figure 10) in section 7.2.

7.1.1 Information personalization

7.1.1.1 Background

The main goal of personalization in ICT applications is to address the specific and differentiated needs and preferences of the persons that interact with them (Reis and Carvalho, 2012). In its strongest form, personalization means that users get the things or results according to their interests and expectations without providing input. Personalized applications facilitate the interaction with information providers and information recipients and allows users to experience easier access to content and services.

The "individuality" of the information consumer is the key aspect in the personalization definition, implying that individual attributes such as identity, preferences, constraints and provision (example, location and presence) have a potential impact on the personalization process (Toth and Nagboth, 2002). In the ICT domain, personalization is a topic commonly considered in the computer science and marketing/e-commerce areas while the assumptions and research agendas for each area vary (Fan and Poole, 2006). With respect to the marketing/e-commerce group personalization focuses on how to manage customer relationships by delivering unique value and benefits to each individual customer. The main uses of personalization are in Web-enabled commerce and mobile commerce. In the case of computer science the focus is on rendering computer technologies more usable by people. The assumption is that systems designed and adapted to user requirements facilitate user goal attainment. In OPTIMUM we will be focusing on the later approach and use personalization to render Intelligent Transportation Systems more accessible by their users.

Based on the features and purpose of an application, various typologies of personalization have been defined in previous work based on different aspects (Fan and Poole, 2006; Anand and Mobasher, 2005), a summary of which is provided in the following.

- Characteristics of the system that are personalized. These may refer to the content, the user interface, the features and channels of information delivery.
- Target users the personalization needs of whom are addressed. These can be specific individuals or groups/ categories of users.
- Actors who participate in the personalization process. This refers to either the system or the user or both. If the personalization is performed automatically by the system then it is called implicit or adaptive/proactive and commonly relies on algorithms that leverage user profile characteristics and the interactions of the user with the system to tailor the personalized aspects to the individual user. An example is a system that uses a collaborative filtering technique to discover movie items the user likes by considering preferences of users who view similar movies. If the user participates in providing information or making choices that will allow the system to adapt the personalization is called explicit or reactive. An example is a system that asks the user to fill a form her/his preferences and adapts the presented content accordingly.

- Ways to reach personalization which can be either through processes that do not require intervention from users, called observational or implicit (Mulvenna et al., 2000), or through processes that require user participation, called intrusive or explicit personalization (Perugini and Ramakrishnan, 2003).

A core element in personalized ICT applications is the user profile. The profile captures relevant user attributes and characteristics including the identification parameters, the user preferences, interests and interactions with the system as well as the user’s behaviours (Hellmund and Hess, 2003).

From a technological perspective, the main technologies for personalization include:

- Collaborative filtering that enables the generation of recommendations based on implicit or explicit collaboration between users and the system. Collaborative filtering is based on the principles that related users have similar preferences.
- Rules-based filtering that generates profiles based on users behaviour and enables the system to present items to groups of individuals according to previously defined standard behaviours for these groups;
- Content-based filtering that allows to generate recommendations of items that have properties similar to other items and have been selected by the users in the past;
- Clustering techniques that allow to infer associations between users that are obtained from similar transactions or from the number of times certain situations occurred in transactions.

### 7.1.1.1 The use of context in personalization

With the advent of personal mobile devices such as smartphones and tablets, recent research has focused on the use of contextual information in order to improve the personalization of information (Adomavicius and Tuzhilin, 2011) and on proactive information delivery in order to ease the access to information.
Context is any information that can be used to characterize the situation of an entity where an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including location, time, activities, and the preferences of each entity (Abowd et al., 1999; Yau & Karim, 2004). Context awareness is about capturing a broad range of contextual attributes (such as the user’s current positions, activities, and their surrounding environments) to better understand what the user is trying to accomplish, and what services the user might be interested (Moon et al., 2007). Recently, the context information of users has been captured and processed on context-aware computing. It is essential that a service must be offered based on a specific context because the kind of services is different according to the context (Lee, 2007). So, the services are provided to users efficiently by utilizing the context (Figge, 2004).

In contrast to traditional models, context aware recommender systems try to incorporate or utilize additional evidence (beyond information about users and items) to estimate user preferences on unseen items. When such contextual evidence can be incorporated as part of the input to the recommender system, the rating function can be viewed as “multidimensional”:

\[
R : \text{Users} \times \text{Items} \times \text{Contexts} \rightarrow \text{Ratings} \quad (1)
\]

where Contexts represents a set of factors that further delineate the conditions under which the user-item pair is assigned a particular rating. The underlying assumption of this extended model is that user preferences for items are not only a function of items themselves, but also a function of the context in which items are being considered. It should be noted that the above mapping is not unique to the static, fully observable view of context, but, for instance — even in the unobservable case — the ratings may depend on a set of latent factors derived from observations of user activity and used implicitly as part of the estimation of user preferences (as mentioned previously) (Adomavicius and Tuzhilin, 2011).

Contextual information can be used in prefiltering, postfiltering, or modeling of information personalization.

- In the contextual prefiltering (or contextualization of recommendation input) paradigm information about the current context \( c \) is used for selecting only the relevant set of data, and ratings are predicted using any traditional 2D recommender system on the selected data.
- In the contextual postfiltering (or contextualization of recommendation output) paradigm contextual information is initially ignored, and the ratings are predicted using any traditional 2D recommender system on the entire data. Then, the resulting set of recommendations is adjusted (contextualized) for each user using the contextual information.
Finally in the contextual modelling (or contextualization of recommendation function) paradigm contextual information is used directly in the modelling technique as part of the rating estimation.

7.1.1.2 Proactivity for personalization

Traditional personalization systems usually follow a request response pattern, i.e. these systems only return item suggestions when a user makes an explicit request. However in mobile systems, users cannot browse through many search results and suffer from other restrictions in the user experience, because of limitations in the user interface such as small display sizes or missing keyboards. In mobile environments, having the user not to submit any request or query to get a personalized suggestion could possibly improve the user experience.

The automatic provision of just-in-time information or recommendations tailored to each user’s needs/preferences contextualised from the user’s activities, location, usage patterns, time, and connectivity may not only facilitate access to information but also remove barriers to the adoption of current and future services on mobile devices.

7.1.1.2 Related work in the transportation domain

Manasseh et al., (2009) present an architecture that allows mobile users to personalize the delivery of transportation related content. The authors try to solve the problem of efficiently selecting information relevant to the user according to her/his location. This problem arises when attempting to deliver large amounts of transportation related data including traffic related information regarding route status such as congestion ahead, incident ahead, better route alternatives, parking availability, next bus real-time arrival, etc. and soft safety applications such as approaching stop sign, wet road ahead, work-zone ahead, pedestrian crossing, etc. The proposed architecture specifies functionalities to ask the user to choose their preferred content and then limit the data sent to the user by knowing the user’s location and matching that with the GPS data elements of the content that the user is interested in.

Holleis et al., (2012) use mobility patterns derived from a mix of data from existing urban infrastructure and data from participatory sensing, and direct feedback via social networks in a dynamic incentive system that tries to influence mobile behaviour on a personal and city-wide scale beyond regular urban planning. The incentives are drawn from the following categories: efficient use, control, saving, and planning of time; saving of money; real-time and personalized information; social recognition. A mobile application is developed that infers users’ mobility patterns with information from mobile device sensors (GPS, Wi-Fi, and GSM measurements) whereas users are asked to complete mobility related challenges in order to earn rewards.

Tsolkas et al., (2012) present a system called busfinder that supports commuters in finding optimal public transportation routes and guidance when following a selected route. The proposed system incorporates a personalization process based on a semantic architecture that,
captures and represents all related metadata (including user, transport and points of interest related data) and correlates them in order to return valid and accurate route results to users.

Aguiar et al., (2012) make use of electronic ticketing infrastructure of public transportation networks in order to determine the user’s position and provide on-trip personalized navigation cues. The authors implement a system called Navi that offers functionalities to plan a trip by selecting Points of Interest in a map (including touristic interest, public offices, or street addresses). Navi calculates the best route and sequence of POIs to visit the desired destinations considering multimodal transportation (by foot, bus, and subway), frequency of public transports, travel times between PTN stops, average waiting times for transport change, walk times to POI and back to the station, and even visiting times for touristic POI. While on the move the system interacts with the electronic ticketing infrastructure and provides assistance in the form of SMS that indicate how the user should proceed with her/his itinerary. The SMS is sent at the entrance to a transport or station where the user’s electronic ticket is validated.

Bertou and Shahid (2013) propose an application design that assists users throughout all phases of travelling, makes navigation more user-friendly and providing an overall better travel experience in public transportation use. Their application aim both commuters (i.e. travellers who use the same route frequently) and “journeyers” (i.e. travellers to a relatively unfamiliar route or a new destination). The design provides screens for visual information on the progress of the current itinerary step, including estimated times of arrival and delays, an overview of the schedule with the current step in the route being highlighted and notifications when and where travellers are expected to get off the train or bus. Moreover the design offers functionalities for personalized advice given during navigation to shift the focus from providing schedule information to creating a better travelling experience. The idea is to provide suggestions based on user preferences and locational data such as walking to the next bus stop in sunny weather and or getting a cup of coffee or browsing a store while waiting.

### 7.1.2 Persuasive Technologies

#### 7.1.2.1 Background

During the last years, the utilization of computing technology has started being considered as a driving force towards lifestyle management and behavioural change, while significant research has been carried out regarding the potential of technology to change people’s beliefs, shaping their attitudes and behaviours. The term persuasive technology (Fogg, 2002) refers to the application of psychological principles of persuasion to interactive media, with the aim to change users’ attitudes and behaviours. Persuasive technologies are now successfully developed in many domains, including environmental sustainability where it has been used to support sustainable choices and promote pro-environmental behaviour, i.e. behaviour that is generally (or according to knowledge of environmental science) judged in the context of the
considered society as a protective way of environmental behaviour or a tribute to the healthy environment (Krajhanzl, 2010).

According to the 7th International Conference on Persuasive Technology 2012, Persuasive Technology is a stimulating interdisciplinary research field that focuses on how interactive technologies and services can be designed to influence people’s attitudes and support positive behavior change. It is influenced by areas such as classic rhetoric, social psychology and ubiquitous computing. According to Torning and Oinas-Kukkonen (2009), persuasive systems deliberately attempt to infuse a cognitive and/or an emotional change in the mental state of a user to transform the user’s current cognitive state into another planned state. The main question of persuasive technology is how behaviour and attitudes can be changed by use of technology, while six key-fields of research for persuasive systems have been identified: human-computer interaction (HCI), computer-mediated communication, information systems, affective computing, psychology and rhetoric.

Midden et al (2008) describe the linkage between technology and behavior that is sustainable by distinguishing four possible roles of technology: a) technology can be a coordinator and intermediary, it should help the user to achieve a goal; b) technology can serve as an amplifier; it can amplify the potential of the user to achieve his goal; c) technology is a determinant, it changes and activates human behaviour by means of affordances, constraints and cues provided by the technological environment; d) technology promotes behaviour by influencing the choices of the users.

Various types of persuasive strategies and techniques can be used in the context of persuasive technology to nudge people towards modifying their behaviour. A taxonomy of persuasive strategies and principles is presented by (Oinas-Kukkonen and Harjumaa, 2009), while Fogg (2002) and Cialdini (2001) define the basic persuasive strategies and principles. According to Fogg, the director of the Persuasive Tech Lab at Stanford University, these are the following seven:

1. Reduction that aims at compromising complex behaviour to simple tasks.
2. Tailoring, which is a persuasive principle suggesting to provide information that is tailored to the individual needs, interests, personality, usage context and other factors that are relevant to the individual. According to B.J. Fogg (2002) and psychology research (Street et al., 2013), tailored applications have the tendency to be more effective than generic information in changing attitudes and behaviours.
3. Tunnelling that describes the principle to guide the user through a process or an experience in the interactive system.
4. Suggestion which is when a behaviour is suggested to a user just in the most opportune moment.
5. Self-monitoring that helps people to achieve predetermined outcomes or goals by eliminating the tedium of tracking performance or status.

6. Surveillance that describes the phenomenon that the observation of a certain behaviour automatically increases the likelihood of achieving the desired outcome.

7. Conditioning which is the reinforcement and shaping of complex behaviour in a positive way and/or the transformation of existing behaviour into habits.

Cialdini (2001) presents six principles of persuasion and shows that persuasion is governed by basic principles that can be taught, learned, and applied: Liking, Reciprocity, Social Proof, Consistency, Authority and Scarcity. With the principle of Liking (people like those who like them) Cialdini describes the phenomenon of the Tupperware party: People mainly buy the Tupperware because they like the hostess, not so much because they like the product. So liking is the key to persuasion. Research has identified two core factors of liking: similarity and praise. The principle of Reciprocity (people repay in kind) refers to the fact that humans tend to treat other people like they get treated themselves. Social Proof (people follow the lead of similar others) means that people tend to rely in many situations on cues of other people concerning their cognition, their affect and behaviour. People need social evidence on how to think, feel and act. As a consequence, persuasion is extremely effective when it comes from peers. A comparison between individuals or groups can be useful in motivating action, particularly when combined with feedback about performance. With consistency (people align with their clear commitments), people need to be committed to what you want them to do. A commitment is a pledge or promise to behave in a specific way or attain a certain goal. People feel obligated to commitments when these commitments fulfil three features: The commitments have to be active, public and voluntary. Authority (people defer to experts) refers to the fact that the opinion and advices of experts have a great effect on the opinion in people. It is common knowledge that when the media presents an experts’ view on a certain topic, the probability that the audience believes this view is high. Scarcity (people want more of what they can have less of) is a strategy of persuasion that uses the fact that items and opportunities are seen to be more desirable the more rare they are.

As in the context of the OPTIMUM project persuasive strategies are examined within the transportation domain, in the following we describe persuasive strategies and principles, which have been integrated in tools (technologies and systems) aiming to change users’ attitudes and behaviour in a pro-environmental way. As already mentioned, pro-environmental behaviour is such a behaviour that is generally (or according to knowledge of environmental science) judged in the context of the considered society as a protective way of environmental behaviour or a tribute to the healthy environment (Krajhanzl, 2010).

Zapico et al., (2010) proclaim that the use of computers as simulation tools is one of the key features in computer-enabled change of user behaviour and attitudes and therefore introduces
simulation as another technique of persuasion especially suitable for that context. When it comes to tools, two principles should be implemented in its design to induce a persuasive effect: First, the principle of virtual rehearsal addresses the fact, that the tool should enable experimentation without consequences that means the user can freely “play” with the tool to “test” different behaviours. Second, the principle of cause and effect should ensure that the intervention of the tool should be designed in a way that shows the link between the behaviour and the effect.

Froehlich et al., (2010) stress the importance of eco-feedback, i.e. the provision of feedback on individual behaviour with a goal of reducing environmental impact. Eco-feedback is based on the working hypothesis that most people lack awareness and understanding about how their everyday behaviours such as driving to work or showering affect the environment; the aim of eco-feedback is to bridge this “environmental literacy gap” by feeding related information back through computerized means (e.g., mobile phones, ambient displays, or online visualizations). Feedback that provides information comparing one’s current behaviour to past behaviour (self-comparison) has been shown to be effective. In their research study Froehlich et al., (2010) conducted a comparative study of 89 papers from environmental psychology and 44 papers from HCI literature to make a summary of key motivational techniques that HCI-designers must be aware of if they want to promote pro-environmental behaviour. One of their most important issues was the way in which information could be used to persuade people to make this change, “Information must be easy to understand, trusted, attract attention and is remembered”. The importance of users gaining confidence in the information and advice that the persuasive system offers is also highlighted by (Pearce et al., 2009).

According to (Ecker et al., 2011) an important persuasive strategy is offering challenges (goals) that incentive the user to show an intended behaviour in a self-competitive context. According to Froehlich et al., (2010) goal-setting is a valuable technique to stimulate environmentally responsible behaviour, particularly when combined with feedback. Goal setting, which is a well-studied source of motivation, operates through a comparison of the present and a desirable future situation (Van Houwelingen and Van Raaij, 1989). Individuals, groups, and external agents (e.g. a coach) can all set goals. Locke and Latham, (2002) summarized 35 years of empirical research on goal-setting and found that goals affect behaviour primarily through four mechanisms: first, goals serve a directive function - they direct attention and effort toward goal relevant activities; second, goals have an energizing function and, in particular, high goals often lead to greater effort than low goals; third, goals affect persistence; and finally, goals affect behaviour indirectly as individuals use, apply, and/or learn strategies or knowledge to best accomplish the goal at hand. When people set goals in public, goal-setting is strongly related to the commitment persuasive strategy. A commitment is a pledge or promise to behave in a specific way or attain a certain goal. A person that expresses commitment increases the probability that s/he will pursue that behaviour (Lu and Perl, 2006). The type of commitment a
person makes, the person or group to whom the commitment is made, and whether the commitment is public or private are three factors that impact behaviour (Froehlich et al., 2010).

Other important persuasive strategies are representation and creating awareness as they are applied in a number of persuasive systems and technologies in the context of pro-environmental behavioural change. Representation aims at the graphical design of certain aspects and facts (for example in application-interfaces). The intended persuasive effect on the user is multiplied through the design of the system used to communicate the persuasive strategies. Designing the system in a way that is diversified and exciting guarantees that the user will not get bored (Ecker et al., 2011). Some exciting aspects of system design may be related to incentives and rewards, relying on game-like (gamification; see below) reward elements (e.g., points, levels, etc.) to promote behaviours (Froehlich et al., 2009). Rewards are consequence motivation techniques – i.e. they come after a behaviour, while they should be linked as closely with the target behaviour as possible (Valente and Schuster, 2002). Rewards need not always be monetary; those rewards associated with status or convenience may also have important effects on pro-environmental behaviour. Representations have to be comprehensible and aim at the peripheral creation of awareness for certain aspects and facts. Persuasion aims at changing human attitudes and behaviour. These two persuasion strategies try to show the targeted attitudes and behaviour directly to the user.

One effective strategy to increase the likelihood that a user behaviour will change towards the desired one is to include in the persuasive system game elements such as scores, competition among players, role playing, elements of chance, rules, goals, levels, rewards, narratives (Deterding et al., 2011; Bedwell et al., 2012). This strategy is called gamification, which refers to the application of digital game design techniques to non-game problems. As stated by Llagostera (2012), the rationale behind the use of game elements, either as an applied subset of design elements or as models for simulating whole activities, is that games are able to engage and motivate players for long periods of time. The reason is that they boost feelings of challenge, achievement and satisfaction and for a person to perform a target behaviour, he/she must: (a) be sufficiently motivated, (b) have the ability to perform the behaviour, and (c) be triggered to perform the behaviour (Fogg, 2009).

Furthermore, according to (Paay et al., 2013) tailored information is more persuasive than generic information, in the sense that it has a greater possibility to persuade users and change their behaviour with respect to conservation of natural resources. On the same direction, Lim et al., (2011) suggest that by tailoring the information presented to a particular user, the information becomes far more relevant, and ultimately more effective. Moreover, Chetty et al., (2008) state that feedback should be tailored to the users’ actual behaviour and profile. This supports Fogg’s (2003) principle of information being more persuasive if it is tailored to the individual’s needs, interests, personality or usage context.
Additionally, Fogg (2008) introduced the phenomenon of Mass Interpersonal Persuasion (MIP), a phenomenon that started together with the possibility for third parties to create and distribute interactive applications (for example applications that persuade people to disclose personal music preferences) on the social media platform Facebook. Fogg states six components of MIP. The first is persuasive experience, which is an experience that changes attitudes and/or behaviours. The second is an automated structure, which is when digital information and communication technology structures the persuasion. The third the social distribution, that is a persuasion that is “shared from one friend to another”. The fourth one is rapid cycle, which is when the persuasion can be quickly distributed from one to another. The fifth one is a huge social graph, which refers to the fact that the persuasion can potentially reach “millions of people connected through social ties or structured interactions. The sixth one is the measured impact, which is when the persuasive effect (change of attitude and behaviour) can be observed.

On the same direction, Ecker et al., (2011) consider the ability of the user to compare his behaviour to friends (social comparison/social proof) and to challenge them of paramount importance with respect to persuasion in a pro-environmental way. Moreover, Khan and Canny, (2008) suggest that one could extract principles from social marketing and use them for designing persuasive technologies and systems. One of these principles is called other person, that is similar to Fogg’s social distribution and huge social graph components and Cialdini’s principles related to social actions: People are significantly influenced by what other people are doing, even if they would self-report that they were not influenced by why other people are doing. Ybarra and Trafimow, (1998) suggest that social influence can operate in two different ways: (a) as social informational influence, where other people are regarded as a significant information source for one’s own behaviour, particularly in situations in which individuals’ are uncertain as to how to behave; (b) as normative social influence, where the individuals are motivated by the desire to obtain social approval and avoid rejection by others.

7.1.2.2 Related work in the transportation domain
One of the first mobile persuasive application in the transportation domain is UbiGreen (Froehlich et al., 2009). It runs on the personal mobile device of the user and adapts the background graphics of the phone to provide visual feedback that aims to reduce driving and to encourage greener alternatives, including carpooling, public transport, and pedestrian modalities. Trees or polar bear avatars are used to visualize the degree of eco-friendliness by analysing the user’s weekly transportation choices. Users’ behavioural data are collected by using semi-automated sensing and self-reported questionnaires.

Wunsch et al., (2013) designed and evaluated three persuasive strategies aiming to encourage biking as a low-energy mode of transportation. The strategies were designed based on: (I) triggering messages that harness social influence to facilitate more frequent biking, (II) a virtual
bike tutorial to increase biker’s self-efficacy for urban biking, and (III) an arranged bike ride to help less experienced bikers overcome initial barriers towards biking. The evaluation, followed a pretest-posttest control group experimental design and showed a significant increase of 13.5 percentage points in share of biking, an increase of perceived self-efficacy for non-routine bikers and a positive experience of urban biking.

Gabrielli and Maimone (2013) examined the effect of a mobile application on supporting eco transport choices of citizens of an urban area. The transport choices and habits of the participants were influenced with several persuasion strategies incorporated in the mobile application, including goal setting, self-monitoring, rewards and social influence. More specifically, an increase of sustainable transport choices of 14%, as well as an increased environmental awareness of the participants, was observed.

Bothos et al., (2014) focus on persuasive strategies supported by a choice architecture approach and incorporated in a smartphone application, aiming at providing urban travellers with a solution that will influence them to consider the environmental friendliness of travel modes while planning a route. The choice architecture approach leverages routing options and results of a commercial routing engine in order to provide proper default options as well as filter and structure the results according to user preferences and contexts while emphasizing environmentally friendly routes.

Schrammel et al. (2015) report the findings of a two months field study analyzing the effectiveness and perception of individual and collaborative challenges in the context of influencing personal mobility through a mobile trip planner application. Their findings suggest that both individual and collaborative challenges have the potential to sustain the interest of users in using behaviour change support systems, that collaborative and individual challenges seem to not attract different types of users, that individual challenges in general are preferred, and that challenges are only a useful means for a subset of users.

Holleis et al., (2012) and Broll, et al., (2012) present the design and architecture of a dynamic incentive system aiming to motivate changes in travel behaviour by providing incentives to users based on their own personal mobility profiles built using the sensing capabilities of smartphones. The incentives are delivered through a smartphone app called TRIPZOOM, through which the user mobility profiles are built by tracking the origins, destinations, modes and trips of users. An analysis of the different types of incentives and their potential impact was conducted, and it was concluded that feedback and self-monitoring in conjunction with rewards and points were more effective than social networks and real-time travel information (Vanegas, 2014).

Jariyasunant et al., (2015) describe the design and evaluation of Quantified Traveler (QT), a computational travel feedback system aimed at supplementing the counselors supporting
travellers using travel diaries in improving their travel patterns. Counselors are guiding the latter to alternate mode or trip decisions that are more sustainable or otherwise beneficial to society, while still meeting the subject’s mobility needs. QT uses an app on the mobile phone to collect travel data, a server in the cloud to process it into travel diaries and then calculates personalized carbon, exercise, time, and cost footprint which are fed back to the traveller. Evaluation of the system revealed significant pro-environmental shifts in subjects’ psychological variables such as their awareness of the impacts of their transportation choices and their attitudes toward sustainable modes of transportation, as well as significant behavioural shift (reduction) with respect to the target behaviour (driving).

Wells et al., (2013) present SUPERHUB, a prototype, open platform for urban-mobility that integrates multimodal journey planning with captology (Fogg, 2013) influenced digital behaviour management in order to encourage increasingly sustainable travel behaviours. The SUPERHUB platform incorporates a persuasion engine for digital behaviour management that uses explicit goal setting and behaviour tracking to help users realising their expressed sustainable travel goals. Results from a SUPERHUB pilot study (Gabrielli and Maimone, 2013) revealed that the deployed digital interventions, a combination of goal-setting, self-monitoring, rewards and sharing features, produced an increase of sustainable transport choices of 14% and contributed to raise participants’ environmental awareness, particularly regarding the consequences of their daily transportation choices.

MatkaHupi (Jylhä et al., 2013) is an application able to motivate people into choosing sustainable modes of transportation, relying on a set of challenges. The peculiarities of this application are represented by the challenges that are continually offered to users based on their observed behaviour. After each detected trip, the system checks whether the same trip could have been made faster (less travel time) and/or with lower emissions (trip challenge) using a sustainable alternative. Therefore the application challenges the user to consider, in the future, the alternative trip proposed. If the user takes up the challenge, then he/she is rewarded with a badge and a certain number of points, depending on the type of challenge.

Meloni et al., (2014) present IPET (Individual Persuasive Eco-Travel Technology), a technology platform that automates phases and activities of Voluntary Travel Behaviour Change programmes (VTBC). IPET aims to replace traditional information provision methods with a direct, automatic, instantaneous and dynamic system that is able to send clear and persuasive information and advice to mobile devices. For information acquisition, analysis, processing and transmission, the platform manages a marketing campaign on sustainable mobility, providing a personalised programme, similarly to a real mobility supervisor, constantly supporting people in their travel choices and encouraging them towards environmentally sustainable behaviour.
7.2 Research Gaps of State-Of-The-Art

A key challenge, in particular for mass persuasion, is that often the target audiences are large and heterogeneous, and include users with wide-ranging goals, needs, and preferences. Thus, influencing the entire audience effectively with a one-size-fits-all persuasive intervention is difficult.

Most persuasive applications employ a one-size-fits-all approach to the delivery of persuasive interventions, failing to deliver personalized persuasion that leverages user characteristics and preferences, or to provide personalized tools that assist users in achieving the intended goals.

Personalized technologies use sophisticated modelling and understanding of user preferences to provide personalized services, but fail to cash in on increased success that could potentially be achieved, if their services were supported by state-of-the-art persuasive communication. For example, many persuasive applications for sustainability, such as IPET (Meloni et al., 2014) that motivates users to more eco-friendly habits by providing visual feedback, have been implemented for a general audience using a single persuasive technique. However, it is known that people differ in their susceptibility to different persuasive strategies. Previous research has shown systematic variation among users in their responses to specific persuasive strategies, such that for some users the effect of using a persuasive strategy is negative, even though the effect of that strategy is significantly positive on average (Kaptein, 2012).

The implementation of personalized and persuasive technologies would enhance the impact of either personalized or persuasive technology applied in isolation. Personalized systems would benefit from incorporating persuasive techniques to gather valuable user information, increase uptake of recommendations, and improve the quality of service and the overall user experience. Persuasive systems could adapt the type and intensity of the persuasive interventions to the preferences and characteristics of each individual user, thus upgrading their persuasive capabilities. We propose that the impact of the combination of these technologies would exceed the impact currently seen by them applied independently, and predict an increased interest in investigating their fusion from both research communities.

More specifically, in OPTIMUM we will work towards filling these gaps by selecting the appropriate persuasive strategy for each individual user on the basis of his/her susceptibility to different persuasive strategies (persuadability). The envisaged approach includes building a persuadability model and using it to identify user susceptibility to the different persuasive strategies, on the basis of user characteristics that may be explicitly provided by the users through questionnaires or may be inferred by analyzing their interactions with the OPTIMUM application, as well as their trips. Special emphasis will be given to characteristics related to the personality of the users and their mobility profile. We plan to dynamically update user
persuadability on the basis of previous successful persuasive interactions of a particular user and other similar users.
8 ITS-related projects, directives, action plans, regional strategic plans, deployment strategies

This section relates to the brief presentation of recent trends on Intelligent Transportation Systems (ITS) at EU level. Within Europe various actions have been recently undertaken at various levels such as:

- The introduction of a European ITS Action Plan in order to contribute towards Transport White Paper’s challenges. The establishment of various ITS Directives regarding transport data management where the EU Member States have adopted.
- The introduction of National Action Plans by the majority of EU Member States based on ITS Directive requirements.
- The deployment of ITS projects at various European countries.

As it can be seen the OPTIMUM objective and deployment actions (pilot cases) are directly related with the EU direction towards the continuous, interoperable and harmonized transport data exchange and management. Transport data collection, processing and diffusion in a structured and dynamic manner seem to be a major challenge at EU level. OPTIMUM is developing a largely scalable, distributed architecture for the management and processing of multisource big data by enabling continuous monitoring of transportation systems and by providing proactive decision and actions on real (or semi-real) conditions.

8.1 ITS Strategy at European Level

8.1.1 EU Strategy

The Lisbon agenda on growth and jobs was aiming to deliver stronger, lasting growth and creating more and better jobs. Furthermore, the White Paper stressed the key role of innovation in ensuring sustainable, efficient and competitive mobility in Europe.

Against this background several major challenges have to be overcome for Europe’s transport system to play its full role in satisfying the mobility needs of the European economy and society:

- Road traffic congestion is estimated to affect 10% of the road network, and yearly costs amount to 0.9-1.5% of the EU Gross Domestic Product (GDP).
- Road transport accounts for 72% of all transport-related CO2 emissions.
- Whilst road fatalities are in regression, their number is still above the intended target of a 50% reduction in fatalities in the period 2001-2010.
These challenges are even more pressing with forecasted growth rates of 50% for freight transport and 35% for passenger transport in the period from 2000 to 2020.

The main policy objectives arising from these challenges are for transport and travel to become:

- cleaner,
- more efficient, including energy efficient,
- safer and more secure.

Conventional approaches such as the development of new infrastructure are not anymore expected to bring the necessary results on the timescales required by the magnitude of these challenges. Innovative solutions are clearly needed to achieve the rapid progress demanded by the urgency of the problems at hand. Intelligent Transport Systems (ITS) are able to play critical role in improve safer, cleaner and more efficient transportation.

“Intelligent Transport Systems (ITS)” means applying Information and Communication Technologies (ICT) to transport. These applications are being developed for different transport modes and for interaction between them - including interchange hubs (Commission of the European Communities, 2008).

EU published 16/12/2008 an Action Plan for the Deployment of Intelligent Transportation Systems aiming to accelerate and coordinate the deployment of Intelligent Transport Systems (ITS) in road transport, including interfaces with other transport modes. The Action Plan outlined six priority areas for action. For each area a set of specific actions and a clear timetable are identified. Fulfilling them by setting a framework to define procedures and specifications will call for the mobilization of Member States and other stakeholders. Finally, this Action Plan was aiming to help to combine the resources and instruments available to deliver a substantial added value for the European Union.

It was recognized that ITS can create clear benefits in terms of transport efficiency, sustainability, safety and security, whilst contributing to the EU Internal Market and competitiveness objectives. The adoption of a common European Approach in ITS based on previous experience where several isolate activities were undertaken by various European countries since the 1980. These activities have traditionally focused, often in an uncoordinated and fragmented manner, on specific areas such as clean and energy-efficient transport, road congestion, traffic management, road safety, security of commercial transport operations or urban mobility. Despite these developments, some issues had to be addressed from a European perspective to avoid the emergence of a patchwork of ITS applications and services. So, a common European approach is expected to enable geographical continuity, interoperability of
services and systems and standardization. They should facilitate pan-European applications, secure accurate and reliable real-time data and an adequate coverage of all travelling modes.

After the development of an Action Plan, specific Directives were produced in order to specify the common European approach.

8.1.2 EU ITS Directives

Based on EU objectives regarding the deployment of Intelligent Transportation Systems (ITS) in order to improve traffic flow, increase transport safety levels and diffuse relevant travellers information, the European Commission issued in 7/7/2010 the Directive 2010/40/EU for the deployment of ITS in the field of road transport and for interfaces with other transport modes.

Few amendments and supplementary EU Directives have been issued in order to update the specifications included within 2010/40/EU Directive.

In this section, the 2010/40/EU Directive, important amendments and supplemented EU directives are briefly presented.

i. DIRECTIVE 2010/40/EU


According to this Directive, the definition of Intelligent Transport Systems (ITS) is provided; means of systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport.

The ITS Directive 2010/40 establishes a framework in support of the coordinated and coherent deployment and use of Intelligent Transport Systems (ITS) within the Union, in particular across the borders between the Member States, and sets out the general conditions necessary for that purpose. Moreover, the development of specifications for actions within the priority areas is provided, as well as, the development of necessary standards. It is applicable to ITS applications and services in the field of road transport and to their interfaces with other modes of transport without prejudice to matters concerning national security or necessary in the interest of defence.

The Directive recognizes four (4) priority areas as listed below:

- **Priority Area I.** Optimal use of road, traffic and travel data.
- **Priority Area II.** Continuity of traffic and freight management ITS services.
- **Priority Area III.** ITS road safety and security applications.
Within the above priority areas, priority actions are determined for the development and use of specifications and standards:

- **Priority Area IV.** Linking the vehicle with the transport infrastructure.

  Within the above priority areas, priority actions are determined for the development and use of specifications and standards:

  - **Priority Action A.** The provision of EU-wide multimodal travel information services.
  - **Priority Action B.** The provision of EU-wide real-time traffic information services.
  - **Priority Action C.** Data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users.
  - **Priority Action D.** The harmonized provision for an interoperable EU-wide eCall.
  - **Priority Action E.** The provision of information services for safe and secure parking places for trucks and commercial vehicles.
  - **Priority Action F.** The provision of reservation services for safe and secure parking places for trucks and commercial vehicles.

Apparently OPTIMUM project and the deployment of the ‘real’ pilot cases comply with the priority actions (and priority areas) set by Directive 2010/40. More specifically:

- Pilot Case 1 (Proactive improvement of transport systems quality and efficiency) is closely related to the provision of EU-wide multimodal travel and real-time traffic information services (Priority Action A and B), i.e. Priority Area I (Optimal Use of road, traffic and travel data).

- Pilot Case 2 (Proactive Charging Schemes for freight transport) is closely related to the provision of EU-wide real-time traffic information services (Priority Action B), as better clarified at the supplementing regulation of EU 2010/40 (see Table 2), i.e. Priority Area I (Optimal Use of road, traffic and travel data).

- Pilot Case 3 (Integrated Car2X communication platform) is closely related to the provision of EU-wide real-time traffic information services (Priority Action B, Priority Area I) and the provision of information and reservation services for safe and secure parking places for trucks and commercial vehicles (Priority Action E and F), i.e. Priority Area III (ITS road safety and security applications).

More specifically by focusing on the OPTIMUM project’s scope, the Priority Area I (Optimum use of Road, traffic and travel data) and Priority Area III (ITS road safety and security applications) specifications are presented in Table 2.
Table 2: Priority actions 2010/40/EU for optimum use of road, traffic and travel data (Priority Area I) and ITS road safety and security applications (Priority Area III).

<table>
<thead>
<tr>
<th>Priority Area</th>
<th>Priority Action</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: Optimum use of Road, traffic and travel data</td>
<td>A</td>
<td>The definition of the necessary requirements to make EU-wide multimodal travel information services accurate and available across borders to ITS users</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The definition of the necessary requirements to make EU-wide real-time traffic information services accurate and available across borders to ITS users</td>
</tr>
<tr>
<td></td>
<td>A &amp; B</td>
<td>The definition of the necessary requirements for the collection by relevant public authorities and/or, where relevant, by the private sector of road and traffic data (i.e. traffic circulation plans, traffic regulations and recommended routes, notably for heavy goods vehicles) and for their provisioning to ITS service providers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The definition of the necessary requirements to make road, traffic and transport services data used for digital maps accurate and available, where possible, to digital map producers and service providers</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>The definition of minimum requirements, for road safety related ‘universal traffic information’ provided, where possible, free of charge to all users, as well as their minimum content</td>
</tr>
<tr>
<td>II: ITS road safety and security applications</td>
<td>D</td>
<td>The definition of the necessary measures for the harmonised provision of an interoperable EU-wide eCall</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>The definition of the necessary measures to provide ITS based information services for safe and secure parking places for trucks and commercial vehicles, in particular in service and rest areas on roads</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>The definition of the necessary measures to provide ITS based reservation services for safe and secure parking places for trucks and commercial vehicles</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>The definition of the necessary measures to support the safety of road users with respect to their on-board Human-Machine-Interface and the use of nomadic devices to support the driving task and/or the transport operation</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>The definition of the necessary measures to improve the safety and comfort of vulnerable road users for all relevant ITS applications.</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>The definition of necessary measures to integrate advanced driver support information systems into vehicles and road infrastructure</td>
</tr>
</tbody>
</table>

In 18/12/2014, a supplementing Regulation to Directive 2010/40/EU was issued regarding the provision of EU-wide real-time traffic information services. The supplementing regulation defines the various data categories such as the type of static road data, the type of dynamic road data and type of traffic data (European Commission, 2014). Table 3 summarizes the required data per dataset type.
Table 3: Specified data per dataset type (2010/40/EU)

<table>
<thead>
<tr>
<th>Dataset Type</th>
<th>Required Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static road data</td>
<td>Road network links and their physical attributes:</td>
</tr>
<tr>
<td></td>
<td>o geometry</td>
</tr>
<tr>
<td></td>
<td>o road width</td>
</tr>
<tr>
<td></td>
<td>o number of lanes</td>
</tr>
<tr>
<td></td>
<td>o gradients</td>
</tr>
<tr>
<td></td>
<td>o junctions</td>
</tr>
<tr>
<td></td>
<td>Road classification</td>
</tr>
<tr>
<td></td>
<td>Traffic signs reflecting traffic regulations and identifying dangers:</td>
</tr>
<tr>
<td></td>
<td>o access conditions for tunnels</td>
</tr>
<tr>
<td></td>
<td>o access conditions for bridges</td>
</tr>
<tr>
<td></td>
<td>o permanent access restrictions</td>
</tr>
<tr>
<td></td>
<td>o other traffic regulations</td>
</tr>
<tr>
<td></td>
<td>Speed limits</td>
</tr>
<tr>
<td></td>
<td>Traffic circulation plans</td>
</tr>
<tr>
<td></td>
<td>Freight delivery regulations</td>
</tr>
<tr>
<td></td>
<td>Location of tolling stations</td>
</tr>
<tr>
<td></td>
<td>Identification of tolled roads, applicable fixed road user charges and available payment methods</td>
</tr>
<tr>
<td></td>
<td>Location of parking places and service areas</td>
</tr>
<tr>
<td></td>
<td>Location of charging points for electric vehicles and the conditions for their use</td>
</tr>
<tr>
<td></td>
<td>Location of compressed natural gas, liquefied natural gas, liquefied petroleum gas stations</td>
</tr>
<tr>
<td></td>
<td>Location of public transport stops and interchange points</td>
</tr>
<tr>
<td></td>
<td>Location of delivery areas</td>
</tr>
<tr>
<td>Dynamic road status data</td>
<td>Road closure</td>
</tr>
<tr>
<td></td>
<td>Lane closures</td>
</tr>
<tr>
<td></td>
<td>Bridge closures</td>
</tr>
<tr>
<td></td>
<td>Overtaking bans on heavy goods vehicles</td>
</tr>
<tr>
<td></td>
<td>Road works</td>
</tr>
<tr>
<td></td>
<td>Accidents and incidents</td>
</tr>
<tr>
<td></td>
<td>Dynamic speed limits</td>
</tr>
<tr>
<td></td>
<td>Direction of travel on reversible lanes</td>
</tr>
<tr>
<td></td>
<td>Poor road conditions</td>
</tr>
<tr>
<td></td>
<td>Temporary traffic management measures</td>
</tr>
<tr>
<td></td>
<td>Variable road user charges and available payment methods</td>
</tr>
<tr>
<td></td>
<td>Availability of parking places</td>
</tr>
<tr>
<td></td>
<td>Availability of delivery areas</td>
</tr>
<tr>
<td></td>
<td>Cost of parking</td>
</tr>
<tr>
<td></td>
<td>Availability of charging points for electric vehicles</td>
</tr>
<tr>
<td></td>
<td>Weather conditions affecting road surface and visibility</td>
</tr>
<tr>
<td>Traffic Data</td>
<td>Traffic volume</td>
</tr>
<tr>
<td></td>
<td>Speed</td>
</tr>
<tr>
<td></td>
<td>Location and length of traffic queues</td>
</tr>
</tbody>
</table>
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**Dataset Type** | **Required Data**
--- | ---
Travel times |  
Waiting time at border crossings to non-EU Member States

**ii. DIRECTIVE 885/2013/EU**

To supplement the 2010/40/EU ITS Directive, the European Commission issued the 885/2013/EU Directive regarding the provision of information services for safe and secure parking places for trucks and commercial vehicles (European Commission, 2013). The Regulation establishes the specifications necessary to ensure compatibility, interoperability and continuity for the deployment and operational use of information services at the specific transport function. It is applicable to the provision of information services situated on the trans-European road network (TERN).

This Regulation seeks to optimize the use of parking places and to facilitate drivers’ or transport companies’ decisions about when and where to park by means of deployment of information services. The provision of security and comfort information contributes to the decision drivers make in choosing the parking area. Guidance may be given by displaying the security, safety and services features offered on a parking. In case of specific persistent heavy demand for safe and secure parking in certain areas, truck drivers should be redirected from a full parking area to another location in the priority zone where free safe and secure places are available in order to avoid unsuitable parking.

The Directive requires that all Member States should designate areas where traffic and security conditions require the deployment of information services on the safe and secure parking places. Priority zones should be also defined where dynamic information will be provided.

The data should be collected easily and remotely in order to facilitate a distant collection by all parking operators. Public or private parking operators and service providers shall use DATEX II (see section below) profiles or other internationally compatible formats in order to ensure interoperability of the information services across the Union.

**Table 4: specified data per dataset type (885/2013/EU)**

<table>
<thead>
<tr>
<th>Dataset Type</th>
<th>Required Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static data for the parking areas</td>
<td>Identification information of parking area (name and address of the truck parking area (limited to 200 characters))</td>
</tr>
<tr>
<td></td>
<td>Location information of the entry point in the parking area (latitude/longitude) (20 + 20 characters)</td>
</tr>
<tr>
<td></td>
<td>Primary road identifier1/direction (20 characters/20 characters), and Primary road identifier2/direction (20 characters/20 characters) if same parking accessible from</td>
</tr>
<tr>
<td>Dataset Type</td>
<td>Required Data</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Information on safety and equipment of the parking area</td>
<td>two different roads</td>
</tr>
<tr>
<td></td>
<td>If needed, the indication of the Exit to be taken (limited to 100 characters)/Distance from primary road (integer 3 digits) km or miles</td>
</tr>
<tr>
<td></td>
<td>Total number of free parking places for trucks (integer 3 digits)</td>
</tr>
<tr>
<td></td>
<td>Price and currency of parking places (300 characters)</td>
</tr>
<tr>
<td></td>
<td>Description of security, safety and service equipment of the parking including national classification if one is applied (500 characters)</td>
</tr>
<tr>
<td></td>
<td>Number of parking places for refrigerated goods vehicles (numerical 4 digits)</td>
</tr>
<tr>
<td></td>
<td>Information on specific equipment or services for specific goods vehicles and other (300 characters)</td>
</tr>
<tr>
<td></td>
<td>Name and surname of parking operator (up to 100 characters)</td>
</tr>
<tr>
<td></td>
<td>Telephone number of parking operator (up to 20 characters)</td>
</tr>
<tr>
<td></td>
<td>E-mail address of parking operator (up to 50 characters)</td>
</tr>
<tr>
<td></td>
<td>Consent of the parking operator to make his contact information public (Yes/No)</td>
</tr>
<tr>
<td>Dynamic data on availability of parking places</td>
<td>Information regarding parking space availability:</td>
</tr>
<tr>
<td></td>
<td>• Full</td>
</tr>
<tr>
<td></td>
<td>• Closed</td>
</tr>
<tr>
<td></td>
<td>• Number of available free spaces</td>
</tr>
</tbody>
</table>

Finally, according to the Directive 885/2013/ EU Service providers collecting information at a specific point should display:

- at least the next two safe and secure parking places along a corridor within approximately 100 kilometres,
- the availability of parking places in a priority zone in at least the next two parking areas within approximately 100 kilometres.

**iii. DIRECTIVE 886/2013/EU**

This Regulation establishes the specifications necessary to ensure compatibility, interoperability and continuity for the deployment and operational use of data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users on a Union level in accordance with Directive 2010/40/EU (European Commission, 2013).

The justification for publishing this Directive is based on the fact that Intelligent Transportation Systems have the potential to play a considerable role for the improvement of traffic safety, for example through the adoption of systems to detect incidents and supervise traffic that are able to provide information to road users in real time.
The events or conditions covered by the road safety-related minimum universal traffic information service shall consist of at least one of the following categories:

- temporary slippery road
- animal, people, obstacles, debris on the road
- unprotected accident area
- short-term road works
- reduced visibility
- wrong-way driver
- unmanaged blockage of a road
- exceptional weather conditions

The information content provided on the road safety-related events or conditions should include the following items:

- location of the event or the condition
- the category of event or condition (as defined previously), where appropriate, short description of it
- driving behaviour advice

The information content should be updated at frequent time intervals in order to present the real event status, i.e. an event be withdrawn as an information if the event or condition cease to subsist, or shall be modified if there is a change in the event status.

Public and/or private road operators and/or service providers should share and exchange the data in the DATEX II (CEN/TS 16157) format or any fully compatible and interoperable with DATEX II machine-readable format through an access point. Member States should manage a national access point to the relevant data, which regroups the access points established by public and/or private road operators and/or service providers operating on their territory.

8.1.3 DATEX Model

On October 5, DATEX II has been published, so than an acknowledged European Technical Specification for modelling and exchanging ITS-related information between many partners. DATEX II has been developed to provide a standardized way of communicating and exchanging traffic information between traffic centres, service providers, traffic operators and media partners. The specification provides for a harmonized way of exchanging data across boundaries, at a system level, to enable better management of the European road network.
DATEX II is expected to play a strong role for the implementation of integrated ITS in Europe. DATEX II is developed and maintained under the umbrella of the EasyWay project and is supported by the European Commission. As it is already described, the EU Directives 885/2013/EU and 886/2013/EU require from the Member States the adoption of DATEX II standard or an equivalent one. Moreover, many of the priority areas and services mentioned in the directive are covered by DATEX II.

Allowing the exchange of traffic information to take place directly between control room operating systems considerably increases the safety and performance of transportation networks. With any exchange taking place at the system level, information is transferred instantaneously and does not involve the intervention of the operator, allowing for faster more responsive management of road networks. This ‘dynamic system state’ lies at the heart of the concept of Intelligent Transport Systems (ITS). When considering the volume, availability and accuracy of data, combined with the many descriptors of traffic state or situations, the importance of the concept becomes obvious. The harmonization and standardization of data structures and data exchange services are fundamental challenges for both the information society as a whole, as well as for ITS. DATEX II is a specification that is meant to operate at and represent the interface between the worlds of dynamic traffic and IT. Today there are over 100 road operators active on the Trans-European Road Network (TERN). Whilst the road infrastructure itself with its general layout, physical properties and signing have considerably converged, this is not necessarily true for ITS applications. Wherever a road operator must adapt his actions to a region beyond his own area of control, they will rely on the availability of comprehensive, relevant and accurate information from others. The coordination and harmonization of traffic management measures between road operators on the TERN is an essential part of maximizing the capacities of their road networks to reduce the negative effects of congestion, whilst improving safety (Easyway, 2011).

DATEX II is of relevance for all applications where dynamic information on the transport systems and notably the road system is concerned. The main usage areas are:

- Rerouting, network management and traffic management planning
- Motorway networks and urban networks are regarded as closely connected here Lane or line control systems and related applications like ramp metering, dynamic speed limits and overtaking control
- Linking traffic management and traffic information systems
- Applications where information exchange between individual vehicles and traffic management is crucial, like for Car-to-infrastructure systems
Applications where information exchange between management systems for different modes is crucial, like multi-modal information systems

Applications where the exchange of measured data is important

Provision of services in the framework of road management with a strong link to network safety or performance like Truck Parking

For all these domains, DATEX II pays special attention to interoperability issues resulting from the need for multiple operator cooperation and the unhindered exchange of data or information. However DATEX II is also designed to be used within single operator systems.

The DATEX model currently covers:

- Level of service on the network, both in terms of messages for specific situations or as an overall status on the network
- Travel times, be it on short network links or for long distance travel itineraries
- All types of incidents and accidents
- Road works
- Road infrastructure status
- Closures, blockages and obstructions
- Road weather, again as events as well as status / measurements
- All kinds of traffic related measurements (speed, flow, occupancy)
- Public events with impact on traffic
- Current settings of variable message signs

8.2 Action Plans

EU countries have developed ITS Actions in order to promote ITS deployments which meet the requirements of Directive 2010/40/EU relatively to the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. The Action Plans according to the EU regulation have been drafted in 2012 and for five (5) years’ time horizon (2013 – 2017). Moreover, the EU Member States have to provide progress reports within this time period. Note that not all Member States seem to meet the requirement for the preparation of an Action Plan.

Indicatively, in the following sub-sections, a brief description of the directions and actions within national ITS Action Plan or national reports is attempted for EU Member States.
Moreover, a consideration of regional ITS Action Plans is also included. The examined EU countries during the preparation of their Action Plans seem to take into account the four priorities area set to the Directive 2010/40/EU:

- **Priority Area I.** Optimal use of road, traffic and travel data.
- **Priority Area II.** Continuity of traffic and freight management ITS services.
- **Priority Area III.** ITS road safety and security applications.
- **Priority Area IV.** Linking the vehicle with the transport infrastructure

The majority of ITS applications across Europe lie within Priority Area I and II, while significant actions are foreseen for Priority Area III. On the other hand, the Priority Area IV seems to be still in-mature in the majority of EU countries.

### 8.2.1 Belgium

In Belgium the road infrastructure is a regional competence. The public bus, tram and metro transport also falls under regional competencies. The railways fall within the competences of the federal government. The technical specification for ITS for vehicles, traffic safety and traffic regulations, goods transport by road, the handling of personal data and market supervision are federal competences. An ITS Committee has been setup in order to coordinate ITS activities at Belgian level; the ITS Committee comprises of representatives from the federal ministries and for the 3 regions: Flemish Region, the Wallon Region and the Brussels-Capital Region (Belgian Ministry for Mobility and Transport, 2012).

The Belgian (Federal Government) has been established one priority area for the time period 2012 – 2017, named as “ITS applications for traffic safety and security”. The specific priority Belgian priority area lies within the “Priority Area III” of the Directive 2010/40/EU (ITS road safety and security applications).

There are plans to contribute to all requirements of the “Priority Area III” of the Directive 2010/40/EU, such as eCall, Provision of information for safe and secure parking of lorries and company vehicles, Provision of reservation services for safe and secure parking for lorries and company vehicles and Strengthening of enforcement.

**For Flanders region**, the main planned actions are summarized in Table 5.

**Table 5: Planned actions for Flanders region in BELGIUM**

<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>Planned ITS Actions/ Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Priority Area I.</strong> Optimal use of road, traffic and travel data</td>
<td>The provision of EU-wide multi-modal travel information services</td>
</tr>
<tr>
<td></td>
<td>The provision of EU-wide real-time traffic information services</td>
</tr>
<tr>
<td></td>
<td>Data and procedures for provision, where possible, of road safety</td>
</tr>
</tbody>
</table>

**Belgium**
<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>Planned ITS Actions/ Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>related minimum universal traffic information free of charge to users</td>
</tr>
<tr>
<td></td>
<td>Dynamic Traffic Management</td>
</tr>
<tr>
<td></td>
<td>Hard shoulder running</td>
</tr>
<tr>
<td></td>
<td>Traffic signs database</td>
</tr>
<tr>
<td></td>
<td>Travel information time services</td>
</tr>
<tr>
<td>Priority Area II.</td>
<td>Implementation of DATEX II</td>
</tr>
<tr>
<td>Continuity of traffic and</td>
<td>Open systems for Traffic Management Centre (TMC)</td>
</tr>
<tr>
<td>freight management ITS</td>
<td>Access to abnormal goods transport regulation</td>
</tr>
<tr>
<td>services</td>
<td>Traffic management plans for corridors and networks</td>
</tr>
<tr>
<td>Priority Area III.</td>
<td>The provision of information and reservation services for safe and secure parking places for trucks and commercial vehicles.</td>
</tr>
<tr>
<td>ITS road safety and security applications.</td>
<td>ITS for enforcement such as speed control, weight-in-motion, HGV distance control, HGV overtaking control</td>
</tr>
<tr>
<td>Priority Area IV.</td>
<td>Interactive intelligent traffic light control with short wave signals for priority vehicles and public transport (buses and tramways)</td>
</tr>
<tr>
<td>Linking the vehicle with the transport infrastructure</td>
<td>For Wallonia region, the following priority areas have been identified for the forthcoming period:</td>
</tr>
<tr>
<td></td>
<td>o Improvement of traffic information</td>
</tr>
<tr>
<td></td>
<td>o Further implementation of traffic management services</td>
</tr>
<tr>
<td></td>
<td>o Specific services for freight and logistics</td>
</tr>
<tr>
<td></td>
<td>o Traffic centre and data exchange</td>
</tr>
<tr>
<td></td>
<td>o Multi-modal travel information services</td>
</tr>
<tr>
<td></td>
<td>o Continuity of traffic ITS services</td>
</tr>
<tr>
<td></td>
<td>o ITS applications on an open in-vehicle platform</td>
</tr>
</tbody>
</table>

**8.2.2 Germany**

To develop the German ITS Action Plan, the Federal Ministry of Transport, Building and Urban Development has created an ITS Advisory Council. The role of this ITS Advisory Council is to adopt by consensus all the steps for the transposition of the Directive into national legislation. The ITS Advisory Council comprises from representatives from the Federal Government, the Federal States, the local authorities, the electrical industry, the automotive industry, the information and communication industry, ITS organizations, broadcasting corporations,
standardization bodies, regulation authorities, the scientific and research community and user associations (Federal Ministry of Transport, Building and Urban Development, 2012).

As it can be seen in Table 6, planned ITS measures in Germany lie within the Priority Area I – III of the Directive 2010/40/EU.

Table 6: Planned ITS Measures in Germany

<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>Planned ITS Actions/ Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Priority Area I.</strong></td>
<td>Guide to the area-wide capture of traffic-related data and incidents</td>
</tr>
<tr>
<td>Optimum use of road, traffic and travel data.</td>
<td>Establishment of a quality management system for the capture and processing of data for ITS services</td>
</tr>
<tr>
<td></td>
<td>Establishment of a mobility data marketplace</td>
</tr>
<tr>
<td></td>
<td>Procedure to optimize the accessibility of map-related road data for ITS</td>
</tr>
<tr>
<td></td>
<td>Safety-related traffic information with no additional charge to the end user</td>
</tr>
<tr>
<td><strong>Priority Area II.</strong></td>
<td>Development of an overarching intermodal ITS vision</td>
</tr>
<tr>
<td>Continuity of the ITS services in the fields of traffic management and traffic information</td>
<td>Development of an ITS framework architecture for the roads</td>
</tr>
<tr>
<td></td>
<td>Development of an ITS reference architecture for traffic management that cuts across responsibilities</td>
</tr>
<tr>
<td></td>
<td>Development of an ITS reference architecture for public transport</td>
</tr>
<tr>
<td></td>
<td>Definition of strategic transport corridors</td>
</tr>
<tr>
<td></td>
<td>Evolution of road works site management</td>
</tr>
<tr>
<td></td>
<td>Harmonization of individual and collective traffic information and adaptive traffic control</td>
</tr>
<tr>
<td></td>
<td>Functional ITS provisions as a basis for the integration of innovative system elements into investment planning</td>
</tr>
<tr>
<td><strong>Priority Area III.</strong></td>
<td>Project Plan for Road Transport Telematics</td>
</tr>
<tr>
<td>ITS applications to enhance the efficiency of transport, road safety and security, and environmental sustainability</td>
<td>Devising and trialling cooperative systems</td>
</tr>
<tr>
<td></td>
<td>Introduction of eCall</td>
</tr>
<tr>
<td></td>
<td>Telematics-controlled HGV parking as part of the information services for safe and secure parking areas for heavy goods vehicles and other commercial vehicles</td>
</tr>
</tbody>
</table>

8.2.3 Greece
The Greek ITS Action Plan has prepared under the supervision of the Department of International Relations – Transport Division of the General Directorate for Transport, Ministry of Development, Competitiveness, Infrastructure, Transport and Networks.

- Jointly competent departments of the General Secretariats at the Ministry of Development, Competitiveness, Infrastructure, Transport and Networks
- Ministry of Shipping (Port Authorities)
- Ministry of Citizen Protection
- Ministry of Finance
- ITS Hellas
- Universities and research institutes
- Public Transport Operators (OSY, ERGOSE, TRAINOSE, OASTH, SASTH, OASA, STASY)
- Federations of Motorists
- Local Authorities
- Motorway operation & management companies (Attiki Odos, Egnatia Odos, Nea Odos, Olympia Odos, Moreas, Aegean Motorway)
- New motorway concession companies
- Operational Programme “Digital Convergence”
- Special Management Services of the Operational Programmes

According to Greek ITS Action Plan, the planned ITS projects for the time period 2013 – 2017 are summarized in Table 7 (Transport Division of the General Directorate for Transport, Ministry of Development, Competitiveness, Infrastructure, Transport and Networks, 2012).

**Table 7: Planned ITS Projects in Greece**

<table>
<thead>
<tr>
<th>Planned ITS Actions</th>
<th>Planned ITS Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priority Area I. Optimum use of road, traffic and travel data.</td>
<td></td>
</tr>
<tr>
<td>Public information on the condition of the road network</td>
<td>Geoportal-Egnatia Odos SA</td>
</tr>
<tr>
<td></td>
<td>Geographic Information System of the North Aegean Region “Application: road accidents”</td>
</tr>
<tr>
<td>Public transport passengers information</td>
<td>Design, Funding, Installation, Operations support, Maintenance and Technical Management of an Integrated Passenger Information and Fleet Management System for Road Transport SA with PPP</td>
</tr>
<tr>
<td></td>
<td>Integrated multi-channel information system for public transport passengers in the Municipality of Rhodes</td>
</tr>
<tr>
<td>Integrated combined public information system for traffic, parking places and routes</td>
<td>Digital Traffic information Services for Municipalities of Crete</td>
</tr>
<tr>
<td></td>
<td>Integrated traffic management and monitoring platform to inform citizens about traffic conditions through multiple communications channels</td>
</tr>
<tr>
<td></td>
<td>Creations of an integrated intelligent transport system with telematics passengers information services</td>
</tr>
<tr>
<td>Integrated public information system for traffic, parking places and routes of public transport modes</td>
<td>Creation of an integrated intelligent transport system with telematics passenger information services in the Municipality of Xanthi</td>
</tr>
<tr>
<td></td>
<td>Intelligent multi-channel information system for municipal transport passengers on the island of Kos</td>
</tr>
<tr>
<td></td>
<td>Integrated multi-channel information system for public transport passengers in the Municipality of Rhodes</td>
</tr>
<tr>
<td></td>
<td>Integrated multi-channel traffic management and monitoring system for the road network of the municipalities of Lamia, Domokos, Makrakomi, Styliada</td>
</tr>
<tr>
<td>Integrated combined public information system for traffic, parking places and routes of public transport modes</td>
<td>Park-n-Ride: Integrated parking guidance and multi-channel passengers information system</td>
</tr>
<tr>
<td></td>
<td>Intelligent Parking and Transport Services in the Municipality of Koropi</td>
</tr>
<tr>
<td></td>
<td>Innovative traffic alert and parking guidance system in the Municipality of Nestos</td>
</tr>
<tr>
<td></td>
<td>Integrated parking guidance system in the Municipality of Kalamaria</td>
</tr>
<tr>
<td></td>
<td>Intelligent Transport and parking services system</td>
</tr>
</tbody>
</table>


### Planned ITS Actions

<table>
<thead>
<tr>
<th>Planned ITS Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic Parking Guidance and Driver Information System in the Municipality of Megara</td>
</tr>
<tr>
<td>Intelligent Public Information System on traffic conditions, municipal public transport arrival times and free roadside parking places via multi-channel communication in the Municipality of Kordelio-Evosmos</td>
</tr>
<tr>
<td>Intelligent telematics traffic and parking guidance information system for drivers and citizens through multi – channel communication in the Municipality of Kalamata – “intelligent transport”</td>
</tr>
<tr>
<td>Integrated traffic management and monitoring platform to inform citizens about traffic conditions through multiple communication channels in the Municipality of Kavala</td>
</tr>
<tr>
<td>Integrated public information system for intelligent transport and municipal parking places management in the Municipality of Pefki</td>
</tr>
<tr>
<td>Integrated public transport information system and parking guidance system in the Municipalities of Vyronas and Ilioupoli</td>
</tr>
<tr>
<td>Collection of traffic data, use statistics</td>
</tr>
<tr>
<td>Observatory of Spatial Impacts of the Egnatia Motorway</td>
</tr>
<tr>
<td>Observatory of the Environment s of the Egnatia Motorway</td>
</tr>
<tr>
<td>Studies, research activities and pilot testing</td>
</tr>
<tr>
<td>VIAJEEO</td>
</tr>
<tr>
<td>EASYTRIP:GR-BG e-mobility solutions(cross-border electronic support service between Greece and Bulgaria)</td>
</tr>
<tr>
<td>SEE-ITS: Intelligent Transport Systems in South East Europe</td>
</tr>
<tr>
<td>COMPASS4D-Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment</td>
</tr>
</tbody>
</table>

### Priority Area II.

**Continuity of traffic and freight management in the context of ITS services**

<table>
<thead>
<tr>
<th>Traffic management system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management System for Elefsina-Korinthos-Patras-Pyrgos-Tsakona Motorway</td>
</tr>
<tr>
<td>Traffic management and public information system</td>
</tr>
<tr>
<td>Upgrade of traffic management system for the Egnatia Motorway</td>
</tr>
<tr>
<td>Motorway management system for traffic and incidents in section Maliakos-Kleidi of the Athens- Thessalonik National Road (E75)-Aegean Motorway</td>
</tr>
<tr>
<td>Implementation of traffic management system for the Patras-Athens-Thessalonik Motorway</td>
</tr>
<tr>
<td>Implementation of traffic management system for IONIA ODOS</td>
</tr>
<tr>
<td>European test field for safe, smart and sustainable road management</td>
</tr>
<tr>
<td>EASYWAY II-ITHACA Euroregional project</td>
</tr>
<tr>
<td>Multimodal transport</td>
</tr>
<tr>
<td>Design, Funding, Installation, Operations support, Maintenance and Technical Management of an Integrated Automatic Fare Collection System for the companies of the OASA with PPP</td>
</tr>
<tr>
<td>Mobile application for the public</td>
</tr>
<tr>
<td>Freight fleet management</td>
</tr>
<tr>
<td>Installation of FLEET MANAGEMENT systems</td>
</tr>
<tr>
<td>Installation of SCHEDULING OPTIMIZATION systems</td>
</tr>
<tr>
<td>Installations of GPS systems</td>
</tr>
<tr>
<td>SEE-ITS: Intelligent Transport Systems in South East Europe</td>
</tr>
<tr>
<td>COMPASS4D-Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment</td>
</tr>
<tr>
<td>Planned ITS Actions</td>
</tr>
<tr>
<td>-------------------------------------</td>
</tr>
<tr>
<td><strong>Priority Area III. ITS applications in the field of road safety and security.</strong></td>
</tr>
<tr>
<td>EU-Wide interoperative e-call service</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Priority Area IV. Integration of the vehicle with transport infrastructure</strong></td>
</tr>
<tr>
<td>Studies, research activities and pilot testing</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

### 8.2.4 Hungary

The main national targets as drafted in strategic documents relating to the field on the field of ITS can be summarized below:

- **Efficiency of transport.** Establish and maintain high quality, economically cost-efficient service system of transport, optimal use of capacity;
- **Safety.** Minimize social loss resulting from road accidents;
- **Sustainability.** Environmental and quality of life aspects taken into account during system development and operation;
- **Competitiveness/economy.** The nation faces the global competition by provision of appropriate transport services.

The Hungarian priorities on the deployment of ITS on road network are listed below (Ministry of National Development, 2012):

- Deployment of ITS traffic management in modern road operation.
- Traffic control and information systems of the motorway network.
- Traffic Control Centres.
- Multimodal traffic information, real-time information systems.
- Electronic fee collection.
- E-ticketing for public transport systems.
- ITS deployment on freight/logistics.
- eSafety systems
- Integrated EU-wide eCall Service.
According to the Hungarian ITS Action Plan, the planned ITS projects per Priority Area (as defined in Directive 2010/40/EU) are presented in Table 8.

Table 8: Planned ITS Projects in Hungary

<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>Planned ITS Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Priority Area I:</strong></td>
<td></td>
</tr>
<tr>
<td>Optimal use of road, traffic and travel data – travel information services (TIS)</td>
<td>Establishing a transport database with data portal to set up travel/transport information services. Installation of travel time determines and display system – M0 motorway and the motorway sections leading to Budapest (continue earlier development, develop a system based on cooperation of operators and data source users in the area of Budapest).</td>
</tr>
<tr>
<td><strong>Priority Area II:</strong></td>
<td></td>
</tr>
<tr>
<td>Continuity of traffic and freight management services – traffic management services (TMS)</td>
<td>Traffic management of the motorway network, cross-border traffic management on the motorway corridors including traffic management of border crossing areas (in the case of non Schengen-zone border crossing). Cross-operation border traffic management with urban interfaces – join traffic management plans on the urban of motorways in the conurbation areas. Development of motorway traffic management systems. Establishing an open and harmonized database of public transport (urban areas, alongside main routes of the public network) in order to establish high quality passenger information services</td>
</tr>
<tr>
<td><strong>Priority Area III:</strong></td>
<td></td>
</tr>
<tr>
<td>ITS road safety and security applications</td>
<td>National Implementation of e-Call Full establishment of the parking management system of M1 motorway, creating pilot reservation systems.</td>
</tr>
</tbody>
</table>

8.2.5 Italy

Italy has long history in deployment of Intelligent Transportation Systems, since early 1980’s and several ITS deployments has been conducted until now. For example, Italy, is actively participating in CIVITAS, with sustainable mobility projects in the areas of Perugia33, Venice34 and Roma35.

In February 2013 a technical guidance and coordination committee for ITS initiatives has been established, known as ComITS with the aim of guaranteeing coordination and integration within Italy. The aim of the ComITS is to ensure the consistency of all new projects of national importance that involve the use of public funding with the priority actions identified above and their interoperability. ComITS expresses a binding opinion on the compatibility of the proposed projects with the national ITS architecture and offer appropriate suggestions for the purposes of ensuring this compatibility. ComITS role is also to monitor for duplication of efforts and consequent wasting of resources.

33 http://www.civitas.eu/content/perugia
34 http://www.civitas.eu/content/venezia
35 http://www.civitas.eu/content/roma
ComITS is chaired by the Head of the Ministry of Infrastructure and Transport’s Department for transport, navigation and IT and statistical systems. The ComITS includes Directors of the Directorates General for road traffic, for road safety, for road transport and for intermodality, for IT, statistics and communication systems, for territorial development, planning and international projects and for Ministry of Infrastructure and Transport road infrastructures as well as one representative of the Ministry of the Interior and one of the Ministry of Education, Universities and Research.

Aiming to achieve efficiency, streamlining and economy of use of ITS, the national authorities undertake to promote the following lines of action (Ministry of Infrastructure and Transport Department, 2013):

- Set up a national telematics platform that can be accessed by users, partly with a view to implementing training activities aimed at the creation of jobs within ITS design, management and maintenance.
- Draw up and use benchmark models and technical standards for the design of ITS, with the aim of achieving interoperability and consistency between national ITSs and similar systems at EU level.
- Introduce a model for classifying roads, partly based on the ITS technologies and services present (for example: sensors, TV cameras, variable message signs, real-time information on traffic and weather, emergency and road safety management systems, automatic toll payment and hazardous freight tracking).
- Use on-board vehicle technologies in order to facilitate V2V (vehicle-vehicle) and V2I (vehicle-infrastructure) communication;
- Set up a knowledge base of the benefits obtained by various users from the use of ITS applications;
- Integrate platforms associated with freight transport, with particular attention to the interfaces between different transport modes, in order to avoid overlaps and conflicts between systems and promote system interoperability;
- Use the satellite system EGNOS (European Geostationary Navigation Overlay Service) and GALILEO for satellite navigation services supporting passenger and freight transport in line with the Action Plan on Global Navigation Satellite Systems (GNSS) drawn up by the European Commission in June 2010;
- Develop the system for the transmission of emergency calls from vehicles (e-call).

According to the Italian ITS Action Plan, the national planned ITS priority actions for the period 2013-2017 are presented in Table 9.

Table 9: ITS Priority Actions in Italy

<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>National ITS Priority Actions</th>
</tr>
</thead>
</table>

Page | 107
Priority Area I: Optimal use of road, traffic and travel data
Databases on traffic and mobility information
Setting up of a Public Index of information on infrastructure and traffic
Publication and deployment of certified information: new services

Priority Area II: Continuity of traffic and freight management ITS services
To promote the setting up within logistics hubs of logistics platforms that are integrated and/or interoperable with the National Logistics Platform UIRNet
To promote the use of ITS for the multimodal management of transport and logistics, in accordance with open and interoperable platforms
To promote the use of ITS for the management of passenger mobility from a multimodal perspective (considering local public transport, private vehicles, alternative transport vehicles) in accordance with open and interoperable platforms
To guarantee the continuity of services on the national network and along borders
To promote the adoption of integrated and interoperable electronic ticketing for the payment of local public transport services
To promote the use of ITS in local public transport
Enabling conditions for smart mobility in urban and rural areas

Priority Area III: ITS road safety and security applications
Development of the national eCall system
To set up a telematic archive of motor vehicles and trailers that are not covered by third-party insurances
Deployment of ITS systems for the management and monitoring of hazardous freight
Use of on-board devices that record vehicle activities (black box) for the extension of ITS services
Promoting the deployment of enforcement systems
Development of security services in local public transport and in transport hubs
Promotion of advanced on-board systems

Priority Area IV: Linking the vehicle with the transport infrastructure
Monitoring the status of the infrastructure and of safe parking areas of freight transport
Checking compliance with safety requirements in the haulage sector and vehicle speed
Technical specifications and standardization for the link between vehicles (V2V) and between vehicles and infrastructure (V2I) for cooperative driving
Monitoring the status of the road infrastructure under adverse weather conditions

8.2.6 Slovenia
The Slovenian Action Plan for 2013-2017 has been compiled by the Ministry of Infrastructure and Spatial Planning in co-operation with Slovenian ITS Association (Ministry of Infrastructure and Spatial Planning, 2012).

Table 10 summarizes the planned ITS actions for the forthcoming period per Priority Area (Directive 2010/40/EU).

Table 10: Planned ITS actions in Slovenia
### Priority Area I.
**Optimum use of road, traffic and travel data.**

<table>
<thead>
<tr>
<th>Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multimodal travel information services</td>
<td>Information portal for passengers in the IPT system</td>
</tr>
<tr>
<td>Real-time travel information services</td>
<td>Mobile IPT services</td>
</tr>
<tr>
<td>Real-time travel and dynamic timetables</td>
<td>TCMS (traffic control and management system) and the upgrading of traffic management centers</td>
</tr>
<tr>
<td>Traffic monitoring</td>
<td></td>
</tr>
<tr>
<td>Integration of traffic meters</td>
<td></td>
</tr>
<tr>
<td>Kazipot (‘Signpost’)</td>
<td></td>
</tr>
<tr>
<td>eParkInfo</td>
<td></td>
</tr>
<tr>
<td>Platforms for the exchange of traffic information</td>
<td></td>
</tr>
<tr>
<td>Availability of road, traffic and transport services data used for digital maps</td>
<td>ITS Data Warehouse</td>
</tr>
<tr>
<td>Road-safety related traffic information</td>
<td>Emergency traffic events</td>
</tr>
</tbody>
</table>

### Priority Area II.
**Continuity of traffic and freight management in the context of ITS services**

<table>
<thead>
<tr>
<th>Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITS framework architecture</td>
<td>ITS architecture v2</td>
</tr>
<tr>
<td>Management of passenger transport across different modes</td>
<td>Management of passenger transport in the Slovenian impact area</td>
</tr>
<tr>
<td>Formulation of a standard for the single electronic ticket</td>
<td></td>
</tr>
<tr>
<td>Management of freight along transport corridors</td>
<td>Freight traffic management</td>
</tr>
<tr>
<td>Tracking and tracing of freight across all modes of transport (freight transport logistics, eFreight)</td>
<td>eFreight</td>
</tr>
<tr>
<td>eFreight</td>
<td>RFID in freight transport</td>
</tr>
<tr>
<td>Urban ITS architecture</td>
<td>Travel Card</td>
</tr>
</tbody>
</table>

### Priority Area III.
**ITS applications in the field of road safety and security**

<table>
<thead>
<tr>
<th>Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information services for safe and secure parking areas for trucks and commercials vehicles</td>
<td>eKlic (‘eCall’)</td>
</tr>
<tr>
<td>ePark Reservation</td>
<td></td>
</tr>
<tr>
<td>Safety and comfort of vulnerable road users</td>
<td>Smart crossings for pedestrians and cyclists</td>
</tr>
</tbody>
</table>

### Priority Area IV.
**Integration of the vehicle with transport infrastructure.**

<table>
<thead>
<tr>
<th>Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative systems (vehicle-vehicle, vehicle-infrastructure, infrastructure-infrastructure)</td>
<td>Telecommunications in transport</td>
</tr>
</tbody>
</table>

### 8.2.7 Portugal


For the time period 2013 – 2017, the following general aims have been set:

- Promote sustainable mobility for passenger and freight transport.
- Minimise the negative externalities of transport and improve efficiency
- Increase technological R&D and knowledge.
Specific national priority areas have been recognized such as:

1. Maximise the potential of existing ITS
2. Central focus of ITS on users
3. Reinforce the role of ITS as effective contributors and instruments on mobility, transport management, transport enforcement and maintenance of transport infrastructure,
4. Establish a national cluster of technologies, products and services for intelligent mobility.

Portugal strategy is to obtain collaborative and integrated services and systems which are user-focused, maximizing the fact that individuals, vehicles and infrastructures are connected in intelligent manner, georeferenced and in-real time in authentic “social networks” (Second Report of the Portuguese State, 2013).

Table 11 summarizes the Portugal’s priority axes for the forthcoming time period, as well as the relevant identified measures.

**Table 11: Portugal’s ITS Priority axes**

<table>
<thead>
<tr>
<th>National Priority Axis</th>
<th>ITS Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interoperability and sharing of data, an indispensable requirement for “maximizing the potential of already implemented ITS”</td>
<td>Contactless ticketing systems allowing the development of combined tickets and integrating different modes and operators</td>
</tr>
<tr>
<td></td>
<td>Operational support systems and passenger information (with integrated manner) allowing full statistical analysis on quality of services, demand of transport and management support</td>
</tr>
<tr>
<td></td>
<td>Traffic information on road safety, congestion and route optimization before and during the trip</td>
</tr>
<tr>
<td></td>
<td>Evolution of the existing Open Roads solution (existing ITS application/database for storing and processing road network data and incidents) in order to extend mining capabilities and convergence with external databases</td>
</tr>
<tr>
<td>Transparency of systems, making the “user the central focus of ITS”</td>
<td>Publish information on the real mobility costs for both passenger and freight transport. Mobility costs relate to parking, tolls, vehicle maintenance, energy costs, emission fees e.t.c.</td>
</tr>
<tr>
<td></td>
<td>Simplifying payment systems and integrating them (regardless of the operators and modes) and implementing mobile communication technologies and devices.</td>
</tr>
<tr>
<td></td>
<td>Reducing the bureaucracy of administrative procedures, integrating them into single documents, regardless the mode and operator.</td>
</tr>
<tr>
<td>Promote the use of “Sounding out” of mobility and support information for the management and maintenance of activities</td>
<td>Evolution of the existing Open Roads solution (existing ITS application/database for storing and processing road network data and incidents) in order to be used as an effective tool for the supervision and management of the road network for the administrative authority and road network managers</td>
</tr>
<tr>
<td></td>
<td>Systems allowing freight service providers to track and monitor wagons, providing information on distance travelled, trip time and road problems.</td>
</tr>
<tr>
<td></td>
<td>Consolidation of information from different technological solutions from different operators, from different transport modes for both road and rail transport</td>
</tr>
<tr>
<td></td>
<td>Reinforcement of driver safety and support systems for public transport and for driving solutions.</td>
</tr>
<tr>
<td></td>
<td>Development of integration systems to verify driving conditions and road state</td>
</tr>
</tbody>
</table>
**National Priority Axis** | **ITS Measures**
--- | ---
| through the automatic detection of obstacles and the conditions of the infrastructure materials | Video surveillance systems and safety devices for security reasons in transport
| Promotion of eco-driving systems on public transport, such as real-time monitoring and driving corrections, advanced training programmes | New rules for loading/unloading operations in urban environment, such as real-time control of vehicle parking, providing penalties for bad practices
| Implementation of flexible transport solution, such as allowing routes or services to be optimised based on real mobility needs | Making new solutions available for mobility, based on sharing of vehicles and routes, such as car sharing, bike sharing, car pooling e.t.c.
| Improving public transport services by providing internet access and travel information within the vehicles |

### 8.2.8 United Kingdom
United Kingdom can be considered as a world leader in the deployment of ITS. The national vision for a transport system is an engine for economic growth, but also greener and safer in order to improve the quality of life in communities. By improving the links that help to move goods and people around, and by targeting investment in new projects promoting green growth, it is feasible to build a balanced, dynamic and low-carbon economy which is essential for national future prosperity (Department for Transport, 2012).

The role of technology is vital tool for delivering policy objectives but ITS can considered only the means to achieve specific transportation targets. So, UK has not established a national ITS architecture but has developed specific architectures to aid the development and the deployment of systems targeted at achieving specific policy goals.

According to UK ITS Action Plan, The UK Actions and interventions per Priority Area (Directive 2010/40/EU) are summarized in Table 12.

**Table 12: UK priorities and actions**

<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>National Priorities</th>
<th>ITS Actions</th>
</tr>
</thead>
</table>
| **Priority Area I:** Optimal use of road traffic & travel data | Using ITS to enable transport users to make informed choices about their journey | Transport Direct
The London 2012 Spectator Journey Planner
Traffic England
Transport Scotland: Traffic Scotland Information Services (TSIS)
Traffic Watch Northern Ireland
The Open Data Agenda and traffic/travel information
ELGIN – open data for road works
Cycle Streets |
| Getting real time information to road users | The Highway Agency’s National Traffic Information Service
Transport Scotland: Traffic Scotland Control Centre |
<table>
<thead>
<tr>
<th>Priority Area (2010/40/EU)</th>
<th>National Priorities</th>
<th>ITS Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Variable Message Signs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Scotland: Variable Message Signs Deployment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public Access CCTV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Scotland: Deployment of CCTV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In-vehicle driver information in the UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In-car Satellite Navigation developments in the UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hands-free Traffic Talker England App</td>
</tr>
<tr>
<td>Highway authorities making use of ITS to assist/deliver their real-time traffic management interventions</td>
<td></td>
<td>Managed Motorways</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Scotland: M77 Hard Shoulder Running</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban Traffic Management and Control (UTMC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCOOT (Split Cycle Offset Optimisation Technique)</td>
</tr>
<tr>
<td>Highway authorities making use of ITS to assist/deliver their real-time traffic management interventions</td>
<td></td>
<td>DRD (Northern Ireland) Roads Service: Foyle Bridge Safety Management System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Scotland: Forth Replacement Crossing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable Mandatory Speed Limits (VMSL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Journey Time Estimations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Wales: Variable Mandatory Speed Limits (VMSL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Scotland: Journey Time System Enhancements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highways Agency: Use of the Internet Protocol (IP) in Roadside Telecommunications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport Scotland: System Architecture Improvements</td>
</tr>
<tr>
<td>Priority Area II:</td>
<td>Smart Integrated Ticketing</td>
<td>The Real Time Information Group (RTIG)</td>
</tr>
<tr>
<td>Continuity of Traffic &amp;</td>
<td>Welsh National Traffic Data System (WNTDS)</td>
<td></td>
</tr>
<tr>
<td>Freight Management Services</td>
<td>Integrated Network Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freight Management &amp; ITS Applications for Freight Transport Logistics (eFreight)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport Scotland: Extension of Weigh-in-Motion</td>
<td>(WIM) Sensors for Automatic Traffic Counting Sites</td>
</tr>
<tr>
<td>Priority Area III:</td>
<td>eCall</td>
<td></td>
</tr>
<tr>
<td>ITS Road Safety and Security Applications</td>
<td>Reservation and Information Services for Safe &amp; Secure Parking Places for Trucks &amp; Commercial Vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Human-Machine-Interfaces, the use of Nomadic Devices &amp; the Security of In-Vehicle Communications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bristol City Council &amp; University of the West of England: Young Drivers &amp; Social Marketing (Wheels, Skills &amp; Thrills)</td>
<td></td>
</tr>
</tbody>
</table>
### Priority Area (2010/40/EU)
<table>
<thead>
<tr>
<th>National Priorities</th>
<th>ITS Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lancashire County Council: Lancashire Intelligent Speed Adaptation</td>
<td>-</td>
</tr>
<tr>
<td>Welsh Government (Transport) initiatives</td>
<td>-</td>
</tr>
</tbody>
</table>

### Priority Area IV: Linking the Vehicle with the Transport Infrastructure
<table>
<thead>
<tr>
<th>Cooperative Systems</th>
<th>Transport for London</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIRA and InnoITS-Advance Test Facility</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 8.2.9 Regional Level

Regions within each EU Member State would be beneficial to introduce ITS Action Plans in order to assess the current region state and to set the objective for the next years regarding the deployment of ITS. The Regional ITS Action Plan should follow the European Directives and the national strategy. Moreover, the Regional ITS Action Plan may examine operability/integration issues for cross-border cooperation. Cross-Border Cooperation Programmes (such as INTERREG) may fund the development of Regional ITS Action Plan.

While existing strategic documents and legal frameworks at EU and national level put emphasis on interoperability and continuity of ITS systems and services, applications at local level can be very fragmented and inhomogeneous and generally not interoperable when transport activities spread out the administrative boundaries of the cities. The main purpose of Regional ITS Action Plan is to align and harmonize all diverse sets of local and regional interests, actions and regulations with the ITS national plans as required by the EC ITS Directive (2010/40/EU).

The scope of regional ITS Action Plan is to break-down overall strategies and plans to a local level, while focusing nevertheless on the specific regional transport bottlenecks and needs of the regions. The Regional ITS Action Plans can be seen as a step forward to a well-aligned policy framework for the integration of ITS. They demonstrate that municipalities, civil society and in particular the regions should no longer be viewed as policy receivers but have a crucial stake in implementing strategies.

An attempt to develop ITS Action Plans at Regions has been undertaken by the European Project “RITS-NET”. The countries and relevant regions participated in the development of regional ITS Action Plan is summarized in Table 13 (European Project: RITS-net, 2012).

#### Table 13: Regional ITS Action Plan (RITS-NET PROJECT)

<table>
<thead>
<tr>
<th>Country</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>Marche Region</td>
</tr>
<tr>
<td>Spain</td>
<td>Gipuzkoa Region</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Evroregion Pleven-Olt</td>
</tr>
</tbody>
</table>
8.3 Related European ITS Projects

This section presents indicative ITS projects implemented across Europe regarding real-time traffic data acquisition, multi-modal data management and processing, as well as real-time data diffusion via various communication channels. The projects illustrate some state-of-the-art ITS implementations, which can provide foundations for the development of the OPTIMUM project.

The majority of projects make use of real-time travel data by various data sources and transportation modes, execute dynamic data processing, provide forecasts of various traffic variables for alternative transport modes and suggest optimum routes and modes by selecting various criteria, such as minimization of travel times, minimization of CO2 emissions, e.t.c.

The projects presented in this section are considered valuable for the deployment of OPTIMUM Working Packages 3 - Observe and Data fusion, WP4 – Decide and WP5 - Pro-act, while the some system architectures could be taken into account during the development of the pilot cases.

8.3.1 Urban Traffic Management & Public Transport in Turin (Italy)

On 1996, in Turin an Integrated Intelligent Transport Control Centre\(^{36}\) has been established. Since now, the Control Centre is continuously upgraded and modernized in order to cover current urban needs. The Integrated ITS Control Centre in Turin covers the total urban road network of the city by collecting in real-time traffic data while uses Dynamic Information Signs at critical sections of the road network and at the bus stops.

The developed integrated ITS in Turin composes mainly of the following systems:

- **Urban Traffic Control.** A central adaptive traffic control system is developed by collecting in real-time traffic data and by providing traffic signal priority at public transport vehicles when it is required. So, the traffic signals are dynamically affected by the pertaining traffic conditions and special needs (e.g. passing of bus vehicle).

- **Public Transport Management.** The total public transport fleet is centrally managed while by using the vehicle location and pertaining traffic conditions provides forecasts for the estimated public transport vehicle arrival at the bus stops. The estimated time of

\(^{36}\) [http://www.5t.torino.it/5t/en/home](http://www.5t.torino.it/5t/en/home)
The arrival of each public transport vehicle is dynamically presented to passengers at the public transport stops.

- Parking Control and Management. A dynamic parking guidance system has been developed for 18 parking areas.

- Public Information Platform. Dynamic information is provided for the public transport, the traffic conditions, the parking space availability and environmental emissions via various communication channels such as internet, teletext and SMS. Some of the public information services is the dynamic navigation within the city via public transport and via car, as well as the dynamic information regarding parking space availability. Moreover, the estimated arrival time at each PT stop is also provided. Dynamic messages regarding traffic condition levels, incidents and other warnings are also available to public.

- Town Supervisor. The ITS Control Centre has installed a Town Supervisor Platform which is the central managerial centre of all systems and provides dynamic forecasts regarding the road network traffic conditions.

- Environmental Monitoring and Control. A system that detects vehicles emissions and provides meteorological forecasts.

- Collective Routing. A system that uses dynamic traffic data in order to provide navigation suggestions via VMS to the drivers.

Since the system operates many years, the evaluation of system impacts has been undertaken. The results are very promising, as shown below:

- The reliability on the estimated arrivals at public transport stops reaches to 91%

- The provision of traffic signal priority at public transport vehicles is up to 70%, so the total public transport trips are estimated to be improved by 20% while there is a reduction of 8% in public transport vehicles emissions.

- The reduction of car travel times is estimated to 24% due to the operation of the advanced traffic signalling system and provision of real-time information via VMS. This improvement has been estimated by comparing the results of the previous traffic signalling system.
The Integrated ITS Control Centre has been established by the Concession Company 5T where stakeholders are the GTT (bus operator), the Piemonte Region, the Municipality of Turin and the province of Turin.

The project can be considered as very mature; it is considered as a good example for the development of big travel data management and provision of real-time multi-modal travellers’ information via various channels for optimising total trip times, for providing alternative multi-
modal routes and contributing on CO₂ emissions by providing more sustainable transport. The project is considered as valuable reference for the development of WP2, WP3, WP4 and WP5.

8.3.2 Traffic Scotland Web Information Services

Transport Scotland\(^{37}\) is the national transport agency for Scotland. It is a Scottish Government agency directly accountable to Scottish Ministers. The Chief Executive is directly accountable to the Transport Minister. The following provides information regarding Transport Scotland’s policies on traveller information and how the Traffic Scotland service is used to deliver these policies:

- **National Transport Strategy.** The Scottish Government's National Transport Strategy (NTS) outlines the policy framework for traveller information provision in Scotland. Its key priorities are:
  - Better journey times, better reliability
  - Improved connections across Scotland
  - Greener transport alternatives, reduced emissions
  - Increased safety, more innovation

The NTS assigns high priority to the provision of travel information and Transport Scotland is committed to delivering continuous improvement to these services. The provision of good consumer transport advice e.g. the promotion of travel and journey planning offers the potential through reduction in the use of the car and greater uptake of public transport journeys to deliver outcomes on a number of key Scottish Government policy objectives.

- **Traffic Scotland Service.** The Traffic Scotland service delivers traveller information through a process of 'monitor, control and inform'.
  - **Monitor.** The Traffic Scotland service monitors the network using CCTV, roadside hardware, communication with the police, weather forecasts and major event management services.
  - **Control.** All information collected through the monitoring process is processed within the Traffic Scotland National Control Centre. The Traffic Scotland National Control Centre operates 24 hours a day to ensure that traffic and travel information disseminated as part of the Traffic Scotland service is accurate.
  - **Inform.** Traffic and travel information processed by the Traffic Scotland National Control Centre is then disseminated via the Traffic Scotland service, including the Traffic Scotland website, the Traffic Customer Care Line, the Traffic Scotland mobile website, the Traffic Scotland Information Kiosks, road side Variable

\(^{37}\) http://www.transportscotland.gov.uk
Message Signs (VMS) and via the multiple Traffic Scotland data services available to public, corporate and media users.

Transport Scotland delivers travel information to the public through the Traffic Scotland service.

- **Traffic Scotland Website** ([https://trafficscotland.org/](https://trafficscotland.org/)). The Traffic Scotland website provides the travelling public with real-time traffic information on the Scottish Motorway and Trunk Road network. It provides up to date information to the travelling public about current and planned road works, accidents, journey times, live traffic camera views, congestion, weather events, park and ride facilities, a carbon calculator etc. The website supports drivers in making informed choices as to the timing, routing and travel mode for current or future journeys. It also signposts drivers to public transport options particularly when there is heavy demand on the network or adverse weather conditions. This in turn helps reduce the disruption caused by incidents, minimizes the effects of congestion and thereby improves the safety and efficiency of the road network (Traffic Scotland). The Traffic Scotland website has the following features:
  - **Planned Events Service.** A comprehensive list of planned events for Scotland, allowing users to search for specific events by name, date or venue and view further information including public transport planning options.
  - **Carbon Calculator.** A multi-modal carbon emissions calculator for Scotland, allowing users to determine approximate emissions for selected journeys.
  - **RSS Feeds.** Providing users with access to alerts, current incident, roadwork and planned roadwork information directly to their desktop using the Traffic Scotland RSS feeds.
  - **Journey Times.** Real-time route journey times for sections of the Scottish TERN, leading to full national coverage in future years.
  - **DATEX II.** Implementation of a DATEX II interface, permitting joined up data sharing and seamless cross border information services with other traffic agencies, including Highways England.
  - **Information for Event Management.** Partnering with major events such as T-in-the-Park music festival to provide a comprehensive traffic information and travel advice service for both event goers and ordinary road users.
  - **Twitter.** providing users with current incident information directly to their desktop using the Traffic Scotland Twitter service.
The project is considered as best practice from a list of state-of-the-art projects regarding the system architecture, data infrastructure, data harmonization and optimization (WP2), as well as providing dynamic transport solutions regarding modes and routes (WP4). It is considered as a system which utilizes and processes various big data sources and diffuses information via various communication channels to end-users. The system architecture can be taken into account for the deployment of OPTIMUM pilot case 1.

8.3.3 Urban Traffic Management System in Bucharest (Romania)

In 2009, the Municipality of Bucharest developed a Traffic Management System (BTMS) in order to streamline urban traffic, reduce fuel consumption (and CO$_2$ emissions) and to significantly reduce travel times, congestion and road events.
The developed system included the main functionalities (a) adaptive urban traffic control, (b) public transport management system, (c) latest LED traffic light equipment, (d) fibre-optic communication, (e) video surveillance system (CCTV) and (f) modern traffic control centre.

Figure 14: Image from BTMS in Bucharest

The Traffic Control centre (BTMS) is based on eight main subsystems integrating the following functionality: Urban traffic control (UTC), public transport management (PTM), closed circuit television (CCTV), supervisor strategy (SS), error management systems (FMS), network management systems (LMS), performance monitoring (PM), interface for information about traffic (TTII) and a common graphical user interface.

Some additional characteristics of the system are presented below:

- There are 140 junctions equipped with specific equipment and functioning in full adaptive traffic control.
- On each junction video cameras monitored by the control centre were installed.
- 300 city buses of Bucharest are part of the Public Transport System and they have priority at each junction.
- Priority at each junction is also given to emergency vehicles, such as police, ambulance and fire brigade vehicles.

The project is contributing to the traffic congestion reduction, to the shift in more environmental friendly transport modes (buses), and to the enhancement of the reaction times for emergency vehicles. The traffic signalling system provides adaptive functionalities, i.e. affecting the traffic signal plans based on real-time conditions in order to affect travellers’ behaviour. The project is considered valuable for the deployment of WP2, WP3 and WP5.
8.3.4 European Project: See-ITS Project (Demonstration Site Vienna)

SEE-ITS (http://www.seeits.eu/) is a transnational project aiming to stimulate cooperation, harmonization and interoperability between isolated Intelligent Transport Systems (ITS) in South East Europe. SEE-ITS focuses on setting the framework for ITS deployment in the field of road transport and for interfaces with other modes of transport based on the guidelines of the European Union's Directive (2010/40/EU) dealing with ITS deployment.

The scope of the project is to enhance the interoperable use of ITS for traffic monitoring and control along road transport networks at transnational, regional and local (urban/peri-urban) levels. The project results will set a long-term sustainable strategic and operational framework for institutional and operational integration of ITS in South East Europe countries.

SEE-ITS project includes 8 core partners by 7 EU Member-States including Austria, Italy, Greece, Slovenia, Hungary, Romania and Bulgaria. As strategic partners are also Albania and Croatia. SEE-ITS projects has implemented 7 demonstration sites. The project has been completed at the end of 2014.

The Vienna demonstration site of SEE-ITS project mainly covers the motorway intersection A2/A23-A4-S1, as well as the interface to the urban road network in the Vienna area with a length of about 45 km. These road sections are operated by the Austrian highways agency (ASFINAG). The site was originally created for the Austrian project “Testfeld Telematik” (telematic testing field). As A23 is the most heavily used motorway in Austria, with 180,000 vehicles per day, it is also more likely for users to experience traffic jams and related obstacles.

The cooperative ITS services demonstrated in the Vienna demonstration site include:

- **In-vehicle signage.** The in-vehicle signage service informs drivers about dynamic road signs. The shown messages comprise the information displayed on variable message signs in the test area at A2/A23, A4, S1.

- **Hazardous location notification.** The hazardous location notification service warns drivers about upcoming hazards, such as broken down vehicles, oil on the road, wrong-way drivers, or lost goods. This service allows warning the user also when there is no VMS or other warning sign deployed on the track.

- **Traffic jams ahead warning.** The traffic jam ahead warning service warns drivers when they are approaching the tail end of a traffic jam and thus assists them in avoiding rear end collisions. This service allows warning the user also when there is no VMS or other warning sign deployed on the track. Therefore, the user can be warned in an effective way wherever a traffic jam is detected.

- **Road works warning.** The road works warning service informs drivers of road works on the route ahead. The purpose is to inform the driver in advance, so as to increase
awareness and to inform them of potential dangerous conditions. The driver is also able to adapt the speed of the vehicle early enough. Additionally, the user is informed about the length of the road works section.

- **Park & Ride information.** Information on the availability of the park and ride facility as well the name of the exit leading to the park & ride facility is provided. With this information, the driver can, for instance, decide to switch to public transport in case of heavy traffic.

- **Floating Car Data service.** The Floating Car Data service uses vehicles as sensors to provide information on the current traffic situation. The application sends periodically information on the current position and speed and transfers it to the SEE-ITS server. This data can be used, at a later stage, to improve the precision of traffic information. The users are also able to deactivate this service.

The project promotes travellers data information interoperability across EU countries and provides useful input for the deployment for WP2 (Observe and Data Fusion). The systems architecture developed under SEE-ITS project can provide useful input for the deployment of pilot case 1 and 3 of the OPTIMUM project.

### 8.3.5 European Project: CO-GISTICS (Demonstration Site: Bordeaux)

CO-GISTICS ([http://cogistics.eu/](http://cogistics.eu/)) is a European project fully dedicated to the deployment of cooperative intelligent transport systems (C-ITS) applied to logistics. CO-GISTICS services are deployed in 7 logistics hubs, Arad (Romania), Bordeaux (France), Bilbao (Spain), Frankfurt (Germany), Thessaloniki (Greece), Trieste (Italy) and Vigo (Spain). With 33 partners including public authorities, fleet operators, trucks, freight forwarders, terminal operators and logistics providers, the CO-GISTICS consortium will install the services on at least 325 vehicles (trucks and vans) and is expected to be completed in January 2016 (CO-GISTICS, 2014).

Seven (7) demonstration sites are implemented where the integration of currently existing freight and transport systems and services, with new solutions such as cooperative services and intelligent cargo. This helps to make operation of their goods, trucks, roads, harbours, airports and rail terminals more sustainable, for example reduce CO$_2$ emissions and improve cost-efficiency. CO-GISTICS project deploys the following services:

- **Intelligent parking and delivery areas.** Optimising the vehicle stops along their route, the delivery of goods in urban areas and the interface with other modes of transport.

- **Multimodal cargo.** Supporting planning and synchronisation between different transport modes during the various logistic operations.

- **CO$_2$ emission estimation and monitoring.** Measuring the CO$_2$ output of the vehicles and providing an estimation of CO$_2$ emissions of specific cargo operation.
- **Priority and Speed advice.** Saving fuel consumption, reducing emissions and heavy vehicle presence in urban areas.

- **Eco-drive support.** Supporting truck drivers in adopting a more energy efficient driving style and therefore reducing fuel consumption and CO\(_2\) emissions.

The CO-GISTICS demonstration site in Bordeaux implements different services in three ways: locally in the city of Bordeaux, a link with the GPMB (Grand Port Maritime of Bordeaux) and on a long-distance corridor between Bordeaux and the Spanish border as well as between Bordeaux and Toulouse.

The city of Bordeaux deploys the CO\(_2\) and the speed advice services by completing the existing C-ITS deployment provided by a previous European Project (Compass4D). The Grand Port Maritime of Bordeaux is located on the Trans-European Transport Network (priority project) High-speed railway axis of south-west Europe. The multimodal cargo service is deployed in the port and more particularly the modules concerning appointments, wine management and delivery optimisation. The 2 corridors permit the CO\(_2\) emission estimation and monitoring with results which will complete the data coming from the city of Bordeaux.

The Bordeaux demonstration site includes the procurement, installation and configuration of the following equipment:

- 1 cargo reader
- 10 additional traffic lights equipped with C-ITS
- 59 on-board units or smartphones
- Several beacons

The project examines freight transport solutions by promoting more sustainable transport operation. The project can provide useful input for OPTIMUM WP’s 2 and 3.

**8.3.6 European Project: Mobis**

The MOBIS project (https://sites.google.com/site/mobiseuprojecteu/) includes 9 partners from 6 countries (Portugal, Slovenia, Spain, Sweden, Holland and Greece). The project is expected to be completed in 2015, with a total project duration of 37 months.

The main goal of MobiS is to create a new concept and solution of a federated, customized and intelligent mobility platform by applying novel Future Internet technologies and Artificial Intelligence methods that monitor, model and manage the urban mobility complex network of people, objects, natural, social and business environment in real-time. MobiS federation and intelligence is based on the symbiotic relation between these stakeholders, innovative
prediction and reasoning methods that are using learned multi-criteria function to provide more efficient, energy-aware and environmental friendly citizen mobility (MOBIS, 2014).

MobiS aims to federate novel artificial intelligence services and traditional information platform services coming from the following sources: a) existing transport private or public service providers, b) ambient data, based on sensor infrastructures and c) social networking data. To achieve these challenging objectives, the project develops the MobiS federated platform, prediction/planning/reasoning services, multi-criteria decision function and, federated mobility-based services that correspond to the above mentioned information sources. Solutions are tested in three pilots, as briefly described below:

1) **An inter-city mobility scenario in Sweden (Stockholm-Hudiksvall-Sundsvall)**, where an existing crowd sourcing application is used. Crowd sourcing from individuals and sensors/actuators via devices in various application domains (e.g., smart grid, health services, transport, smart home, etc.) will become a service i.e., Crowd Sourcing as a (parameterized, self-organizing) Service (CSaaS). More particularly, on the Swedish case, it is expected an improvement in energy savings and mobility efficiency since people consider not only private cars but also other transport modes like car sharing, bus and train. Also car optimization and energy consumption in public, private property is foreseen as impact of MobiS operation.

2) **An intra-city scenario in Greece (Thessaloniki)** combining a traffic information system and the crowd sourcing application, the users of the system are able to experience advanced services by using the enhanced information provided through the federated environment to be deployed through MobiS. Users are able to provide input and data on traffic events and will in turn be updated with information regarding more accurate forecasted travel times or alternative itinerary, which could also include public transport. Finally, FCD crowd-sourcing information collected through available /equipped fleets can also be provided to fleet users/drivers resulting in that way in a collaborative environment of data provisioning/consuming users/entities/devices enabled and established through the federation.

3) **A country-wide (inter-city) mobility scenario in Slovenia** with a social media application, and selected traffic information system already operated in various parts of the country and in the main cities. AMZS expects from MobiS to get the generic prediction and route planning service that will particularly supplement their existing services but in particular to grow their membership AMZS will use MobiS as service to which they intend to include other mobility services throughout Slovenia thus giving them unique competitive advantage.
The project deals with the provision of multi-modal travellers services by the use of advanced technologies. The project can provide useful input for the deployment of WP2, WP3 and WP4.

8.3.7 European Project: Viajeo

The VIAJEEO project (http://www.viajeo.eu/) consists of 24 partners from 8 countries (Belgium, Brazil, China, Greece, French, Germay, Dania and Italia). The project has been completed on October 2012, with total project duration of 37 months.

The VIAJEEO project aim was to design, demonstrate and validate an open platform which is able to: (a) support the transport operations, planning and a wide range of traveller information services, (b) deliver dynamic information independent from the language to improve their provision of transport information and traveller services through integrated traffic data collection and management, (c) to deliver a solution that enables cross-modal journey planning, dynamic route guidance and improved personal mobility, etc., and (d) to provide standardised interfaces to connect a variety of entities needed for the mobility services (VIAJEEO, 2009).

The open platform facilitates the integration of components for data management allowing integration of European and local components as most convenient in Athens, Sao Paulo, Beijing and Shanghai. The demonstration cities in Europe, China and Brazil have been carefully chosen to ensure that they have a reputation as national role models, allowing the results of successful demonstrations to be extended to other cities in these countries and also potentially to other countries in the respective continents.

The scientific and technical objectives of the project are:

(1) Design of an open platform with interfaces to a wide range of mobility services

(2) Implementation of the open platform in Europe, and in the emerging Economies, i.e. China and Brazil.

(3) Validation of the open platform

(4) Assessment of social and transport impacts of the implementation and demonstration of the open platform

A brief description of each ITS demonstration site is presented below:

i. Athens (Greece)

The Athens demo site relates to an integrated and distributed approach for (a) multi-modal data collection and content aggregation/maintenance, (b) multi-modal and real time route guidance service delivery to consumers and professional drivers via web, telephone and on-board devices and (c) integrated transport and traffic strategic planning mechanisms.
Demonstration in Athens focused on collection of real-time traffic data for transport planning and real-time transport control, as well as multi-modal journey planner.

![Traffic Map](image)

**Figure 15: ON-TRIP Traffic Events in Athens**

**ii. Sao Paulo (Brazil)**

In Sao Paulo, the open platform connects the traffic control centre of Sao Paulo (CET) and motorway tolling data in order to estimate real-time traffic condition in urban and motorway networks in Sao Paulo. The real-time data are stored in a historical data base. The real-time information and historical database are used to support a web-based journey planner. Moreover, the open platform support traveller information services via mobile applications. Real-time traveller information in Sao Paulo is disseminated through mobile media such as PND (windows mobile).

A limited number of floating vehicles are equipped and driven during the demonstration period. Due to the small sample size, the floating vehicle data are unable to provide reliable travel time measurements. However, this is a proof-of-concept demonstration to calibrate travel time estimation algorithms based on floating vehicle data. Functionality of the open platform which can fuse floating vehicle data with other data sources will also be demonstrated.

**iii. Beijing (China)**

The demonstration in Beijing aims to encourage usage of public transport, so improving passenger information service is one of the main tasks. Integrated real-time traffic data will be used to forecast real-time bus arrival time. The real-time bus arrival time helps operators in public transport planning (frequency, timetable, etc.) and real time fleet operation. The real-time bus arrival time is delivered to passengers at bus stops and interchanges, displayed on buses and via SMS for comfort, confidence in service reliability and personal safety. A number of terminals with internet connection are installed on buses and passenger can use them to
access the multi-modal journey planner to plan their journeys or obtain real-time information about next steps of their multi-modal journeys. The multimodal journey planner also provides information on walking directions and safe cycling routes. The multimodal journey planner will also provide functions for car-sharing and taxi-sharing.

**iv. Shanghai**

As in Athens and Beijing, the open platform in Shanghai integrated data from different data sources, such as roadside units and floating vehicles to deliver real-time estimation and short-term forecast of traffic condition. The real-time estimation and short-term forecast of traffic condition are used to forecast real-time bus arrival times which are displayed at bus stops and also support multi-modal journey planner.

Although use of the open platform to integrate data from various sources to estimate real-time traffic condition is implemented and demonstrated, the focus of the demonstration is given to integrate traffic data with environmental data in order to develop substantial understanding of environmental impacts of road transport. Within the project, a number of environmental sensors with GPS and GPRS unit are installed on buses to measure air pollution along the bus route. The open platform collects and merges the environmental data with traffic data in order to produce a real-time vision of the air quality over a large area related to the traffic situation. This is used to develop and validate a traffic simulation model which can simulate environmental impacts of road traffic. The traffic model is used for appraisal of transport policy and planning. Within the project, the environmental data is used to identify “hot spots” of air pollution in Shanghai and mitigation plan, such as introducing of new public transport services and improvement of interchange, will be developed by the traffic model.

The project relates to the real-time data acquisition by various sources, the dynamic processing and forecasting of various traffic variables in order to provide multi-modal travellers information services. The system developed in this project can be taken into account for the deployment of the WP2, WP3, WP4 and WP5 for the OPTIMUM project.

**8.3.8 European Project: Peacox**

The aim of the European co-funded project Peacox “Usable Persuasive Trip Advisor for Reducing CO2-consumption” (http://www.project-peacox.eu/) was to provide the means to help people reducing their ecological impact in their everyday transportation. The project provides travellers with personalized multi-modal navigation tools that allow, help and persuade them to travel and drive ecological friendlier. To convince users in making more sustainable travel choices the project enriched navigation systems with innovative approaches and features:

- Integrated automated travel mode detection based on real-time GPS data into the trip planning thereby minimizing the need for explicit user input.
Modules to automatically detect users’ trip purpose through the analysis of behavioural patterns allowing tailoring trip suggestions to these purposes.

Dynamic user models allowing personalizing recommendations based on prior trip choices and individual preferences.

Advanced door-to-door emissions models that provide accurate feedback on the ecological/carbon footprint and exposure levels in planning as well as during travelling and car driving activities.

Persuasive interface strategies to give feedback about the ecological impact of individuals’ behaviour as well as make the ecological friendliest behavioural pattern visible and attractive.

The project is related to the work which will be performed in WP5 of the OPTIMUM project. In more details OPTIMUM will built upon the generic persuasive strategies which were defined in PEACOX and offer personalized persuasion in order to support travellers in their efforts to reduce their CO2 footprint. Moreover within OPTIMUM we will examine the use of the readily available travel mode and trip purpose detection and provide any necessary extensions required within the context of OPTIMUM.

8.3.9 European project: TEAM
TEAM (http://www.collaborative-team.eu/) is an integrated mobility system, where travellers, drivers, vehicles and the infrastructure construct a seamless and sustainable collaborative network. TEAM develops systems for participants in transportation networks, which help them to behave better - by explicitly taking into account the needs and constraints of other participants and the network itself.

The main objective is to develop an elastic and collaborative mobility management system; test, demonstrate, and evaluate its benefits in various environments by:

- moving to a concept of elastic infrastructures and collaborative behaviour of travellers and drivers,
- making infrastructures change pro-actively and in real-time based on user needs (and also vice versa) and by making mobility behaviour change based on the infrastructure demands,
- making use of data-driven operations enabled by novel data aggregators, cloud computing and interaction between all nodes of the envisaged mobility network namely of the travellers, vehicles and infrastructure.

The project is built around four basic themes:

1. Basic technologies to realise collaborative mobility: Use of advanced communication technologies that underpin V2X by integrating LTE technologies, and by developing an
automotive cloud-computing platform to support advanced and decentralised traffic management algorithms.

2. **Infrastructure-centric technologies and algorithms for elastic mobility**: Development of proactive infrastructure-centric algorithms and technologies to enable behavioural change in order to improve transportation networks in a way that takes into account real-time needs and constraints of all network users.

3. **Distributed technologies and algorithms to realize elastic mobility**: Development of proactive user-, community- and group-centric algorithms and technologies.

Several pilots have been developed in four (4) EU countries: Italy, Berlin, Finland and Greece. A brief description of the 4 pilot’s objective is shown below.

TEAM brings the idea of cooperative traffic ahead by joining travellers (which include drivers and any type of road users) and infrastructure operators in a collaborative network to solve various travel needs all the way from eco-friendly parking to short-term decisions on trip planning. Collaboration is the key concept of TEAM approach, which extends the cooperative concept of the first generation systems and applications, by integrating the human user in a highly integrated cooperative, interactive, and participatory network. In this collaborative concept, it is not only the systems that communicate, but all actors (systems and humans) are engaged in a continuous bi-directional, dynamic exchange of information. Compared to the current cooperative projects, i.e. DRIVE C2X, TeleFOT and others, the TEAM concept thus significantly extends their work towards collaborative and pro-active traffic system management which encourages active participation and interaction of road users through empowering communication and data aggregation technologies.

TEAM adds value to this prior work by fostering collaborative and eco-friendly co-modal mobility based on a converged communication architecture covering traditional infrastructure-based communication (UMTS, LTE, etc.) with ad-hoc bi-directional vehicle-2-x communication technologies. The use of ICT to improve the efficiency of transportation networks is an area that is currently being promoted by many regulatory bodies. Basically, the direction of current work is in using ICT to improve the efficiency of vehicles, to develop ICT to promote the use of fully electric and plug-in hybrid vehicles, to use ICT to improve the planning and use of our transportation networks, and to use ICT to reduce carbon emissions in freight transportation. Work on those topics has been funded partially by the EU, and partially also by other regulatory bodies and industry—also the use of user participation as a tool to achieve emissions reduction has been discussed in many different contexts.

The project relates to the development of cooperative systems in order to enable travellers data exchange. The system developed can be taken into account for the deployment of the WP2, WP3, WP4 and WP5, as well as the implementation of the Pilot Case 3.
8.3.10 CIVITAS Initiative
Exploring innovative solutions to the challenges posed by creating a more sustainable urban mobility culture is at the heart of the CIVITAS Initiative ([http://www.civitas.eu/](http://www.civitas.eu/)). In some instances the challenges are technical or logistical, in others extensive citizen engagement is required to really achieve change. Each city is different and has to address the particularities of its own situation. However, there are many similarities and it is very likely that at least one of the over 70 CIVITAS demonstration cities has experimented.

CIVITAS measures undertaken which are considered relevant to the OPTIMUM project are briefly described below:

8.3.10.1 Collective Passenger Transport
The scope of demonstration sites is to develop a high-quality, modern and energy-efficient public transport system that is well integrated with other modes in order to reduce car traffic and creating an appealing urban environment.

CIVITAS cities have worked on innovative ways to maximise the potential for local public transport through an accessible service that is a fast and convenient alternative to the private car. Efforts include for instance improving security and safety, and making it accessible to people with reduced mobility. There is also a focus on building up clean and energy-efficient public transport fleets. Moreover, integrated ticketing is crucial to make public transport and intermodal travel attractive options. Examples include smart cards that allow users to travel on different modes of public transport, or Park and Ride services that integrate parking fees and public transport fares.

Indicative CIVITAS projects including relevant measures are MIMOSA, ELAN, ARCHIMEDES, 2MOVE2, D@NAMO.

8.3.10.2 Access Management and Road Pricing
The scope is to reduce local traffic levels by implementing demand management strategies based upon economic incentives, regulatory measures including zoning and spatial planning and tele-services. In the field of demand management strategies, CIVITAS cities worked on access management; road pricing; parking strategies; and walking and cycling enhancements.

Parking management involves innovations in design, communications and enforcement. Differentiated pricing schemes for parking are an effective means to reduce congestion and pollutant emissions in an urban context.

Indicative CIVITAS projects including relevant measures are MIMOSA, ARCHIMEDES, SMILE, RENAISSANSE, TELLUS, TRENDSETTER, SUCCESS.
8.3.10.3 Car Independent Lifestyles

Except of promoting more environmental transport modes, CIVITAS seek ways to make more sustainable use of the car through car-pooling and car sharing.

Car-pooling involves sharing rides among two or more travellers in the same vehicle headed for the same destination. It can be facilitated by organised “matching” services. Car sharing, on the other hand, involves sharing cars among a group of people that do not necessarily need a car on a daily basis. It is usually based on a membership arrangement with the vehicle parked nearby and can avert purchases of second cars.

The benefits form travellers is money saving while for employers is the reduction of need for on-site parking while there are obvious benefits that come with fewer cars on the road.

Indicative CIVITAS projects including relevant measures are 2MOVE2, SUCCESS, ARCHIMEDES, MIMOSA.

8.3.10.4 Urban Freight Logistics

In the field of urban freight CIVITAS cities worked on distribution schemes and fleet management including cleaner fleets. Distribution schemes aim for more efficiency of goods delivery, while relying on information systems that support the use of clean road vehicles, bikes and boats. Innovative logistics plans require cooperation from local authorities with logistics providers and they can include a wide range of actions, such as consolidation of goods including urban distribution centres, delivery time windows, delivery to home or park-and-ride sites, consolidation of goods and piping logistics. Better coordination of freight logistics can save money and time for companies and consignees by reducing mileage and alleviating road congestion. Productivity can be increased by streamlining collection and delivery processes. But there are also multiple positive effects for the city itself which makes taking a pro-active role among city authorities increasingly important: more safety, less pollution, less noise.

Indicative CIVITAS projects including relevant measures are TELLUS, 2MOVE2, ARCHIMEDES, MIMOSA, ELAN.

8.3.10.5 Real-time road user information

Innovative transport telematics systems for traffic management and traveller support can make urban passenger transport faster, more reliable and more efficient and as such more passenger friendly. In the field of transport telematics CIVITAS cities have worked on ITS for traffic monitoring, management and enforcement; ITS-based enhancement of public transport; and real time road-user information.

The implementation of these traffic information and management systems assists users in their choice of transport mode and facilitates a more efficient use of resources and existing road
infrastructure. Road safety and congestion can be addressed as well because hazardous locations or situations are identified and mitigated on a real-time basis.

Indicative CIVITAS projects including relevant measures are 2MOVE2, D@NAMO, MODERN, RENAISSANCE, SMILE, MIRACLES.

8.3.10.6 ITS-based enhancement of public transport
Public transport can be made faster, more efficient and more passenger friendly by enhancing the use of innovative transport telematics systems for traffic management and traveller support. ITS enhancements of public transport include fleet management systems based on automatic vehicle location technologies, which can be used to improve services, to optimise routing and scheduling, and to feed real-time information into various passenger information channels. This subtheme also encompasses intelligent traffic lights and priority schemes for buses and trams. By implementing such measures, public transport becomes more convenient, comfortable, accessible and understandable for everyone. The number of passengers who use public transport should increase and disadvantaged people can be made to feel less excluded from society.

Indicative CIVITAS projects including relevant measures are ARCHIMEDES, 2MOVE2, ELAN, MIMOSA, D@NAMO.

8.4 Discussion
As it can be seen, there were various deployments of ITS in various countries for many years, however, there was no sign of coordination at European and National level. The first coordinated action of ITS along Europe is the EasyWay Programme which initiated at 2002. The EasyWay Programme aims to tackle issues regarding ITS interoperability, standardization and harmonization among various EU countries.

From 2010, significant steps were taken at EU level in order to endorse ITS standardization, harmonization and interoperability along Europe. Significant EU milestone on the introduction of ITS regulation was the EU Directive 2010/40 where all Member-States adopted in the national laws. The ITS Directive 2010/40 establishes a framework for support of the coordinated and coherent deployment and use of Intelligent Transport Systems (ITS) within the Union, in particular across the borders between the Member States, and sets out the general conditions necessary for that purpose. The Directive recognizes four (4) priority areas: (a) Optimal use of road, traffic and travel data, (b) Continuity of traffic and freight management ITS services, (c) ITS road safety and security applications and (d) Linking the vehicle with the transport infrastructure. Except of few amendments, two supplementary Directives to 2010/40/EU were issued: (a) the 885/2013/EU Directive regarding the provision of information services for safe and secure parking places for trucks and commercial vehicles, and (b) the Directive 886/2013/EU which establishes the specifications necessary to ensure compatibility,
interoperability and continuity for the deployment and operational use of data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users.

The majority of EU Member States conducted, according to the requirements of Directive 2010/40/EU, Action Plans where the existing and short-term (within 5 years) ITS measures and deployments were described. As it is seen, many ITS applications on the field of Travelers Information have been already implemented, while many are planned for short-term implementation. It should be mentioned that a nice action would be to develop an EU observatory of ITS measures and projects along Europe where all ITS per functional service will be described for the existing conditions as well as the future conditions. This ITS observatory or European ITS Projects inventory should be based on National Action Plans. To enable this objective, it would be helpful to introduce within the National Action Plans a specific template with specific requirements regarding the required information. This would enable the decision-makers to understand the current trends along the Europe and to promote more effective interoperability and harmonization standards. The proposed ITS observatory would be useful to be updated at annual basis in order to monitor frequently the real progress. Moreover, it has to be mentioned that the development of regional plans within each EU Member State would be helpful in order to draw a realistic and reliable picture regarding the existing and future ITS interventions of each country. Consequently, the regional ITS plans should be updated at frequent time intervals.

Today, EU provides several funding tools and strategies which could be used for the deployment of ITS projects, such as CEF and EasyWay Programme. Public and private sector should exploit those opportunities in order to develop ITS projects. Critical issue remains the coordination among ITS deployment at national and European level in order to ensure harmonized and standardized technical implementation of ITS projects. The use of the various EU funding mechanisms is very beneficial for the promotion of ITS, however, it is essential to ensure that all ITS developments are undertaken in coordinated and harmonized manner; a central ITS supervision management body could contribute towards this scope.

Finally, as it is seen, there are various ITS applications on the field of travellers’ information services regarding real-time traffic information, incidents information, public transport time-schedules and freight transport information. Again, a significant issue is a potential integration and expandability of the various systems, as well as the adoption to EU harmonization and interoperability standards.

ITS projects seem to have bright future for providing cost-effective solutions in the various transportation operations, but coordination is necessary in order to avoid the phenomenon of technological “islands” within the countries and within Europe.
9 Conclusions

This deliverable presents the work done in WP1 as part of the task T1.1 “State of the Art Update”. It provides a survey of the research methods, models and tools in all the disciplines related to the project, as well as of ITS-related projects, directives, initiatives, action plans, regional strategic plans and deployment strategies.

The survey of the research literature concludes with the identification of the main research gaps and limitations of the existing state-of-the-art in the research areas analysed. This will provide the basis for enabling OPTIMUM to build upon existing research practices in the various areas and go beyond the current state-of-the-art in the context of the research WPs (WP2-WP5), where the OPTIMUM models, architectures, methods and services will be designed and developed.

The survey of the ITS-related projects, directives and action plans, provides the necessary knowledge to ensure that OPTIMUM will rely on and build upon the results of previous projects and best practices, as well as that the OPTIMUM solution will be in line with related EU policies, regulations and norms.

Moreover, D1.1 provides the basis for building a common understanding among partners of different disciplines. As such, this deliverable will serve as a basis for further tasks in WP1, including the development of the OPTIMUM Conceptual Architecture which will in turn provide the foundation for further developments in work packages WP2, WP3, WP4 and WP5.
10 References


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APPENDIX 1: Traffic forecasting models

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Network Type</th>
<th>Developed or investigated Models / Algorithms</th>
<th>Model type</th>
<th>Direct Model Input (Traffic Engineering Parameters)</th>
<th>Temporal Data Intervals for Input</th>
<th>Data Source</th>
<th>Forecasting Step</th>
<th>Performance Observations</th>
<th>Transport Network &amp; Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moorthy &amp; Ratcliffe</td>
<td>1988</td>
<td>Motorway</td>
<td>ARIMA</td>
<td>Parametric</td>
<td>Flow</td>
<td>1 month</td>
<td>Inductive Loop Detectors</td>
<td>1 month</td>
<td>Multivariate Box-Jenkins time series models demonstrated good forecasting potential</td>
<td>Motorway traffic</td>
</tr>
<tr>
<td>Faghri &amp; Hua</td>
<td>1995</td>
<td>Various</td>
<td>Artificial Neural Network (ANN)</td>
<td>Non-parametric</td>
<td>Flow</td>
<td>24 hour</td>
<td>Inductive Loop Detectors</td>
<td>24 hour</td>
<td>Performed better than cluster and regression analysis</td>
<td>Urban, rural and motorway network types</td>
</tr>
<tr>
<td>Lingras &amp; Adamo</td>
<td>1996</td>
<td>Motorway</td>
<td>Linear regression, ANN</td>
<td>Hybrid</td>
<td>Flow</td>
<td>24 hour</td>
<td>Inductive Loop Detectors</td>
<td>24 hour</td>
<td>Linear regression and ANN resulted in similar errors</td>
<td>Motorway traffic</td>
</tr>
<tr>
<td>Smith &amp; Demetsky</td>
<td>1997</td>
<td>Motorway</td>
<td>Nonparametric regression, ARIMA, Historical average, ANN</td>
<td>Hybrid</td>
<td>Flow</td>
<td>15 min</td>
<td>Inductive Loop Detectors</td>
<td>15 min</td>
<td>Nonparametric regression performed better than others</td>
<td>Motorway traffic</td>
</tr>
<tr>
<td>Dougherty &amp; Cobbett</td>
<td>1997</td>
<td>Motorway</td>
<td>ANN</td>
<td>Non-parametric</td>
<td>Multivariate</td>
<td>5 min</td>
<td>Inductive Loop Detectors</td>
<td>5 min</td>
<td>ANN didn’t outperform ‘naive’ predictors and demonstrated poor accuracy for speed prediction</td>
<td>Different motorway conditions, including flow disruptive events, such</td>
</tr>
</tbody>
</table>

38 ‘Motorway’ network type, include limited-access, control-access highways, expressway and inter-urban networks
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Type</th>
<th>Methodologies</th>
<th>Time</th>
<th>Detection Method</th>
<th>Comments</th>
</tr>
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<tr>
<td>Dia</td>
<td>2001</td>
<td>Motorway</td>
<td>Different ANN Architectures</td>
<td>20 sec</td>
<td>Inductive Loop Detectors</td>
<td>The performance of time-lag recurrent networks (TLRN) and hybrid TLRN was better than that of the static classifiers, e.g. multi-layer perceptrons (MLP)</td>
</tr>
<tr>
<td>Chen, Grant-Muller, Mussone &amp; Montgomery</td>
<td>2001</td>
<td>Motorway</td>
<td>ANN and ARIMA supported by SOM</td>
<td>15 min</td>
<td>Inductive Loop Detectors</td>
<td>SOM-ANN performed better than SOM-ARIMA and single models</td>
</tr>
<tr>
<td>Smith, Williams &amp; Oswald</td>
<td>2002</td>
<td>Motorway</td>
<td>Nonparametric regression, ARIMA</td>
<td>15 min</td>
<td>Inductive Loop Detectors</td>
<td>ARIMA forecasting outperformed nonparametric regression</td>
</tr>
<tr>
<td>Yin, Wong, Xu &amp; Wong</td>
<td>2002</td>
<td>Urban Network</td>
<td>Fuzzy logic, ANN</td>
<td>5 min</td>
<td>Simulation, Traffic Surveys</td>
<td>The on-line fuzzy supported ANN performed better than the off-line and conventional ANN</td>
</tr>
<tr>
<td>Zhang &amp; Rice</td>
<td>2003</td>
<td>Motorway</td>
<td>Time-varying coefficient linear model</td>
<td>30 sec</td>
<td>Inductive Loop Detectors, Probe vehicles</td>
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<tr>
<td>Stathopoulos &amp; Karlaftis</td>
<td>2003</td>
<td>Urban Network</td>
<td>ARIMA, Kalman filtering</td>
<td>3 min</td>
<td>Inductive Loop Detectors</td>
<td>Kalman filtering performed better than ARIMA</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Urban signalised arterial network, Upstream detectors used to predict</td>
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<tr>
<td>Study</td>
<td>Year</td>
<td>Network Type</td>
<td>Model Type</td>
<td>Flow Interval</td>
<td>Flow Measurement</td>
<td>Results</td>
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</tr>
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<td>Clark</td>
<td>2003</td>
<td>Motorway</td>
<td>Nonparametric regression</td>
<td>Nonparametric Flow</td>
<td>10 min Inductive Loop Detectors</td>
<td>Proposed model performed better than a ‘naïve’ alternative</td>
</tr>
<tr>
<td>Yu &amp; Zhang</td>
<td>2004</td>
<td>Urban Network</td>
<td>Switching ARIMA</td>
<td>Parametric Flow</td>
<td>15 min Inductive Loop Detectors</td>
<td>Switching ARIMA model performed better than various types of conventional ARIMA models</td>
</tr>
<tr>
<td>Schadschneider, Knospe, Santen &amp; Schreckenberg</td>
<td>2005</td>
<td>Motorway</td>
<td>Statistical analysis</td>
<td>Microscopic Simulation Flow</td>
<td>1 min Inductive Loop Detectors</td>
<td>Study focused on the identification of bottlenecks</td>
</tr>
<tr>
<td>Vlahogianni, Karlaftis &amp; Golias</td>
<td>2005</td>
<td>Urban Network</td>
<td>GA optimised ANN</td>
<td>Nonparametric Flow</td>
<td>3 min Inductive Loop Detectors</td>
<td>GA optimised ANN performed well for high flow scenarios</td>
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<td>Jiang &amp; Adeli</td>
<td>2005</td>
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<td>Wavelet ANN</td>
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<td>The wavelet ANN outperformed the conventional ANN</td>
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<td>Turochy</td>
<td>2006</td>
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<td>Nonparametric regression</td>
<td>Nonparametric 15 min Flow</td>
<td>15 min Inductive Loop Detectors</td>
<td>Nonparametric regression coupled with condition monitoring performed better</td>
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<td>Chai, Pasquier</td>
<td>2006</td>
<td>Motorway</td>
<td>Fuzzy ANN</td>
<td>Nonparametric Flow</td>
<td>5 min Inductive and</td>
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<td>Zhang &amp; HE</td>
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<td>Urban Network</td>
<td>PCA, ANN Hybrid Flow</td>
<td>Simulation</td>
<td>Simulated traffic flow of an intersection</td>
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<td>Xie, Zhang &amp; Ye</td>
<td>2007</td>
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<td>Kalman filtering &amp; Wavelet Hybrid Flow</td>
<td>5 min Inductive Loop Detectors 5 min</td>
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<td>Stathopoulos, Dimitriou &amp; Tsekeris</td>
<td>2008</td>
<td>Urban Network</td>
<td>ANN, Kalman filtering combined using a FuzzyRule Based System (FRBS) Hybrid Flow</td>
<td>3 min Inductive Loop Detectors 3 min</td>
<td>Signalised arterial network</td>
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<td>Ghosh, Basu &amp; O'Mahony</td>
<td>2009</td>
<td>Urban Network</td>
<td>Structural Time-Series (STM) Parametric Flow</td>
<td>15 min Inductive Loop Detectors 15 min</td>
<td>Multiple junctions within a congested urban network</td>
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<td>Lee, Tseng &amp; Tsai</td>
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<td>Urban Network</td>
<td>Rule-based system with data mining Non-parametric Travel Time 5 min</td>
<td>On-board Units (OBUs)</td>
<td>Urban traffic</td>
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<td>Zhu &amp; Zhang</td>
<td>2009</td>
<td>Motorway</td>
<td>SOM, ANN Non-parametric Multivariate 10 min</td>
<td>Inductive Loop 10 min</td>
<td>ANN with more complicated structures such as Motorway traffic under different flow</td>
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<tr>
<td>Authors</td>
<td>Year</td>
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<td>Model Description</td>
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<td>Huang &amp; Sadek</td>
<td>2009</td>
<td>Motorway</td>
<td>Spinning Network (SPN) model, k-NN, ANN</td>
<td>TLRN and principal component analysis didn’t provide better forecasts from ANN</td>
<td>5 min</td>
<td>Proposed model performed better than 3-NN &amp; ANN</td>
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<tr>
<td>Wang, Shang &amp; Zhao</td>
<td>2010</td>
<td>Urban Network</td>
<td>Nonparametric regression optimised using pattern recognition</td>
<td>Model performed better than nonparametric regression and ANN, but had similar performance of a SARIMA model</td>
<td>5 min, 6 min</td>
<td>Urban arterial network with large passenger flow volumes</td>
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<tr>
<td>Fei, Lu &amp; Liu</td>
<td>2011</td>
<td>Motorway</td>
<td>Bayesian inference-based dynamic linear model</td>
<td>Proposed method outperformed an auto regressive predictor</td>
<td>5 min</td>
<td>Motorway traffic under recurrent and non-recurrent conditions</td>
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<tr>
<td>Hong</td>
<td>2011</td>
<td>Motorway</td>
<td>SARIMA, ANN, Seasonal Holt-Winters (SHW), Support Vector Regression (SVR) with Chaotic simulated annealing</td>
<td>Seasonal SVRCSA performs better other methods</td>
<td>1 hour</td>
<td>Motorway traffic</td>
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<td><strong>Coric, Wang &amp; Vucetic</strong></td>
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<td>Linear predictors coupled with decision trees</td>
<td>Parametric</td>
<td>Flow</td>
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<td><strong>Khosravi, Mazloumi, Nahavandi, Creighton &amp; Van Lint</strong></td>
<td>2011</td>
<td>Various</td>
<td>ANN, Generic Algorithms</td>
<td>Non-parametric</td>
<td>Multivariate</td>
<td>5 min for freeway study</td>
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<td>SOM, SVM</td>
<td>Hybrid</td>
<td>Multivariate</td>
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<td>10 min</td>
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<td><strong>Hong, Dong, Zheng &amp; Wei</strong></td>
<td>2011</td>
<td>Motorway</td>
<td>SVR with GA-Simulated Annealing, SARIMA, ANN, Holt-Winters</td>
<td>Non-parametric</td>
<td>Equivalent of Passengers (EOP)</td>
<td>1 hour</td>
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<td>Guo, Krishnan &amp; Polak</td>
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<td>Urban Network</td>
<td>k-Nearest Neighbour (kNN), SSA</td>
<td>Non-parametric Flow</td>
<td>Seasonal Hold-Winters Winters, Seasonal Hold-Winters models</td>
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<td>The SSA-kNN model performed better than kNN, Grey System and SVR</td>
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<td>Urban traffic under normal and incident conditions</td>
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<td>Kamarianakis, Shen &amp; Wynter</td>
<td>2012</td>
<td>Various</td>
<td>Linear predictors, LASSO</td>
<td>Parametric Speed</td>
<td>LASSO technique produced better results than ordinary least square method</td>
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<td>Different configurations of freeway networks</td>
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<td>Wibisono, Sina, Ihsannuddin,</td>
<td>2012</td>
<td>Urban Network</td>
<td>ANN</td>
<td>Non-parametric Tweets</td>
<td>ANN produced travel time predictions with good accuracy</td>
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<td>Hafizh, Hardjono, Nurhadiyatna, Jatmiko &amp; Mursanto</td>
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<td>Urban traffic</td>
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<td>Yeh &amp; Chang</td>
<td>2012</td>
<td>Urban Network</td>
<td>Neuro-fuzzy inference system (NFIS), ANN</td>
<td>Non-parametric Flow</td>
<td>NFIS and ANN had similar accuracy levels, but NFIS needed more time for training</td>
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<td>Urban streets leading to an intersection</td>
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<td>Sun, Huang &amp; Gao</td>
<td>2012</td>
<td>Urban Network</td>
<td>Graphical Lasso, ANN, Gaussian Process Regression</td>
<td>Hybrid Flow</td>
<td>Multi-link approaches outperformed single-link ones</td>
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<td>Urban traffic with multiple intersections</td>
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<td>Yang, Yang, Zhao &amp; Gong</td>
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<td>ANN, Wavelet transform</td>
<td>Hybrid Flow</td>
<td>Wavelet ANN performed better than Urban traffic</td>
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<td>He, Lu &amp; Wang</td>
<td>2013</td>
<td>Motorway</td>
<td>Self-Organising Map (SOM), Genetic Algorithm (GA) - Chaos optimised ANN</td>
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<td>Wang &amp; Shi</td>
<td>2013</td>
<td>Motorway</td>
<td>SVR optimised using Wavelet analysis and Chaos theory</td>
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<td>Lippi, Bertini &amp; Frasconi</td>
<td>2013</td>
<td>Motorway</td>
<td>SVR, ANN, SARIMA, ARIMA, Kalman filtering</td>
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<td>He, Shen, Divakaruni, Wynter &amp; Lawrence</td>
<td>2013</td>
<td>Urban Network</td>
<td>Regression analysis with Social Data input</td>
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<td>Li, Hong &amp; Kang</td>
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<td>Urban Network</td>
<td>SVR with Gauss loss function, Chaotic cloud particle swarm optimisation</td>
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<td>Prasad &amp;</td>
<td>2014</td>
<td>Motorway</td>
<td>Decision Tree</td>
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</table>
### D1.1 - State-of-the-art Report, Version 2.0, 31/03/2017

**Ramakrishna**

<table>
<thead>
<tr>
<th>Year</th>
<th>Network</th>
<th>Methodology</th>
<th>Model</th>
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<th>Forecasting</th>
<th>Evaluation</th>
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<tbody>
<tr>
<td>2014</td>
<td>Urban</td>
<td>K-nearest neighbour with Linearly Sewing Principle Component (LSPC) algorithm</td>
<td>Non-parametric</td>
<td>Flow</td>
<td>1.5 min</td>
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**Zheng & Su**

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<tr>
<td>2014</td>
<td>Various</td>
<td>Random Forest, Regression tree, ANN</td>
<td>Hybrid</td>
<td>Multivariate</td>
<td>1 hour (LT) 15 min</td>
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**Hou, Edara & Sun**

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<tr>
<td>2015</td>
<td>Public Transport Network</td>
<td>Agent-based system, Simulations</td>
<td>Hybrid</td>
<td>Social Data</td>
<td>Ad-hoc Simulation</td>
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**Patina & Karlapalem**

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<th>Data</th>
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<tr>
<td>2015</td>
<td>Urban</td>
<td>Coefficients Optimization Algorithm based on Fuzzy Neural Network</td>
<td>Non-parametric</td>
<td>Flow</td>
<td>5 min</td>
<td>Microwave detectors</td>
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**Lu, Sun, Qu & Wang**

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<tr>
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<td>Motorway</td>
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**Kumar and Vanajakshi**

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