MIT Portugal

Transportation Systems

Working Paper Series

State of the Practice Overview of Transportation Data Fusion: Technical and Institutional Considerations

Paper# ITS-CM-09-01

January 2009

Andrew Amey (MIT), Liang Liu (MIT), Francisco Pereira (CISUC), Christopher Zegras (MIT), Marco Veloso (CISUC), Carlos Bento (CISUC), Assaf Biderman (MIT)

Massachusetts Institute of Technology (MIT) & Centro de Informática e Sistemas da Universidade de Coimbra (CISUC)

State of the Practice Overview of Transportation Data Fusion: Technical and Institutional Considerations

MIT Portugal Program

Transportation Systems Focus Area

Research Domain:
Intelligent Transportation Systems

Research Project:
CityMotion

Paper#:
ITS-CM-09-01

January 2009

Andrew Amey, Graduate Student Researcher, Dept. of Urban Studies & Planning (DUSP), Massachusetts Institute of Technology (MIT),
amamey@MIT.EDU
Liang Liu, Post Doctorate Associate, SENSEable City Laboratory, DUSP, MIT,
liuliang@MIT.EDU
Francisco Pereira, Professor, Cognitive and Media Systems Group (CMS), Centro de Informática e Sistemas da Universidade de Coimbra (CISUC),
camara@dei.uc.pt
Christopher Zegras, Professor, DUSP, MIT,
czegras@MIT.EDU
Marco Veloso, PhD Student Researcher, CMS, CISUC,
mveloso@dei.uc.pt
Carlos Bento, Professor, CMS, CISUC,
bento@dei.uc.pt
Assaf Biderman, Associate Director, SENSEable City Laboratory, DUSP, MIT,
abider@MIT.EDU

This publication was made possible by the generous support of the Government of Portugal through the Portuguese Foundation for International Cooperation in Science, Technology and Higher Education and was undertaken in the MIT-Portugal Program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

The rapidly evolving area of Information and Communication Technologies (ICTs) has clear implications for the transportation sector, including activity choice decisions, where to perform activities, and the transportation modes and routes to choose to get there. Metropolitan areas today have quite literally become saturated with various types and sources of real-time data that can, in theory, be utilized to improve mobility services by influencing demand and altering the supply of transport services.

These data sources include “traditional” transportation sources, often associated with Intelligent Transportation Systems (ITS), such as toll road operators, public transportation service providers, road sensors, image capturing technology and commercial fleet tracking. At the same time, the increasing ubiquity of a range of different mobile devices and other ICT-related technologies introduces new information sources, including distributed mobile sensor networks, mobile devices, direct citizen engagement, and web-based platforms which provide close-to-real-time information (e.g. on city events).

A principal practical challenge to capitalizing on the potential offered by these data sources relates to the need for integration or data fusion – compiling and aggregating the data into an augmented and value-added whole in such a form that applications and users can access relevant information, otherwise inaccessible from individual sources, with appropriate representation and level of detail.

Data fusion poses both technical challenges, related to gathering the data in a timely and consistent fashion and computationally manipulating it for different user groups; and, institutional challenges, related to the numerous public and private agencies and companies potentially involved and issues such as financing, ownership of the computational platform for data collection and fusion, data ownership, privacy concerns, etc.

This paper aims to provide a state of the practice review of data fusion by focusing on technical and institutional aspects. The focus will largely be on data fusion as it relates to transportation, with a wider-reaching discussion of data fusion architectures and models from other disciplines. The paper begins with a discussion of the opportunities that data fusion creates for the transport sector. We then discuss the technical aspects of data fusion, presenting several system architectures and models for data fusion. Institutionally, we review some of the predominant industry players in relevant application fields (primarily in North America and Europe) and then examine case studies at the federal and metropolitan levels to understand what different levels of government have gone through when developing their data fusion applications. Metropolitan-area data fusion experiences in the United States are discussed in more detail, with the goal of identifying various factors that might enable advanced, multi-modal data fusion adoption. We conclude by identifying some prospects for transport data fusion, as revealed through the technical and institutional analyses.

Data Fusion Overview

Data fusion (DF) involves the seamless detection and combination of data, from multiple sources, with the goal of extracting new knowledge from the data and generating improved information (including estimations, predictions) that can be transmitted to relevant users for better decision making. More specifically, we consider that a system uses *data fusion* whenever:

- More than one source of data is being fed simultaneously;
- Each data source has distinct inherent properties (i.e. specific technology, type of data, etc.); and,
- Data sources are integrated to create at least one sort of unified information.

Considerable work exists on the topic of multi-sensor data fusion, the integration of distinct low-level signals into a unified result (e.g., estimating a precise position from a GPS receiver and an accelerometer); at the level of information fusion (i.e. the integration of two or more signal-level processed sources), however, much more work remains. When aiming to fuse data into higher-level information that people can perceive and use to address complex tasks, we face an increase in the number and variety of types of sensor data that can be combined. Data fusion of dramatically different types and levels of representation becomes increasingly complex, also increasing the quantity of information the system must handle. For a range of end use sectors (e.g., transportation), the employment of more than one sensor can bring increased robustness and reliability, larger coverage, increased dimensionality of measurement, confidence in and reduction of measurement time, but, often, at higher costs (Thomopoulos, 1989).

In transportation applications, we can envision three basic “classes” of DF user groups: transportation system users (e.g., passengers), service providers (e.g., public transport, supply chain management, disaster response), and system planners (e.g., government planning agencies). In the most general sense, these user classes operate at the operational, tactical, and strategic levels, with immediate-, short-/medium-, and longer-term time frames, respectively. For example, a traveler could use DF applications to assist in an immediate, mode choice (operational) decision; a public transport company could use DF applications to modify certain routes (tactical); a planning agency could use DF applications to integrate long term transportation and land development plans. No formal barriers exist between these user classes and time-frames, as, for example, planning agencies may make operational decisions. In this paper, we focus primarily on DF implications for operational (immediate-/short-term) decisions by system users.

In theory, the range of sensors present in a metropolitan area is sufficient to develop real-time, nearly-omniscient travel information systems for individuals, yet the underlying DF challenge remains; how best does one effectively capture this information, process it and deliver it in a format that users can easily interpret and act upon?

2 Opportunities for Data Fusion/Mining in Transportation

Transportation systems are complex and include physical, spatial, temporal, social and psychological aspects. With the rapid growth of transportation networks (Road, Rail, Airline, Maritime and underground transportation systems) and the development of new transportation facilities (High-speed railway, scooter, smart car, etc), it is more complicated than ever. Energy and environmental considerations simply add more complexity to the transportation system.

In this complex system, enormous amounts of distributed, heterogeneous data are produced every day, across three different levels, i.e. transport strategic planning, transport tactic planning and transport operation. Generally speaking, transportation engineers need to explore the data and find the rules and relationship behind them to develop solutions.

One of the main challenges for transportation is how to analyze data from such distributed heterogeneous sources. Data can be continuous or categorical (e.g. numerical values or discrete tags such as ‘congestion’), and it can be structured or unstructured. Structured data sources include parametric data from sensors, volume records, and so on. Structured data (e.g. derived from a form or a database table) is much more easily mined than unstructured data. Traditional transport data are generally structured data, such as census data and sensor data.

Massive unstructured data is likely important for transportation. Sources such as news feeds and emails are well-established, and new technologies, such as Blogs, Wikis and other methods of personal communication that will supersede them, are spreading rapidly. Unstructured data such as a web pages containing a transport related news story is more challenging to process. It either needs to be transformed into structured data (involving disciplines such as natural-language processing and semantic mapping), or specialized data mining tools need to be created. Analysis of such data poses particular challenges, not least of which is the problem of semantic mapping between domains, but it is likely to yield valuable information for transportation.

However, data is raw and does not, of itself, have meaning, whereas information is data that has been processed to be useful, given meaning by way of relational connections, semantics, etc. Knowledge results from reasoning over information.

Data fusion and data mining are two promising techniques to finish data/information/knowledge transfer in transportation. Data fusion is a set of techniques for combining data, which may be noisy or conflicting, from multiple, heterogeneous sources. Data mining is the analysis of data to establish relationships and identify patterns. The two have great influence on transportation.

2.1 Data Fusion/Mining Potential in Transportation

2.1.1 Reveals the Wealth of Information that can be extracted from Unstructured Data

There are obvious data gaps in transportation because of dynamic change of socio-economic conditions, such as car ownership, demography, income, etc. Data fusion and mining is useful to apply additional resources to close the data gap and improve the quality of transportation planning, management, operation and traveler information.

Most existing traditional transport data is structured data. Well-established data fusion/mining techniques require the data to be structured into records with clearly defined data types and to be accessible as a single, authoritative source integrated from distributed (and possibly differently structured) databases. However, in addition to the structured data sources (e.g. record-based, forms, fields-with-values) that have fed traditional data mining systems and algorithms, a wealth of information is stored in unstructured data, such as transport related news, wikis, blogs, video, audio, etc, and these sources are likely to contribute enormously to transportation.

2.1.2 Computational Linguistics and Text Mining

Computational linguistics and text mining are essential techniques for working with unstructured text and natural speech. This is a valuable capability for transportation. Most user-generated, unstructured data is text based, such as traffic incident reports, personal reviews of daily transit trips, etc.

The ability to extract information from different languages and present the results in a single language has been identified by the US Government as one of the grand challenges in national security (DARPA GALE project, 2005). The Topic Detection and Tracking (TDT) has contributed to the rapid development of information extraction and retrieval technologies in recent years (NIST Speech Group, 2004). Current systems can identify structured information (e.g. time, date, and address), named entities (e.g. organizations, people, and places), concepts (e.g. actions, objects) and their relationships (e.g. 'he', 'she', 'it' or 'they' references) in unstructured text (ACL, 2005). Existing solutions are typically domain-dependent. The research challenge is open domain, multi-lingual information extraction: a system that can understand everything in many languages.

Chung and McLeod (2003) describe a topic mining framework that supports the identification of meaningful topics (themes) from news stream data. It aims to utilize the mapping from news feeds to content descriptions (ontologies) in order to determine the higher-level meanings of the stories. This involves clustering and hierarchical document searching in order to provide classifications that can be mapped onto the ontologies.

Advances in computational linguistics and text mining will enable an automated system to gather up-to-date information in a variety of languages from unstructured information sources and generate a translated summary of the information to aid decision support. This ability is especially useful for urban and transportation planners in their effort to understand the state-of-the-art applications all over the world.

2.1.3 Multimedia Content

Much of the data used in transport will be non-textual, for example, satellite imagery, video surveillance footage, or photographs of the traffic congestion at different geographic locations and times. As a result, image and video processing using content-based analysis techniques are likely to become significant features of data mining in transport. Analysis of video surveillance footage has already been applied to situations relevant to transport, including automated plate number recognition and vehicle counting (Rana, 2007), surveillance in public transport (Sun, 2004), and image analysis has been used as the basis for automated condition classification (Lewis, 2004).

Bridging the semantic gap between the image analysis domain and transport application domain (congestion and accidents detection, monitoring “un-watched” sites) is one of the major problems of image classification and content-based search and retrieval. Techniques do exist to help bridge this gap, but these are relatively immature compared with the larger body of work on content descriptors. In general, supervised learning techniques (e.g. training of neural networks) are used with an example set of images with known application-domain semantics to build classifiers that can label images based on the value of one or more content descriptors.

Instead of developing ever more sophisticated content descriptors, one approach to the problem of 'bridging the semantic gap' is to propagate existing human annotations, e.g. semantic annotations extracted from existing textual descriptions, across a collection of content items. We rely on people to describe the semantics of a subset of images or video, either by providing new annotations, or by using existing metadata. These human-authored annotations are then propagated to similar items in a database. Propagation is done via content-based analysis to identify similar items. In this way, content analysis is not used to attach semantics to content per se, but instead to propagate high-quality, manual annotations from items with known semantics to items that need further semantic annotation.

2.2 Reveals Conceptual/Semantic Gaps in Transportation

Data for analysis in transportation will typically come from a variety of sources. A major issue with such data is that it may be incompatible – from simple mismatches, such as the use of different date representations, to more subtle matters of semantics and interpretation. In general, the semantic gap refers to a mismatch between understandings across domains and among different transport-related users, such as policy makers, planners and end users.

Semantic gaps may arise in transportation due to the heterogeneous nature of the different sources of data. Ensuring that the same term in two different sets of data actually means the same thing, and establishing the appropriate transformation rules between different data sources and users, is a major challenge.

2.2.1 Semantic Web

By far the most promising aspect of the semantic web is the use of ontologies for describing domains of knowledge. Ontologies are used as the basis for semantic inference, where new, implicit knowledge can be generated from existing, explicit knowledge using rule-based systems. These techniques are just beginning to be researched (Crubézy et al, 2005).

Currently, two competing standards exist for representing data on the semantic web, namely the Resource Description Framework (RDF) and Topic Maps. The Web Ontology Language (OWL) is the only description logic standard.

The semantic web has the potential to help solve the interoperability problems that exist in transport. Semantic mark-up provides a semi-structured and standardized format for data interchange; ontologies provide formal semantics for concepts and relationships in datasets as well as semantic interoperability; and semantic inferencing yields new knowledge.

2.2.2 Blogs, Wikis and Collaborative Personal Communication

There is an implicit expectation that the discovery of the spread of congestion will be through analyzing weather and traffic sensor data. However, the rapid spread of disruptive technologies such as Blogs and Wikis and new collaborative means for personal communication (MSN, Skype, Twitter, Facebook) will also be important sources. Using these new technologies, people share a wide range of personal information including traffic matters and concerns. Such publicly accessible information is becoming universally available. The dynamic social networks by which it spreads can be analyzed and may reveal the emergence of new traffic problem much more rapidly than any other method. Targeted analysis of traffic sensor data may then be used to discover if there is any substance behind the concerns being expressed in the personal communications. This is clearly a worthwhile area for further research.

2.3 Alleviating Privacy Concerns

There is considerable ongoing debate about loss of privacy with data fusion and mining. An architecture has been proposed for privacy considerations to be integral to database design in the so-called ‘Hippocratic Database’ (Agrawal, 2002). This takes its name from the Hippocratic Oath, whereby medical doctors swear they will keep confidential anything discovered as a result of their professional relationship with a patient, thus protecting the patient’s privacy regarding their health. The Hippocratic Database takes its basic principles from the OECD data protection guidelines (OECD, 1980). Countries around the world have used these as the basis for data protection laws. Central to the architecture is the concept of purpose – the purpose for which the data is accessed. In compliance with the OECD data protection guidelines, this must be stated and available to the person the data represents.

Work has continued using the Hippocratic Database concept, and has resulted in IBM’s Hippocratic Database Technology (HDB), described by Agrawal (2005). This is a commercial product based on the Hippocratic Database Architecture.

2.4 Addressing Social and Psychological Concerns

Most data fusion projects consider only spatial and temporal factors (physical or hard data fusion) and do not consider the social and psychological aspects (soft data fusion). While physical data fusion is ongoing, there still lacks semantic (social and psychology, such as attitude, belief and social norms) data fusion.

Most human conceptions are semantic information such keywords, concepts and commonsense, so building an ontology and knowledge base is very useful for different groups to share information. Data fusion can achieve better interaction between transport customers and service providers by adding human's attitude to car use, environment and mobility.

2.5 Distributed Data Fusion and Mining

As distributed computing and grid technologies have developed, data fusion and mining is starting to be applied in far more heterogeneous environments. As this is exactly the scenario in which transport is likely to benefit, developments in this area are particularly relevant.

2.5.1 Web Mining

The web is a massive source of information. To attempt to mine this huge resource is an obvious target, and this is a current field of research. There are three different types of web mining (Liu, 2004):

• web content mining, where the actual content of web pages is analyzed. It is very useful for transport related websites. For example, the reported transport incidents from the radio station websites during rush hour and large events.

• web usage mining, where common patterns of the web's usage are found from access logs. It is useful for personalization, system improvement, site modification and business intelligence for transport related websites.

• web structure mining, where the focus is on deriving patterns from the structure of the hyperlinks in the web pages. It is useful for the design of transport related websites.

2.5.2 Grid-based Data Fusion and Mining

As mobility continues to improve, trips crossing cities and countries (especially in Europe) increase rapidly. It is impossible to set and store all of the data sources in one data warehouse. Middleware to facilitate access and integration of data from separate sources is therefore a key requirement which is being addressed by e.g. the Open Grid Services Architecture Data Access and Integration project (OGSA-DAI Project, 2008). This is supported by several current grid middleware projects (Globus Project, 2008; GRIA Project, 2008 and OMII Project, 2008).

Grid-based data mining, and the workflow necessary to orchestrate it, is at the leading edge of current work (Au et al, 2004) describe work done in the Discovery Net e-Science project, and highlights the following major benefits:

- Data from disparate sources may be mined and patterns found in the data as a whole rather than in its source components.
- Workflows can dynamically integrate many different (non co-located) data and analysis services.
- The large computational resources available to a grid user permit different (more computationally intensive) analyses.

In the study of urban air pollution (Au et al, 2004), a sensor array generates huge amounts of data, and the large number of computational resources available on a grid is ideal for processing this data and also permits the correlation with other data sources of different types (for example, weather on the day of collection, traffic concentration, and a wide variety of data about the population's health).

2.6 Data Fusion for Dense Street Networks

There are seldom applications of data fusion occurring in dense street networks, mainly because the quality and quantity is not sufficient. Most data sources are a byproduct (GPS as dispatching, cell phone as voice call, etc) so there are no data quality and sample size requirements for the data. More sensors and more precise data mean more investment, which is unrealistic in some areas.

2.6.1 New Hardware to Harness Multi-Data Sources

Focusing on the dense street network, generally in center cities, there are more communication networks (Wifi, RDS-TMC, Fiber Networks, WiMax, etc), these networks can be used for sensor fusion. New hardware that can receive multiple signals is promising for data fusion.

2.6.2 New Software and Algorithm

For street networks, we must consider the impact of red light, pedestrians, other transportation facilities (bicycle and scooter) and street parking (search for parking behavior). So street traffic conditions should be isolated to only speed information, it should include the red light period, pedestrian behavior and street parking place availability. Data fusion in this case means more advanced algorithms considering the large number of data sources.

2.7 Trends in Future Transport

2.7.1 From "Transport 1.0" to "Transport 2.0"

The existing model in transportation is "Transport 1.0", where data providers (public or private) collect, process and publish data. Pervasive computing environments facilitate a new style, "Transport 2.0", where transport end users can contribute information to define conditions. This pattern may encourage citizens become more involved in the definition of their transport system and, to some degree, will change the transport decision making process from top-down to bottom up.

2.7.2 WikiOK4T (Wiki Ontology and Knowledge for Transportation)

Ontology/Concept/Knowledge gap between different users (policy maker, planner, end user) plays an important role on ensuring an efficient transport system. WikiOK4T will allow every one to define his/her ontology and knowledge and visualize the gap, making it easier for different transport users to achieve the same goal.

2.7.3 From Centralized Architecture to Decentralized Architecture

Most ATIS (Advanced Traveler Information System) need a centralized traffic management center (TMC) that integrates different data sources, which always means the combination of different transport institutions and the need for extensive political skills and negotiations. The massive data sets and personalized data sources make this architecture less scalable. Distributed architectures will make full use of the existing data sources.

2.8 Impacts on the Traditional 4-Step Transportation Planning Model

Transportation has 3 levels: strategic level (strategic transportation planning), tactic level (transportation management) and operation level (transportation operation). Most data fusion happens on the latter two.

2.8.1 Transport Strategic Planning (5-10 years)

The top level requires an integrated city vision (national vision and regional vision) with other information, such as population growth, lifestyle shifts, land use and available land, water and other resources. Data fusion in this level is high-level knowledge fusion. Successful transport planning rests heavily on the particular talents of individual artisans, rather than on State-Of-Practices and best practices.

Data fusion and mining which extracts high-level knowledge about the city is useful to aid policy makers, and urban and transportation planners to make better planning decisions. Data fusion in this level fundamentally changes trip generation, distribution, model split and traffic assignment.

2.8.2 Transport Tactical Planning (6 months-1 year)

Generally speaking, the middle level is the annual transport scheme. This requires transferring long term vision into short time goals. It should consider trip generation and distribution if there are dramatically land use changes (newly built large citizens community, employment transfer from one TAZ (Traffic Analysis Zone) to another TAZ).

Data fusion in this level integrates annual goals with different data sources, such as the infrastructure construction plans, car ownership change, and new transport facilities with daily transport data.

2.8.3 Data Fusion in Transport Operation (Days, Hours, Minutes)

The ground level is the most active level in data fusion. Hundreds of companies are working on this field to provide services to individual drivers. Generally, this level can not change trip generation and destination and even little to do with mode split for most users. However, more detailed and accurate information for public transit may change the quality of service in people's mind, leading to high transit use.

3 Computational Architectures and Models for Data Fusion

The concept of data fusion is not unique to the field of transportation. Work in the fields of Physics, Computer Science and Mathematics has tackled important challenges of sensor fusion. For example, estimators such Kalman Filters, Neural Networks, Fuzzy Sets or Bayesian Networks already allow for the aggregation of information from different sources. However, these are ideal for *signal* level detail (e.g. aggregating GPS positioning with accelerometer information) as opposed to tasks that demand *information* level detail (e.g. inferring that a car is at a traffic light rather than in congestion by adding GIS map and speed information). We thus need to consider a broader system, one able to cope with several levels and kinds of information, integrate it, and add value to it.

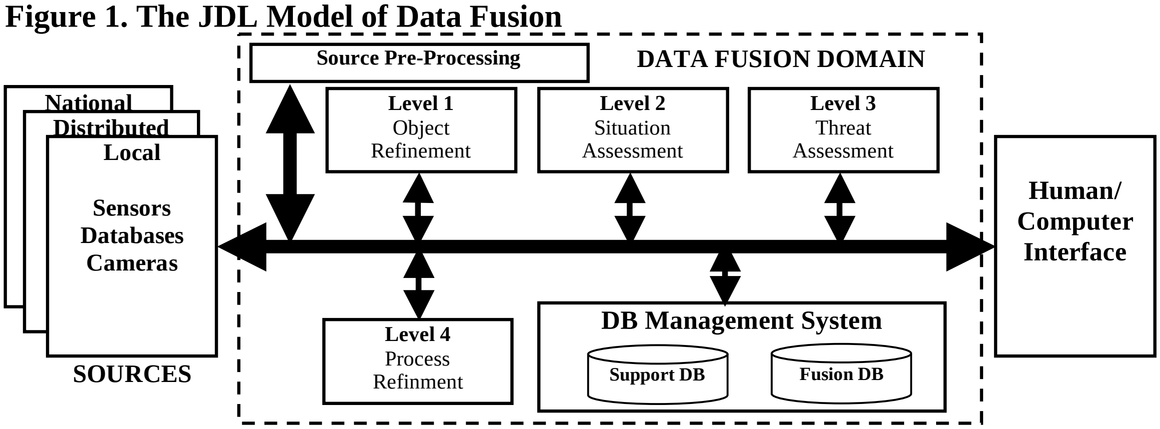
Data fusion technology targets the problem of aggregating data, recorded from multiple data sources, together with knowledge in order to more accurately estimate conditions in the environment and allow for a variety of applications (Wang, 2004). The heterogeneous nature of the data sources demands a robust model that embodies different levels of integration and some specific semantics or protocol to communicate between all system-components. Esteban et al. (2005) synthesize the architectural issues that must be taken into account to develop a platform for multi-sensor data fusion:

- Sensor Distribution for Network Formation: Should sensors be organized in a parallel or a serial (iterative) bus, or combination of both? A parallel sensor configuration is more adapted to identical and to physically and/or distinct sensors, whilst a serial configuration is appropriate to a system where one sensor delivers information to another, augmenting the knowledge available in a hierarchical form.
- Level of Data Representation: A multi-level architecture can enrich the information available, fusing data and knowledge from different sources through different treatments, and providing data with different degrees of representation according to need.
- Architecture Type: Centralized (using raw data) or decentralized (using a pre-processed data)? The former requires less computational capabilities in the sensors and a central hardware capable of dealing with a greater quantity of data, while the latter distributes computational power through the system nodes, adding complexity to the DF process.
- System Feedback: Allows for control of the system via recommendations provided by the architecture's different nodes and levels, implying, of course, more complex architecture.

Several models developed thus far face some or all of these issues. We now describe three of the most representative ones currently in use. JDL (Llinas et al, 2004), first proposed in 1986 as a result of a sub panel from the US Department of Defense to aid the development of military applications (Esteban et al, 2005), presents 4 levels (see Figure 1).

- Level 1, object refinement attempts to locate and identify objects (can be further divided into four processes: data alignment, data association, object estimation, object identity).
- Level 2, situation assessment attempts to construct a picture from incomplete information provided by Level 1, that is, to relate the reconstructed entity with an observed event.
- Level 3, threat assessment interprets Level 2 results in terms of possible operational opportunities, analyzing relative advantages/disadvantages of different courses of action.
- Level 4, process refinement loops around these three levels to monitor performance, identify potential sources of information enhancement, and optimize allocation of sensors.

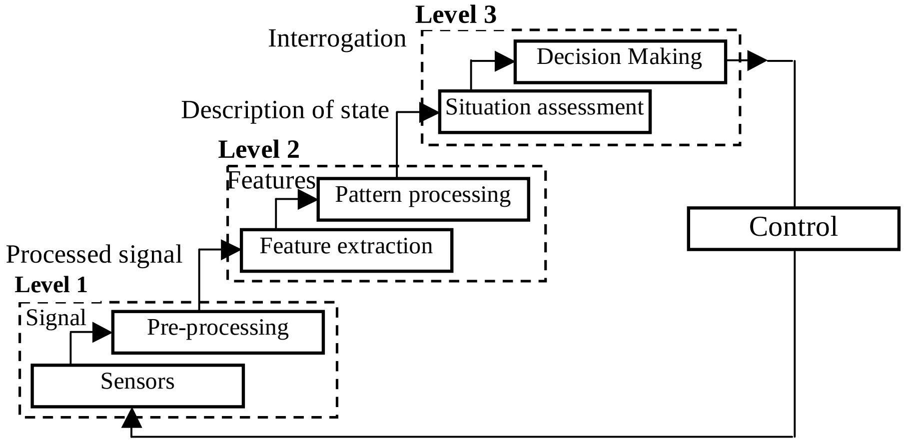
Figure 1. The JDL Model of Data Fusion



JDL assumes a parallel organization of input data (all information fed into the pipeline), although a serial process could be acceptable. It has several internal levels of information representation, not implying a specific one for input. A centralized architecture, it does all the "pre-processing" itself. Finally, the system has a feedback mechanism.

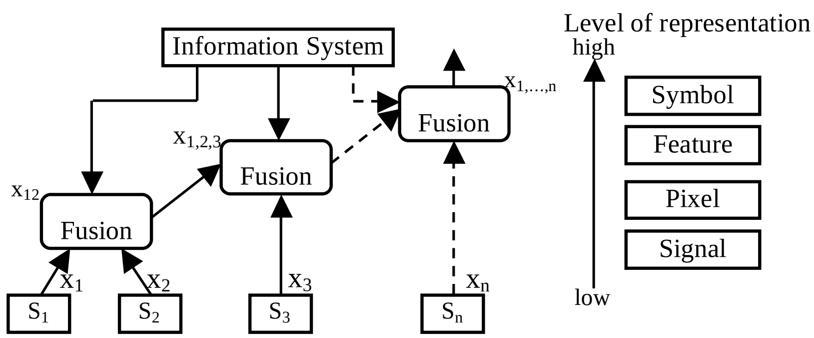
Harris et al. (1998) proposed the Waterfall model, hierarchical in nature, with the information from one module feeding into the next (Figure 2). The last module (Decision Making) delivers enough information to the control module to calibrate and configure the sensors. Each of the architecture's three levels has two modules, with a closed loop acting in the system. The first level gathers and transforms data from the environment, delivering the processed data and information about the sensors to the next level. The second level extracts and fuses the main features of the data from the first level, thus reducing the quantity of data transmitted and increasing information richness. Building on the previous levels' processing, the third level creates a scenario of events and assembles possible routes of action.

Figure 2. The Waterfall Model of Data Fusion



The Waterfall model does not clearly state that the sources should be parallel or serial (though processing is serial). It assumes centralized control, allows for several levels of representation (similar, in this aspect, to JDL), and proposes a feedback mechanism.

Figure 3. Luo and Kay's (1988) Model of Data Fusion



Luo and Kay (1988) presented a hierarchical model, different from the Waterfall model. While in the Waterfall model all data gathered is processed in a sequential way for all modules, in the Luo and Kay model data from the sensors are added incrementally on different fusion centers (multi-sensor fusion), thus increasing the level of representation from the raw data or signal level to more abstract symbolic representations at the symbol level. This model explicitly proposes the parallel input and processing of data sources, which may enter the system at different stages and levels of representation (as depicted in Figure 3). It is decentralized and does not assume a feedback control.

For ITS applications, the choice of which architecture to implement in each case depends highly on physical, economic, and institutional constraints. Multiple sources of information (e.g. different private data providers and types of data) or centralized institutional relationships (e.g. several private data providers send information to a single public institution) require parallel sensor distribution. Serial distribution is mostly possible with a consortium of closely related providers (that enables the sequential provision of information through a virtual pipeline). The data representation level is strongly linked to the degree of involvement and mutual confidence of institutions, particularly when considering the value of data detail. Higher detail (low level of representation) allows for better accuracy, signifying higher value added; higher detail also introduces important privacy concerns which may pose barriers. Higher levels of representation permit information abstraction that can often be useful (e.g. traffic managers can focus on movement patterns, not individuals). If these choices cannot be clearly decided in the beginning, a flexible model (e.g. Luo and Kay's) will be a good option.

Due to their nature, intelligent transportation applications can become extremely complex (a broad geographic distribution of many different data sources, end users, control mechanisms); on the other hand, their control tends to be centralized, suggesting a centralized organization of the architecture. However, this model is typically less reliable since it depends on a single entity and communications with it. Although the design of distributed architectures is considerably more complex, this complexity makes it more flexible to new additions. This factor should be taken into account, particularly for rapidly growing metropolitan areas.

Finally, feedback raises a number of challenges to DF-based ITS applications, relating to decisions on how to act in the environment to make the system more efficient and how to continuously tune the sensor levels to adapt to the intentions of the control levels. This can become important both for ITS and for quality improvement in the DF system (e.g. changing sensors' parameters to improve estimates). The ideal system will use the sensor information to control the actuators (traffic lights, variable message signs, etc.) with the users following every suggestion made by the system. It will also improve the sensor performance with attention to the dynamics of the system. Due to individual users' behavior and/or the quality of available technologies, the feedback loop design must contribute more to the efficiency of the system than to its entropy.

4 Institutional Players in Transportation Data Fusion

Having reviewed a number of the technical challenges associated with transport data fusion, this section will begin to examine the historical roles that various institutions have played in the transport data fusion/ITS realm. Institutional players have been split into three categories; federal governments, municipal governments, and private industry. We begin with data fusion/ITS initiatives at the federal level.

4.1 Federal Initiatives in data fusion and ITS

As with many federal transportation programs, the majority of the guidance, regulation and initial investment in the ITS realm comes from the Federal level while implementation and the majority of the benefits of ITS are received at the state and metropolitan levels. While the focus of this paper is mainly to understand data fusion and intelligent transportation applications as they relate to metropolitan regions, one cannot ignore the impact that federal policy and funding have had on metropolitan level adoption and implementation of ITS systems. This section will give a brief overview of several Federal level ITS initiatives from around the world.

4.1.1 United Kingdom

4.1.1.1 <u>Introduction</u>

The Transport Direct (TD) program is the national traffic information portal aiming to provide a comprehensive, easy-to-use multi-modal travel information and ticketing service, including integrated journey planning information, real-time information and ticket information.

4.1.1.2 <u>History and background to Transport Direct</u>

Transport Direct was announced as part of the Government's 10-year Plan (Transport 2010) in 2000 as a new, comprehensive, national transport information service, covering all modes of transport, which was a platform to take a radical look at transport policy. The focus is on shifting demand to public transport. The political developments led the Deputy Prime Minister to announce a Transport Direct initiative (Transport Direct Website, 2008). The title Transport Direct is based on the National Health Services' hotline NHS Direct.

The non-profit service is funded and developed by the UK Department for Transport (DFT), the Welsh Assembly Government and the Scottish Executive (DFT, 2008).

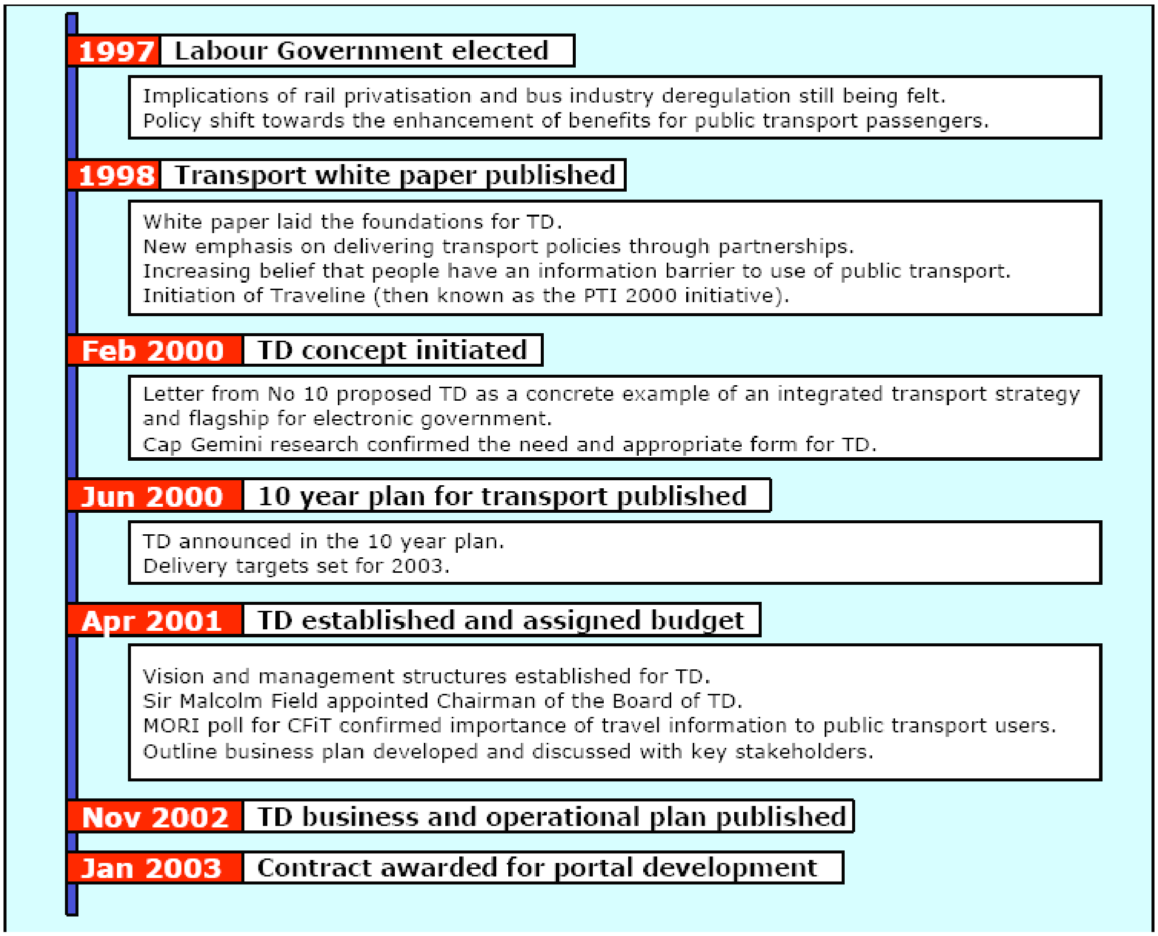
In December 2002, a consortium led by Schlumberger, (now Atos Origin) was awarded the contract to design, build and operate the Transport Direct Portal. The Portal will provide the main point of access to the information provided by the Transport Direct program (AEA Technology, 2007).

The first build of the Portal was completed in December 2003 and was made publicly available in July 2004. This was replaced by an enhanced version on 20 October 2004 and was officially launched on 31 December 2004. (Chris Gibbard, 2006)

Transport Direct works with public and private transport operators, who provide information either directly to Transport Direct or through its partner - traveline, who operate a public transport internet, telephone and text service.

The background and history of Transport Direct is summarized as a timeline in Figure 4, with key dates highlighted in red.

Figure 4: The background and history of Transport Direct



Source: AEA Technology, 2007

4.1.1.3 Vision and Objectives

The vision for Transport Direct, as stated in its business and operational plan, is: “To provide a comprehensive, easy-to-use multi-modal travel information and ticketing service. In the long-term this will provide travelers with integrated journey planning information, real-time information and through ticketing. The vision covers all modes, including mixtures of all the modes.” (AEA Technology, 2007)

Four strategic objectives have been identified for Transport Direct:

- Encourage and stimulate each passenger transport sector to develop high quality and accurate information and retailing systems.
- Create a web Portal to enable users to find all available electronic travel information from a wide range of sources and ticket e-tailers.
- Build on strategic objectives so that transport operators and retailers can develop integrated information and ticket sales for journeys involving more than one mode of transport, including, in the long term, how to get to public transport points by car.
- Deliver Transport Direct as an integrated and comprehensive information service for all travel modes and mode combinations, which allows the user to submit their selection to an e-tailer without re-keying the enquiry.

The government role in Transport Direct is to identify stakeholders, set the pace and direction in terms of targets and audits of the targets, provide standards support, and offer facilitation.

4.1.2 Germany

4.1.2.1 Strategies for the introduction and use of transport telematics

Since 1993, the German Federal Government has intensively addressed the issue of the wide-scale introduction of transport telematics, in order to achieve the following objectives (Federal Ministry of Transport, Building and Housing, 2004):

- to make more efficient use of existing transport infrastructure, especially by reducing and avoiding congestion, empty journeys and traffic in search of its destination;
- to better exploit the inherent advantages of the road, rail, waterborne and air modes by interlinking them to form an integrated overall transport system;
- to enhance traffic safety;
- to reduce traffic-related pollution, especially CO_2 emissions, by exploiting the new technological possibilities for transport organization and management.

In 1995, the Minister of Transport reached agreement with senior transport policymakers from the Federal Government, the federal states and local authorities, and with leading representatives from the public transport sector, the freight transport sector, the automotive, electrical and electronics industries and the service sector on the following principles (Federal Ministry of Transport, Building and Housing, 2004):

- The planning, organization and operation of telematics services are subject to competition and are primarily the task of the private sector. The provision of transport policy guidance remains the responsibility of the appropriate local or regional authorities.
- Priority has to be given to regional and interregional telematics services that strengthen the overall transport system and not just parts thereof.
- Telematics services have to be designed such that they are interoperable and meet uniform European standards.
- Telematics services and systems have to comply with current and any future European and national legislation.

4.1.2.2 National research programs

The Federal Government provides great support to the development of telematics systems and services for transport applications by granting financial assistance to research and development activities.

The Federal Ministry of Education and Research, in close cooperation with the Federal Ministry of Transport, Building and Housing, provided assistance totaling around € 75 million to the five key projects that make up the "Mobility in Conurbations" initiative. The project consortia, comprising representatives from industry, research institutes, the transport sector, service enterprises and advocacy groups, are contributing the same sum from their own resources. The five key projects are,

- WAYflow (Frankfurt/Main),
- Stadtinfo (Cologne),
- Mobinet (Munich),
- Mobilist (Stuttgart) ,
- Intermobil (Dresden)

This initiative is designed to support transport policymakers, the transport industry and the freight transport sector in solving the increasingly complex transport problems. A competition was organized in 1998 and five regions (Munich, Stuttgart, Frankfurt/Main, Dresden and Cologne) were identified in which sustainable organizational forms and technologies were to be developed and tested (BMBF, 2002). The objective was to develop, for each conurbation, a coordinated traffic management concept that takes all transport systems and regional requirements (trade fair traffic, links to long-distance transport, et al) into account. New services, e.g. for commuters, help improve the occupancy rates of passenger cars and make public transport easier to use. The efficient matching of supply to demand, especially in public transport, by introducing new operating procedures was another key area.

The "Mobility in Conurbations" project networks are not, however, defined only by technology and traffic management. Their success depends to a great extent on whether new kinds of transport services in conurbations are accepted by the individual transport users. Demonstrating the solutions developed and evaluating them in terms of transport have thus been an integral part of the projects right from the outset.

An initial review reveals that the findings of the key projects have laid the technological and organizational foundations for public-private traffic management strategies, which will be one of the major challenges of the future. (BMBF, 2002)

4.1.3 United States

The US was one of the first countries worldwide to recognize the importance of technology in managing transportation systems. One of the earliest examples of technology use in the field of transportation in the US was the TOPICS (Traffic Operation Improvements to Increase Capacity and Safety) program from 1968, focusing on the use of engineering techniques to improve traffic efficiency and safety (FHWA, 2008a). This was followed in the 1970's by federal mandates requiring MPO's to develop transportation system management plans, which often relied on technology.

Official program status for ITS was established in 1991 with the authorization of ISTEA, the Intermodal Surface Transportation Equity Act, the US Highway Bill. Title VI of ISTEA established the Intelligent Vehicle-Highway System (IVHS) Program, which was eventually renamed the Intelligent Transportation System (ITS) Program (Franklin COG, 2007). The IVHS Program aimed to facilitate the deployment of new technologies, and to improve efficiency, safety and traveler convenience. To accomplish these goals, the program focused on three main efforts:

- Basic Research and Development
- Operational tests serving as bridges between basic research and full deployment, and
- Deployment support activities that facilitate the implementation of integrated ITS technologies (FHWA, 2008a).

With the creation of the IVHS Program, a plan of action for guiding the direction of ITS growth was needed. ITS America, an ITS advocacy group, was established and helped direct this effort through the creation of the IVHS Strategic Plan in 1992 and the National ITS Program Plan in 1995, establishing a national ITS architecture. ITS America was established in 1991 as the organization responsible for guiding research, development and deployment of ITS services. They work with various levels of government, research institutions and private industry in the ITS field (ITS America, 2008).

Initial funding at the federal level was substantial, with authorizations through ISTEA (1992 – 1997) totaling $1.2 Billion USD and through TEA-21 (1998 – 2003) totaling $1.3 Billion. These funds were for a combination of research & development, and deployment. With SAFETEA-LU (2005 – 2009), funding for ITS deployment ended although $110 Million for further research was authorized. This does not mean that ITS deployment has ceased; since TEA-21, states may still use Federal-aid funding sources such as State Transportation Planning (STP) funds to deploy ITS services (FHWA, 2008a).

The current focus of US federal ITS research is the Vehicle-Infrastructure Integration (VII) initiative. The VII initiative aims to improve safety and congestion by creating information systems that enable vehicle-to-vehicle and vehicle-to-roadside infrastructure communication (FHWA, 2008a).

4.1.4 Japan

The history of ITS initiatives in Japan began in 1973 with the Comprehensive Automobile Traffic Control System, one of the first examples of technology used to improve traffic. In the 1980's, the federal government was involved in two major initiatives called the Road-Automobile Communications System (RACS) and the Advanced Mobile Traffic Information and Communication System (AMTICS). Both of these systems were the foundation upon which the Vehicle Information Communication System (VICS) was built, Japan's nationwide Advanced Traveler Information System (Japanese MILT, 2004).

Beginning in the early 1990's, the federal government began planning for a nationwide traveler information system and for an integrated ITS system more generally. The information would eventually be called VICS, or Vehicle Information Communication System. Three government agencies were actively involved in ITS system planning in Japan, namely the Ministry of Land, Infrastructure & Transportation, the National Police Agency and the Ministry of Economy, Trade & Industry (VICS Center, 2008). A demonstration of the in-vehicle technology was undertaken in 1993 and by 1995 the Traffic Information Systems Center was open for testing and initial operation. VICS was officially launched in 1996 and the Japanese government announced that they would expand their investment in ITS related systems and services by allocating 59.6 Billion Yen ($545 Million USD) for system and infrastructure and 7.4 Billion Yen ($68 Million USD) for continued Research and Development (Japanese MILT, 2004). The VICS system is an in-vehicle navigation device that receives real-time information through a variety of mediums including roadside RF beacons, infrared beacons and through a dedicated FM radio band. The institutional arrangement with VICS was interesting; the federal government established standards regarding minimal levels of service that would be required for a VICS-compatible in-vehicle device and approached industry to actually construct the infrastructure. Any private firm in Japan can produce VICS devices so long as they meet the federal standards. Users may choose to purchase VICS devices as an after-market addition to their vehicle, or purchase a vehicle with a VICS device already installed. Users pay once for the hardware and receive updates and information free of charge for the life of the device. By 2003, nationwide deployment of the VICS infrastructure and communication technology was complete (Japanese MILT, 2004). In 2007, 20.4 Million VICS devices were installed in Japanese vehicles (Japanese MILT, 2007). With a total private vehicle population of approximately 57 Million in Japan, this is a penetration rate of approximately 36%, assuming all VICS devices are still in service.

ITS Japan (known until 2001 as VERTIS, the Vehicle, Road & Traffic Intelligence Society) is Japan's ITS advocacy organization and had been encouraging collaboration between different levels of government, industry and academia. ITS Japan established Japan's initial ITS standards and continues to be actively involved in this area (ITS Japan, 2008).

Japan has recently embarked on the next phase of their ITS strategy with a program called SmartWay. Initial planning began in the early part of this decade and the program was approved in 2005. SmartWay relies on Dedicated Short Range Communication (DSRC) technology from roadside infrastructure to communicate events to drivers. The main focus is on safety with applications encouraging drivers to slow down, or be aware of sharp curves in the road ahead. The range of information services is also being expanded with the provision of weather and parking information. A demonstration of the service was conducted in May 2007 (Japanese MILT, 2007).

4.1.5 Korea

Growth in ITS applications began to take off in Korea in the early 1990's, fueled by advances in information processing, advanced communication technologies and sophisticated vehicle technologies. The Ministry of Construction and Transportation created a National ITS Master Plan in 1997 (updated in 2001) and followed it with a Research and Development Plan in the same year (Ministry of Construction and Transport, 2002). The ITS Master Plan aimed to guide development in Korea in four phases over a 20 year period. The major outcomes envisioned included improved safety, increased transportation system efficiency, increased driving comfort and reduced environmental effects. To achieve these outcomes, the plan focused on seven service areas:

- Transportation Management Optimization
- Electronic Fare/Toll Collection
- Traffic Information Services
- Value Added Travel Information
- Public Transportation Services
- Freight Transportation Services, and
- Advanced Vehicle and Highway Services

Over the 20 year life of the Plan, $123 Million USD was committed for Research and Development and nearly $7 Billion USD for design and systems implementation. Of this budget, approximately 70% was dedicated to Transportation Management Optimization (Ministry of Construction and Transport, 2002).

By 1999, the federal government had approved legislation that would help guide ITS development (the Transportation Systems Efficiency Act) and funded their first demonstration project called the ITS Model Cities Project (Ministry of Construction and Transport, 2002). ITS Model Cities selected three Korean municipalities of different sizes and provided $75.5 Million (USD) in grant funding over two years. The goal of the project was to demonstrate advanced ITS applications and encourage private-public coordination (Cheol et al., 2006). ITS Korea was established in 1999 to encourage cooperative ITS research and development between government, academia and private industry. The following year, in 2000, the National ITS Architecture and National ITS standards were approved (ITS Korea, 2008).

4.1.6 Singapore

Singapore is widely seen as one of the earliest adopters of technology for improving transportation systems, but it was not until very recently that they had a national level ITS strategy. Every five years, the Land Transport Authority creates a new Transport Land Use Master Plan to guide growth. Historically, this master plan has included a section on the uses of technology in Singapore but it wasn’t until the 2008 Land Transport Master Plan that a formal Singapore ITS Master Plan was developed (Kuang, 2007; Singapore LTA, 2008b). The ITS Master Plan had not been released at the time of paper publication, but it is expected to project forward to 2020.

Some would argue that Singapore’s use of technology in the transportation realm began in the 1970’s with the Area Licensing Scheme, a highly manual system of charging motorists entering the CBD. Others would likely suggest that Singapore’s ITS experiences commenced in the early 1990’s with the review and implementation of the Electronic Road Pricing (ERP) system in 1996 (Singapore LTA, 2008a). Since than, Singapore has implemented a variety of ITS applications including an expressway monitoring system, an automated traffic signal system, an intersection monitoring system and most recently a parking guidance system (Singapore LTA, 2008c).

Singapore has had several ITS projects cancelled in the early part of this decade. In 2000, the LTA embarked on a GPS-based location identification system for their transit buses. In 2003, after several delays, the project was cancelled due to technical and institutional issues. In 2002, they also embarked on a GPS-based, integrated fare system for their transit buses. The system was to charge passengers based on the distance they traveled. The project was cancelled in 2004 due to technical issues related to the urban canyon effect, and the inability to accurately determine fares when transit vehicles deviated from their fixed routes (Fwa, 2004).

4.2 The Metropolitan Contexts, US Cases

There are a variety of metropolitan-level ITS applications that have been developed across the US. In this section, we select two typical cities as case studies. The analysis describes the systems based on institutional, functional, physical, financial and performance characteristics.

4.2.1 Metropolitan Atlanta ATIS/ATMS System

4.2.1.1 Introduction

The metropolitan area of Atlanta, GA has used various systems over time to provide information to travelers in the region. Two such systems, the Atlanta Traveler Information Showcase (TIS) and the Georgia NaviGAtor system, were both implemented prior to the city's hosting of the 1996 Olympic Games. While effectively separate systems, results from the TIS were used to inform how information from the NaviGAtor program could be most effectively shared with travelers. Both systems combined various sources of travel information in one system and disseminated it to the public for better transport decision-making.

4.2.1.2 Institution

The Georgia NaviGAtor system is a collaborative effort among different stakeholders. The main Traffic Management Center (TMC) is located in Atlanta and will be connected to a second TMC under construction in Macon, GA. Five additional traffic control centers in the counties surrounding Atlanta have full access to TMC resources as does the control center within MARTA, the regional transit provider. These control centers can use the TMC data and can add incidents that they are aware of in their area to the main TMC data feed. MARTA drivers frequently communicate incidents and delays for inclusion in the NaviGAtor system. The physical building in which the TMC resides also houses the Highway Emergency Management Center, ensuring a rapid response to incidents (Koser, 2005).

From a contractual standpoint, this system was one of the first examples of an ITS system implementation using a systems integrator. GDOT began with a "Design-Bid-Build" contract but split the design component and build component between two separate contractors. For an ITS contract that relies on ever changing technologies, this can be a very risky method of contracting. To ensure that the design and construction of the system took place smoothly, GDOT hired a third contractor to oversee the design and construction contractors. The systems integrator contract was a cost plus fixed-fee arrangement. By proceeding in this manner, GDOT ensured that they received a well integrated and functional system based on the latest technology, while still remaining within state and federal procurement rules (Trombly & Luttrell, 2000).

4.2.1.3 Functionality

Atlanta's TIS Kiosk system was developed using a grant from FHWA as a demonstration of advanced traveler information systems. The project installed 130 information kiosks through out Georgia, with the majority placed in Atlanta. A traveler could use the kiosk to obtain up-to-date information on the best route to a destination, local attractions, real-time traffic and incidents, MARTA bus and train schedules, special events and Olympic Game schedules (during the Games) (Williams, 1996). Although the transit component was not in real-time, this was one of the first basic multi-modal traveler information systems.

The Georgia NaviGAtor system was funded by the FHWA as an advanced traffic management system demonstration. In sponsoring the NaviGAtor system, the federal government was eager to demonstrate that ITS systems were not simply a tool for transportation management agencies but could provide important information directly to the public. While the primary goal was to showcase an advanced traffic and incident management system at the 1996 Olympic Games, the Georgia NaviGAtor has become an essential tool in dealing with congestion in the Atlanta metro area and now forms the backbone for Georgia's state-wide ITS system (Trombly & Luttrell, 2000).

4.2.1.4 Physical Characteristics

The Atlanta Traveler Information Showcase consisted of 130 travel information kiosks. The kiosks consisted of a computer terminal with a touch screen and a printer, connected to the internet via a modem (Williams, 1996).

The NaviGAtor system has grown over time into an elaborate array of data detection devices. The TMC has access to 350 full color CCTV cameras used to monitor roadways and confirm incident events, 1,360 fixed position, black-and-white cameras used to measure traffic speed and volume, several dozens Highway Emergency Response Operators (HEROs) that respond to incidents and provide real-time updates on road conditions, 100 variable message signs to communicate traffic events to commuters on the network, and a feed of cellular-based, floating car data provided by Cellint on the GA-400 segment of the Atlanta network (Schuman & Sherer, 2001). In addition to these advanced technologies, NaviGAtor also uses incident/delay information provided by MARTA, the regional transit provider, motorists, police and local agencies engaged in construction activities (FHWA, 1999).

Information from NaviGAtor is disseminated in a variety of ways including RSS feed, personal e-mail messages, through web access, via handheld devices such as PDAs and cellular phones and via a toll-free phone number (GDOT, 2008).

The NaviGAtor system has gathered an enormous amount of traffic volume and speed information over time. With this archived data, estimated travel times from certain points on the system to other points is available to travelers during the morning and evening peak periods (Schuman & Sherer, 2001). This information is only available for Interstate highways and major state routes within the Atlanta area.

One of the most innovative aspects of the NaviGAtor system is the "myNaviGAtor" feature which allows users to create and save personalized profiles including travel maps, the most relevant traffic cameras on their journeys and estimated trip times for their most popular routes. This feature is accessible through any device with an internet connection and can save users substantial time (Meehan & Rupert, 2004).

4.2.1.5 Financial

The Atlanta TIS system was funded entirely by the FHWA, FTA and several state agencies to the tune of $14 Million. The TIS system was more expensive than anticipated and post-implementation evaluation had to be scaled back (FHWA, 1998a). Ongoing operating expenses are not known.

The NaviGAtor system was financed through an 80% federal/20% state demonstration grant. Federal monies were provided through Intermodal Surface Transportation Equity Act (ISTEA), Congestion Mitigation and Air Quality (CMAQ) funding stream. The initial cost was $140 Million (FHWA, 1999). Additional costs associated with system improvements and ongoing operating expenses are unknown. For example, the financial arrangements surrounding GDOT's agreement in 2006 to begin using floating car data provided by Cellint are unknown.

4.2.1.6 Performance Metrics

The Atlanta TIS system gathered anonymous information regarding use of the kiosks throughout the trial period, and user surveys were conducted to determine user preferences. The system was rated slightly more favorably during the Olympic Games than after the Games (FHWA, 1998a). Interestingly, during the Games the most popular content accessed from the kiosks was weather information followed by Olympic information and tourist activities. Traffic information was the 4th most commonly accessed type of information, but was deemed to be the most valuable type of information provided by the system (FHWA, 1998a). Results from tourist centers employing the kiosks after the Games had very similar results with tourist information being the most popular and traffic information remaining a less popular type of information.

While no formal performance metrics have been outlined for the Atlanta NaviGAtor system, it is regarded as one of the most advanced ATIS/ATMS systems in the US.

4.2.2 Seattle and the Washington State Traveler Information System

4.2.2.1 Introduction

The Seattle and Washington State traveler information system is an interesting comparison and contrast to the Atlanta NaviGAtor system. While the Seattle system has been funded largely by the federal government and focuses on providing advanced traveler information much like the NaviGAtor system, it is also a successful example of a public-private partnership in ITS systems implementation. The Seattle system also has a much stronger focus on multi-modal functionality and statewide coverage. The final defining characteristic of the Seattle system is that rather than funding the development of ITS applications and infrastructure, the focus of the work in Seattle was on properly integrating a number of existing ITS applications.

4.2.2.2 Institution

One of the unique institutional factors with ITS development in Seattle was the focus on public-private partnerships in developing ITS applications. At the outset, this arrangement led to many delays as government agencies and private firms had to determine what their roles and responsibilities were on specific task orders (FHWA, 2000).

Much like the Georgia NaviGAtor system, the Seattle ITS initiatives required a "systems integrator" to oversee the integration of applications. However, unlike the NaviGAtor example, the public-private partnership approach allowed the Washington State DOT to sole-source their contracts to private sector participants while still complying with federal procurement regulations, thereby speeding up the deployment and evaluation process (FHWA, 2000). Georgia DOT was forced to accept competitive bids, requiring a lengthy and involved procurement process.

It should also be noted that the Seattle region has long been a leader in using technology to address transportation problems. Understanding this inherent difference in Seattle, namely that ITS applications already existed and the focus was on integration, may suggest that the results observed in Seattle are not particularly relevant to other metropolitan areas.

4.2.2.3 Functionality

The Seattle Metropolitan Model Deployment Initiative (MMID), also known as SmartTrek, was initiated in the fall of 1996 by a grant from the Federal government to showcase various ITS applications used by specific agencies in the Puget Sound region and throughout the State of Washington. The two overarching goals of the program were to build upon existing institutional relationships working specifically with private sector partners, and showcasing an integrated, regional, multi-modal traveler information system (FHWA, 2000).

SmartTrek evolved into a partnership between 25 public agencies and private firms working to integrate 29 intelligent transportation applications (Wilbur, 1998). These applications fit into several broad categories including an advanced transportation management system with a traffic/transit management center, multi-modal traveler information including a 511 telephone information system, coordinated signal operations and a commercial vehicle information system including state-wide road, weather & border crossing information (IBI Group, 2001).

4.2.2.4 Physical Characteristics

The Seattle MMID system comprises numerous ITS applications, for which adequate summaries of the technological capabilities of all applications was not feasible. The major systems are described here.

Seattle's freeway management system comprises 2,500 roadways sensors (mostly loop detectors), 200 CCTV cameras providing live transportation feeds, +100 variable message signs, 113 ramp meters and numerous call boxes. This information is fed back to two Traffic Systems Management Centers via a fiber optic communications network (Wilbur, 1998). This information is processed and transmitted to users through a variety of mediums.

ITS applications are also being used to provide better travel information for transit services in the Seattle region. King County Metro, the Seattle regions' primary transit provider, has GPS-based Automatic Vehicle Location (AVL) systems on all 1,300 of their buses. This data is used for fleet tracking and management as well as providing customers with almost real-time information on the location of buses through their 'Tracker' feature. The 'Tracker' feature allows users to view the current location of buses on a map, create personal alerts that notify users once a bus passes a certain point on its route, such as a pre-determined intersection, and provides predicted arrival times for the next bus if a specific bus stop is chosen (King County Gov., 2008). All Washington State ferries are also equipped with GPS-based AVL systems. Through the State Ferries website, users can access real-time ferry locations, estimated wait times at the ferry terminals & almost real-time, still images of ferry terminal queues (WSDOT, 2008b).

Commercial vehicles were also considered when designing the statewide architecture. Commercial vehicle operators have reacted positively to the Highway Advisory Radio (HAR) broadcasts and the provision of estimated border crossing wait times at the Canadian border. WSDOT has installed Weigh-in-Motion sensors on major highways that allow frequent commercial vehicle drivers to by-pass traditional weigh stations if they have an Automatic Vehicle Identification (AVI) transponders installed (FHWA, 2000).

Weather information in the Seattle area (and across the state) can be highly variable so WSDOT provides a variety of weather information. Users can access current air temperature and weather conditions across the state, pavement temperatures, ocean conditions that may affect ferry schedules, highway advisories and detailed forecasts (FHWA, 2000).

All of this information is provided through a variety of communications means. The most popular information source according to surveys is the WSDOT website, which is used heavily by both commuters and occasional drivers. The heaviest use of the website was generally seen on days with adverse weather. TrafficTV, a cable television channel providing real-time traffic, weather and incident information, had a much smaller set of frequent users. Highway Advisory Radio broadcasts were not particularly popular with daily commuters, but received high marks from commercial vehicle drivers. Transit information was provided on the King County Metro website, at transit centers and at the Seattle-Tacoma International Airport. Real-time bus arrival/departure times were the most popular sources of information for users, although surveys suggested that this information did not increase user satisfaction of their transit experience (FHWA, 2000).

4.2.2.5 Financial

The Seattle MMDI initiative had a total cost of $17.9 Million. Seattle was one of four cities chosen to showcase ITS applications in a metropolitan setting. The Federal government, through funding provided by FHWA and FTA, contributed $13.7 Million, or 77% of total project funds (FHWA, 2000). It is not clear which stakeholders contributed the remaining $4.2 Million. Given the Public-Private nature of the initiative, it is conceivable that private firms contributed some the remaining funds. It is also possible that state and local agencies covered the additional amounts.

Once again, it should be noted that this relatively low project cost is largely attributed to the fact that the MMID contract was mainly for systems integration rather than ITS application design or development.

4.2.2.6 Performance Metrics

One of the main focuses of the Seattle MMID initiative was to gauge user perceptions of different ITS applications. Numerous surveys were conducted and yielded some interesting results. The detailed survey results can be read in FHWA (2000). Some of these results were particularly helpful at determining the types of travel information and the communication methods that users find most beneficial.

At the highest level, one of the most interesting findings was that only 37% of respondents said they made any sort of change to their daily travel (changed departure time, switched modes, etc.) based on the real-time information provided to them, yet 75% of respondents claimed that access to real-time information helped them “reduce the stress of traveling in the Seattle area” (Pierce & Lappin, 2003). One interpretation of these results is that although travel information does not cause users to modify their behavior, the greater level of travel time reliability (or decrease in uncertainty) is a psychological benefit to users. A different interpretation may be that real-time information is viewed as beneficial to many users, yet individual travel schedules do not allow for mode switching, departure time changes, etc.

4.3 The Metropolitan Contexts, EU Cases

Different cities have different strategies in their development of advanced traveler information systems. In this section we discuss four European cities (Berlin, Munich, Stockholm and London). Different aspects of their respective ITS adoption strategies are described.

4.3.1 Berlin, Germany

4.3.1.1 <u>Institution</u>

The VMZ Berlin project, led by Siemens AG and Daimler Chrysler, is the development of mobility management in Berlin. Berlin entered into a 10-year public-private partnership with a Daimler Chrysler/Siemens-led consortium to provide new detection devices, a state-of-the-art TMC (Traffic Management Center), and value-added user services called "The Berlin Model." Private-sector organizational control of VMZ is held by Daimler Chrysler AG Services (51 percent) and Siemens AG (49 percent). (Bernd Leitsch, 2003)

Berlin is the first city in Germany with a public-private partnership (The Berlin Model). The partnership covers capital costs (13.8 million Euros). The city owns the system and will provide start-up funding/operating subsidization for the first 2 years (2.5 million Euros) to help the private sector reach its goal.

The city provides all its data from the TCC (Traffic Control Center) to the private partner at the TMC. The TMC and TCC are connected and have a common data pool. All data is required to be shared with the TCC and be available to public agencies. Value-added services developed by the TMC would not be available to the agencies. TCC data must be available to everyone—even if another private group comes in. The TMC information will not be available to all. The TMC/TCC share workspace and some equipment. The city would prefer that the TMC be a solely private operation (i.e., with private money), but this was not realistic, so the public-private partnership was created. The TMC will install new equipment that will be maintained by VMZ, which will cover all maintenance costs. Data quality is specifically addressed in the contract (Siemens AG, 2006a, 2006b, 2008). The TMC will provide on-line itinerary/trip planning and traffic forecasting to the users. The overall result of VMZ (TMC) and the TCC combined will be to influence demand and provide sustainable traffic management.

The contract contains no profit- or revenue-sharing provisions. The city would prefer that VMZ put profits into new user services or system enhancements. VMZ must provide the TCC with free data and information and make sure that the TMC is state of the art. The VMZ must provide information from the motorway and public transport systems as well. The request for proposals and subsequent contract focused on functional specifications and quality of data, not on technical specifications.

With regard to intellectual property, the City of Berlin can use the data collected and system provided by VMZ in Berlin. Daimler Chrysler and Siemens can sell the data and market the system elsewhere. The city financed the system and it will receive the system, including software, hardware, etc., at the end of the contract (10 years).

4.3.1.2 Functionality

4.3.1.2.1 Multimode route planner (inside the city)

The multimode route planner considers several Travel modes, including Auto Routes, Park & Ride, Bike & Ride, Public Transport, Public Transport & Bike, Bicycle and Walking. Users can choose the departure time or arrival time, select economic or fastest route. The results of intermodal routing are based on historic travel time patterns and police reports. This capability will enable comparisons of transit versus car travel times.

4.3.1.2.2 To and from Berlin(Intercity by car) designed by PTV RouteService

The platform considers the characteristics of vehicles and drivers. Users can choose faster car/driver, average car/driver and slower car/driver choices to get related route recommendations. The algorithm allows three optimizations, namely, quickest route, cheapest route and shortest route. (Peter Vortisch, 2001)

4.3.1.2.3 Public Transport route planner

The Public Transport route planner provides Time Tables information, Route Information, Transit Maps, Fares & Tickets information and Passenger Services.

4.3.1.2.4 Other Means of Travel

Other means of travel includes Long Distance Bus, Taxi Cabs, Liftsharing, Rent a Bike, Car Rental, Sightseeing, Ship - Round Trip and Airplane - Round Trip.

4.3.1.2.5 Traffic Information

The traffic information includes real time traffic incidents, traffic maps, real time traffic situation and forecasts, and real time traffic camera streaming data.

4.3.1.2.6 Weather Information

Weather information provides current weather information, three day forecasts, weekend forecasts and weather worldwide.

4.3.1.2.7 Other functionality

Other functionality includes parking information and real time flight information, Jam Warning services and city maps

4.3.1.3 Physical Characteristics

Data sources include public transport, parking garages, detection devices, RDS-TMC, floating car data, and others. Data collection consists of the infrared traffic eye. There are 180 infrared detectors on arterials, 25 in parking garages, and traffic information on 25 VMSs in Berlin. Parking garage information is provided by one of the partners, BMW, which is in charge of this element of the project. The infrared traffic eye contains a solar panel and cabinet and can be placed on many types of structures. It provides vehicle speed and length and needs one cabinet for up to six detectors. (Reinhard Gielher & Ralf Kohlen, 2006)

4.3.1.4 Information dispatching

The website is **www.vmzberlin.de.** Customer access will be through the Internet using a PC or PDA, GSM, GRPS/WAP mobile telephones, print media, TV, radio, telephone, fax, and information panels (VMS).

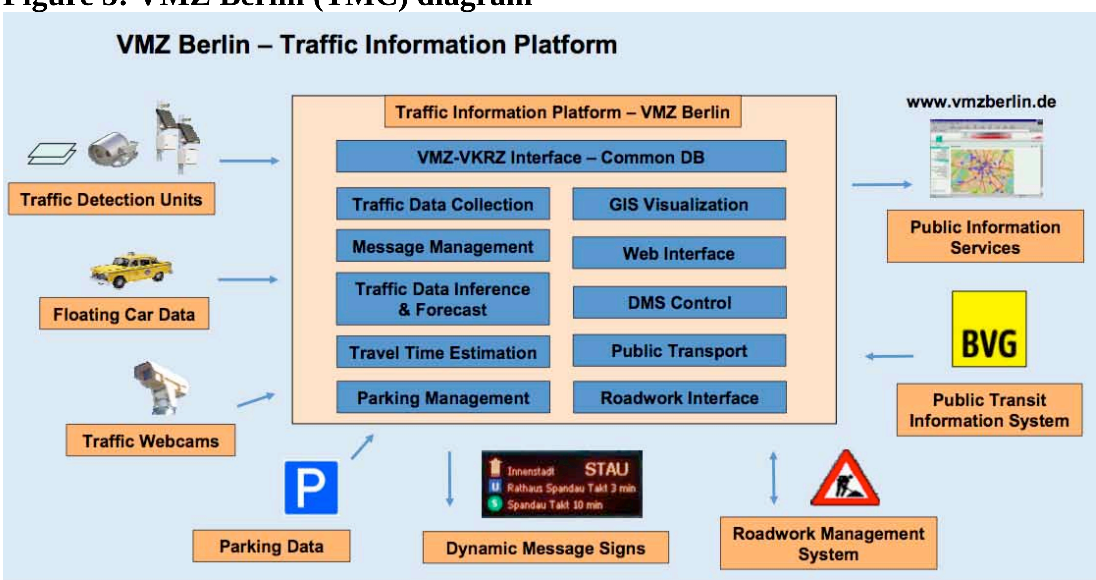
4.3.1.5 Data requirements and standards

VMZ will create a standard interface where necessary and will make its data feeds available. Currently, it is using XML and SOAP protocol interfaces for data collection and data feeds.

4.3.1.6 Technical description

VMZ data is directly obtained from a wide number of sources (infrared road sensors, inductive loops, cameras, FCD), but the system is open and expandable. VMZ Berlin platform diagram is shown in Figure 5, Figure 6 and Figure 7.

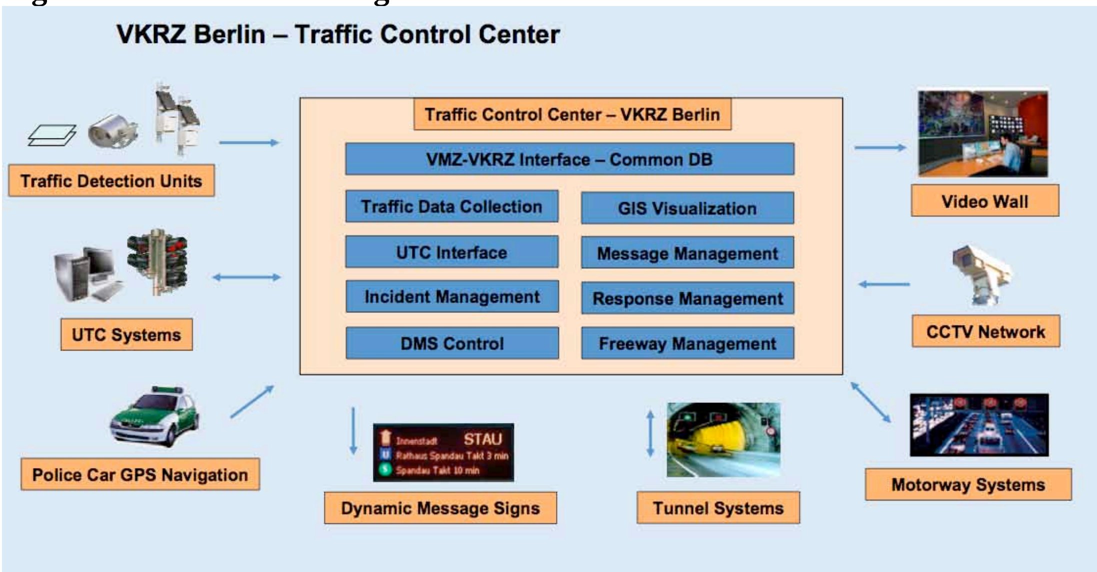
Figure 5: VMZ Berlin (TMC) diagram



Source: Siemens AG, 2006b

Aside from the "default" TMC sources, provided by Siemens and DaimlerChrysler, other sources are being added that improve the quality of the system. VKRZ Berlin, a Traffic Control Center (TCC) also provides information from other sources (additional road sensors, police GPS information and additional cameras).

Figure 6: VKRZ Berlin diagram



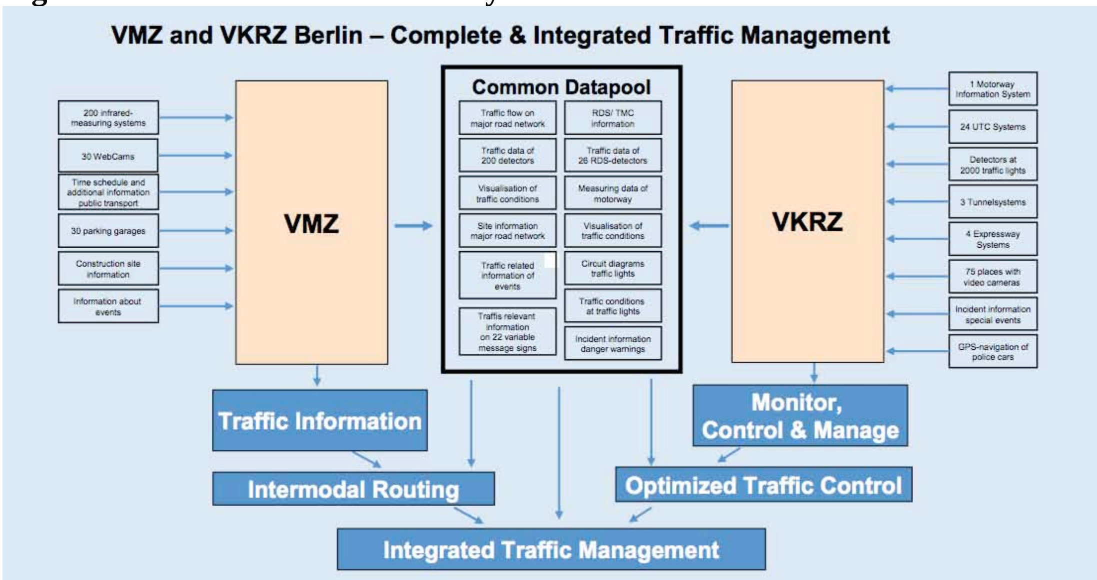
Source: Siemens AG, 2006b

The integration of the TMC and TCC sides is made via a shared datapool. At this level, we cannot know where exactly data fusion occurs. It seems clear that there are many subsystems on both sides and that different subsets of data are fused in different subsystems. For example, the traffic forecast module integrates knowledge from about 200 road detectors of traffic volumes and speeds, and applies a Path Flow Estimator (PFE) to generate forecasts for the next 5 minutes or for the near future (Vortisch & Moehl, 2003). This is however a simple kind of Data Fusion in the sense that information comes from different places in the map, but always has the same representation.

Another example of a Data Fusion subsystem in this platform is the sophisticated image recognition subsystem, ANTAR+Traffic Finder, developed by DLR (German Aerospace), which is also being used in VMZ. ANTAR includes a conventional camera and a thermal imaging camera, as well as an inertial measurement unit for online geo-referencing and a computer unit for the data management. The Traffic Finder software analyses incoming images online – that means identifying cars, classifying by the shape and measuring its velocity – and defines road-based traffic parameters (PTV AG, 2008).

In terms of Data Fusion, VMZ Berlin functions according to several different levels of complexity, from lower levels (e.g. ANTAR+Traffic Finder; PFE) to higher levels (e.g. estimation of flow from cameras, infrared, police, etc.).

Figure 7: VMZ and VKRZ Berlin system



Source: Siemens AG, 2006b

4.3.2 Munich, Germany

The City of Munich is the capital of Bavaria. The City District Administration, which includes transportation, has 2,500 employees. The city has 45,000 employees. The Road Traffic Division (Division IV) is responsible for traffic lights, local traffic control, traffic management, and driver registration. Munich has a 1.2 million population in an area of 370 sq km. In the outer ring highway, there are 2.4 million people in the region of 5,500 sq km. There are 2,200 km of roads in the city, while the region comprises 3,800 km of roads.

Public transport is well developed, with 79 km of underground and 100 km aboveground fast trains in the city. Each weekday, 500,000 people use public transportation. Another 580 km of rail is available outside the city. There are 21 million passengers using the "new" airport every year.

Various ITS benefits have been identified. Dynamic message sign (DMS) are used to tell motorists what is happening up ahead and to provide parking information (park-and-ride) when the sign is not used for traffic management.

4.3.2.1 Institution

Munich’s ITS project (MOBINET Project) includes collaboration between State of Bavaria and City of Munich. The Munich Traffic Control Center includes cooperation among state, city, transit, and rail.

BayernInfo has its origin in a subproject of BAYERN ONLINE - an initiative launched by the Bavarian Government within the framework of the "Offensive Zukunft Bayern" project. (Bayerninfo Websites, 2008)

Initiated and established between 1995 and 2001, the Superior Construction Authority at the Bavarian State Ministry of the Interior operated the service until 2005. During that time its expansion and operation were tendered for another 10 years in form of a Public Private Partnership. (Siemens AG, 2005)

With the contract's conclusion, the VIB Consortium (Verkehrsinformationsagentur Bayern) continued service operations beginning in 2006. Members of the consortium are Siemens, PTV, mdv, micKS and DDG. (Sven Kesselring, 2004)

Over time, the range of services will be revised and expanded until 2008. More modern maps, more accurate information, better forecasts and more details about minor roads as well as the integration of information about neighboring regions are planned.

4.3.2.2 Functionality

Infrastructure-based traveler information systems focus on traffic management (alternate routing, lane control, and urban traffic control), collecting information, public transport (in-vehicle and at stations), and DMS for urban traffic control. Personal traveler information services include telematics applications, Internet/WAP, radio, and RDS-TMC.

Mobinet focuses on multimodal transportation management, innovative transport technologies, and novel mobility services. The structure of MOBINET includes a data network and urban and regional centers. This structure will aim at optimizing traffic in the primary road network; providing multimodal information services, which will try to shift demand to public transport; and applying innovative concepts for a mobile society. With regard to intermodal choice, the project will manage parking spaces, improve public transport, reorganize buses to Underground stations, provide more direct links on the Underground, provide alternate routing signage, and provide information signs. The DMS will show congestion on the network so drivers can choose their ultimate routing. Information services will include urban information (city information, events) and shortest route algorithms; public transport information such as electronic timetables and the integration of various systems; parking information, including available spaces; and information on recreation and leisure (MOBINET Website, 2008).

Four systems will be developed in MOBINET: multimodal infrastructure control; DINO – an on-line traffic model; SAM – strategic management of roads in the Munich area; and PIZ – a parking information center (Fritz Busch, 2005). The multimodal infrastructure control will be a platform to store traffic data, including event data, system operations, and weather and environmental conditions. Strategy implementation will assist with decision rules that will recognize a situation and provide predefined measures. The traffic data analysis will use a spatial filter. Planned types of strategies include large-scale traffic congestion (predicted), local incidents, planned events, environmental situations, weather conditions, and public transport disruptions. The dynamic network modeling will perform traffic assignments in an O-D matrix with 24,000 links, and the output will be estimated current traffic conditions in 15-minute intervals.

Information will include pre-trip and en-route information, transportation alternatives, and the optimizing of personal choice of means of transport.

4.3.2.2.1 Multimode route planner

The multimode route planner includes several travel modes: public transport such as Deutsche Bahn, Commuter train, Underground, Urban underground, Tram, City bus, Regional bus, Night bus, Cable-/Rack railway, Ship, Public Taxi; private transport such as car, taxi, bicycle and walking. User can select departure time or arrival time to calculate the route.

For private car, user can select the speed (fast, normal, slow) and the route (fastest, shortest, cheapest). For bicycle, maximum length of route can be set by the user. For walking, user can set the maximum duration of walk, the walking pace (normal, fast, slowly) and whether carrying heavy luggage. Also the transfer frequency can be set by the user.

4.3.2.2.2 Real time flight information

The platform also provides Real time flight information for departure and arrival information in Munich and Nuremberg.

4.3.2.2.3 Real time and forecast traffic condition

The platform provides traffic reports, Real time and forecast traffic condition, FCD data from Nuremberg and ADAC traffic jam forecasts for the weekend.

4.3.2.3 Physical Characteristics

Munich Traffic Control Center system includes 1,000 traffic lights and detectors and 77 cameras (traffic and in pedestrian areas). The Motorway Control Center (VRZ) uses rain and fog monitors as well as speed detectors. Speed enforcement is performed with radar mounted in the DMS. Other detection includes loops, radar/ultrasonic, and ramp metering. The system has 58 weather stations, 120 visibility (fog) meters, 452 sensor loops, and 93 video cameras. The algorithm uses variable speed per lane, speed of cars, volume of traffic, and ramp metering. (Fritz Busch, 2005)

For Traffic Information System—BayernInfo, Data are collected from detectors, floating cars, traffic counts, and weather. Other information is provided by police, the German Automobile Association, and TV and radio.

4.3.2.4 Information dispatching

For RDS-TMC, BMW’s navigation units use icons instead of text to provide information to drivers. Messages are generated by acquiring data from the traffic information center and other sources. The data are then forwarded to the message processing center at the Bavarian Regional Center and then to the German Automobile Association for transmission to the car.

BMW also has a beacon warning system along motorways (including Munich) that lights red beacons along the road when there is an incident ahead (warning).

Personal travel assistants include cell phones, PDAs, etc. Congestion, incidents, and delays are factored in and changes can be sent out (pushed) to people.

4.3.2.5 Technical description

Mobinet becomes a large array of interconnected projects. Sensor data comes from many sources, mainly road sensors, cameras and Floating Car Data of taxi fleets. Such information is vital for several services such as traffic information, forecasting, route planning and traffic control.

From the available literature, Data Fusion is recognizable in some keys elements of this platform. The most relevant one is the dynamic traffic estimator, DINO (Dynamic Network Monitor), which is executed every 15 minutes. DINO starts by receiving traffic measurements (detector data and floating car data, FCD) valid for the current time interval. Detector data include volumes and either speeds (from motorways double loop detectors) or occupancy rates (from detectors on the city streets). FCD are available from a fleet of taxis. DINO also receives as input a set of previously estimated trip matrices as well as reference trip matrices for the current and future time intervals (selected on the basis of time-of-day, day-of-week and the Occurrence of special events) (Filippo Logi et al, 2001).

The digital network used by DINO is based on a modified version of the GDF-based network acquired by the commercial provider Navigation Technologies B.V. (Navtech), for the state of Bavaria. Specific software was developed to cut the section corresponding to the Munich metropolitan area out of the whole Bavaria network. This section includes all motorway links and all roads in the urban area with the exclusion of minor residential streets. With DINO, MOBINET can use and provide to external users a re-construction of the traffic conditions of the entire network every 15 minutes. The Data Fusion degree involved is clearly complex (different data sources; map matching; O/D Matrix update; several levels of forecasting).

4.3.3 Stockholm, Sweden

Stockholm is a dynamic city located on 14 islands where Lake Mälaren opens into the Baltic Sea. Only two major bridges provide access into central Stockholm and each carries 120,000 to 130,000 vehicles per day. Some 240,000 commuters enter the city each day from a region with 1.8 million inhabitants (760,000 in the city of Stockholm). While Sweden is experiencing traffic growth of 1.5 to 2.0 percent a year, Stockholm’s traffic is increasing at twice that rate, even though the share of peak commuter trips carried on public transport is an impressive 75 percent.

4.3.3.1 Institution

Trafik Stockholm is the brand new joint TMC between the Swedish National Road Administration (SNRA) and the City of Stockholm. The intelligent car and road system is a public-private initiative with SAAB and Volvo. (Trafiken Website, 2008)

4.3.3.2 Functionality

The aim is to describe traffic in greater Stockholm with still pictures on different modes and to present conditions for multimodal travel. It provides information on traffic disruptions; traffic advisories (CCTV, travel times, etc.); travel planning (right now, later); and information on smart travel (best route, combined modes of transport).

Information is currently available on road works and construction; traffic disruptions for commuter cars, buses, subway; rush-hour traffic; road surface conditions; ferry information; park-and-ride information; LOS (colored segments); and normal and actual travel times.

The national traffic information system/database (TRISS) includes road weather, accidents, roadworks, local bearing capacity reductions, and other obstacles, and can be accessed at www.vv.se . This database serves the road conditions website and telephone service.

4.3.3.3 Physical Characteristics

Road weather data include dew point, air temperature, precipitation amount, wind conditions, and road surface temperature. Other Data sources include inductive loops, video, microwave (motorways and south tunnel), infrared, and Sweden is also looking at using GPS data, mobile telephones, Bluetooth, and others.

SNRA is investigating using a probe system in Stockholm. Public transport vehicles will be used as probes for test purposes (around 5,000 vehicles). The project will be expanded to include probes in commercial vehicles and taxis. There is a filtering mechanism between what is sent and what the SNRA receives (speed, directions, coordinates, time, and flag for type of vehicle, because of high occupancy lanes for buses).

The traffic monitoring and data collection is performed in partnership with the police, SOS Alarm (emergency information company), rescue services, public transport, commercial traffic operators, radio stations (traffic advisories), City of Stockholm, and the SNRA. The system uses surveillance cameras, road weather information system, sophisticated signal systems, and motorway control systems.

4.3.3.4 Information dispatching

The SNRA website (www.trafiken.nu), traffic advisory radio and the VMS, telephone service. RDS-TMC provides up-to-the-minute information about accidents, road works, and congestion.

4.3.3.5 Financial

The project funding per year is 20,000,000 Swedish kronas or about $2 million. Seventy-five percent is provided by the SNRA and 25 percent by the city. A Trafik Stockholm Board runs the operation and consists of three SNRA personnel and three city members. (Swedish Road Administration Website, 2008)

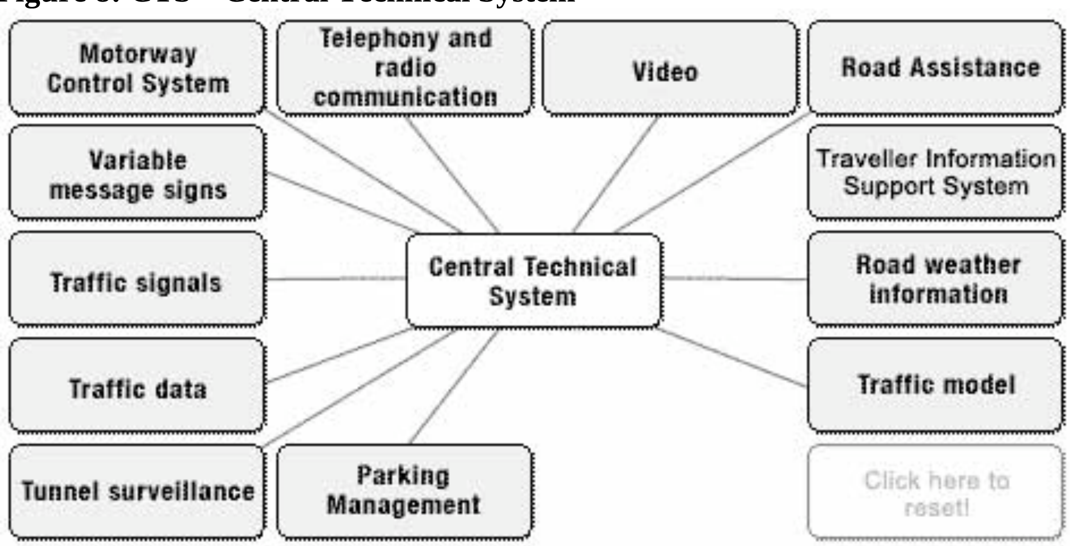
4.3.3.6 Data requirements and standards

The SNRA has developed data quality definitions and documented them. The definitions include data specifications, including quality declarations for the short term and long term. The SNRA has adopted DATEX as the data exchange standard. DATEX was developed by the CEN (European Committee for Standardization).

4.3.3.7 Technical description

Stockholm's traffic management company, Trafik Stockholm, has its core at the Central Technical System (CTS), which basically serves three purposes (eSafety Compendium, 2006, Stockholm CTS, 2008):
- Integrate all the technical systems at Trafik Stockholm
- Provide the traffic operators at Trafik Stockholm with a unified user interface
- Suggests suitable Actions Plans based on incoming information

Figure 8: CTS – Central Technical System



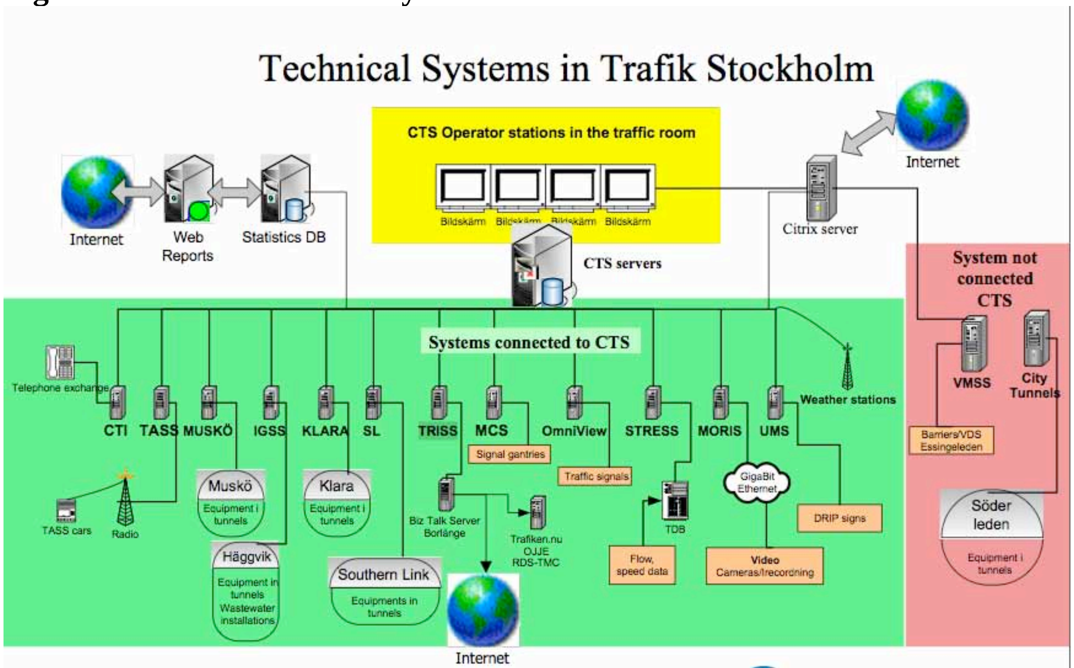
Source: Trafik Stockholm, 2001

In Figure 8, we can seen the organization of the Stockholm CTS, with its 12 subsystems (starting bottom right, counter-clockwise) (Trafik Stockholm, 2001):

- Traffic model - Simulation program containing a large number of traffic situations and possible ensuing scenarios. Helps the operators at Trafik Stockholm make the right decision and take the correct action when an incident occurs.
- Road weather information – RWiS stations (detailed below) installed in and around Stockholm to measure the air and road surface temperature, wind velocity and atmospheric humidity. A camera is used to monitor any changes in the road conditions. This system, combined with information obtained from SMHI (Swedish Meteorological and Hydrological Institute) enables Trafik Stockholm to provide highly accurate information on how and when different weather situations will affect the road conditions, and thereby traffic.

- Traveler Information Support System (TRISS) - TRISS serves as the interface with external users (e.g. road users) via different distribution channels for example e-mail, fax, Internet (www.trafiken.nu), Radio/TV and RDS/TMC.
- Road Assistance - A joint undertaking between the police authorities, the City of Stockholm and the Swedish National Road Administration. The role of Trafik Stockholm is to manage and direct the "Road Assistance" vehicles in their day-to-day operations so that they can quickly be on the spot and help at minor breakdowns, provide petrol for empty tanks, remove hazardous objects lying on the road, etc. The "Road Assistance" team can also provide protection to road users forced to stop at unsuitable spots.
- Video - Image-processing software "reads" the images and sound an alarm at any disruption in the normal traffic pattern.
- Telephony and radio communication. Communication via telephone or radio between the Trafik Stockholm operators and various radio channels, the police, SOS Alarm, the rescue services, the "Road Assistance" team, contractors, etc
- Motorway Control System (MCS) - Automatic traffic queue warning system, activated by sensors that register the speed at which traffic is moving as well as where the queues start and end. Signs above the roadway advise drivers to slow down and/or change lane. At present, an MCS is installed along (E4 European Highway) between the Kista and Norrtull. During the autumn of 2002, the system will be put into operation on the stretch of the E4/Essingeleden from the Eugenia Tunnel to Västberga. There are also plans to install it on several central routes within Stockholm City and on new urban motorways, like Södra Länken.
- Variable message signs. Traffic signs using text characters for dynamic messages
- Traffic signals. Surveillance system for traffic signals. If out of order or affect traffic otherwise, information is sent immediately to the Swedish National Road Administration or the City Streets and Real Estate Administration so that action can be taken.
- Traffic data. Database for traffic information in real time.
- Tunnel surveillance. Monitoring and control of traffic in tunnels in and around Stockholm using a system of cameras, sensors and barriers. Alarm for any malfunctioning in the electrical, cable, control or ventilation installations.
- Parking Management - Automatic surveillance system to assist drivers in finding parking spots in Stockholm City. This helps reduce the amount of "searching" traffic on busy streets.

Figure 9: Trafik Stockholm system architecture



Source: Trafik Stockholm, 2001

In Figure 9, we can also see a more detailed view of the internal architecture of the CTS. As with all the cases previously studied (particularly Berlin and Munich), it is a geographically and conceptually distributed, heterogeneous, system, which has its focus on a central controlling institution (the CTS). The CTS then integrates all of them into a single controlling "room" (Stockholm CTS, 2008). This architecture follows the DATEX guidelines, which is to say that it follows the common European rules for Transportation Infrastructure Telematics. DATEX consists of a set XML standards for communication (DATEX website, 2008).

4.3.4 London

In London, Transport for London (TfL) manages traffic, administers the Congestion Charging Scheme, and oversees public transport, including London's extensive underground and bus networks. Greater London is Europe's largest urban area with more than 7 million inhabitants and employment of 1 million in Central London.

4.3.4.1 <u>Institution</u>

Transport for London is a statutory corporation regulated under local government finance rules. It is governed by the GLA (Greater London Authority) Act. It has three subsidiaries: London Transport Insurance Guernsey Ltd, the TfL Pension Fund Trustee Company and Transport Trading Ltd (which owns all the public transport related companies). The unified institution guarantees the integration of different data sources. (Transport for London, 2008)

It also has collaboration with TrafficMaster, AA and iTIS holdings, Bosch radio TMC system, Volvo navigation system, Toyota in-vehicle RDS-TMC.

4.3.4.2 Functionality

4.3.4.2.1 Multimode Journey Planner

The multimode Journey Planner includes all public transport modes: Rail, DLR, Tube, Tram, Bus, Coach, Boat and Cycle. Users can choose different algorithms, such as the fastest routes, routes with the fewest changes and routes with the least walking between stops. Individual mobility requirements are also considered, e.g. whether user can use stairs, escalators and lifts or need wheelchair accessible vehicles. Meanwhile, passengers can set the cycling and walking options.

4.3.4.2.2 Other functionality

Other functionality includes live travel news about public transit system and road condition (using video cameras); tickets and timetable; parking information; maps of city and transit networks

4.3.4.3 Physical Characteristics

Infrared detectors, license plate readers, Video cameras, advanced floating car data (from Trafficmaster)

4.3.4.4 Information dispatching

The website http://www.tfl.gov.uk/, mobile alerts, SMS, email, RDS-TMC

4.3.4.5 Technical description

In terms of traffic flow management, the London Traffic Control Center (LTCC) uses three different subsystems to control traffic flow with their 6000 traffic lights: locally configured control (3100 units); LTCC configured control, according to time of day (1100 units); Dynamic management with SCOOT (1800 units). SCOOT coordinates the operation of all the traffic signals in an area to give good progression to vehicles through the network.

It obtains information on traffic flows from detectors, which should be ideally on every link, positioned at the upstream end of the approach link. Inductive loops are normally used, but other methods are reportedly being developed (Department for Transport, 2008).

When vehicles pass the detector, SCOOT converts the information into "link profile units" (lpu), a hybrid of link flow and occupancy. This is the unit used by SCOOT in its calculations. "Cyclic flow profiles" of lpu’s over time are constructed for each link.
A SCOOT network is divided into "regions", each containing a number of "nodes" (signaled junctions and pedestrian crossings which are all run at the same cycle time to allow co-ordination). Nodes may be "double cycled" (i.e. operate at half of the regional cycle time) at pedestrian crossings of *undersaturated* junctions. Region boundaries are located where links are long enough for lack of coordination not to matter.
SCOOT has three optimization procedures by which it adjusts signal timings - the Split Optimiser, the Offset Optimiser, and the Cycle Time Optimiser. These give SCOOT its name - Split Cycle and Offset Optimisation Technique. Each optimiser estimates the

effect of a small incremental change in signal timings on the overall performance of the region's traffic signal network. A performance index is used, based on predictions of vehicle delays and stops on each link (Department for Transport, 2008).

Differently from the cases of Berlin or Munich, there is no single integrative platform planned as far as we are aware of. In fact, London contains a highly fragmented set of transportation services and subsystems. There are many reasons for it, namely the dimensions and heterogeneity of the Greater London area both in demographical and in administrative terms, and the privatization of the railways back in 1993 followed by the split of the national bus and London Tube networks into franchises.

4.4 Established Private Industry Players

This section is meant to introduce a variety of established private industry players in the data fusion market. For our purposes, "established private industry player" is defined as a company that is currently offering a product or service to the marketplace and has some form of revenue model in place.

It should become apparent while reading through this section that the largest and most recognized industry players are operating in the Advanced Traveler Information Systems (ATIS) marketplace. ATIS is currently the area where the majority of the development is taking place and where the most innovative examples of data fusion are occurring. One of the main reasons behind this level of activity in the ATIS market appears to be consumer demand, which creates revenue opportunities for firms. Non-ATIS applications do exist but have been overshadowed by developments in the ATIS marketplace.

While we have attempted to cover the majority of the major private industry players in the data fusion realm, we acknowledge that there are ones that we have likely missed. As such, this section should be viewed as a relatively comprehensive list of established industry players, rather than an exhaustive one.

4.4.1 Data Providers – GPS-based

4.4.1.1 <u>INRIX</u>

INRIX is a US-based traffic data provider founded by former executives from Microsoft. INRIX's technology was a spin-off of Microsoft's previous SmartPhlow technology (INRIX, 2005). Traffic data is gathered from stationary sources (DOT data including sensor loops and camera data), toll systems, 650,000 GPS-enabled vehicle probes and a variety of dynamic data including sports events, construction schedules, incidents, weather and even the legislative calendar in Washington, DC (INRIX, 2008). INRIX can provide real-time flow data for 109 US markets and real-time incident data for 113 US markets. Although they have access to fewer fixed sensors than their competitors in the US (namely Navteq), their GPS probe fleet data is by far the most extensive. Once data is gathered, it is cleaned and fused together using a proprietary technology. INRIX also owns a predictive algorithm used to estimate future traffic flow based on past and existing conditions. They provide real-time traffic data, historical average traffic flows & speeds based on archived data. They have recently added real-time gasoline prices to their service offerings. Their fused real-time data is transmitted through a variety of communication channels including SMS text alerts, through the internet, mobile devices, satellite radio, RDS-FM radio, TV and in-car navigation devices. They provide data to TomTom, Garmin and DASH, three of the most advanced navigation device manufacturers. They are also actively working to provide data to state DOT's in the US and have recently agreed to begin providing real-time traffic data to the I-95 Corridor Coalition. They have strategic alliances with Clear Channel Communications, TomTom and iTIS Holdings.

4.4.1.2 iTIS Holdings

iTIS Holdings is a UK-based company that specializes in real-time traffic information and archived traffic data for their traffic prediction service. They gather traffic data from stationary sources (recorded incidents mostly) and GPS-enabled fleet vehicles (AA, National Coach & a large logistics firm). They have approximately 50,000 floating vehicles sensors on the road each day and the largest data warehouse of archived floating vehicle data in the world (iTIS, 2008a). They have been experimenting with cellular-based floating vehicle data with trials in Belgium (nationwide), Tel Aviv, Baltimore & unknown locations in the Czech Republic and Australia (iTIS, 2008b). In 2004, iTIS was awarded a three-year contract to supply the UK Department for Transportation with traffic flow and congestion data. At the completion of that contract, TrafficMaster, another UK based traffic information company, was awarded the new contract. In Feb. 2008, the company announced that they would present trial data from Barcelona, Spain with the intention of moving towards nationwide implementation of floating vehicle sensor data (this is an interesting development as another firm in the marketplace, Navteq, has signed a similar agreement in Spain using data from the same telecom, Telefonica). iTIS has an agreement with INRIX allowing the US company access to UK traffic data for INRIX's international customers.

4.4.1.3 TrafficMaster

TrafficMaster collects, aggregates and disseminates traffic data from 7,500 proprietary fixed sensors, 600 CCTV cameras and 50,000 vehicle probes covering the majority of UK roads (TrafficMaster, 2008). They also process and provide real-time data for 65,000 probe vehicles operating in the US through an agreement with Navteq. They currently hold a three-year contract to provide traffic data to the UK DfT (TrafficMaster, 2007). In addition to data, TrafficMaster provides a fleet tracking package aimed at commercial fleets, navigation services for commuters and a vehicle theft tracking service. The fleet tracking and theft tracking services are GPS-based with GPRS two-way communication capability. The traffic services are offered through existing GPS-enabled devices and as basic traffic data available online and through RTS-FM. TrafficMaster provides the infrastructure and processes all of the data needed for Norwich Union's UK Pay-as-you-Go variable rate insurance (they track distance traveled, road type as well as time of day) (TrafficMaster, 2006).

4.4.1.4 Skymeter

Skymeter is a Canadian-based technology company offering pay-as-you-go services. They became well known for submitting one of the only non-RFID technology proposals for congestion pricing in New York City (Skymeter, 2007a). Skymeter uses GPS satellites and on-board hardware to track vehicles. Their service offerings include congestion pricing systems, PAYG vehicle insurance and real-time parking (Skymeter, 2007b). Their unique achievement is the ability to reduce the "urban canyon" effect in downtown environments. They mention that standard GPS data is fused with their "unique, tamper-proof in-vehicle sensor technology" to generate highly reliable path data.

4.4.2 Data Providers – Cellular-based

4.4.2.1 CellInt

CellInt is based in Israel and New Jersey and provides traffic information by tracking cellular telephone signals through a proprietary technology called TrafficSense. They do not rely on cellular tower handoffs to determine location, rather they use a cell-phone signature recognition algorithm to detect positioning. Since it is signature based, this system needs an initial phase of "off-line mapping and signature preparation" (CellInt, 2007), which consists on a set of terrain readings of all necessary GSM signatures. CellInt proposes the use of TrafficSense for slowdown detection, travel time measurement and incident detection. According to CellInt, the maximum precision is "a few tens of meters in the best case scenario" and 10% average difference to the "real value" of speed.

The company has operational projects in Kansas City, Atlanta, Israel and has a further project approved for development in southern Sweden (CellInt, 2008). In the Georgia SR400 deployment, it was found that "…between 10 and 20 mph, the system could only guarantee that a data point was accurate within a range of 24 mph. Thus, data reported as 15 mph could, in reality, be anywhere between 3 mph and 27 mph. This suggests that the system does not necessarily provide accurate data at low speeds. The GDOT and URS believe, however, that these results might be caused, at least in part, by small sample sizes during low flow periods." (FDOT, 2007). The deployment in Kansas showed more promise. When comparing TrafficSense results with the state's existing traffic speed measurement system (SCOUT), TrafficSense "speed trends tracked speeds reported by detectors, but were often off by 5 mph". It was also found that a time lag of 3 minutes to 10 minutes existed between when slowdowns occurred and when they were reported. (FDOT, 2007).

4.4.2.2 IntelliOne

IntelliOne is a US-based company founded by graduates from the University of California – Berkeley. IntelliOne's technology utilizes network measurement report (NMR) records, which provide cell phones' signal power for all cellular towers within reach. NMR records are already created by cellular providers and are produced when a call is made and cell phones transfer between towers. In order for IntelliOne's technology to track a signal, the cellular phone must be in use rather than simply on and idle (IntelliOne, 2007). The company has had a system operating in Tampa, FL since 2005.

4.4.2.3 AirSage

AirSage is a US-based company providing real-time traffic information by tracking cellular telephone signals. AirSage's WISE (Wireless Signal Extraction) technology works by mining data that is already collected by cellular service providers. A cell phone's location is estimated when it leaves and enters a cell within the cellular network using characteristics of the signal. Essentially, it determines location through cell phone hand-offs. The information is then transferred to the main AirSage computer system where information is aggregated and converted to travel time and speed estimates (AirSage, 2008). AirSage claims the information can be used for construction management, emergency management & special event planning. The company is privately held with their major shareholder being Constellation Group of Zurich, Switzerland.

AirSage has conducted demonstrations in Virginia, Georgia, Utah, Minnesota, Wisconsin & California. In the Hampton Roads, Virginia pilot test, the results were subject to an independent study by the University of Virginia. On arterials and congested freeways, the results show that 84 percent of the speed estimates have an error greater than 15 miles/hour. Further, “when speeds were slower than 22 mph, the average error was 25 mph or 113 percent of the actual speed” (FDOT, 2007). Since congested periods are the times in which real-time speed information becomes more important, the results suggest that cellular hand-off location determine approaches are unusable for real-time applications that demand high accuracy.

4.4.2.4 DeCell

DeCell is an Israeli and American company that gathers and processes traffic data from cellular phones (DeCell, 2008). It is not clear how exactly DeCell determines location and speed. The company has systems live and operational in Vienna, Austria and in Israel.

4.4.2.5 TrafficCast

TrafficCast is a US-based company offering route-specific, real-time and predictive travel time information. They currently offer travel time services in 70 metro areas across the US covering interstates, expressways and major arterials. They appear to use data from publicly available sources such as DOT sensors, however they are currently testing both cellular and GPS location based services (TrafficCast, 2008). The company’s Chinese subsidiary has been using cellular probes in Shanghai to generate traffic data (up to 10 Million China Mobile customers). Through its TrafficCast Channel, the firm acts as a wholesaler of real-time and predictive travel time and traffic data, enabling them to deliver traveler information to end-users via the Internet, in-vehicle devices, and other wireless devices. They also have a strategic partnership with Yahoo! to broadcast their traffic information through Yahoo! Maps.

4.4.2.6 Trisent

Trisent is a Scottish-based technology company that has developed a cellular-based location service called the Tri-Cell Intelligent Location Server (TILS). TILS is marketed heavily to business users and fleets for such activities as fleet tracking and employee safety at remote employment locations. Trisent will archive daily movement data for future customer analyses and planning. The Trisent application will work on any GSM mobile phone without any additional software required (Trisent, 2008).

4.4.3 Data Providers – Traditional Sensors (Loops, RFID, CCTV Cameras, Microwave, etc.)

4.4.3.1 SpeedInfo

SpeedInfo Inc. is a private company based in California that has developed an extremely low-cost, roadside-mounted, traffic speed measurement sensor that relies on Doppler Radar technology. This sensor is entirely self-contained – it is solar powered (with a battery backup) and utilizes a GPRS-based wireless data connection to transmit/receive data to/from SpeedInfo's server (SpeedInfo, 2008). The company maintains that their sensors are capable of performing maintenance-free for at least five (5) years. The company currently works almost exclusively with state and local agencies through either outright purchase agreements or multi-year contracts. They have negotiated some private sector agreements to provide travel information, namely with TrafficGauge and TrafficCast.

4.4.3.2 Sensys Networks

Sensys Networks uses in-road, wireless, magnetic sensors to generate traffic data. The company claims that the magnetic sensor can count vehicles, determine occupancy and take point speed measurements (Sensys Networks, 2008). The sensors are battery operated with a 5 – 7 year life. The wireless sensors communicate with access points installed on roadside infrastructure along the corridor. Trials of the technology have been undertaken in San Diego, CA, Scottsdale, AZ and in Texas.

4.4.3.3 GlobisData

GlobisData is a Canadian traffic information company. They use data generated by government owned sensors to determine levels of congestion on the major expressways in Toronto and Montreal (GlobisData, 2008). This data is converted into a color-coded map that is updated every three minutes on their website. Access to the service is free. GlobisData was involved in a trial using Assisted GPS (A-GPS) cellular phones as probes to determine roadway speeds and traffic congestion. The study suggested that A-GPS was quite accurate on expressways, but that algorithms for arterial roads required significant changes (Transport Canada, 2006).

4.4.3.4 TrafficGauge

TrafficGauge is a US-based firm that collects aggregates and distributes real-time traffic information. It sells its own specific traffic device similar to a PDA/GPS in-vehicle device in four markets (SF, Seattle, Chicago & LA). The device is relatively simple with no other use except to provide traffic information for the specific city that it was built for (no dynamic maps, no routing, etc.). TrafficGauge gathers their data from "DOT and private data feeds" (TrafficGauge, 2008). They currently receive some of their traffic data in the San Francisco area from SpeedInfo. TrafficGauge is unique in that it is one of the only companies in the traffic information segment that appears to be completely vertically integrated (data collection, aggregation, distribution, primitive mapping & end user device). They disseminate their traffic information on proprietary devices, cellular phones & online.

4.4.4 Data Aggregators / Distributors

4.4.4.1 Clear Channel Communications

Clear Channel Communications is a large and diversified media company based in the US. They own 13,000 radio stations in the US representing 9% of the radio market. Clear Channel gathers their own traffic data through conventional means (police reports, private citizen calls) and fuses it with traffic data from INRIX. They broadcast this fused information to users through the web, HD radio and RDS-FM (Clear Channel Communications, 2008).

4.4.4.2 Westwood One / SmartRoute Systems

Westwood One is the largest provider of real-time traffic information in the US, transmitted through the 5,000 radio stations that it owns. A division within Westwood One (Metro Networks) operates a traffic gathering and reporting operation composed of over 2,000 reporters, 65 fixed-wing aircraft, 35 helicopters, and thousands of traffic cameras, reporting through 65 operation centers located in major US cities (SmartRoute Systems, 2008). SmartRoute Systems was purchased by Westwood One in 2000 and provides local traffic and weather information to wireless, Internet, and voice portal customers. Traffic reports include information on traffic incidents, road and lane closures, construction delays, scheduled roadwork, event delays, and estimated travel times. Westwood One has agreements with TrafficCast to provide predictive traffic information to its customers, and with Yahoo! Maps to broadcast traffic information online.

4.4.4.3 Automobile Association UK

UK Automobile Association is the largest advocacy group for roadway users in the UK. They provide a variety of services including insurance, maps, towing and real-time travel information. They have an agreement with iTIS Holdings, also based in the UK, whereby AA incident response vehicles are fitted with GPS-based AVL systems and provide real time probe data to iTIS Holdings. In return, iTIS provides the real-time information that the UK Automobile passes onto their members (The Automobile Association, 2008).

4.4.4.4 TrafficLand

TrafficLand provides public agencies with access to secure, IP-based CCTV video in support of enhanced operations and a streamlined approach for sharing live video with multiple user groups. The company has access to over 4,000 CCTV camera feeds in 50 cities in six countries (TrafficLand, 2008). TrafficLand’s Video Distribution Service (VDS) enables agencies to monitor the roadway network to quickly respond to incidents and provide remote access to video feeds for use by agencies and the public. TrafficLand works extensively with state DOT’s and provides real-time data to media providers including CNN and Traffic.com.

4.4.5 Digital Mapping

4.4.5.1 Navteq / Traffic.com

Navteq is a US-based company headquartered in Chicago that collects and processes traffic data, develops digital maps for location based services and distributes traffic information through its web portal Traffic.com. Navteq claims to have the largest road sensor network of any data provider in North America, although that likely only considers fixed sensors such as loop detectors and cameras. They offer real-time traffic and incident coverage in over 50 US metro areas. Navteq broadcasts their traffic data through their Traffic.com web portal and through various other communication methods (satellite radio, RDS-FM, XML and hybrid digital) (NAVTEQ, 2008). Traffic.com was the center of some controversy during the FHWA TTID demonstration initiative. Metropolitan areas were provided with federal funding to purchase traffic information services for their metro area, yet the legal requirements in the earmark stipulated that Traffic.com was the only provider that could be contracted with. Many believed that this amounted to federal investment to support a monopoly business (Traffic.com, 2008a).

Navteq has a number of interesting products worth discussing:

- Map Reporter: This application allows a customer to log in to the Navteq system and identify problems with existing maps and make changes to them, add points of interest, etc.
- Discover Cities: This product has a lot of potential in the future. Discover Cities is a service designed specifically for handheld PDA's, providing base maps of the transportation network in a given city with enhanced pedestrian routing, points of interest, bridge access and other items that are not generally mapped well for pedestrians. The product also includes a map of the local transit network and the transit schedules. Discover Cities was designed for tourists but can also be used by residents to explore their city. Unfortunately the device does not utilize the GPS capabilities that many PDA's now have to show your real-time position on the map and alert you to when you've deviated from your specified route.
- Traffic Patterns: Navteq has taken a slightly different approach from other data providers and rather than focusing heavily on real-time services, they are providing lots of information on historical traffic patterns based on archived data. Having the largest fixed sensor network in North America, they then use the data to calculate average roadway speeds for different times of day, days of the week, and for different cities. This database has been designed to be "open", thereby allowing software developers to develop their own traffic prediction algorithms (access to the database is not free, but they have apparently used open standards). Navteq announced expansions of this product into the UK and Germany earlier this year (Feb 2008). PTV will provide archived data for arterials in Germany, its unknown who will provide archived data for the UK (presumably TrafficMaster, but possibly iTIS or others).
- Floating Car Data – Spain: Navteq has been testing the feasibility of using floating car data for traffic purposes. They signed an agreement with Telefonica Spain (February 2008) to use cellular floating car data to measure real-time traffic speeds. This is Telefonica's second such agreement, and less than a week after one with ITIS Holdings. Telefonica has ~22 Million customers in Spain.

4.4.5.2 TeleAtlas / TomTom Navigation

TeleAtlas was one of only two large digital map providers worldwide (Navteq being the other), until it was purchased by TomTom Navigation in May 2008 for $4.5 Billion.

TeleAtlas provides a variety of digital mapping applications for various market segments including navigation devices, internet mapping and government services. Additional services include audio driving instructions/directions, points of interest mapping, etc (TeleAtlas BV, 2008).

4.4.5.3 OpenStreetMap

OpenStreetMap is an editable digital map that is free to use by anyone. It was created by users so as to avoid copyright and use restrictions associated with the use of "traditional" digital maps (OpenSourceMap, 2008). This is essentially data fusion from hundreds of individual GPS-data feeds.

4.4.5.4 EveryTrail

EveryTrail is a California-based company that encourages users to post digital location information on trips they've taken. Participants use their own GPS-enabled device to electronically trace their route (EveryTrail, 2008). The information can than be uploaded to the EveryTrail website with pictures for others to see. This is an interesting example of visual mapping.

4.4.6 End User Devices

4.4.6.1 TomTom Navigation

TomTom Navigation is based in the Netherlands and originally focused on in-vehicle navigation devices. They have since expanded into a variety of other areas associated with real-time travel information and data fusion. TomTom's main products are GPS-enabled, in-vehicle navigation devices. They also offer software applications for mobile phones and PDA's. In 2006, TomTom purchased Applied Generics, a small start-up owning a technology that could determine traffic delays in the road network by monitoring the movement of mobile phones (RoDIN24). This is now the underlying technology supporting the TomTom High Definition Traffic service (TomTom NV, 2006). In 2008, TomTom purchased digital map maker TeleAtlas in their ongoing diversification strategy. In the US, TomTom receives real-time traffic data from Clear Channel Communications and INRIX (Clear Channel uses its own traffic data and integrates INRIX data). In the US, the company offers an array of very interesting services (TomTom NV, 2008a):

- Mapshare: Mapshare allows users to connect online and correct map inconsistencies, add Points of Interest (such as gas stations), etc. Mapshare recorded 1 Million updates in February 2008, less than 6 months after being launched.
- TomTom Work: TomTom Work was designed for mobile businesses. It incorporates mapping services with two-way data communications functionality and vehicle tracking. Payment plans are similar to a cell phone plan (monthly payments, minimum 3 year activation). All data generated by the fleet must be sent back to the TomTom WebFleet application, begging the question as to whether TomTom is using these vehicles as data probes for their HD Traffic service.
- TomTom HD Traffic Receiver: In March 2008, the company released their HD Traffic Receiver, an add-on component that turns in-vehicle navigation devices into a

two-way communication device. The receiver connects wirelessly through the cellular network (GPRS) to receive real-time traffic information as well as software updates.

- TomTom IQ Routes: Beginning in March 2008, TomTom began offering IQ Routes, an application that determines the quickest route based on historical average travel speeds on road network segments, rather than simply using posted speed limits. This appears to be the beginnings of a predictive travel time service. The IQ Routes database receives more than half a billion measurements per day, ensuring that the time and spatial accuracy of the routes will increase continually.
- TomTom Weather: TomTom Weather provides real-time weather conditions with a 5-day forecast.

In Europe, TomTom services are perhaps even more interesting:

- TomTom Traffic Camera: The application alerts the driver of upcoming speed enforcement cameras with an audible signal, allowing drivers to slow down.
- TomTom High Definition Traffic: This is the company's most advanced product and the one that they are developing the most quickly. TomTom High Definition Traffic collects information from traditional traffic sources, European government sources and through anonymously collected data from mobile telephone signals. Agreements to use mobile phone data have taken off in the last 18 months. TomTom now has contracts to gather mobile phone data in the Netherlands (Vodafone Netherlands, 4 Million customers), the UK (Vodafone UK, 17.4 Million customers), Germany (Vodafone Germany, 34 Million customers), France (SFR France [minority owned by Vodafone], 18 Million customers) & Switzerland (Swisscom [partner with Vodafone], 5 Million customers). They plan on having HD Traffic available to 50% of their entire installed base in Europe by the end of 2008 (TomTom NV, 2008b).

4.4.6.2 Garmin

Garmin is based in the US and is the largest manufacturer of GPS-enabled navigation products in the world. They have not been nearly as active in the real-time traffic realm as TomTom, preferring to focus on end user devices. Garmin receives their traffic information from INRIX, Clear Channel Communications or Navteq/Traffic.com, depending on customer requirements (Garmin, 2008). Their digital maps appear to be provided through Navteq.

4.4.6.3 Dash Navigation

Dash Navigation is a California-based start-up company that manufacturers in-vehicle navigation devices. Their only product currently available for purchase was released in early 2008 and features GPS functionality with cellular and WiFi capabilities for two-way communication. GPS provides real-time location on the road network, the cellular and WiFi connections act as the communication channel to send back data on the location/speed/etc of the vehicle, and to connect to local search engines. Dash receives real-time traffic flow information from INRIX and fuses it with its own sensor-probe data. Because of the continuous internet access, users can connect to Yahoo! Local Search and other online search services (local services are automatically mapped). Dash Navigation also features a predictive capability and can suggest two alternate routes depending on real-time conditions (DASH Navigation, 2008).

4.4.6.4 General Motors On-Star & Vehicle to Vehicle (V2V) System

General Motors On-Start system is one of the original telematic applications built into consumer vehicles. GM continues to offer GPS and cellular-based services including incident support, turn-by-turn navigation, stolen vehicle location assistance and customized information on local services (OnStar Corp, 2008).

General Motors has also been working on their Vehicle-to-Vehicle (V2V) system, an extension of their OnStar vehicle-to-service center driver assistance communications system that is supported by the same satellite- and cellular-network based GPS technology as OnStar. Using an antenna, on-board computing power, and GPS geo-location technology, the V2V system is designed to enable a vehicle to detect the position and movement of other vehicles up to a quarter-mile away in a 360-degree radius. This technology will enable vehicles to assess the potential for collisions to occur and let all V2V enabled cars around them know an impact is about to happen. The vehicle will also be capable of taking pre-emptive actions to avoid or reduce the severity of the impact (General Motors Corp, 2007).

4.4.7 Public Transportation

4.4.7.1 NextBus

NextBus is a firm specializing in tracking and arrival time prediction for public and privately owned buses. NextBus uses GPS-based, automatic vehicle location (AVL) systems already installed on buses to gather service data and provide arrival time predictions for particular services. NextBus will also provide smaller firms with the GPS AVL hardware if needed. The firm offers a variety of support services including custom management reports, real-time alerts if a vehicle is substantially off schedule and variable message signs capable of transmitting estimated arrival times (NextBus, 2008c).

4.4.7.2 HopStop

HopStop provides users access to a digital map showing transit stops and an online database of transit schedules for several large US cities (New York, Washington DC, Boston, Chicago & San Francisco). Transit departure/arrival times and estimated travel times are accessible from a computer or mobile device (HopStop.com Inc, 2008). This service is unique in that it provides estimated travel times for combinations of bus, rail and walking, or each mode individually (including only walking). Users can also customize their search by indicating whether they want more or fewer transfers and whether they would consider using private shuttle services. This application would be very interesting if it incorporated estimated drive times and driving costs in a personal vehicle. This added functionality would make it one of the more sophisticated multi-modal applications available. It should be noted that none of the transit information provided is in real-time; it is all schedule-based.

4.4.7.3 Google Transit

Google Transit is an additional application offered by this well-known company that provides the location of transit stops and links those to local transit providers' service schedules. This is a very similar to HopStop described above, only Google began with a number of smaller US and International transit systems. They have now begun adding larger systems including Chicago, Seattle & Portland. Google Transit provides travel time estimates for trips on both public transit and private automobile, thereby allowing commuters to compare different driving modes. Their service also provides public transit fare costs and estimated driving costs. The driving costs are based on Internal Revenue Service average per-mile vehicle allowances so they do not take actual vehicle operating characteristics and roadway conditions into account (Google Corporation, 2008b).

4.4.8 Parking

4.4.8.1 ParkingCarma

ParkingCarma is a San Francisco-based technology company that has developed a comprehensive list of parking lots and garages around the United States. Their hope is to negotiate agreements with parking providers to allow advanced parking "reservations". Users would then be able to go online and search for a parking lot near their destination and reserve a spot on an hourly or daily basis. ParkingCarma has fused a number of interesting sources of data including a local search feature (enabling users to find parking near their destination if they don't know the address), a listing of major daily events planned in each city, traffic data from an unknown source and a CO2 emissions reduction calculator (ParkingCarma, 2008). It is not clear what revenue model ParkingCarma has in place, but it does not appear to involve charging the user directly. Most likely they receive a certain fixed fee or percentage of the parking revenue from the parking facility operators based on the number of ParkingCarma users that frequent each participating parking facility.

4.4.8.2 SpotScout

SpotScout is a Boston-based technology company that operates a parking service using a concept similar to eBay. SpotScout posts available spots for drivers searching for parking. SpotScout does not own any of the spots; they simply pair drivers with free spots nearby. Drivers preparing to leave a spot can advertise their departure time and sell that knowledge to a driver looking for a parking spot at that same time. A small fee is charged to the driver looking for parking and the company takes a percentage of the fee (SpotScout Inc, 2008). The company reports that they planned on offering service beginning in Boston in February 2008, although it does not appear that they have stuck to that timeline.

4.4.9 Other

4.4.9.1 Vodafone Group Plc [Communications / Cellular Floating Car Data]

Vodafone Plc is a large, multi-national telecommunications company based in the Netherlands. They operate wireless phone services around the world including owning a 45% stake of Verizon wireless in the US. The majority of the cellular-based floating vehicle data probe contracts that have been announced recently for the purpose of generating traffic data have come from Vodafone, one of their subsidiaries or one of their partner companies (the only other telecommunications provider announcing similar contracts has been Telefonica Spain). Vodafone has contracts to share cellular data in the Netherlands, the UK, Germany, France and Switzerland (Vodafone PLC, 2008).

4.4.9.2 Delcan [ITS Architectures / ATIS Systems Design]

Delcan is a large services company based in Canada with worldwide operations. They are one of the largest players in the development of state ITS architectures and implementation of traveler information systems. They have been involved in many notable data fusion related projects including a joint-venture with iTIS Holdings to test cellular probe data accuracy in Baltimore, the integration of multiple ITS systems into the NaviGAtor ATIS system in Atlanta, and the development of Vancouver, BC's iMove system, one of only a few integrated, multi-modal ATIS systems currently operating in North America (Delcan, 2008).

In the Baltimore, MD pilot test, Delcan and iTIS Holdings field tested a vehicular probe technology, named Cellular Floating Vehicle Data (CFVD). CFVD uses cellular "hand-offs" to infer momentary location and then matches the data to an underlying map and compares various data points to calculate a speed. When the CFVD results were compared against GPS and road sensors, "average errors were approximately 10 mph on freeways and 20 mph on arterials. The quality degraded significantly though during a.m. and p.m. peak periods, rendering the average error metric somewhat suspect." (FDOT, 2007).

4.4.10 Summary Table

Many of the industry players described above operate in many different segments of the data fusion marketplace and do not fit cleanly into any particular category. Table 1 provides a summary of geographic region in which each industry player operates and which segments of the market they operate in.

Table 1: Established Private Industry Players – Categorization by Type of Business

Industry Players	Deployment Locations	Data Provider - GPS-based	Data Provider - Cellular-based	Data Provider - Traditional Sensors	Data Aggregators / Distributors	Digital Mapping	End User Devices	Public Transport	Parking	Other
INRIX	US, UK	☑		☑	☑					
iTIS Holdings	UK, EU, US, Israel	☑	☑	☑	☑					
TrafficMaster	UK	☑		☑	☑					
Skymeter	CAN	☑								
CellInt	US, Israel		☑							
IntelliOne	US		☑							
AirSage	US		☑							
DeCell	EU, Israel		☑							
TrafficCast	US, China		☑	☑	☑					
Trisent	Scotland		☑							
SpeedInfo	US			☑						
Sensys Networks	US			☑						
GlobisData	CAN	☑		☑						
TrafficGauge	US	☑		☑	☑	☑	☑			
Clear Channel	US				☑					
Westwood One	US			☑	☑					
AA UK	UK	☑			☑					
TrafficLand	US			☑	☑					
Navteq/Traffic.com	US, UK, Worldwide		☑	☑	☑	☑	☑			
TeleAtlas	Worldwide					☑				
OpenStreetMap	Worldwide					☑				
EveryTrail	US					☑				
TomTom Navigation	EU, UK, US		☑		☑		☑			
Garmin	US, EU, UK						☑			
DASH Navigation	US		☑		☑		☑			
GM OnStar	US	☑					☑			
NextBus	US	☑						☑		
HopStop	US							☑		
Google Transit	US, CAN, EU							☑		
ParkingCarma	US								☑	
SpotScout	US								☑	
Vodafone Plc	EU, UK		☑							☑
Delcan	US, CAN, EU				☑					☑

5 ITS & DF Implementation – Drivers at the Metropolitan Level

5.1 Introduction

In the previous section, a number of stakeholders involved in ITS development broadly, and data fusion applications more specifically, were described in some detail. An interesting observation resulting from the summary was that in many cases there appears to be an "institutional dichotomy" when it comes to ITS and data fusion initiatives. The national level of government has been actively involved in the US and around the world at developing systems standards and funding initial ITS demonstration projects. Private industry, the other major "institution", has been involved in the design of system architectures, developing applications & algorithms and deploying ITS systems. The irony in this "institutional dichotomy" is that while the national government and private industry players have been the most active participants, ITS system deployments have taken place, and have tended to benefit users, at the metropolitan level. Cities and regions receive the largest benefits from Intelligent Transportation Systems, yet frequently appear to be excluded from the systems planning process. Given this background, the primary research questions that will be explored in this section are: (1) "Do regional, or metropolitan-level, governments have a role in ITS and Data Fusion applications implementation?" and, (2) "Are there institutional factors that encourage the adoption of data fusion applications within a metropolitan area, particularly multi-modal data fusion?" The chapter will focus on the US metropolitan and institutional experience however it is hoped that some of the general findings will apply to other metro areas around the world.

5.2 Research Methodology

Before describing the metropolitan areas selected and the variables of interest, the three-part research methodology is presented. The first part involved selecting & comparing metropolitan areas, and attempting to understand which variables might be associated with data fusion and ITS implementation. The second part introduces the Data Fusion Matrix, a method of describing "higher" levels of data fusion implementation. The third part combines the results of the first two steps; having established which metropolitan areas appear to have higher levels of data fusion, trends in the metro area variables are examined and some generalizable trends are identified.

The methodology described below has an important quantitative component whereby metro-level variables were used to compare regions against one and other. The goal of this comparison of variables should not be viewed as an attempt to quantify the importance of one metro-level variable over another. Rather, the analysis was used to determine the ***relative*** importance of one metro-level characteristic over another. Readers should not assume that any one variable is more important that any other in ***absolute*** terms.

The first step in the research was the identification of metro-area variables that are measurable and consistently calculated, so as to allow fair comparisons between regions. The purpose of identifying these variables was two-fold; (1) to categorize metro areas and thereby choose a smaller sample with varying combinations of characteristics, and (2) to attempt to identify the main factors explaining differing levels of data fusion implementation across metro areas. After comparing a variety of variables, three main ones were chosen.

The second step was to select metropolitan areas for comparison. With the comparison variables chosen, 39 metro areas were evaluated based on whether they ranked “High”, “Medium” or “Low” on each particular variable. A smaller of sample of eleven (11) metro areas was identified for greater analysis. Some effort was made choosing metro areas with variability between the initial selection criteria. Some additional effort was also placed on choosing metro areas from across the country so as not to bias a specific region.

The third step was to create a ranking system that identifies different levels of data fusion and ITS adoption within a metro area. A Data Fusion Matrix was chosen that evaluates metro areas based on the temporal complexity of the travel information they provide (static schedules, real-time data & real-time data with predicted travel time) and the level of multi-modal systems integration they have achieved (single mode, multiple modes on separate systems & integrated system with multi-modal information).

The fourth and final methodological step was to identify characteristics common to metro areas with “high” levels of data fusion implementation. Physical characteristics, characteristics of the regional Metropolitan Planning Organization (MPO) and characteristics of the transit agencies were the three categories of interest. Critical characteristics were identified and some generalizable conclusions were drawn.

5.3 Selection Criteria – Characteristics of Metropolitan Areas

The first step in analyzing drivers of metropolitan level data fusion implementation was to select a variety of variables, or selection criteria, upon which metropolitan areas could be compared. The goal was to choose a reasonable number of criteria that were believed to influence ITS/data fusion systems adoption and to choose metro areas with different combinations of these criteria. For example, if there was a belief that metropolitan population has a major influence on data fusion adoption, the methodology would select equal numbers of high, medium and low population metro areas for analysis and see if there are observable differences between them. The goal is to try to determine the relative influence of each selection criteria on data fusion implementation. After considering a variety of data sets, three primary variables were chosen as selection criteria; (1) the Net Change in Annual Hours of Delay per Peak Hour Traveler from 1996 to 2005, (2) the relative ranking of a given metro area’s technology industry presence, and (3) the number of grants received from the Federal government in support of ITS and data fusion application deployments.

The Net Change in Annual Hours of Delay per Peak Hour Traveler from 1996 to 2005 was calculated from the Texas Transportation Institute’s 2007 Annual Urban Mobility Report (TTI, 2007). It is believed that the change in the level of congestion over the last 10 years may have lead to the provision of more comprehensive travel information as commuters have attempted to reduce commute times through the use of alternate routes and modes of transportation.

Identifying a metro area's technology industry ranking was difficult, given the varying definitions and methodologies used by different groups. In the end, the Metropolitan New Economy Index from 2001 was used (PPI, 2001). The rationale for using this criterion is somewhat intuitive; data fusion and ITS applications are based upon, and driven largely by, advances in new technology. It is believed that those regions with substantial technology or knowledge-based industry representation will be more likely to develop data fusion applications.

The third criterion, federal government grants, was a simple count of metro areas receiving funding through the FHWA Integrated Corridor Management "Pioneer" sites program, USDOT "Urban Partnerships" Congestion Initiative, or through the FHWA ITIP/TTID program (FHWA, 2006a; FHWA, 2006b; FHWA, 1998b). It should be noted that this measure has several drawbacks. To begin, these are not the only grants provided to metro areas from the federal government, however they were the ones that were most likely to involve investment in data fusion applications and advanced transportation technologies. On the other hand, the use of these funds was discretionary in nature and there is no guarantee that they have been (or will be) used entirely for ITS or data fusion applications. Nevertheless, the goal is to determine the relative impact of federal funding on ITS adoption at the metro level, so a simple count of grants received rather than a dollar figure seems somewhat reasonable. Secondly, the timing of these grants varies. The ICM "Pioneer" project only announced a preliminary selection of sites in 2006 and a funding decision for the four final regions has not yet been announced. The "Urban Partnerships" Congestion Initiative was only funded in 2007 and has already seen one participating region withdraw. The FHWA ITIP/TTID grants were authorized beginning in 2001 and distributed starting in 2002, suggesting that implementation may be farther along. Even with the relatively recent timing of the federal grants, the assumption is that metro areas that have applied for financial support from the federal government to undertake ITS projects are more likely to have had positive experiences with ITS systems in the past, or are more receptive to using technology to improve regional transportation. Ideally, a measure of state level financial support would contribute to the analysis, but these sources are time consuming to collect and analyze.

There were several challenges associated with the selection of the evaluation criteria. The first was the difficulty in finding metrics with a similar spatial area. For example, the measure of average annual hours of peak period delay per commuter provided by the Texas Transportation Institute (TTI) was based on the US Census definition of an Urbanized Area (UZA), the New Economy Index technology ranking has an unknown spatial definition, and federal grant funding has generally been provided to a regional consortium involving at least the state DOT and the regional Metropolitan Planning Organization (MPO), which is defined by a regions' urbanized area (UZA) in addition to lands that are expected to be developed in the next 20 years, incorporating jurisdictions with at least 75% of the metropolitan population (Dempsey et al., 2000). No attempt was made to account for these different spatial measures, other than to acknowledge the discrepancy here. The second major challenge was choosing selection criteria with a common timeframe. The TTI measure was based on 2005 data, the New Economy Index was based on a 2001 evaluation and the federal grants were authorized and/or distributed between 2001 and 2008. Once again, this was the data that was available at the time and as such it was used.

While the three measures presented above were the primary variables for selecting metro areas, a larger of number of variables were collected for evaluation and comparison purposes. These variables fit into three broad categories: metropolitan characteristics, MPO characteristics & local transit agency characteristics. The specific variables used along with a brief hypothesis on their expected influence on data fusion implementation, the source, the year of the information and the spatial scale of the information are all presented in Table 2.

Table 2: Variables and Expected Influence on DF Adoption in US Metro Areas

	Variable of Interest	Hypothesis	Source	Year	Spatial Scale
Metropolitan Characteristics	Population	Small cities might have little demand for DF based applications; very large cities may present management challenges to DF	TTI	2005	UZA
	Congestion Levels	Cities with higher congestion levels might have greater impetus for DF	TTI	2005	UZA
	Congestion Increase	Cities experiencing more rapid increases in travel delay might have more demand for DF	TTI	1996-2005	UZA
	Auto Dependence	Cities with a higher dependence on auto travel relative to public transport might have less demand for integrated DF	TTI	2005	UZA
	"High Tech" Industry	Cities with a higher relative share of technology or knowledge-based industry might have a stronger "local lobby" for deploying advanced DF	PPI	2001	n.a.
	Federal ITS Support	Cities receiving a greater share of Federal government support for ITS should have more advanced DF	FHWA	2001-2007	MPO/ State DOT
MPO Characteristics	MPO Tax Authority	MPOs with some fiscal independence might have more flexibility for DF implementation	AMPO, MPOs	2005, 2008	MPO
	MPO Representation	MPOs that have more elected representation on their Boards might be more empowered to implement DF	AMPO, MPOs	2005, 2008	MPO
	MPO Jurisdictions	MPOs that represent a larger number of jurisdictions might face greater challenges in DF implementation	AMPO, MPOs	2005, 2008	MPO
Transit Agency Characteristics	Number of Transit Providers	Metropolitan regions with a larger number of transit agencies are likely to face systems coordination issues associated with DF implementation	NTD	2006	UZA
	Local Funding Share	Transit Agencies with a greater share of non-Federal, non-State funding might have more flexibility for DF deployment	NTD	2006	UZA
	AVL Technology Use	Transit Agencies with greater use of Automatic Vehicle Location technology are more likely to have DF systems in use	FHWA RITA	2006	n.a.

5.4 Metropolitan Area Selection

5.4.1 Initial Sample Selection – 39 Metropolitan Areas

With 465 metro areas in the US (2000 Census definition of an urbanized area) (AMPO, 2005), the second step in analyzing data fusion implementation was to select a smaller sample of regions for analysis. The initial process involved selecting a sample of regions that had mostly complete information for the three variables of interest outlined in Section 5.3. While attempts were made to allow data availability to dictate what would be included in the final sample, some self-selection was required to choose the final four regions. A justification for the choice of these final four regions is described below.

The two variables that were likely to limit the selection of metro areas were the TTI's Net Change in Annual Hours of Delay and the New Economy technology industry presence ranking. Additionally, it was felt that larger regions (those meeting the 'Large' or 'Very Large' ranking according to TTI) would be most likely to have some form of multi-modal data fusion application in use. When the available data from these two sources was overlaid with greater weight placed on larger regions, 35 had complete data. The original hope had been that all regions with a TTI ranking of 'Large' or 'Very Large' (39 in total) could be used, however four cities were missing a technology industry ranking. It was decided that the sample should remain 39 regions in total, so four additional regions from the TTI 'Medium' size category were chosen. These four regions were essentially self-selected, with some effort placed on regions with varying technology rankings and congestion levels. The four regions selected were Charlotte, NC, Hartford, CT, Oklahoma City, OK & Salt Lake City, UT. The 39 regions, the values for each variable considered, the ranking out of 39 for each variable and the tercile rank for each variable are displayed in Table 3.

Table 3: Initial Sample of 39 Metropolitan Areas and Comparison Variables

Metro Region	Population (000's)	Rank (Tercile)	Congestion Level	Rank (Tercile)	Congestion Increase	Rank (Tercile)	Auto Dependence	Rank (Tercile)	"High Tech" Presence	Rank (Tercile)	Federal ITS Support
Atlanta GA	4,170	8 (1)	60	2 (1)	-15	39 (3)	116	18 (2)	11	10 (1)	1
Boston MA-NH-RI	4,088	10 (1)	46	14 (2)	15	6 (1)	43	5 (1)	8	7 (1)	1
Buffalo NY	1,133	32 (3)	11	39 (3)	4	18 (2)	192	27 (3)	31	28 (3)	0
Charlotte NC-SC	860	38 (3)	45	17 (2)	19	3 (1)	222	31 (3)	30	27 (3)	0
Chicago IL-IN	8,139	3 (1)	46	15 (2)	10	11 (1)	27	2 (1)	19	18 (2)	1
Cincinnati OH-KY-IN	1,620	25 (2)	27	30 (3)	1	27 (3)	188	26 (2)	34	30 (3)	1
Cleveland OH	1,890	20 (2)	13	38 (3)	-4	35 (3)	104	13 (1)	33	29 (3)	0
Columbus OH	1,194	31 (3)	33	27 (3)	4	19 (2)	423	36 (3)	36	32 (3)	1
Dallas-Fort Worth-Arlington TX	4,442	6 (1)	58	5 (1)	24	1 (1)	212	30 (3)	12	11 (1)	1
Denver-Aurora CO	2,088	19 (2)	50	11 (1)	10	12 (1)	98	12 (1)	7	6 (1)	0
Detroit MI	4,040	11 (1)	54	8 (1)	2	23 (2)	323	33 (3)	28	25 (2)	1
Hartford CT	894	37 (3)	19	33 (3)	6	15 (2)	186	25 (2)	22	20 (2)	0
Houston TX	3,789	12 (1)	56	7 (1)	21	2 (1)	155	20 (2)	14	13 (1)	1
Indianapolis IN	1,025	33 (3)	43	20 (2)	-10	38 (3)	540	37 (3)	29	26 (2)	1
Kansas City MO-KS	1,505	26 (2)	17	36 (3)	-2	31 (3)	561	38 (3)	24	22 (2)	0
Las Vegas NV	1,366	28 (3)	39	23 (2)	2	24 (2)	112	15 (2)	35	31 (3)	1
Los Angeles-Long Beach CA	12,628	2 (1)	72	1 (1)	0	28 (3)	89	10 (1)	20	19 (2)	1
Memphis TN-MS-AR	1,016	34 (3)	30	29 (3)	7	14 (2)	346	34 (3)	47	38 (3)	0
Miami FL	5,325	4 (1)	50	12 (1)	15	7 (1)	114	16 (2)	13	12 (1)	1
Milwaukee WI	1,457	27 (3)	19	34 (3)	-1	29 (3)	159	23 (2)	40	36 (3)	0
Minneapolis-St. Paul MN	2,520	16 (2)	43	21 (2)	9	13 (1)	132	19 (2)	10	9 (1)	2
New Orleans LA	1,005	35 (3)	18	35 (3)	-1	30 (3)	107	14 (2)	38	34 (3)	1
New York-Newark NY-NJ-CT	17,803	1 (1)	46	16 (2)	14	8 (1)	11	1 (1)	17	16 (2)	1
Oklahoma City OK	853	39 (3)	21	32 (3)	3	21 (2)	1482	39 (3)	39	35 (3)	1
Orlando FL	1,360	30 (3)	54	9 (1)	-3	32 (3)	183	24 (2)	25	23 (2)	0
Philadelphia PA-NJ-DE-MD	5,288	5 (1)	38	25 (2)	11	9 (1)	51	6 (1)	18	17 (2)	0
Phoenix AZ	3,273	13 (1)	48	13 (1)	11	10 (1)	240	32 (3)	16	15 (2)	1
Pittsburgh PA	1,838	21 (2)	16	37 (3)	-3	33 (3)	95	11 (1)	37	33 (3)	0
Portland OR-WA	1,729	23 (2)	38	26 (2)	2	25 (2)	59	8 (1)	15	14 (2)	0
Sacramento CA	1,750	22 (2)	41	22 (2)	2	26 (2)	209	29 (3)	23	21 (2)	1
Salt Lake City UT	967	36 (3)	27	31 (3)	-3	34 (3)	75	9 (1)	9	8 (1)	1
San Antonio TX	1,362	29 (3)	39	24 (2)	17	5 (1)	156	22 (2)	49	39 (3)	1
San Diego CA	2,896	15 (2)	57	6 (1)	19	4 (1)	114	17 (2)	5	4 (1)	2
San Francisco-Oakland CA	4,156	9 (1)	60	3 (1)	3	22 (2)	36	3 (1)	1	2 (1)	3
San Jose CA	1,680	24 (2)	54	10 (1)	5	16 (2)	203	28 (3)	1	1 (1)	1
Seattle WA	3,009	14 (2)	45	18 (2)	-6	36 (3)	54	7 (1)	3	3 (1)	3
St. Louis MO-IL	2,110	18 (2)	33	28 (3)	-6	37 (3)	156	21 (2)	27	24 (2)	1
Tampa-St. Petersburg FL	2,249	17 (2)	45	19 (2)	5	17 (2)	367	35 (3)	43	37 (3)	1
Washington DC-VA-MD	4,278	7 (1)	60	4 (1)	4	20 (2)	36	4 (1)	6	5 (1)	2

Sources: TTI, 2007 / PPI, 2001 / FHWA, 2006a / FHWA, 2006b / FHWA, 1998b

5.4.2 Selection of an Evaluation Sample – Eleven Metropolitan Areas

With an initial selection of 39 regions with relatively complete data, the next step was to choose a small subset of regions for further analysis. All regions were ranked as "High" or "Low" on each of the three variables of interest. "High" ranking regions were those in the top half of the ordered rank of 39, "Low" ranking regions were those in the bottom half of the ordered rank of 39. With three selection criteria (change in congestion, technology ranking & federal grants) and two levels (high & low), eight unique combinations of 'variables-levels' can be established. Using this combination of criteria, eight metro areas were chosen. Where multiple regions shared the same unique combination, an attempt was made to choose regions from different geographic areas across the country. The metro areas were reasonably well balanced based on the combination of 'variables-levels', however there was a distinct lack of metro areas from the US Northeast.

At this point, a decision was made to self-select three additional metro areas and include them in the analysis. Since the primary goal with this analysis was to identify factors that influence multi-modal data fusion implementation, there was a desire to have at least a couple of regions included in the sample where advanced traveler information systems are already in use. From a methodological point of view, this is a poor approach to selecting regions for analysis as it introduces bias; however with a larger sample of metro areas that have successful systems in place, it may be possible to identify additional factors influencing multi-modal data fusion implementation. The three additional metro areas selected were Portland, OR, San Francisco, CA & Minneapolis, MN. Table 4 and Table 5 summarize the analysis used to select the eleven metro areas, and display the variables and High/Low rankings for each one.

Table 4: Evaluation Sample of Eleven Metropolitan Areas and Comparison Variables

Metro Region	Population (000's)	Rank (Tercile)	Congestion Level	Rank (Tercile)	Congestion Increase	Rank (Tercile)	Auto Dependence	Rank (Tercile)	"High Tech" Presence	Rank (Tercile)	Federal ITS Support	Geographic Region
Charlotte NC-SC	860	38 (3)	45	17 (2)	19	3 (1)	222	31 (3)	30	27 (3)	0	South East
Cincinnati OH-KY-IN	1,620	25 (2)	27	30 (3)	1	27 (3)	188	26 (2)	34	30 (3)	1	Midwest
Denver-Aurora CO	2,088	19 (2)	50	11 (1)	10	12 (1)	98	12 (1)	7	6 (1)	0	Center West
Minneapolis-St. Paul MN	2,520	16 (2)	43	21 (2)	9	13 (1)	132	19 (2)	10	9 (1)	2	Center West
Orlando FL	1,360	30 (3)	54	9 (1)	-3	32 (3)	183	24 (2)	25	23 (2)	0	South East
Pittsburgh PA	1,838	21 (2)	16	37 (3)	-3	33 (3)	95	11 (1)	37	33 (3)	0	Midwest
Portland OR-WA	1,729	23 (2)	38	26 (2)	2	25 (2)	59	8 (1)	15	14 (2)	0	West Coast
San Antonio TX	1,362	29 (3)	39	24 (2)	17	5 (1)	156	22 (2)	49	39 (3)	1	Center West
San Diego CA	2,896	15 (2)	57	6 (1)	19	4 (1)	114	17 (2)	5	4 (1)	2	West Coast
San Francisco-Oakland CA	4,156	9 (1)	60	3 (1)	3	22 (2)	36	3 (1)	1	2 (1)	3	West Coast
Seattle WA	3,009	14 (2)	45	18 (2)	-6	36 (3)	54	7 (1)	3	3 (1)	3	West Coast

Sources: TTI, 2007 / PPI, 2001 / FHWA, 2006a / FHWA, 2006b / FHWA, 1998b

Table 5: Evaluation Sample of 11 Metropolitan Areas with "High/Low" Ranking based on Three Primary Variables

Metropolitan Area	Net Change in Annual Hours of Delay per Peak Hour Traveler (1996-2005)	Technology Industry Presence (Ranking)	Federal Government Grants (Count)	Combination of Selection Criteria
Charlotte NC-SC	High	Low	Low	H-L-L
Cincinnati OH-KY-IN	Low	Low	High	L-L-H
Denver-Aurora CO	High	High	Low	H-H-L
Orlando FL	Low	High	Low	L-H-L
Pittsburgh PA	Low	Low	Low	L-L-L
San Antonio TX	High	Low	High	H-L-H
San Diego CA	High	High	High	H-H-H
Seattle WA	Low	High	High	L-H-H
Minneapolis-St. Paul MN	High	High	High	H-H-H
Portland OR-WA	Low	High	Low	L-H-L
San Francisco-Oakland CA	Low	High	High	L-H-H

Sources: TTI, 2007 / PPI, 2001 / FHWA, 2006a / FHWA, 2006b / FHWA, 1998b

5.5 Regional Evaluation – Establishing Levels of Data Fusion Implementation

5.5.1 The Data Fusion Evaluation Matrix

With eleven metropolitan areas selected, the task shifts to measuring metro level, multi-modal data fusion implementation. In order to quantify progressively more advanced levels of data fusion implementation, a data fusion evaluation matrix has been created.

The data fusion matrix axes measure the level of data fusion implementation in terms of technology use and level of systems integration. The vertical axis has been labeled 'Time' and categorizes applications' use of technology as non-existent (schedule-based services), moderate (real-time conditions provided) or complex (real-time conditions reported with predictive travel times and/or delays). This is essentially a measure of technology use, as it requires increasing levels of sensor complexity to achieve higher levels along this spectrum. The horizontal axis has been labeled 'Modality' and categorizes data fusion in terms of increasing integration of travel information from basic (single mode information) to more advanced (multiple modes, separate systems, possibly with links) to fully integrated multi-modal systems (multiple modes, integrated system, possible provision of routing using multiple modes). This axis essentially measures the level of systems integration and institutional cooperation, as it's unlikely that the same entity owns and distributes all information on all modes of transport in a metropolitan area. Table 6 shows the data fusion matrix with the relevant quadrants.

Table 6: The Data Fusion Evaluation Matrix

		Modality		
		Single mode	*Multi-modal, separate systems*	*Multi-modal, integrated system*
Time	*Static*	Table-based system, no sensors	Table-based systems, no sensors	Table-based system, many tables, no sensors, synchronization and communication between subsystems needed
	Real time	Real Time Traffic Conditions (RTT), sensor fusion needed	RTT, sensor fusion needed	RTT, sensors, tables fusion and synchronization needed; complex communication
	Real-Time with Predictions	RTT, sensors and historical data fusion needed	RTT, sensors and historical data fusion needed	RTT, sensors, tables and historical data fusion and synchronization needed; complex communication

5.5.2 Measuring Levels of Data Fusion Complexity

Having selected eleven metro areas for evaluation, and having defined increasing levels of data fusion, measures of multi-modal data fusion need to be defined. Since the level of data fusion implementation is being evaluated at the metropolitan level, advanced traveler information applications that provide automobile and public transit information were considered. These applications are generally developed by local/regional governments, by private firms, by transit agencies or by some combination of these institutions.

Applications for private automobile travel that were examined included state and regional ‘511’ travel information services, Google Traffic and Traffic.com. All eleven regions examined had real-time traffic information provided by Google Traffic and Traffic.com. The state/regional traveler information systems had greater variability in the type of information that was offered.

In terms of public transportation applications, the general observation was that the sophistication of information provided to users was less than it was for private automobile travel. The applications evaluated included Google Transit, NextBus (a provider of real-time transit information for transit agencies), transit agency traveler information applications, and state/regional traveler information systems. All regions analyzed had schedule-based transit information although only a handful had real-time transit information and even fewer had real-time transit information integrated with traffic information, allowing potential users to make fully informed mode choice decisions.

5.5.3 Metropolitan vs. Municipal Data Fusion – The San Francisco Case

One of the difficulties in using traffic and transit applications as a measure of data fusion implementation is the discrepancy in spatial areas covered. Traffic information applications tend to be implemented at the regional level with the support of state departments of transportation, so coverage tends include the entire metro area. Transit information, on the other hand, is generally provided by the transit agencies themselves. In many metro areas, there is one dominant transit agency that operates region-wide. In these cases, the spatial coverage of both the traffic and transit applications tends to be region-wide. However, in a number of US cities, there are a variety of transit providers that only offer services in specific municipalities or areas within the metro-region. This is particularly true in New York, Los Angeles, Chicago and San Francisco. In these metro areas, traffic information coverage is region-wide while transit information is offered at less than the regional level. Table 7 presents the major transit providers within the eleven metro areas of interest, their share of unlinked transit trips and the percentage of regional population that they serve.

Table 7: Transit Agency Service Characteristics for the Eleven Evaluation Metro Areas

Metropolitan Area	Metropolitan Planning Organization	Transit Agency	% of Metro Area Unlinked Transit Passenger Trips by Agency	% of Metro Area Population Served by Agency
San Francisco-Oakland CA	MTC	San Francisco Municipal Railway (MUNI)	50%	25%
		San Francisco Bay Area Rapid Transit District (BART)	25%	26%
		Alameda-Contra Costa Transit District (AC Transit)	16%	44%
Charlotte NC-SC	MUMPO	Charlotte Area Transit System (CATS)	100%	90%
Cincinnati OH-KY-IN	OKI RCOG	Southwest Ohio Regional Transit Authority (SORTA / Metro)	87%	56%
Denver-Aurora CO	DRCOG	Denver Regional Transportation District (RTD)	100%	131%**
Minneapolis-St. Paul MN	Metro Council	Metro Transit	86%	71%
Orlando FL	MetroPlan	Central Florida Regional Transportation Authority (LYNX)	100%	133%**
Pittsburgh PA	S.W. PA Comm.	Port Authority of Allegheny County (Port Authority)	96%	81%
Portland OR-WA	Portland Metro	Tri-County Metro Transportation District of Oregon (TriMet)	94%	79%
San Antonio TX	SA-BC MPO	VIA Metropolitan Transit (VIA)	100%	113%***
San Diego CA	SANDAG	San Diego Metropolitan Transit System (MTS)	81%*	>79%
Seattle WA	PSRC	King County Department of Transportation	63%	66%
		Washington State Ferries (WSF)	14%	106%****

*Includes MTS, MTS Trolley & MTS Contract Services
**RTD &LYNX provide Purchased Services, Vanpool & Demand Response services beyond the UZA border
***VIA provides Vanpool & Demand Response services beyond the UZA border
***WSF operates ferry services in multiple UZA's
Source: NTD, 2006

As can be seen in Table 7, all regions with the exception of San Francisco and Seattle have a dominant transit agency that captures more than 80% of regional transit trips. In Seattle's case, if the Washington State Ferry service is included in the count, the two primary agencies account for 78% of transit trips. San Francisco is significantly different than these regions in that no transit agency claims more than 50% of regional transit trips or serves more than 45% of the regional population. While it was originally assumed that this would create a problem given our method of measuring transit data fusion implementation, the evidence suggests that the largest three transit operators in San Francisco have been working with the regional MPO to develop an integrated transit information service. Through cooperation and the strong support of the MPO, these agencies plan on offering an integrated, transit information service on a regional level by the end of 2008. More about this integrated system will be discussed in Section 5.7.

5.5.4 Data Fusion Applications offered by the Metro areas

In this section, the traffic and transit data fusion applications offered within each metro area will be described briefly. Private applications including Google Traffic and Traffic.com are not mentioned individually as they provide information services in all metro areas analyzed. All of the information discussed below is summarized in Table 8 at the end of Section 5.5.4.

5.5.4.1 San Francisco - Oakland, CA

San Francisco's '511' travel information system is perhaps the most advanced multi-modal data fusion application analyzed in this section. The system integrates real-time traffic information, rideshare matching, cycling information and static transit information in one easy to use system. The system expects to provide real-time transit information for the San Francisco MUNI system online by the end of 2008; real-time transit information is already available by phone. Traffic features include real-time conditions, predicted drive times based on current conditions and multiple route options between the designated origin and destination with expected travel times. Currently the system only covers major freeways and highways (SF MTC, 2008b).

While real-time transit functionality has not yet been incorporated into the '511' system, San Francisco MUNI, AC Transit and BART all provide real-time conditions with predictive transit arrival times. MUNI and AC Transit arrival times are provided by NextBus (NextBus LLC, 2008a), BART arrival times can be found on their website (BART, 2008).

5.5.4.2 Charlotte, NC

Charlotte's traffic information is provided through North Carolina DOT's '511' system. It is fairly basic, providing real-time conditions in the form of traffic camera images. No speed information or predicted travel times are provided (NCDOT, 2008).

Charlotte's transit provider, CATS, offers transit schedules online. No real-time transit information is available (CATS, 2008).

5.5.4.3 Cincinnati, OH

Cincinnati's travel information is provided through a regional system called ARTIMIS. ARTIMIS provides real-time traffic conditions with predicted travel times and delays. The service only provides information on major freeways and highways and only provides estimated travel times between major roadway interchanges (ARTIMIS, 2008).

Cincinnati's main transit provider (SORTA) offers schedule-based information online. No real-time transit information is available (SORTA, 2008).

5.5.4.4 Denver, CO

Colorado DOT (CDOT) provides real-time traffic information for the Denver region. They offer real time traffic condition on major roadways, but do not offer any predicted travel times (CDOT, 2008).

Denver RTD, the regional transit provider, provides real-time bus arrival information online through their GoRTD website. The system apparently provides predicted arrival times for transit buses when a given route and stop are specified (Denver RTD, 2008). Having tried the system several times, all predicted times have been identical to the posted bus schedules. There is no integration with any other travel information system.

5.5.4.5 Minneapolis - St. Paul, MN

Minnesota DOT provides traffic information through their statewide '511' system. They provide real-time travel conditions and predicted travel times on major roadways (MnDOT, 2008).

Metro Transit, Minneapolis' main transit agency, provides real-time predicted arrival times for buses and light rail through their NextTrip system. If buses are within 20 minutes of a specified stop, real-time information will be provided, otherwise scheduled arrival times are given (Metro Transit, 2008). There is no integration with any other travel information system.

5.5.4.6 Orlando, FL

Orlando's traffic information is provided through the state of Florida's '511' traveler information system. It provides real-time traffic conditions on major roadways with predicted drive times between major freeway interchanges (FDOT, 2008).

Orlando LYNX transit offers transit schedules online. No real-time transit information is available (LYNX, 2008).

5.5.4.7 Pittsburgh, PA

Pittsburgh has no state-level traveler information system in place; its expected launch date is 2009. For the time being, travelers seeking traffic information receive it from private sources such as Google Traffic or Traffic.com.

The Port Authority of Allegheny County offers schedule-based information online. No real-time transit information is available (Port Authority, 2008).

5.5.4.8 Portland, OR

Oregon State DOT provides traffic information through their TripCheck ‘511’ traveler information service. The system provides real time traffic information but does not have predicted travel times (ODOT, 2008).

TriMet, Portland’s main transit agency, provides predicted arrival times for transit buses and light-rail through their TransitTracker application (TriMet, 2008b). They have also launched an new interactive trip planner that allows users to find transit services between two specified points (although the travel times are based on scheduled services, not on real-time information), provides a link to Google Maps so that the user can estimate drive time (although once again, drive times are based on posted speed limits, not real time conditions) and provides a link to allow cyclists to find the best travel route (TriMet, 2008a). While this feature lacks real-time functionality, it is one of the more advanced trip planners examined in terms of multi-modality. It is not currently integrated with the TripCheck system.

5.5.4.9 San Antonio, TX

The Texas Department of Transportation operates a statewide ‘511’ traveler information system that is known as TransGuide in the San Antonio region. TransGuide provides numerous forms of traffic information including current traffic conditions, drive times along major routes and a customizable route builder function with real-time expected travel times (TxDOT, 2008).

VIA, the transit operator in San Antonio offers schedule-based information online. No real-time transit information is available (VIA, 2008).

5.5.4.10 San Diego, CA

The ‘511’ traveler information system that is operational in San Diego is very similar to the one in San Francisco; it integrates real-time traffic information with schedule-based transit information (not real-time), ridesharing information and bicycling information into a single application for users. Traffic features include real-time conditions, predicted drive times based on existing conditions and multiple route options between the designated origin and destination with expected travel times. The system only covers major freeways and highways (SANDAG, 2008a).

5.5.4.11 Seattle, WA

Seattle traffic information is provided through Washington State’s ‘511’ traveler information system, which is run by the state DOT. Traffic features include real time traffic conditions for major routes, predicted travel times with expected delays with different reporting for freeway portions and HOV portions of the network. WSDOT also provides a service called 95% reliable travel times, based on historical congestion levels. It calculates with 95% certainty the amount of time needed to travel between two points at a specified time of day (WSDOT, 2008a). The selection of locations is minimal, but is an interesting service offering nonetheless.

There are also several real-time transit applications offered in the Seattle region. King County Metro, the region's largest transit agency, provides their Bus Tracker application, which provides the real time location of transit buses and predicted arrival times when a stop is specified (King County Metro Transit, 2008). The Washington State Ferry system also offers Vessel Watch, a real time ferry tracker that shows the location of all ferries. If a ferry is running more than 20 minutes behind schedule, users can opt to receive a text message notifying them of the delay and the revised arrival/departure time (WSDOT, 2008c). Unfortunately, there is no integration between any of the three systems.

Table 8: Traffic and Transit ITS Systems Applications and Degree of Systems and Modal Integration

		Traffic Applications			Transit Applications			
Metropolitan Area	**Transit Agency**	**Google Traffic**	**Traffic.com**	**Regional 511 Traffic Info. System**	**Google Transit**	**NextBus Predicted Arrivals**	**In-House Predicted Arrivals**	**Integration (Systems, Modes)**
San Francisco-Oakland CA	SF MUNI	Yes	Yes	Yes, RT Traffic, Predicted Drive Times, Multiple Route Options	Yes	Yes, 1999	No	Yes, Integration of Agencies & Modes, RT*
San Francisco-Oakland CA	SF BART	Yes	Yes	Yes, RT Traffic, Predicted Drive Times, Multiple Route Options	Yes	No	Yes, 2008	Yes, Integration of Agencies & Modes, RT*
San Francisco-Oakland CA	AC Transit	Yes	Yes	Yes, RT Traffic, Predicted Drive Times, Multiple Route Options	Yes	Yes, 2001	No	Yes, Integration of Agencies & Modes, RT*
Charlotte NC-SC	Charlotte CATS	Yes	Yes	Yes, RT Traffic	No	No	No	No Integration
Cincinnati OH-KY-IN	SORTA / Metro	Yes	Yes	Yes, RT Traffic, Predicted Drive Times	No	No	No	No Integration
Denver-Aurora CO	Denver RTD	Yes	Yes	Yes, RT Traffic	Yes	No	Yes, 2001	No Integration
Minneapolis-St. Paul MN	Metro Transit	Yes	Yes	Yes, RT Traffic, Predicted Drive Times	Yes	No	Yes, 2008	No Integration
Orlando FL	Orlando LYNX	Yes	Yes	Yes, RT Traffic, Predicted Drive Times	No	No	No	No Integration
Pittsburgh PA	Port Authority	Yes	Yes	No	Yes	No	No	No Integration
Portland OR-WA	TriMet	Yes	Yes	Yes, RT Traffic	Yes	No	Yes, 2002	Yes, Integration of Modes, Static**
San Antonio TX	VIA Metro Transit	Yes	Yes	Yes, RT Traffic, Pred. Drive Times, Multiple Routes	No	No	No	No Integration
San Diego CA	San Diego MTS	Yes	Yes	Yes, RT Traffic, Pred. Drive Times, Multiple Routes	Yes	No	No	Yes, Integration of Modes, Static Transit***
Seattle WA	King County Metro	Yes	Yes	Yes, RT Traffic, Predicted Drive Times	Yes	No	Yes, 1998	No Integration
Seattle WA	WA State Ferry	Yes	Yes	Yes, RT Traffic, Predicted Drive Times	No	No	Yes, 2000	No Integration

*511.org expects to integrate real-time transit information from multiple agencies in late-2008.

**TriMet does not integrate the information directly, but provides external links

***SANDAG 511 provides real-time traffic information and schedule-based transit information, all on the 511 website.

Sources: CATS, 2008 / CDOT, 2008 / Denver RTD, 2008 / FDOT, 2008 / Google Corp., 2008a / Google Corp., 2008b / King County Metro Transit, 2008 / LYNX, 2008 / Metro Transit, 2008 / MnDOT, 2008 / MTC, 2008b / NCDOT, 2008 / NextBus, 2008a / ODOT, 2008 / OKI COG, 2008 / Port Authority, 2008 / SANDAG, 2008a / SORTA, 2008 / Traffic.com, 2008b / TriMet, 2008a / TriMet, 2008b / TxDOT, 2008 / VIA, 2008 / WSDOT, 2008a / WSDOT, 2008b

The information presented in Table 8 can be easily re-organized into the original DF evaluation matrix described in Section 5.5.1. The populated matrix is shown in Table 9. Note that traffic applications are shown in blue while transit applications are shown in red. Those metro areas with applications further to the bottom right quadrant have higher levels of integrated, multi-modal data fusion applications in use while those in the top left have fewer applications in use.

Table 9: Traffic and Transit ITS Systems Applications when applied against the Data Fusion Evaluation Matrix

		Modality		
		Single mode	*Multi-modal, separate systems*	*Multi-modal, integrated system*
Time	*Static*	**Pittsburgh Transit**	**Charlotte Transit** **Cincinatti Transit** **Orlando Transit** **San Antonio Transit**	**Google Transit** **San Diego 511 Transit**
	Real time		**Denver CDOT Traffic** **Charlotte NCDOT Traffic**	**Google Traffic** **Portland TripCheck Traffic**
	Predictive	**Traffic.com** **NextBus**	**Seattle Transit Tracker** **WA State Ferry Vessel Tracker** **Seattle WSDOT Traffic** **Minneapolis NextTrip** **Minneapolis 511 Traffic** **Denver RTD Transit** **Cincinnati ARTIMIS Traffic** **Orlando 511 Traffic** **San Antonio TransGuide Transit**	**San Francisco 511 Traffic** **San Francisco 511 Transit (Y.E 2008)** **San Diego 511 Traffic** **Portland TriMet Tracker**

*Private Vehicle (Traffic) Applications written in Blue, Public Transport (Transit) Applications written in Red

Sources: CATS, 2008 / CDOT, 2008 / Denver RTD, 2008 / FDOT, 2008 / Google Corp., 2008a / Google Corp., 2008b / King County Metro Transit, 2008 / LYNX, 2008 / Metro Transit, 2008 / MnDOT, 2008 / MTC, 2008b / NCDOT, 2008 / NextBus, 2008a / ODOT, 2008 / OKI COG, 2008 / Port Authority, 2008 / SANDAG, 2008a / SORTA, 2008 / Traffic.com, 2008b / TriMet, 2008a / TriMet, 2008b / TxDOT, 2008 / VIA, 2008 / WSDOT, 2008a / WSDOT, 2008b

5.6 Variables that Appear to Influence Data Fusion Implementation

The results of this research identified seven findings related to the implementation of data fusion applications / ITS systems within a metropolitan area. Four of these relate to metropolitan characteristics of the region, the remaining three relate to the structure of the regional MPO and characteristics of the local transit agencies. Please refer to Table 10 for a full list of metropolitan characteristics.

5.6.1 Metropolitan Characteristics Influencing Data Fusion Implementation

5.6.1.1 Regional Technology Industry Presence

One of the strongest links observed between the selected metro areas and data fusion implementation was the presence of a regional high technology industry. Of the top 6 regions examined, five were in the top tercile for regions with a technology sector. Portland, OR was the single exception, and even it was at the very top of the second tercile. Intuitively, this finding is reasonable as start-up firms with new applications often collaborate with local institutions to test their products. However, one should be careful not to confuse correlation with causation when considering the interaction between metro-area data fusion implementation and technology sector presence. While it seems more likely that technology sector presence encourages ITS adoption, it is possible that technology firms choose metro areas that have a history of investing in new technology.

5.6.1.2 Financial Support from the Federal Government

While this relationship was not as strong, there is some evidence that financial support from the federal government appears to be associated with multi-modal data fusion deployments. Of the top six regions analyzed, four have received grants from the federal government. This may suggest that federal financing of new technology is important in encouraging deployment, as metro areas may not be willing to make higher-risk investments in technology. However Denver and Portland, two of the leading metro areas in terms of data fusion applications, have not received any federal funding for ITS projects suggesting that some other factor(s) may be of importance, such as institutional structure. The timing of federal support may also be a consideration as Denver and Portland were two of the earliest adopters of multi-modal data fusion applications, yet federal funding for demonstration projects has not generally become available until more recently.

5.6.1.3 Lower Auto Dependency

It appears that regions with lower auto dependency tend to have higher levels of multi-modal data fusion. Once again, intuition suggests this is a reasonable finding. As a region's reliance on non-auto modes of transport increases, the demand for travel information that spans multiple modes is likely to increase. Some caution is warranted when determining the importance of this measure; when the metro areas were selected, emphasis was placed on selecting larger population centers, which are more likely to have a strong transit presence. With such a small sample of *relatively* transit friendly regions, it is difficult to say with any certainty that this relationship holds true for all regions. Further analysis with a sample of less populated regions may provide further evidence to support/disprove this finding.

5.6.1.4 Geographic Location

While geographic location is not likely to have a substantial influence on data fusion implementation, it is interesting to note that all metro areas with some form of real-time transit information, or some form of multi-modal systems integration are located west of the Mississippi.

Table 10: Ranked (Highest to Lowest Levels of Multi-Modal DF) Table for Eleven Metropolitan Areas – Original Evaluation Criteria

Metro Region	Population (000's)	Rank (Tercile)	Congestion Level	Rank (Tercile)	Congestion Increase	Rank (Tercile)	Auto Dependence	Rank (Tercile)	"High Tech" Presence	Rank (Tercile)	Federal ITS Support	Geographic Region
San Francisco-Oakland CA	4,156	9 (1)	60	3 (1)	3	22 (2)	36	3 (1)	1	2 (1)	3	West Coast
Portland OR-WA	1,729	23 (2)	38	26 (2)	2	25 (2)	59	8 (1)	15	14 (2)	0	West Coast
San Diego CA	2,896	15 (2)	57	6 (1)	19	4 (1)	114	17 (2)	5	4 (1)	2	West Coast
Seattle WA	3,009	14 (2)	45	18 (2)	-6	36 (3)	54	7 (1)	3	3 (1)	3	West Coast
Minneapolis-St. Paul MN	2,520	16 (2)	43	21 (2)	9	13 (1)	132	19 (2)	10	9 (1)	2	Center West
Denver-Aurora CO	2,088	19 (2)	50	11 (1)	10	12 (1)	98	12 (1)	7	6 (1)	0	Center West
San Antonio TX	1,362	29 (3)	39	24 (2)	17	5 (1)	156	22 (2)	49	39 (3)	1	Center West
Cincinnati OH-KY-IN	1,620	25 (2)	27	30 (3)	1	27 (3)	188	26 (2)	34	30 (3)	1	Midwest
Orlando FL	1,360	30 (3)	54	9 (1)	-3	32 (3)	183	24 (2)	25	23 (2)	0	South East
Charlotte NC-SC	860	38 (3)	45	17 (2)	19	3 (1)	222	31 (3)	30	27 (3)	0	South East
Pittsburgh PA	1,838	21 (2)	16	37 (3)	-3	33 (3)	95	11 (1)	37	33 (3)	0	Midwest

Sources: TTI, 2007 / PPI, 2001 / FHWA, 2006a / FHWA, 2006b / FHWA, 1998b

5.6.2 MPO & Transit Agency Characteristics Influencing Data Fusion Implementation

5.6.2.1 MPO Taxation Authority

One of the strongest institutional trends observed was the existence of regional taxation authority among regional governments with data fusion applications in use. Among the top six regions analyzed, four have regional taxation powers, and those four are the only MPO's analyzed that had such powers. Although it's difficult to draw solid conclusions from the analysis, it is assumed that greater taxation power gives regional governments more flexibility to invest in data fusion applications. It also seems likely that with greater regional taxation power, there would be a greater emphasis placed on the implementation of projects and applications that generate region-wide benefits, rather than municipal or statewide benefits. The added accountability that comes with regional taxation powers may encourage governments to make investments that have strong perceived region-wide benefits.

5.6.2.2 Transit Funding Predominantly from Local Sources

Although a relatively weak relationship, it appears that those transit agencies with more funding from local sources tended to have more advanced data fusion applications deployed. It could be that transit agencies with local funding have greater flexibility in how they spend their funds and can implement solutions more quickly than metro areas that rely on larger amounts of state and federal funding. While not a direct contradiction, it is difficult to reconcile the finding that higher levels of federal grant funding could lead to data fusion implementation while higher levels of local transit funding could lead to the same outcome.

5.6.2.3 Presence of Technology does not Necessarily Translate into Data Fusion Implementation

The evidence suggests that simply having the underlying technology that enables further data fusion does not necessarily lead to the implementation of data fusion applications. Of the fourteen transit agencies analyzed, twelve had their entire fleet (or nearly their entire fleet) of transit vehicles outfitted with automatic vehicle location (AVL) technology, yet only eight of those had any form of predictive information available to the public. This may indicate that while technology is needed to implement data fusion, the actual decision to undertake real-time applications is influenced by other institutional factors.

Table 11: Ranked (Highest to Lowest Levels of Multi-Modal DF) Table for Eleven Metropolitan Areas – MPO and Transit Agency Characteristics

				MPO Characteristics			Transit Agency Characteristics			
Metropolitan Area	**Relative Rank - Metro Level, Multi-Modal Data Fusion**	**Metropolitan Planning Organization**	**Transit Agency**	**Tax Authority**	**MPO Board Representation**	**Jurisdictions within MPO (Counties, Local Governments)**	**# of Transit Providers in UZA**	**% of Funding from Local Sources - By Agency***	**% of Funding from Local Sources - By DF Complex.**	**% of Fixed Route Vehicle Fleet with AVL Tech.**
San Francisco-Oakland CA	1	MTC	SF MUNI	Yes	Elected Locally, Appointed to Board	(9, 101)	11	71%	76%	100% (Bus & Rail)****
			SF BART					84%		100%
			AC Transit					73%		100%
Portland OR-WA	2	Portland Metro	TriMet	Yes	Elected Regionally	(3, 25)	3	79%		100%
San Diego CA	3	SANDAG	San Diego MTS**	Yes	Elected Locally, Unknown Board Selection	(1, 18)	5**	62%***		100%
Seattle WA	4	PSRC	King County Metro	No	Elected Locally, Elected to Board	(4, 70)	9	74%	57%	100%
			WA State Ferry					12%		100%
Minneapolis-St. Paul MN	5	Metro Council	Metro Transit	Yes	Appointed	(7, 189)	3	32%		100%
Denver-Aurora CO	6	DRCOG	Denver RTD	No	Elected Locally, Appointed to Board	(9, 56)	1	77%		97%
San Antonio TX	7	SA-BC MPO	VIA Metro Transit	No	Partially Elected Locally, Appointed to Board	(1, >25)	1	75%	51%	100%
Cincinnati OH-KY-IN	8	OKI RCOG	SORTA / Metro	No	Elected Locally, Appointed to Board	(8, 198)	4	70%		100%
Orlando FL	9	MetroPlan	Orlando LYNX	No	Elected Locally, Appointed to Board	(3, n.a.)	1	55%		0%
Charlotte NC-SC	10	MUMPO	Charlotte CATS	No	n.a.	(2, ~17)	1	66%		100%
Pittsburgh PA	11	S.W. PA Comm.	Port Authority	No	Appointed	(10 & 1 City, n.a.)	6	25%		0%

*"Local Sources" are considered fare revenue & local funding. "Non-Local Sources" include, state, federal and other sources of funding. Percentages include Operating & Capital Funding
**San Diego - MTS, MTS Trolley & MTS Contract Services considered one agency
***2006 San Diego MTS Trolley Financial Data had consistency issues, 2004 data was used for MTS Trolley
****SF Muni AVL Data from TCRP 48: Real-Time Bus Arrival Information Systems

Sources: AMPO, 2005 / DRCOG, 2008 / FHWA, 2008b / Metroplan Orlando, 2008 / Minneapolis Metro Council, 2008 / MTC, 2008a / MUMPO, 2008 / NTD, 2006 / OKI COG, 2008 / Portland Metro, 2008 / PSRC, 2008 / San Antonio-Bexar County, 2008 / SANDAG, 2008b / SPC, 2008

5.7 Why has San Francisco been successful at Multi-Modal DF Implementation?

It is clear that the quantitative analysis performed is limited in its ability to explain institutional factors that affect data fusion implementation. As such, supplementary research was conducted on the history of San Francisco's '511' traveler information system, the most advanced multi-modal data fusion application examined in this research. The goal is to gain further insight into the institutional relationships in the San Francisco region that may have influenced the current '511' system.

San Francisco's experience with real-time travel information began in 1993 when the federal government provided funding for advanced traveler information systems. TravInfo, San Francisco's first traveler information system, was operational by 1996 and provided users with telephone-based information. The system was managed by the region's transportation planning body, the Metropolitan Transportation Commission (MTC) (FHWA, 2001). In 2000, the Federal Communication Commission (FCC) designated the three digit telephone number '511' to be reserved for regional traveler information. The MTC set about updating their services to take advantage of the new '511' number (FHWA, 2001). After some initial complications with the regional telecommunication providers, the MTC launched their '511' traveler information system in December 2002 (SF MTC, 2006). The system is managed by a partnership of public agencies including MTC, Caltrans (California's state department of transportation) and the California Highway Patrol (CHP). The initial focus of the system was on providing real-time traffic conditions and a complex combination of sensors was used to generate the needed information (SF MTC, 2008a). Information from Caltrans freeway sensors and closed circuit television (CCTV) cameras was fused with information from CHP's highway incident database. Initial coverage was incomplete so the MTC announced that they would allow FasTrak electronic toll collection (ETC) tags to be used for data collection purposes (SF MTC, 2006). The MTC also partnered with SpeedInfo, a local technology company, to provide 320 additional roadside radar speed detectors to ensure more complete regional coverage (SpeedInfo, 2007). Parsons Brinckerhoff Farradyne (now Televent Farradyne) was hired to fuse the data, perform data quality control functions and disseminate the information online (Telvent Farradyne, 2006). In 2006, these day-to-day functions were contracted to Science Applications International Corp (SAIC).

On the transit side, the beginnings of an integrated real-time information system began in 1999 with the MUNI system in San Francisco. After several years of severe service problems, San Francisco MUNI was approached by a small start-up technology company based in the Bay area called NextBus, offering to provide them with predictive arrival time technology for their transit fleet. NextBus offered MUNI a three month free trial of the technology at which point they could choose to purchase it or have it removed from their fleet (SF MTC, 1999). SF MUNI saw the NextBus system as an opportunity to improve customer satisfaction and accepted the three month trial. In late 1999, the MUNI signed a formal $900K contract with NextBus to provide real-time transit information on a limited number of lines (Mass Transit Magazine, 1999). After several years of successful implementation, AC transit in the East Bay purchased NextBus services in 2001 (NextBus, 2008b).

With the underlying technology being deployed and used on highways and within transit agencies by 2001, and with the new '511' traveler information system operational by 2002, the MTC set about expanding real-time coverage and integrating the various sources of information. In 2004, Bay area voters approved MTC Regional Measure 2 (RM2), a transportation funding bill aimed at relieving congestion on regional freeways. The measure was funded through a $1.00 increase on the seven state-owned toll bridges (SF MTC, 2008c). RM2 provided $20M in funding for the establishment of the 'Real-Time Transit Information Grant Program' and this was supplemented with an additional $4.5M from the federal government, provided at the request of Congresswoman Pelosi (SF MTC, 2008c; SF Chronicle, 2005). In 2005, the funds were distributed to eight regional transit providers including the SF MUNI (SF MTC, 2005). Since 2006, San Francisco's '511' system has provided real-time transit information by telephone. They plan on offering additional real-time information from other transit providers (including ferries) in the future (SF MTC, 2008b). In an effort to provide further integration of systems, MTC has considered a data sharing agreement with the East Bay Smart Corridors Program to provide additional transit information and coverage of some major arterials not currently covered by the '511' system (SF MTC, 2006).

There are a number of findings that can be drawn out of San Francisco's '511' system history:

- Initial funding support from the federal government was important in promoting the use of advanced technologies. The initial grant in the 1990's to establish a traveler information system was critical to encouraging technology use within the region.
- The presence of local technology companies was particularly important in San Francisco's implementation of traveler information applications. Two of the companies that provided important technology products included NextBus (located in Emeryville, CA) and SpeedInfo (located in San Jose, CA).
- Partnerships between private industry, the MTC, other government agencies and other programs have existed throughout the implementation process. It's clear that the complexity of integrating a variety of data types from a number of sources requires cooperation among many entities.
- While private industry and the federal government were important actors in promoting the use of data fusion technologies, the coordination and integration of multiple data feeds into a single system was due largely to the leadership of the MTC, San Francisco's regional transportation planning body.
- Related to the previous point, while the transit agencies took the initial leap and trialed advanced transit technology, credit for expanding the use of that technology and ensuring region-wide coordination was led by the MTC with the help of Caltrans.
- While MTC showed strong leadership in pushing for advanced traveler information systems, they would not have experienced the success they did without the significant support they received from Caltrans (FHWA, 2001). The state agency was open to sharing sensor data, but more importantly it allowed the MTC to develop the Bay-area '511' system rather than taking on the task itself.

5.8 Prospects for Metropolitan-Level Data Fusion Implementation and its Drivers

At the outset of this section, two questions were asked regarding the role of metropolitan governments in multi-modal data fusion implementation; (1) "Do regional, or metropolitan-level, governments have a role in data fusion applications implementation?" and, (2) "Are there institutional factors that encourage the adoption of data fusion applications within a metropolitan area, particularly multi-modal data fusion?" To some extent, the answer to both of these questions is 'Yes'.

At the outset, it appeared that the federal government and private industry were the two dominant institutions driving data fusion application use. No specific evidence has been found that disproves that link, however it appears that regional government may be playing a more significant role than first thought, at least in a handful of metropolitan areas. While federal grants and partnerships with private industry are important first steps in enabling basic data fusion, it appears that strong leadership from regional government (with the support of state government) is a critical driver for advanced levels of data fusion, and particularly data fusion systems integration.

The research findings suggest that several factors may be influential in the implementation of multi modal data fusion applications. The strong presence of a technology industry and financial support from the federal government appears to influence the initial implementation of data fusion applications. As the applications become more advanced and integration of systems becomes more critical, it appears that institutional variables become the dominant drivers. MPO's that see the value in advanced traveler information and have the ability to raise revenue to support the development and integration of systems appear to be more successful at providing multi-modal data fusion applications. Finally, cooperation among regional government and local transit agencies appears to be an important element. When all parties agree that providing advanced traveler information has regional benefits, integration of information systems appears to proceed more smoothly.

6 Conclusions

Overall, although much of the necessary technology exists, the elaborate use of DF for transportation remains far from its potential. Both technical and institutional challenges remain. A number of different computer architecture models exist, with the best architecture for any particular case dependent upon numerous context-specific constraints relating to the number of different information sources, the relationships among relevant institutions, data detail (level of representation) necessary and possible, and so on. The ultimate architecture underlying a data fusion application will likely need to: be flexible enough to enable a high degree of accuracy while ensuring respect for privacy *and* ease of abstraction (e.g., to higher level traffic patterns); accommodate a broad geography and number of jurisdictions and agencies; incorporate a diverse range of sensor types; enable various potential applications and delivery media to users; and, allow for some degree of feedback to improve both the efficiency of applications and the DF system itself (e.g. modifying sensors). Overarching these general specifications come questions regarding the degree of centralization: a centralized architecture allows for clearer control over the varying dimensions of complexity; on the other hand, a less centralized system may prove more robust and likely more flexible to new additions.

The private sector appears to be heavily involved in the necessary DF activities, with many companies now spanning across related areas such as data provision (from various sensor types), data aggregation, and delivery to end users. In reviewing relevant business activity (primarily in North America), we perceive at least two relevant trends. First, the most advanced applications appear for private vehicle-based (automobile) users, providing real time traffic conditions, route choice suggestions, and so forth, delivered via the increasingly prevalent in-vehicle devices and mobile devices. The most advanced services tend to be subscription-based and, for the moment, the information available seems to be confined to highways and major arterials. Second, private sector activities on the public transportation side seem much more limited, with only a few companies active in the area. The one company providing real-time information with predictive capabilities, NextBus, has public transport service providers (as opposed to travelers) as its direct clients. The current tilt in activity towards car-based applications may simply be due to the paper's heavy focus on the US experience (more dominant private vehicle use in the US), perceived or actual market potential (nationally, public transport accounts for just 5% of all trips in the USA), a more difficult revenue model to implement for public transport applications, and/or some combination of these and other factors.

We suspect that the greatest societal value for transportation applications will eventually come when data fusion can be utilized to introduce needed information at the exact moment(s) in time that it is needed, allowing users to answer questions such as "should I travel now for that purpose? Should I take this mode and if, so, what time should I leave? What are the time-money-reliability-environmental trade-offs of my various options?" and so on. Market forces alone may not provide enough incentive to develop a fully operable, integrated, multi-modal real-time application (with predictive capabilities) that would be necessary to answer such questions. The public sector, in collaboration with private industry, will play a key role in bringing such applications to realization. Yet the institutional challenges remain non-trivial and may indeed exceed the technical challenges. In some cases, existing agreements (contracts) with parties responsible for system elements (e.g., with a company to operate and maintain traffic signal control systems) may significantly hamper data fusion by, for example, prohibiting data sharing. This raises important issues related to data “ownership” and privacy concerns, issues that require adequate attention before DF applications can reach their full potential.

Our brief examination of several metropolitan area cases from the US suggests that some factors might accelerate multi-modal, real-time DF adoption. Market potential plays some apparent role, as more auto-dependent places have focused more heavily on traffic applications while places with higher transit use have progressed more quickly towards multi-modal, DF adoption. High-tech industry presence also seems to be associated with adoption of more advanced systems. Governance structures may also play a role, particularly the influence of the MPO, the regional transportation planning organization. MPO’s and other local agencies with greater financial independence and with greater autonomy have shown more progress towards the use of more advanced DF applications. Ultimately, advanced DF will require public-private partnerships within metropolitan areas, perhaps following the Berlin approach. Such partnerships will not only have to create the right incentive structure to ensure substantial public benefits, but will also have to work to create the right standards, etc. Fully integrated DF systems require interoperability protocols and efforts are underway to standardize transport systems communication, normally based on XML (e.g. DATEX in EU, TIH in the UK, NTCIP in the US, to name a few). Further advances in widespread transport communications such as Car-to-Infrastructure (C2I) and Car-to-Car (C2C) will further expand the opportunities for, and challenges to, data fusion.

Finally, important questions remain relating to how users will actually respond to the information generated and made available through such systems. Will users utilize the information to make “better” travel decisions? Will such information further blur the lines between users, service providers, and planners? We can fairly characterize the current state of DF in transportation as analogous to “transport 1.0,” where data providers (public or private) collect, process and publish the data. However, pervasive computing environments and the Internet make possible a new model of “transport 2.0,” where end users can contribute information to describe travel conditions and more.[1] This may encourage citizens to increase their participation in the planning and operation of the transportation system, introducing stronger bottom-up structures. Such developments would mirror the “open source” software model and, more generally, the new communication methods, applications and usage patterns appearing almost daily (e.g., Blogs, Wikis, etc.). Using unstructured data such as a web page containing a transport-related news story, pictures (e.g. Flickr), audio and video (e.g. YouTube) for transport applications presents a formidable challenge in terms of DF, requiring either the structuring of data via transformation (involving technologies such as natural-language processing and semantic mapping) or creating specialized data mining tools. While challenging, such applications may provide substantial scale benefits, ultimately reducing the need to deploy physical hardware throughout transportation infrastructure systems.

[1] A number of “transport 2.0” projects already exist, in which citizens send traffic information (via internet or phone) or even map corrections (e.g. TomTom MapShare).

7 Bibliography

Automobile Association (AA) Ltd. (2008). *AA Roadwatch*, UK. Accessed February 2008 from: http://www.theaa.com/travelwatch/roadwatch.jsp.

Association of Computational Linguistics (ACL). (2008). *ACL Introduction*, Accessed 25 June, 2008 from: http://www.aclweb.org

AEA Technology.(2007). *Transport Direct Evaluation- Final Report for the Department for Transport*. UK. Accessed 20 July, 2008 from: http://www.dft.gov.uk/162259/245385/249577/TD_Final_Report_Version_1.21.pdf

Agrawal, R., Asonov, D., Bayardo, R., Grandison, T, Johnson, C. and Kiernan, J. (2005) *Managing Disclosure of Private Health Data with Hippocratic Databases.* IBM White Paper. Accessed 20 June, 2008 from: http://www.almaden.ibm.com/cs/projects/iis/hdb/Publications/papers/nc_hdb_white_paper_health.pdf

Agrawal, R., Kiernan, J., Srikant, R. and Xu, Y. (2002) *Hippocratic Databases.* Proceedings of the 28th International Conference on Very Large Databases, Hong Kong, China.

AirSage Driving Solutions. (2008). *AirSage – Redefining Traffic Information*, US. Accessed January 2008 from: http://www.airsage.com/.

Association of Metropolitan Planning Organizations (AMPO). (2005). *2005 Profiles of Metropolitan Planning Organizations*, AMPO Publications, US.

Advanced Regional Traffic Interactive Management & Information System (ARTIMIS). (2008). *ARTIMIS – Segment Map*, US. Accessed from May 2008 from: http://www.artimis.org/segaccess1.html.

Au, A.K.T.P., Curcin, V., Ghanem, M., Giannadakis, N., Guo, Y., Jafri, M.A., Osmond, M., Oleynikov, A., Rowe, A.S., Syed, J., Wendel, P. and Zhang, Y. (2004). *Why Grid-based Data Mining Matters? Fighting Natural Disasters on the Grid: from SARS to Land Slides.* In Proceedings of the 3rd UK e-science All-Hands Conference, Nottingham, UK., 121–-126. ISBN 1-904425-21-6.

Bayerninfo Websites.(2008). *About Bayerninfo*. Accessed 25 April, 2008 from: http://www.bayerninfo.de/vib/info/showAGB.do;jsessionid=AEA2BF2727C1368B2E70E46543B5B1C9

Bay Area Rapid Transit (BART). (2008). *BART – Real Time Arrivals*, US. Accessed May 2008 from: http://www.bart.gov/schedules/eta/index.aspx.

Bernd Leitsch.(2003). *Mobility and Traffic Management Centre for Berlin- A Public-Private Partnership for Mobility*, International Conference EPIC 2003, Berlin. Accessed May 2008 from: http://www.azvt.de/media/de/Leitsch.PDF

CellInt Traffic Solutions. (2008). *CellInt Traffic Solutions – Making it Work for You*, US. Accessed January 2008 from: http://www.cellint.com/.

CellInt Traffic Solutions. (2007). *Performance and Limitations of Cellular-Based Traffic Monitoring Systems.* Ohio Transport Engineering Conference.

Central Florida Regional Transportation Authority (LYNX). (2008). *LYNX Trip Planner*, US. Accessed May 2008 from: http://trip1.golynx.com/.

Charlotte Area Transit System (CATS). (2008). *CATS – Riding CATS*, US. Accessed April 2008 from: http://tripplanner.ridetransit.org/tripplanning/jnot/start.oci.

Cheol O. et al. (2006). *Introduction to ITS Systems in Korea*, Hanyang University, Korea. Accessed March 2008 from: http://www.ncts.upd.edu.ph/CBP/archive/PDF/ITS/ITS-20061206-O.pdf.

Chris Gibbard.(2006). *Transport Direct*, ENT3 4th Meeting, Brussels. Accessed March 2008 from: http://www.predim.org/documents/TransportDirect_Presentation_ENT3_4thMeeting.PDF

Chung, S. and McLeod, D. (2003) *Dynamic Topic Mining from News Stream Data.*, In *On the Move to Meaningful Internet Systems 2003: CoopIS, DOA, and ODBASE* (R. Meersman, et al., Eds). New York: Springer LNCS 2888, pp. 653–670.

Clear Channel Communications. (2008). *Clear Channel Communications*, US. Accessed January 2008 from: http://www.clearchannel.com/.

Colorado Dept. of Transportation (CDOT). (2008). *CDOT Speed Map*, US. Accessed May 2008 from: http://www.cotrip.org/atis/web.ZoomboxMarshal?device=Speedmap&Zoombox=12.

Crubézy, M., O'Connor, M., Pincus, Z., Musen, M.A. and Buckeridge, D.L. (2005) Ontology-centered Syndromic Surveillance for Bioterrorism. *IEEE Intelligent Systems*, Vol. 20, pp. 26–-35.

Defense Advanced Research Projects Agency (DARPA). (2005) *Global Autonomous Language Exploitation (GALE) project*, Accessed 25 June, 2008 from: http://www.darpa.mil/ipto/programs/gale/gale.asp

DASH Navigation, Inc. (2008). *About DASH Express*, US. Accessed February 2008 from: http://www.dash.net/product/traffic.php.

DATEX Website(2008). *DATEX Introduction*. Accessed April 2008 from: http://www.datex2.eu/

DeCell Technologies Ltd. (2008). *DeCell – Mobile Network-based, Cellular Traffic Data Collection*, US. Accessed January 2008 from: http://www.decell.com/.

Department for Transport (DFT). (2008a). *The "SCOOT" Urban Traffic Control System*, UK. Accessed March 2008 from: http://www.dft.gov.uk/pgr/roads/tpm/tal/signsandsignals/thescooturbantrafficcontrols4107.

Department for Transport (DFT). (2008b). *Transport Direct*. UK. Accessed May 2008 from: http://www.dft.gov.uk/transportdirect.

Delcan. (2008). *Delcan Project Data Sheets – Transportation Systems*. Accessed February 2008 from: http://www.delcan.com/?id=projects/projects.

Dempsey, P.S. et al. (2000). *Metropolitan Planning Organizations: An Assessment of the Transportation Planning Process – A Report to Congress, Volume II, Section IV*, University of Denver Intermodal Transportation Institute & the National Center for Intermodal Transportation. Accessed April 2008 from: http://www.du.edu/transportation/TransportationResearchProjects/MPOStudy.html.

Denver Regional Council of Governments. (2008). *DRCOG Website – About DRCOG*, US. Accessed May 2008 from: http://www.drcog.org/index.cfm?page=AboutDRCOG.

Denver Regional Transit District (Denver RTD). (2008). *RDT – Mobile'n'Go*, US. Accessed May 2008 from: http://www.gortd.com/.

eSafety Compendium(2006). Addendum I. E-Safety Support EU initiative.

Esteban J., Starr A., Willetts R., Hannah P., Bryanston-Cross P. (2005). A Review of Data Fusion Models and Architectures: Towards Engineering Guidelines. *Neural Comput & Applications*, Vol. 14, pp. 273–281.

EveryTrail.com. (2008). *About EveryTrail*, US. Accessed January 2008 from: http://www.everytrail.com/about.php.

Federal Highway Administration. (2008a). *ITS Overview*, USDOT, Research and Innovative Technology Administration, Intelligent Transportation Systems Division. Accessed February 2008 from: http://www.its.dot.gov/its_overview.htm.

Federal Highway Administration. (2008b). *Deployment Statistics – Fixed Route Buses Equipped with Automatic Vehicle Location*, USDOT, FHWA, Research and Innovative Technology Administration, Intelligent Transportation Systems Division. Accessed September 2008 from: http://www.itsdeployment.its.dot.gov/Results.asp?year=2006&rpt=M&filter=1&ID=376.

Federal Highway Administration. (2006a). *Integrated Corridor Management (ICM) Pioneer Sites - Leaders, Innovators in Congestion Management*, USDOT, FHWA, Research and Innovative Technology Administration, Intelligent Transportation Systems Division. Accessed March 2008 from: http://www.its.dot.gov/icms/pioneer.htm.

Federal Highway Administration. (2006b). *Urban Partnerships Congestion Initiative*, National Strategy to Reduce Congestion on America's Transportation Network Initiative, USDOT. Accessed March 2008 from: http://www.upa.dot.gov/.

Federal Highway Administration. (2001). *511 Case Studies – San Francisco Bay Area, MTC*, USDOT, FHWA, Research and Innovative Technology Administration, Intelligent Transportation Systems Division. Accessed October 2008 from: http://www.its.dot.gov/511/Travinfo.htm.

Federal Highway Administration. (2000). *Metropolitan Model Deployment Initiative: Seattle Evaluation Report, Final Draft*, USDOT, FHWA, Intelligent Transportation Systems Division. Accessed March 2008 from: http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13071.pdf.

Federal Highway Administration. (1999). *Metropolitan Transportation Management Center*, *A Case Study: Georgia NaviGAtor*, USDOT, FHWA, ITS Joint Program Office. Accessed March 2008 from: www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/11124.pdf.

Federal Highway Administration. (1998a). *ITS Field Operational Test Summary: Atlanta ATIS-KIOSK Project*, USDOT, FHWA, Office of Travel Management and ITS Applications. Accessed March 2008 from: http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/9366.pdf.

Federal Highway Administration. (1998b). *Transportation Technology Innovation and Demonstration (TTID) Program*, USDOT, FHWA, Office of Operations, Real-Time Traveler Information Program. Accessed March 2008 from: http://ops.fhwa.dot.gov/travelinfo/ttidprogram/ttidprogram.htm.

Federal Ministry of Education and Research (BMBF).(2002). *Mobility in Conurbations--First Results.* Germany. Accessed May 2008 from: http://www.bmbf.de/pub/mobility_in_conurbations.pdf

Federal Ministry of Transport, Building and Housing. (2008). *Transport Sector Introduction.* Germany. Accessed May 2008 from: http://www.bmvbs.de/en/-,1873/Transport.htm

Federal Ministry of Transport, Building and Housing. (2004). *Transport Telematics—Developments and Success Stories in Germany* . Germany. Accessed May 2008 from: http://www.bmvbs.de/Anlage/original_971906/Transport-Telematics-Developments-and-Success-Stories-in-Germany.pdf

Filippo Logi, Marc Ullrich, Hartmut Keller. (2001). *Traffic Estimation in Munich: Practical Problems and Pragmatic Solutions.* 2001 IEEE Intelligent Transportation Systems Conference Proceedings - Oakland (CA), USA - August 25-29, 2001

Florida Department of Transportation (FDOT). (2008). *Florida 511*, US. Accessed May 2008 from: http://www.fl511.com/default.html.

Florida Department of Transportation (FDOT). (2007). *White Paper – Cell Phone Location System, Final Version 2*. ITS Section, Traffic Engineering and Operations Office, FDOT.

Franklin Regional Council of Governments. (2007). *Chapter 11: Intelligent Transportation Systems (ITS) and Telecommunications*, 2007 Franklin Region Transportation Plan, Franklin COG. Accessed February 2008: http://www.frcog.org/pubs/transportation/2007RTP/Ch11_ITS_Apr07.pdf.

Fritz Busch. (2005). *Concepts and Instruments of Modern Transport Management - State of the Art*. 5th STRC Swiss Transport Research Conference. Switzerland. Accessed February 2008 from: http://www.strc.ch/conferences/2005/STRC05_Keynote_Busch.pdf

Fwa, T.F. (2004). *Sustainable Urban Transportation Planning and Development – Issues and Challenges for Singapore*, Center for Transportation Research, National University of Singapore, Singapore. Accessed March 2008 from: http://csur.t.u-tokyo.ac.jp/ws2004/papers/B2-Fwa.pdf.

Garmin Ltd. (2008). *About Garmin*, US. Accessed January 2008 from: http://www8.garmin.com/aboutGarmin/.

General Motors Corp. (2007). *General Motors Develops Vehicles with a Sixth Sense*, US. Accessed January 2008 from: http://www.gm.com/experience/technology/news/2007/tech_veh2veh_060107.jsp.

Georgia Department of Transportation. (2008). *NaviGAtor website.* Accessed March 2008 from: http://www.georgianavigator.com/.

GlobisData Inc. (2008). *DRIVES Canadian Traffic Information*, Canada. Accessed January 2008 from: http://www.globisdata.ca/.

Globus Project. (2008). *Globus Project website.* Accessed March 2008 from: http://www.globus.org/toolkit/

GRIA Project (2008). *GRIA Project website.* Accessed March 2008 from: http://www.gria.org
Google Corporation. (2008a). *Google Maps – Multiple Cities*, US. Accessed April & September 2008 from: http://maps.google.com/.
Google Corporation. (2008b). *Google Maps Transit – Plan a Trip using Public Transportation*, US. Accessed April & September 2008 from: http://www.google.com/transit.
Harris C.J., Bailey A., Dodd T.J. (1998). Multi-sensor Data Fusion in Defence and Aerospace. *Aeronaut Journal*, Vol. 102, No. 1015, pp. 229–244.
HopStop.com Inc. (2008). *HopStop Directions*, US. Accessed February 2008 from: http://www.hopstop.com/?action=dir_home.
IBI Group. (2001). *Puget Sound Regional ITS Architecture*, Puget Sound Regional Council. Accessed March 2008 from: http://psrc.org/projects/its/pubs/regarch.pdf.
INRIX. (2008). *INRIX – The Leading Provider of Traffic Information*, US. Accessed January 2008 from: http://www.inrix.com/.
INRIX. (2005). *INRIX Press Release - Microsoft Makes Its Intellectual Property Available to Businesses of All Sizes*, US. Accessed January 2008 from: http://www.inrix.com/pressrelease.asp?ID=1.
IntelliOne Technologies. (2007). *IntelliOne – Life in Motion Made Simple*, US. Accessed December 2007 from: http://www.intellione.com/.
iTIS Holdings. (2008a). *About iTIS Holdings*, UK. Accessed February 2008 from: http://www.itisholdings.com/article.asp?id=101.
iTIS Holdings. (2008b). *Case Study – Maryland Department of Transportation*, UK. Accessed February 2008 from: http://www.itisholdings.com/article.asp?id=300.
ITS America. (2008). *ITS America History*, Intelligent Transportation Systems America. Accessed February 2008 from: http://www.itsa.org/itsa_history/c48/Inside_ITSA/ITS_America_History.html.
ITS Japan. (2008). *Outline of ITS Japan*, Japan. Accessed March 2008 from: http://www.its-jp.org/english/outline_e/index.htm
ITS Korea. (2008). *Establishment of ITS Korea*, Korea. Accessed March 2008 from: http://www.itskorea.or.kr/eng/index.html.
Japanese Ministry of Land, Infrastructure & Transportation. (2007). *Introduction of Japanese SmartWay 2007*, Japan. Accessed March 2008 from: http://www.its.go.jp/ITS/Smartway/SW2007/SMARTWAY2007PublicRoadTest.pdf.
Japanese Ministry of Land, Infrastructure & Transportation. (2004). *Chapter 1 – Significance of Promoting ITS – Section 1.3(2)*, Road Bureau, MLIT, Japan. Accessed March 2008 from: http://www.mlit.go.jp/road/ITS/
King County Government. (2008). *Metro Online*. Accessed March 2008 from: http://transit.metrokc.gov/.
King County Metro Transit. (2008). *Bus Tracker*, US. Accessed April 2008 from: http://transit.metrokc.gov/oltools/tracker.html.
Koser, Steve. (2005). *Statewide strategies for TMC's.* Transportation Engineering & Safety Conference. Accessed March 2008 from: http://www.outreach.psu.edu/programs/tesc2005/images/8b_hunt.pdf.

Kuang, Loh Chow. (2007). *Singapore's Approach to Developing a Sustainable, Integrated Transport System*. EMBARQ Workshop 'Transforming Transportation Institutions', Washington, DC. Accessed March 2008 from: http://embarq.wri.org/tt07/tt2-07/LohChowKuang-EMBARQ-TT2-2007.pdf.

Lewis, P.H., Martinez, K., Abas, F.S., Ahmad Fauzi, M.F., Addis, M.J., Lahanier, C., Stevenson, J., Chan, S.C.Y., Mike J.B. and Paul, G. (2004) An Integrated Content and Metadata Based Retrieval System for Art. *IEEE Transactions on Image Processing*, Vol. 13, No. 3, pp. 302–313.

Liu, B., and Chang, K.C.-C. (2004) *Editorial: Special issue on web content mining.*, ACM SIGKDD Explorations Newsletter 6, 2, 1–4.

Llinas, J., Bowman, C., Rogova, G., Steinberg, A., Waltz, E., White, F. (2004). *Revisiting the JDL Data Fusion Model II.* Accessed March 2008 from: http://www.fusion2004.foi.se/papers/IF04-1218.pdf

Luo R., Kay M. (1988). Multisensor Integration and Fusion: Issues and Approaches. *SPIE Sensor Fusion*, Vol. 931, pp. 42–49.

Mass Transit Magazine. (1999). *Muni teams with NextBus*, US.

Mecklenburg-Union Metropolitan Planning Organization. (2008). *MUMPO Website – About MUMPO*, US. Accessed May 2008 from: http://www.mumpo.org/About_Us.htm.

Meehan, B. & Rupert, B. (2004). *Putting Travelers in the Know*, USDOT, FHWA, Public Roads website. Accessed March 2008 from: http://www.tfhrc.gov/pubrds/04nov/06.htm.

Metro Transit, (2008). *Metro Transit NexTrip*, US. Accessed June 2008 from: http://nextrip.metc.state.mn.us/NextripFull.aspx.

Metroplan Orlando. (2008). *Metroplan Website – About Us*, US. Accessed May 2008 from: http://www.metroplanorlando.com/site/about/default.asp.

Minneapolis Metropolitan Council. (2008). *Metropolitan Council Website – About the Council*, US. Accessed May 2008 from: http://www.metrocouncil.org/about/index.htm.

Minnesota Dept. of Transportation (MnDOT). (2008). *Minnesota Road Traveler Information Service – Traffic and Road Conditions*, US. Accessed May 2008 from: http://www.511mn.org/default.asp?area=TC_Metro.

Ministry of Construction and Transportation, Republic of Korea. (2002). *Intelligent Transport Systems – ITS Model City Development in Korea*, MCT, ITS Division, Transportation Policy Bureau. Accessed March 2008 from: http://152.99.129.29/its/model/%EB%AA%A8%EB%8D%B8%EB%8F%84%EC%8B%9C(%EC%98%81%EB%AC%B8).pdf

MOBINET.(2008). *MOBINET introduction*. Germany. Accessed March 2008 from: http://www.mobinet.de/Fachinformation/english/allgemein/frameset2.html

National Transit Database (NTD). (2006). *2006 Annual Database*, USDOT, FTA, NTD. Retrieved September 2008 from: http://www.ntdprogram.gov/ntdprogram/data.htm.

NAVTEQ. (2008). *NAVTEQ Advanced Solutions – Traffic*, US. Accessed January 2008 from: http://www.navteq.com/about/advanced_traffic.html.

NextBus LLC. (2008a). *NextBus – Bus Stop Selector*, US. Accessed May 2008 from: http://www.nextbus.com/predictor/newUserWelcome.shtml.

NextBus LLC. (2008b). *NextBus – Press Releases*, US. Accessed May 2008 from: http://www.nextbus.com/corporate/press/index.htm.
NextBus LLC. (2008c). *How NextBus Works*, US. Accessed January 2008 from: http://www.nextbus.com/corporate/works/index.htm.
NIST Speech Group.(2004), *Topic Detection and Tracking Evaluation*, Accessed 25 June, 2008 from: http://www.nist.gov/speech/tests/tdt/
North Carolina Department of Transportation (NCDOT). (2008). *NCDOT – Traveler Information Management System – Metrolina Region*, US. Accessed April 2008 from: http://www.ncdot.org/traffictravel/.
OECD guidelines on the protection of privacy and transborder flows of personal data. (1980). OECD Document C(80)58(Final), Accessed April 2008 from: http://www.oecd.org/document/18/0,2340,en_2649_34255_1815186_1_1_1_1,00.html
OGSA-DAI project.(2008). *OGSA-DAI project introduction.* Accessed April 2008 from: http://www.ogsadai.org.uk/
Ohio, Kentucky, Indiana Regional Council of Governments. (2008). *OKI Website – OKI Overview*, US. Accessed May 2008 from: http://www.oki.org/overview/index.html.
OMII Project.(2008). *OMII-UK Project Introduction.* Accessed January 2008 from: http://www.omii.ac.uk
OnStar Corp. (2008). *OnStar by GM – Plans and Services*, US. Accessed January 2008 from: http://www.onstar.com/us_english/jsp/plans/index.jsp.
OpenStreetMap. (2008). *OpenStreetMap – The Free Wiki World Map.* Accessed February 2008 from: http://www.openstreetmap.org/.
Oregon Dept. of Transportation (ODOT). (2008). *Oregon TripCheck – Portland Metro*, US. Accessed May 2008 from: http://www.tripcheck.com/Pages/RCMap.asp?mainNav=RoadConditions&curRegion=14#.
Parking Carma. (2008). *ParkingCarma – The Company*, US. Accessed February 2008 from: http://www.parkingcarma.com/About-Us/.
Peter Vortisch. (2001). *Use of PTV-Software in the traffic management centre (VMZ) Berlin*, 11th ptv vision User Group Meeting, Berlin. Accessed February 2008 from: http://www.ptvag.com/download/traffic/library/2001%20VISUM%20on-line%20ptv%20users%20group%20mtg.pdf
Pierce, S. & Lappin, J. (2003). *Acquisition of Traveler Information and its Effects on Travel Choices: Evidence from a Seattle-area Travel Diary Survey*, USDOT, Volpe National Transportation Systems Center. Accessed March 2008 from: http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13813_files/13813.pdf.
Port Authority of Allegheny County (Port Authority). (2008). *Port Authority Interactive Scheduler*, US. Accessed May 2008 from: http://www.portauthority.org/PAAC/Schedules/TripPlanner/tabid/164/Default.aspx.
Portland Metro. (2008). *Portland Metro – About Metro*, US. Accessed May 2008. From: http://www.oregonmetro.gov/index.cfm/go/by.web/id=24201.
Progressive Policy Institute (PPI). (2001). *The Metropolitan New Economy Index: Benchmarking Economic Transformation in the Nation's Metropolitan Areas*, PPI

Technology and New Economy Project, US. Accessed March 2008 from: http://www.neweconomyindex.org/metro/index.html.
PTV AG.(2008), *Traffic Management Centre (VMZ) Berlin: VMZ keeps Berlin moving.* Accessed March 2008 from: http://www.ptvag.com/fileadmin/files_ptvag.com/download/logistics/ref/Ref_VMZBerlin_e.pdf
Puget Sound Regional Council. (2008). *PSRC Website – About PSRC,* US. Accessed May 2008 from: http://psrc.org/about/index.htm.
Rana Ilgaz. (2007). *Image Recognition and Incident Detection in the real world*, 14th World Congress on ITS, Beijing, October.
Reinhard Gielher, Ralf Kohlen.(2006), *Applications of Goods Traffic in the VMZ Berlin (Traffic Management Center)*, 2nd BESTUFS Round Table, Modelling approaches on Urban Goods Transport, Wildau. Accessed May 2008 from: http://www.bestufs.net/download/Roundtables/2nd_Roundtable_Wildau06/BESTUFS_Wildau_Jun06_Gielher-Kohlen_VMZ.pdf
San Antonio-Bexar County Metropolitan Planning Organization. (2008). *San Antonio-Bexar County MPO Website – What We Do*, US. Accessed May 2008 from: http://www.sametroplan.org/pages/About_MPO/whatwedo.html.
San Diego Association of Governments (SANDAG). (2008a). *SANDAG 511 – San Diego Traffic, Transit and Commute Information*, US. Accessed May 2008 from: http://www.511sd.com/.
San Diego Association of Governments. (2008b). *SANDAG Website – About SANDAG*, US. Accessed May 2008 from: http://www.sandag.org/index.asp?fuseaction=about.home.
San Francisco Chronicle. (2005). *Muni to Expand Automated Tracking System - Officials Hope Alerts on 'Next Bus' Will Ease Wait Anxieties.* Accessed October 2008 from: http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2005/11/04/BAGQ8FJ3EB1.DTL.
San Francisco Metropolitan Transportation Commission. (2008a). *MTC Website – About MTC*, US. Accessed May 2008 from: http://www.mtc.ca.gov/about_mtc/about.htm.
San Francisco Metropolitan Transportation Commission. (2008b). *MTC 511 System – About 511*, US. Accessed October 2008 from: http://511.org/global_items/global_info.asp.
San Francisco Metropolitan Transportation Commission. (2008c). *MTC Funding – RM2 Funding*, US. Accessed October 2008 from: http://www.mtc.ca.gov/funding/RM2/index.htm.
San Francisco Metropolitan Transportation Commission. (2006). *MTC 511 Strategic Plan*, US. Accessed October 2008 from: http://www.mtc.ca.gov/services/511/FINAL_511_Strategic_Plan.pdf.
San Francisco Metropolitan Transportation Commission. (2005). *MTC Press Release - Real-Time Muni Arrival Information Just a Free Call Away*, US. Accessed October 2008 from: http://www.mtc.ca.gov/news/press_releases/2005/rel316.htm.
San Francisco Metropolitan Transportation Commission. (1999). *MTC Transactions Online – It's 8 a.m. -- Do You Know Where Your Bus Is?*, US. Accessed October 2008 from: http://www.mtc.ca.gov/news/transactions/ta05-0699/next_bus.htm.

Schuman, R. & Sherer, E. (2001). *ATIS US Business Models Review*, USDOT, FHWA, ITS Joint Program Office. Accessed March 2008 from: www.atlantic.net/AtDocs/ATIS_Business_Models_Review_Nov2001.doc.

Sensys Networks. (2008). *Sensys Networks – The 21st Century Standard in Traffic Detection Systems*, US. Accessed January 2008 from: http://www.sensysnetworks.com/default.asp.

Siemens AG.(2008). *Three Complex Tasks – One Common Platform.* Germany. Accessed October 2008 from: http://www.industry.siemens.de/broschueren/pdf/traffic/en/Three_complex_tasks_en.pdf

Siemens AG.(2006a). *SITRAFFIC Concert Solves Traffic Problems Intelligently—Throughout Europe.* Germany. Accessed October 2008 from: http://www.industry.siemens.de/traffic/EN/pdf/references/highlights/SITRAFFIC_Concert_en.pdf#page=6

Siemens AG.(2006b). *Traffic Management Systems - Solutions from Siemens.* Germany. Accessed October 2008 from: http://www.siemens.nl/its/getfile.asp?id=148

Siemens AG .(2005). *A Public Private Partnership for Traffic Information—Bavarian Traffic Information Agency VIB.* Germany. Accessed October 2008 from: http://www.connekt.nl/www/filelib/userfiles/file/Studiereizen/PPS%20for%20Traffic%20Info%20Siemens.pdf

Singapore Land Transport Authority. (2008a). *Land Transport Authority*, Singapore. Accessed March 2008 from: http://www.lta.gov.sg/.

Singapore Land Transport Authority. (2008b). *Singapore Land Transport Masterplan 2008*, LTA, Singapore. Accessed April 2008 from: http://app.lta.gov.sg/ltmp/index.asp

Singapore Land Transport Authority. (2008c). *One Motoring*, Singapore. Accessed March 2008 from: http://www.onemotoring.com.sg/publish/onemotoring/en/on_the_roads/traffic_management/intelligent_transport_systems.html.

Skymeter Corporation. (2007a). *Skymeter Corporation*, Canada. Accessed December 2007 from: http://www.skymetercorp.com/cms/index.php.

Skymeter Corporation. (2007b). *Skymeter Corp. – Ending Congestion in New York City*, Canada. Accessed December 2007 from: http://www.skymetercorp.com/cms/images/news/NYCEDCresponseSKYMETER.071002.pdf.

SmartRoute Systems. (2008). *SmartRoute Systems*, US. Accessed January 2008 from: http://www.smartroute.com/.

Southwest Ohio Regional Transit Authority (SORTA). (2008). *SORTA Trip Planner*, US. Accessed May 2008 from: http://tripplanner.go-metro.com:8082/hiwire?.a=iTripPlanning.

Southwestern Pennsylvania Commission. (2008). *SPC Website – About SPC*, US. Accessed May 2008 from: http://www.spcregion.org/about.shtml.

SpeedInfo.com. (2008). *SpeedInfo – The Most Reliable Real-time Traffic Speed Data*, US. Accessed January 2008 from: http://www.speedinfo.com/.

SpeedInfo.com. (2007). *SpeedInfo Featured Projects – MTC 511 Bay Area Project*, US. Accessed October 2008 from: http://www.speedinfo.com/07government/gov-partner01.html.
SpotScout Inc. (2008). *SpotScout Explained*, US. Access January 2008 from: http://www.spotscout.com/spotscout_explained.html.
Stockholm CTS.(2008). *SERCO website.* Access January 2008 from: http://www.serco.com/markets/transport/stockholm.asp
Sun, J., Velastin, S.A., Lo, B., Vicencio-Silva, M.A. and Khoudour, L. (2004) *A Distributed Surveillance System to Improve Personal Security in Public Transport.* Proceedings of European Workshop on the Integration of Knowledge, Semantics and Digital Media Technology, London, UK.
Sven Kesselring.(2004). *Mobile Politics in Munich--Learning from Deliberation Under the Conditions of Reflexive Modernization.* 4S/EASST conference. Paris. Access January 2008 from: www.csi.ensmp.fr/WebCSI/4S/download_paper/download_paper.php?paper=kesselring.pdf
Swedish Road Administration Website.(2008). *SNRA introduction*. Sweden. Access May 2008 from: http://www.vv.se
TeleAtlas BV. (2008). *TeleAtlas Milestones*, EU. Accessed January 2008 from: http://www.teleatlas.com/WhyTeleAtlas/Innovation/Milestones/index.htm.
Telvent Farradyne. (2006). *Building the Future of ITS – 511, San Francisco/Oakland Bay Area, CA*, US. Accessed October 2008 from: http://www.telvent-farradyne.com/services/deployment/511.pdf.
Texas Department of Transportation (TxDOT). (2008). *Transguide Traffic Conditions*, US. Accessed May 2008 from: http://transguide.dot.state.tx.us/Traffic/index.php.
Texas Transportation Institute (TTI). (2007). *2007 Annual Urban Mobility Report*, Texas A&M University System, US. Accessed March 2008 from: http://mobility.tamu.edu/ums/.
Thomopoulos, S. C. (1989). Sensor Integration and Data Fusion. *Proceedings of SPIE 1198, Sensor fusion II: Human and machine strategies*, pp. 178–191.
TomTom NV. (2008a). *TomTom – All TomTom Services*, EU. Accessed March 2008 from: http://www.tomtom.com/services/service.php?id=11.
TomTom NV. (2008b). *TomTom Mobility Solutions & HD Traffic*, EU. Accessed March 2008 from: http://www.mobility.tomtom.com/.
TomTom NV. (2006). *TomTom acquires Applied Generics Ltd.*, EU. Accessed March 2008 from: http://www.tomtom.com/news/category.php?ID=4&NID=223&Year=2006&Language=1
TrafficCast International Inc. (2008). *TrafficCast – Actionable Traveler Information for the Road Ahead*, US. Accessed January 2008 from: http://www.trafficcast.com/.
Traffic.com Inc. (2008a). *Traffic.com Government Solutions*, US. Accessed January 2008 from: http://corporate.traffic.com/government/.
Traffic.com Inc. (2008b). *Traffic.com – Metropolitan Areas*, US. Accessed April 2008 from: http://www.traffic.com/allCities.html?ct=hm_map.
TrafficGauge Inc. (2008). *TrafficGauge Mobile Traffic Maps*, US. Accessed January 2008 from: http://www.trafficgauge.com/index.html.

TrafficLand Inc. (2008). *About TrafficLand*, US. Accessed January 2008 from: http://corporate.trafficland.com/about.html.

TrafficMaster PLC. (2008). *TrafficMaster – Intelligent Driving*, UK. Accessed February 2008 from: http://www.trafficmaster.co.uk/home.php.

TrafficMaster PLC. (2007). *TrafficMaster wins DfT contract*, UK. Accessed February 2008 from: http://www.trafficmaster.co.uk/__assets/t02qoimls9ozxenjsl.pdf.

TrafficMaster PLC. (2006). *TrafficMaster partners with Norwich Union*, UK. Accessed February 2008 from: http://www.trafficmaster.co.uk/__assets/jyc6lhqslisfuvlfdt.pdf.

Trafik Stockholm.(2001). *The Stockholm Joint Traffic Management Center*. Sweden. Accessed February 2008 from: http://www.escope.info/download/alf%202Trafik%20Stockholm%20visning%20ENGELSK.pdf

Trafiken Website.(2008). *Trafiken introduction*. Sweden. Accessed February 2008 from: http://www.trafiken.nu/

Transit Cooperative Research Program. (2003a). *TCRP Synthesis 48: Real-Time Bus Arrival Information Systems*, TCRP, TRB, NAS. Accessed September 2008 from: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_syn_48.pdf.

Transit Cooperative Research Program. (2003b). *TCRP Synthesis 84v4:e-Transit: Electronic Business Strategies for Public Transportation, Volume 4: Advanced Features of Transit Websites – Real-time Display, Notification Systems and CRM*, TCRP, TRB, NAS. Accessed September 2008 from: http://gulliver.trb.org/publications/tcrp/tcrp_rpt_84v4s6.pdf.

Transport Canada. (2006). *Development and Demonstration of a System for Using Cell Phones as Traffic Probes (TP 14359E)*, ITS R&D Plan, Strategic Highway Infrastructure Program, Transport Canada, Government of Canada. Accessed January 2008 from: http://www.tc.gc.ca/tdc/summary/14300/14359e.htm.

Transport for London. (2008). Intelligent Transportation System, Transport for London. Accessed March 2008 from: http://www.tfl.gov.uk/corporate/projectsandschemes/technologyandequipment/5731.aspx.

Transport Direct Website.(2008). *Transport Direct Introduction*. UK. Accessed January 2008 from: http://www.transportdirect.info/

Tri-County Metropolitan Transportation District of Oregon (TriMet). (2008a). *TriMet Interactive Trip Planner*, US. Accessed May 2008 from: http://ride.trimet.org/.

Tri-County Metropolitan Transportation District of Oregon (TriMet). (2008b). *TriMet Transit Tracker*, US. Accessed May 2008 from: http://trimet.org/arrivals/index.htm.

Trisent Communications Ltd. (2008). *Trisent – Mobile Phone Location Technology*, UK. Accessed February 2008 from: http://www.trisent.com/.

Trombly, J. & Luttrell, T. (2000). *A Case Study: Georgia's Intelligent Transportation System NaviGAtor Systems Integrator Contract*. Science Applications International Corporation. Accessed March 2008 from: www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13459.pdf.

Vehicle Information and Communication System Center. (2008). *History of VICS*, Vehicle Information and Communication Systems, Japan. Accessed March 2008 from: http://www.vics.or.jp/english/about/history.html.

VIA Metropolitan Transit (VIA). (2008). *VIA Interactive System Map*, US. Accessed May 2008 from: http://www.viainfo.net/BusService/InteractiveMap.aspx.

Vodafone PLC. (2008). *TomTom and Vodafone Germany Sign Agreement to Bring the World's Most Advanced Traffic Information Service to Germany*, Germany. Accessed February 2008 from: http://www.vodafone.com/start/media_relations/news/local_press_releases/germany/germany_press_release/tomtom_and_vodafone.html.

Vortisch, P. and Moehl, P.(2003). *Traffic State Estimation in the Traffic Management Center of Berlin*. 82nd Transport Research Board (TRB) Annual Meeting Sessions. 2003.

Wang, X., Qi, H., Iyengar, S. S. and Chakrabarty, K. (2004). Multisensor Data Fusion in Distributed Sensor Networks Using Mobile Agents. *IEEE Transactions on Knowledge and Data Engineering*, Vol. 16, No. 6, pp. 740-753.

Washington State Department of Transportation (WSDOT). (2008a). *Seattle Area Traffic*, US. Accessed May 2008 from: http://www.wsdot.wa.gov/Traffic/seattle/default.htm .

Washington State Department of Transportation (WSDOT). (2008b). *Statewide Traveler Information*. Accessed March 2008 from: http://wsdot.wa.gov/traffic/.

Washington State Department of Transportation (WSDOT). (2008c). *Washington State Ferries Vessel Watch*, US. Accessed September 2008 from: http://www.wsdot.wa.gov/ferries/commuter_updates/vesselwatch/.

Wilbur, Toni. (1998). *The ITS Metropolitan Model Deployment Initiative*, FHWA, Public Roads website. Accessed March 2008 from: http://www.tfhrc.gov/pubrds/novdec98/its.htm.

Williams, D.F. (1996). *Atlanta to showcase ITS Traveler Information*, FHWA, Public Roads website. Accessed March 2008 from: http://www.tfhrc.gov/pubrds/summer96/p96su35.htm.