THE FUTURE OF OPEN INTELLIGENT TRANSPORTATION SYSTEMS (OPEN-ITS)

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ABSTRACT

Information and communication technologies (ICT) are emerging very rapidly offering a new paradigm for delivering the intelligent transportation systems (ITS) services. The demand for ITS services is therefore increasing with the evolution of these technologies. In addition numerous information channels and data providers are penetrating the ITS community with different quality and requirements needs. This poses challenges to researchers and practitioners if the same methods/tools of delivering the ITS services remain the same. In this paper we propose a three-prolonged framework that responds to the needs and challenges of delivering ITS services while harnessing the potential for open service innovation, the potential of methods/tools to ubiquitously collect traffic and travel data, and the potential of using rigorous data fusion techniques to integrate and fuse the new emerging data sources together with existing traditional loop detector data.

Keywords: intelligent transportation systems, open service innovation, ubiquitous data collection, smartphone applications, data fusion.

INTRODUCTION

Information and communication technologies (ICT) are emerging very rapidly offering a new paradigm for delivering the intelligent transportation systems (ITS) services. The demand for ITS services is therefore increasing with the evolution of these technologies. In addition numerous information channels and data providers are penetrating the ITS community with different quality and requirements needs. This poses challenges to researchers and practitioners if the same methods/tools of delivering the ITS services remain the same.

This paper therefore discusses the following three themes that are centric to the state-of-the-art ITS enabling technologies in an attempt to address the current and future challenges facing ITS:

1. The potential of a *new open service innovation* model for developing and sustaining ITS services in the knowledge-intensive tight-budget economy of the 21st Century;
2. The potential of methods/tools to *ubiquitously collect traffic and travel data* at low cost (e.g., vehicles as probes, smartphone sensors, connected vehicle data, etc.); and
3. The potential of using *rigorous data fusion techniques* to integrate and fuse the new emerging data sources together with existing traditional loop detector data.

The three themes above are seen as complementary and cross-linked. The first theme establishes the open service innovation concept and the relating enabling software platform in a generic sense for any future ATMS (Advanced Traffic Management Systems) or TIS (Traveller Information System) applications. The second theme presents a wide scale data collection via an array of sensors and communication channels to be strategically located and distributed across the transportation network. The third theme focuses on fusing the heterogeneous data collected from multiple sources (provided by Theme II) into a single estimate (e.g. travel time or speed information) which is the underlying performance indicator for provision of traveller information services in many cities via the open platform provided in Theme I.

- **Theme I**: Open service innovation model, co-creation and mass customization are the state of the art models for delivering services in an era that is becoming highly driven by the customer needs rather than typical productization models. Major organizations (e.g., IBM (Pine J., 1993)) are transforming the way they do business by adopting open service innovation that allows seamless flow of innovation from within to without the organization and vice versa. “Open service innovation” is the latest trend in open innovation that focuses on the provision of ‘services’ to the customer (transportation stakeholders inclusive of the traveller side and the operator/service provider side). Mass customization recognizes that customers have different needs and empowers customers (travellers and stakeholders in general) with services that match their context-based needs such as subscribing to specific traveller information systems or incident/event notification system. This paper will furnish the foundation for open transport service innovation and mass customization for the new generation of ITS by proposing an Open-ITS system.
- **Theme II**: One step towards open innovation is the open and ubiquitous collection of transport data and intelligence. Ubiquity will not only expand the spatial and temporal coverage of transport intelligence gathering but will also provide agile deployment in remote areas as needed and will relief major cities of the burden of installing and maintaining expensive and traffic-disruptive traditional detection technologies. For example, connected vehicles data and the establishment of two way communication with the car can enable the real-time transmission of rich vehicle sensory and engine data to a central server. In addition to time-stamped GPS data, the system can upload data directly from the engine of the vehicle (through On-board Diagnosis Device- OBD) that will enable accurate measurement of speed, fuel consumption (and emissions), engine diagnostic data, to name a few.
- **Theme III**: With the richness of data tsunamis from all sources above, transportation agencies and roadway authorities will always face the challenging question of “which system monitoring technology is the best to use”. In the authors’ view, this should not be the question as technology always and rapidly changes. System performance

monitoring should be technology agnostic. With this in mind, fusion of sensory information offers improved accuracy and retains healthy redundancy in the system in a technology agnostic fashion. This theme therefore discusses data fusion methods that could alleviate the burden of choice of a given technology and amalgamates all data sources into one single and most accurate estimate using rigorous mathematical data fusion techniques. It is our belief that no data or a single source of information should be wasted; however, the outcome will be more accurate than any of the individual data sources.

The remainder of the paper is organized as follows; first the motivation of the proposed framework is highlighted; then a discussion on each theme is presented in details, and finally the paper concludes with three applications that illustrate the potential of the proposed framework and the underlying processes.

BACKGROUND AND MOTIVATION

The Transportation Challenge

Efficient and secure movement of people and goods is paramount to our economy. Excessive delays and unreliable travel times in urban areas, on busy urban and trade corridors and across borders pose significant challenges to the future of both the mobility of people and the economic competitiveness of firms that rely on fast and reliable transportation of goods. The cost of congestion forms a significant percentage of Countries' total GDP as in the case of South Korea (5.4%); Bangkok (4%); OECD Countries (3%); Seoul (3%), Australia (1.9%); US (1.5%), and Canada (1%) (Deloitte, 2003; Urban Transportation Task Force , 2012; Transport Canada , 2008; UITP, 2010; OECD, 2007; Scottish Government, 2006; Victoria Transport Policy Institute, 2011) . For example, in Canada alone, this results in a total cost of congestion around $15B a year.

The proactive management of transportation and freight infrastructure generally requires continuous and real-time performance monitoring, control and management decisions, and dissemination of information and guidance to motorists and trucks. Over the past two decades, numerous technologies and methods have been developed and deployed for real-time monitoring of these infrastructure systems. In general, emerging advanced solutions to congestion and delays (in urban areas or at border crossings) rely on the collection, dissemination and sharing of information among stakeholders including travellers and system operators. It is of benefit to all to equip vehicles with sensors and communication capabilities to "talk" to the infrastructure, and equip the infrastructure with economic means for gathering information from vehicles and relaying content and services back to vehicles.

The Sustainability of Transport Innovation Challenge

Traditionally, organizations, large and small, innovate internally to breed solutions to their self-identified technical and business challenges. For decades, agencies have relied on breeding innovation internally by identifying needs, procuring services and solutions, fully funding projects, fully bearing the operational and maintenance costs, and the full risk in the entire ideas-products-services cycle. In the highly competitive business world and dwindling economies worldwide, sustaining innovation using such ‘solo’ or closed business model is neither affordable nor sustainable. Government agencies in particular, as opposed to for-profit-organizations, feel the innovation challenge, which is exacerbated by a continuous trend of budget cuts. Luckily, the trend of closed innovation is rapidly shifting towards service-orientation, open innovation and mass customization. It is our vision that agencies should seize the opportunity furnished by this trend and examine the potential of this paradigm shift to engage transportation stakeholders and customers alike in a sustained eco-system of co-creators and open transportation service providers; and therefor the need for open service innovation. Open service innovation can reduce the cost of transport innovation, quality service provision, customer satisfaction and help to share the risks and rewards of transport innovation, and accelerate the time required to deliver innovative solutions to travellers, firms and the population at large.

Connected Vehicles and Aspiring for the Connected Traveller

Cars and transit vehicles are increasingly outgrowing their traditional role of being motorized cabins for transportation from A to B. The authors use the term “vehicles” here as opposed to “cars” because connectivity must not be limited to the private automobile only but will rather encompass all moving vehicles, including public transit buses, light rail and rail vehicles as well as commercial trucks. Vehicles are turning into social and technical (socio-technical) hubs that connect themselves to other machines (other vehicles and components of the infrastructure) and connect their driver/passengers to his/her social and business world, in a productive but safe manner. Around ninety percent of cars today (2013) have Bluetooth, which is just the dawn of vehicular connectivity. Vehicles will be more and more connected via mobile devices, embedded telematics, dedicated communication channels and broadcast services. Connections can enhance emergency services, security features, traffic, weather and navigation information and services, Internet search and infotainment and, of course, business productivity. Equally importantly, connectivity can be capitalized upon to draw ridership to public transit where travel time can become travel-time-well-spent if put to good use. Our daily transactions go through a complex intertwined mesh of “live” networks and the vehicle is just a mobile node navigating its passenger in time and space through those overlapping and intersecting networks. In essence, experts envision the vehicle as a mobile device that must safely connect drivers and passengers to the world around them, while being particularly cognizant and aware of the context in which the traveller is. It is not just connected vehicles, however, that we aspire for. We aspire for “connected travellers”, a concept that is not fully born yet. In such a rapidly changing world, traveller services (information provision is one of them) are becoming essential services that must seamlessly stream into the vehicle (car, bus, train, truck and even planes), into mobile devices and ultimately into our daily activity chains and activity scheduling of travellers.

The Tsunami of Data Opportunities and Challenge

A key component of creative transportation service provision is “data”. The basis of any transportation improvement decision is a set of performance indicators that reflects how the transportation system has been and is operating. With the increased market penetration of modern communication technologies such as Bluetooth, WIFI, Zigbee, and the emergence of

LTE (Long Term Evolution) communication, we face both an opportunity and a challenge. The opportunity is to tap into the wealth of information and availability of wide bands of communication that provide microscopic system information at the level of individual vehicles and individual travellers. The challenge however is how to pick and choose between the alternative surveillance technologies. For instance, a simple task such as gathering traffic speeds can be achieved using many technologies including conventional loop detectors, Bluetooth and WIFI data collection stations or gateways, or from GPS devices carried by the travellers or embedded into their cars. Different technologies offer different data accuracies and we therefore face the challenge of how to choose the best and most accurate technology. Luckily, modern data fusion techniques not only alleviate the burden of choosing among surveillance technologies but also offer a fused estimate that is better than any of the individual technologies, which makes data fusion a sensible choice.

THEME I: OPEN TRANSPORT SERVICE INNOVATION PLATFORM

The concept presented herein is highly inspired from the work of renowned business experts around the word, including the work of Henry Chesbrough of the Haas School of Business at the University of California Berkeley (Chesbrough H., 2011).

In the context of this paper; *Transportation* is viewed as a *service*; *Transportation Agencies* are viewed as *agents* of *customer-oriented service* providers eager to innovate to contribute to the wellbeing of the society; and *ITS* is viewed as a suite of *knowledge-intensive services*.

In the knowledge-intensive service economy of the 21st century, large and small organizations realized that they must open up and work with external partners to innovate and provide their customers with the services that they need.

The future for advanced businesses and government organizations and advanced economies is shifting from products to 'services' and rethinking business models to innovate and build them. Services, in the context of this paper, refer to knowledge-intensive services that are becoming the engine of growth for the entire developed world. Today services comprise roughly 80 percent of economic activity in the United States and 60% in other developed countries (Chesbrough H., 2011). Isolated products are becoming a smaller and smaller share of the economic pie. Most of the growth in services is happening in the knowledge-intensive portion of the service sector (Hertog P., 2000). Not only services but also particularly services through an *open innovation platform* that allows for a co-creation business model.

To clarify the concept more clearly, open service innovation is perhaps best explained via an example (Figure 1) that is intended to emphasize the need to confront and transcend the so called commodity trap (Chesbrough, 2011). The well-known Motorola once dominated the cell phone market when they released the *Razr* cell phone model. The Razr was the thinnest, slickest and coolest cell phone on the market that everyone wanted to buy. But, where is it today? Motorola has fallen in the commodity trap, where their innovative '*product*' was soon copied and improved upon by many competitors and Motorola is no longer near the top of cell phone suppliers in the world. Coming up with even better cell phone products is no longer enough. Cell phone manufacturers face fierce pressures from newer entrants like Apple, Google, and Microsoft who are working hard to continue to innovate new handsets, either by themselves or with partners. *But each is doing far more than offering newer products* (Chesbrough H., 2011). They are building *platforms* that attract thousands of other companies to design applications and services that run on their portable platforms, i.e. they are crushing the competition via adopting an *open service innovation business model and open platforms.* The Apple iPhone for instance, introduced in 2007 also had a catchy sleek design, an elegant customizable user interface, and a novel touch screen (i.e. interesting product). However, the iPhone was not just a device; it was a *platform* that attracted many third-party applications and services to provide users with a wide range of experiences on a single device. They created an eco-system of co-creators. More than 100,000 individuals and companies have created ‘‘apps’’ that run on top of the iPhone, and more than 2 billion apps have been downloaded by customers around the world.

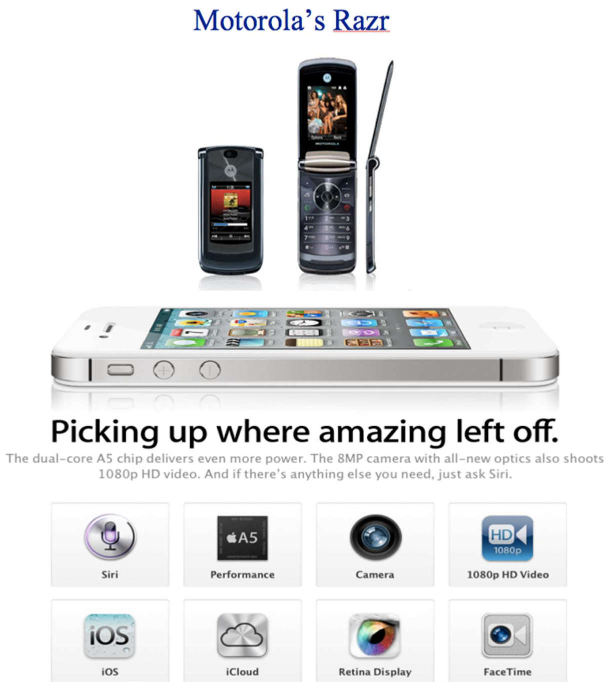


Figure 1: iPhone Platform vs. Motorola Device

Apple created an ecosystem of innovators that, in addition to innovating for their own sake, serve apple’s interests in the process. For other big companies such as Google and Microsoft to compete they are striving/struggling to create parallel ecosystems similar to Apple’s. While it may arguable which of the three dominant eco-systems (Apple, Google or Microsoft) is more “truly open” than the other, they all have in common an open business model and an open platform.

While transportation agencies are not producing cell phones and are not competing, in a sense, with other agencies, they provide ‘*transportation services’* to travellers and can benefit from a similar transportation-specific ecosystem. In the ITS domain in particular, transportation agencies face that challenge of how to fit amongst a myriad of new private sector entrants into this ‘service market’. Agencies also face the challenge of how to collaborate with the many organizations that hold a stake in this ‘business’.

Open innovation in services is a clear and sustainable way to sustain and grow the transportation agencies’ services and influence. As in the Apple case, creating platforms that incorporate internal and external innovative services and surrounding these platforms with a variety of value-added services, agencies can invigorate transportation service innovation to ultimately offer travellers with state of the art services, at low cost and low risk. This business model will lead the transportation sector by offering an entire constellation of innovative services created both internally (at the agency level) and externally by others and made available to their customers through an open single point of access or platform.

The Proposed Open Service Innovation Framework

Capturing the Chesbrough model (Figure 2), we summarize the four foundational concepts that must be established and that together create the driving framework in ITS:

1. Adopt the mindset of transportation business (e.g. TIS, ATMS) as an open services business in order to create and sustain operations in the knowledge-intensive and limited budget economies of today and to create differentiation in a commodity-trap world (e.g. avoid creating and investing in a closed owned service such TIS that may be made obsolete by Google/INRIX/Tom Tom in a few years).
2. Invite customers (or stakeholders in general such as municipalities, Emergency Management Services (EMS), universities, software providers, etc.) to co-create innovation in order to generate the experiences they will value and reward.
3. Use Open Innovation to accelerate and deepen services innovation, making innovation less costly, less risky, and faster. Use Open Innovation to create a platform for others to build on perpetually.
4. Transform the transportation services business model with Open Services Innovation, which will help to profit from internal innovation activities and from others' innovation activities as well.

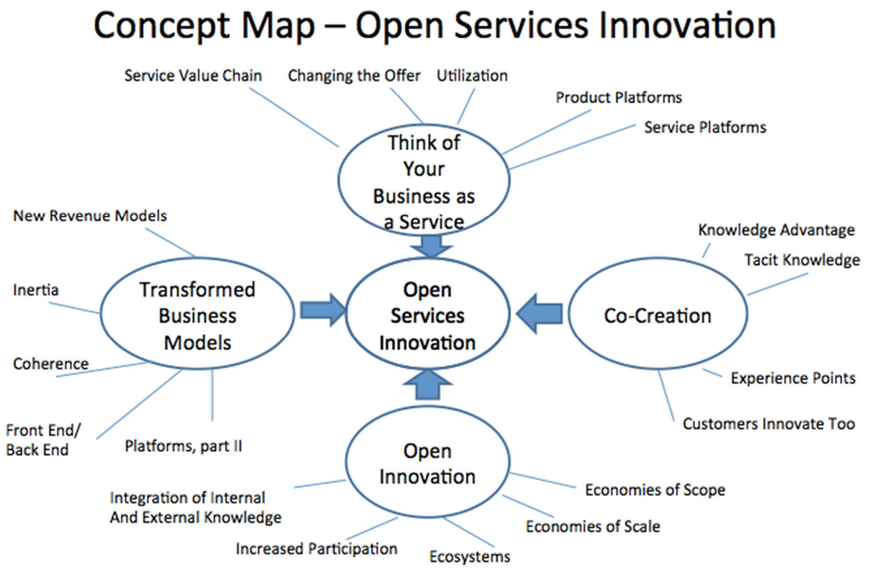


Figure 2: Open Service Innovation (Chesbrough H., 2011)

Coupled with the above concepts is to pursue open services innovation by bringing stakeholders and customers directly into the innovation process through a common platform as opposed to treating them as passive one-way recipients of whatever transportation agencies provide. An important aspect of this open innovation business model is to be able to capture stakeholders' tacit knowledge via adding social networking dimensions to the service innovation platform.

The key benefit from the open service innovation business model is harness the power of participation of many more innovators from outside the transportation agencies. With the diffusion of knowledge, ideas, data and access to infrastructure, more organizations can experiment in parallel with possible ways of using and combining these resources in novel ways. No other single organization can hope to compete with this external explosion of potential offerings by relying exclusively on their own internal knowledge. In fact, external organization will not want to compete but rather collaborate. When the internal and external elements are combined, they produce a wealth of offerings for customers (travellers, operators etc.) while allowing the other providers to specialize in their own distinctive competences.

In summary, transportation agencies would 'purposively' use external ideas as well as internal ideas, and internal and external paths to market, to create new services, new architectures, and new systems as illustrated in Figure 3 below.

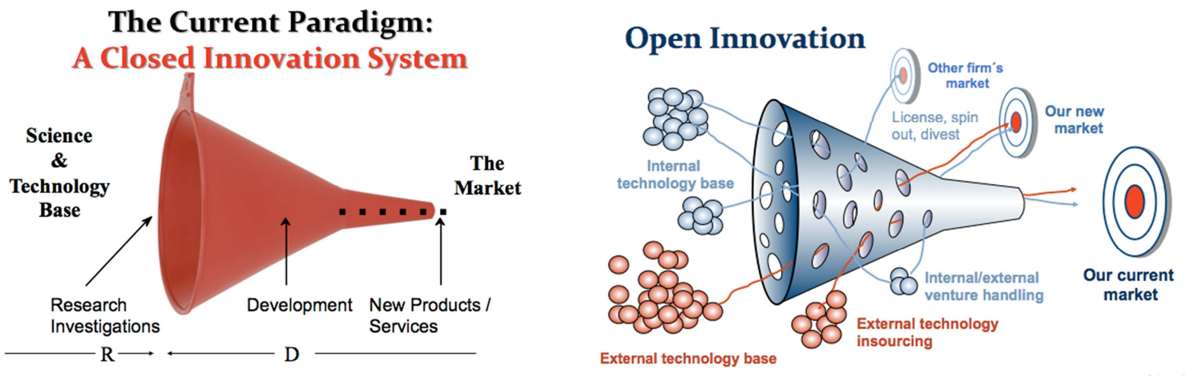


Figure 3: Closed vs. Open Service Innovation Business Models (Chesbrough H., 2011)

THEME II: A SENSING PLATFORM AND GATEWAY FOR TRAFFIC, TRANSIT AND FREIGHT MONITORING

This theme is motivated by the associated high costs as well as the inherent limitations (e.g. power consumption, telemetry, etc.) of existing traffic monitoring technologies. Infrastructure monitoring is typically conducted either on a short-term basis or only at the most critical locations or both. Continuous real time monitoring is typically deployed only at specific key locations (e.g. on major freeways in large cities). Furthermore, limiting the space and time of collected data may consequently limit the utility of collected data, particularly when real time applications are of interest for either efficiency and/or security purposes. This theme intends to propose pervasive low cost technologies to enable ubiquitous/pervasive sensing and tracking of mobile units (cars, trucks, containers, cell phones, PDAs, etc.) and enable communication and connection between transportation infrastructure (roads, terminals, border crossings, etc.) and vehicles (aka connected vehicles) and/or the mobile units.

Generally, there are three main components for wireless monitoring of infrastructure systems. First, there are the sensing devices collecting the information from the environment. Second, there are the delivery components (i.e. devices, algorithms and protocols), delivering the sensed data to processing elements. Finally, there is the data management center responsible for developing applications based on the collected data. In this paper, we discuss the integrated device or gateway as well as system components that facilitates sensing and delivery of information.

A Gateway for Multi-Protocol Data Sensing and Delivery

In this development, we design and integrate a sensing, delivery and management platform and gateway for monitoring traffic, transit and freight information as follows:

1. as vehicles drive anywhere in the network, using On Board Diagnostic (OBD) scanner and mobile data sensing and telecommunication technology, and/or

2. as vehicles drive near a road-side mounted gateway.

In the first case, an OBD scanner sends vehicle sensor information to a mobile smartphone using Bluetooth and/or WIFI (depending on the user device preferences). The smartphone augments the OBD information with GPS geocoding and time stamp and sends the information via the Internet to a central server. The collected information is saved in a GIS database at the central location (e.g. in the ONE-ITS platform, which will be described later). Figure 4 shows the software architecture that runs on the smartphone with the OBD scanner.

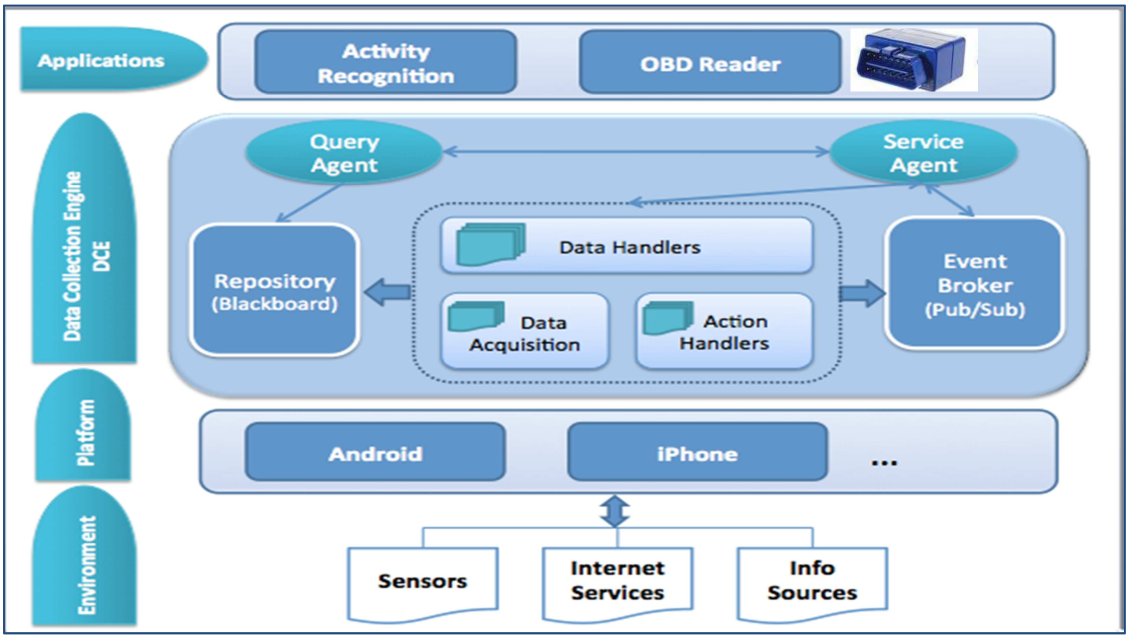


Figure 4: Smartphone Application Architecture

In the second case, a road side gateway gathers information for vehicles in the vicinity that have RFID, Bluetooth, WiFi or ZigBee devices, and then forward gathered information to the central server. Each gateway is configured to run an open-source Linux distribution for embedded devices. For the purposes of interfacing with different sensors, the gateway is augmented with dongles for RFID, Zigbee, WiFi and Bluetooth as well as low cost camera. With this setup, each gateway is controlled to scan the wireless medium for sensors in proximity. The gateway is capable of retrieving information reported by the sensors. The gathered information is then relayed to a centralized server on the Internet using TCP/IP.
It is to be emphasized that the proposed gateway, components and overall platform offer the following features:

- **Infrastructure-light**: as it relies on crowed-sourced data collection techniques;

- **Open & Sustainable**: as it can be extended to incorporate different data management algorithms and techniques and/or operate with other wireless technologies;
- **Uses unlicensed wireless technologies** (e.g. ZigBee, Bluetooth, Wi-Fi & RFID), which are available as consumer electronics and with minimal requirements for usage licenses;
- **Cost-effective**: to allow for pervasive deployment;
- **Scalable**: uses hierarchy capability of increasing the size of the coverage area in a manner that does not adversely affect system performance; and
- **Flexible**: Both ZigBee and Wi-Fi can self-configure themselves to build wireless mesh networks with virtually no deployment cost. This suits the dynamic environment inherent to travelling cars, buses, trucks and containers.

THEME III: MULTI-SENSOR DATA FUSION

Widespread technological development and deployment has created an abundance of data sources for traffic monitoring. Often, there are multiple independent measurements of the current traffic conditions for the same portions of the network. In these cases, a variety of data fusion techniques can be used to achieve better estimates while helping to overcome information overload. These data fusion techniques will be applied to the data streams from the gateways described under Theme II above and fused together with any other data source such as loop detectors.

Data fusion is the process of combining data such that the fused estimate is better than those based on individual data sources (Mitchell, H.B, 2007; Hall, D.L., Llinas, J., 2001). Fusing data from competitive sensors, those that provide independent measures of the same property (e.g., speed of traffic), can be challenging, as the quality of these data sources must be evaluated (Brooks, R.R., Iyengar, S.S., 1998; Luo, R.C., Kay, M.G, 1989).

Depending on the problem at hand, data integration and fusion can realize a number of benefits including: *Reliability/Robustness/Redundancy* - as the system does not depend on a single source of input; *Accuracy/Certainty* – as combining several readings from the same sensor makes a system less sensitive to noise and temporary malfunctions; *Completeness/Coverage/Complementarity* – as more data sources will provide extended coverage of information on an observed object or state.

In summary, data integration is about bringing data together in one place. Data fusion is about using the data together such that there is some new or better inference to be had. Together, data integration and data fusion can create a variety of benefits.

Emerging Technologies for Traffic Data Collection: The Need for Data Fusion

Loop detectors are the most widely, and conventionally, used sensors in freeway traffic management (MTO, 2013). The main function of loop detectors is to detect the presence and speed of vehicles on the freeway.

Probe vehicle data have been traditionally more difficult to obtain. But recently, there has been an interest in developing an anonymous probe vehicle monitoring system to measure travel times on highways and arterials based on wireless signals available from technologies such as Bluetooth. Other technologies also lend themselves well to probe vehicle data collection. For example, cellular telephone tracking is becoming another popular method for collecting probe vehicle traffic speeds, especially smartphone and OBD data collection as discussed in Theme II. There is a general shift from stationary (loop detectors, traffic cameras) to mobile (Bluetooth, GPS, OBD, Smartphones, etc.) sensors. Collecting probe vehicle data is desirable because the measurements can be more accurate, although of variable quality, and generally have good spatial coverage. In addition, the required infrastructure for probe vehicle tracking is very light and relatively inexpensive. However, while probe vehicles describe the state of traffic on the entire road segment, they are not exhaustive as only a small portion of the vehicles is tracked.

However, there are numerous issues to consider with each type of sensors. GPS data, cell phone data, and Bluetooth data require a substantial amount of refining (e.g., map matching) in order for the data to be useful and reliable. Also, there are limitations to using fleet vehicle data (including buses or taxis) because the operational characteristics of these vehicles are different from normal traffic. For example, when buses stop to serve passengers, their travel time will include the dwell time and deceleration and acceleration delay. Even when not stopping to serve passengers, buses have different performance characteristics because of their large size, and they generally travel slower than standard passenger vehicles. Similar issues exist for truck and taxi fleets. The sample size of probes from these fleets is also an issue that should be considered in fusion efforts. Lastly, these data arrive in different formats and require various amounts of pre-processing before data fusion can be applied.

An integrated framework such as ONE-ITS (one-its.net), described in the next section, will maximize coverage of the network given the available data from different sources. For example, loop detectors and traffic cameras might monitor busy freeways, while GPS data from vehicle probes may cover urban streets. In this way, data integration alone is all that is necessary for successful traffic management and operations.

However, the same location might be covered by more than one competitive sensor. That is, the data will be providing independent measures of the same property at certain times in certain locations. For example, the traffic operations center might receive loop detector data and Bluetooth device data describing the state of traffic on the same stretch of freeway at the same time. Note that a traffic operations center would not benefit from several different technologies providing what *should* be the same information (e.g. travel time data). In fact, the abundance of data would only overwhelm decision makers and slow down their ability to make timely decisions. Rather, a single fused intelligent inference resulting from all of these data sources would be preferred. Therefore, data fusion is required to use the data most effectively and efficiently. Figure 5 summarizes the various technologies, collection methods, and stakeholders required for data integration and fusion.

The discussion in Theme III is built on the recent theoretical data fusion contribution conducted at the University of Toronto (Bachmann, Abdulhai, Roorda and Moshiri 2011), in which we present a fusion platform based on the most promising methods for combining measurements from competitive sensor networks. After investigating data fusion methods from a wide variety of fields such as target tracking, artificial intelligence, multi-criteria decision-making, and other data fusion literature; it was found that all these methods share the ability to take multiple estimates, and fuse them to make one superior estimate.

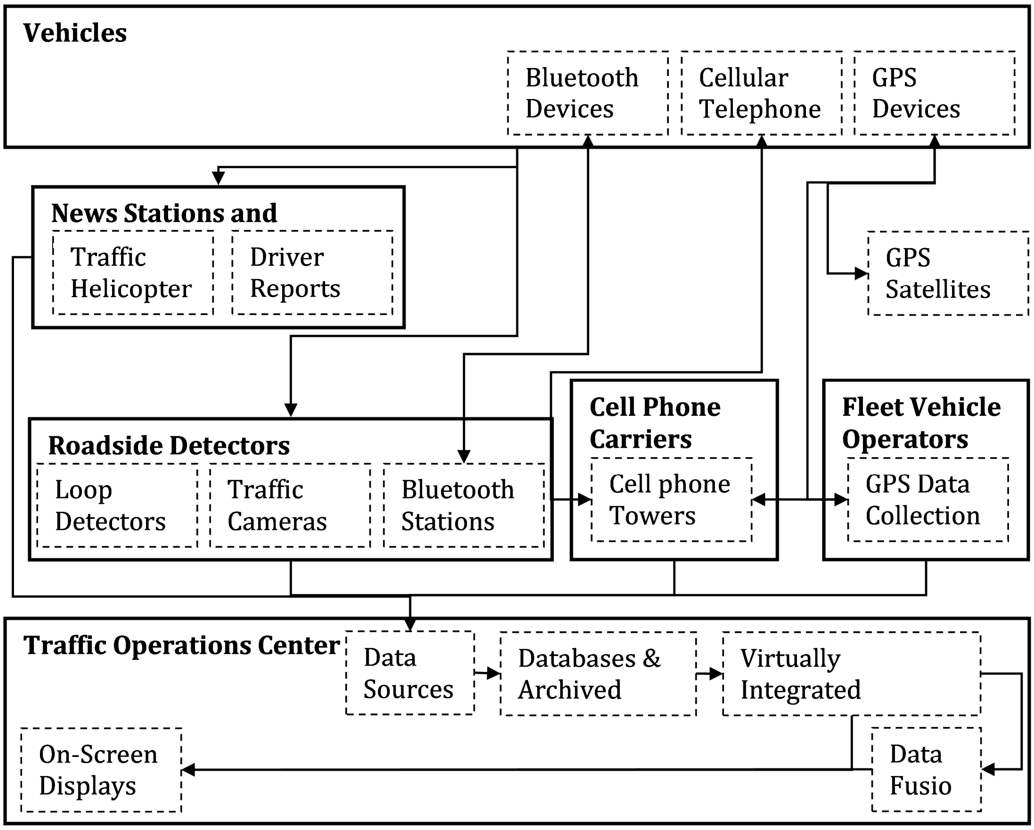


Figure 5: System Architecture for Traffic Monitoring (Bachmann, C., Abdulhai, B., Roorda, M.J. and B. Moshiri, 2013)

The methods investigated in this research include:

- Simple Convex Combination
- Bar-Campo/Shalom combination
- Measurement fusion Kalman filter
- Single Constraint At A Time (SCAAT) Kalman filter
- Ordered Weighted Averaging (OWA)
- Fuzzy Integrals
- Artificial Neural Networks

The above fusion techniques all require calibration, either by training data or in some cases parameter estimation. The logic that underpins the fusion operations and calibration procedures varies greatly. Accordingly, their performances and suitability for different fusion problems also varies greatly. An application of the data fusion techniques is presented in the next section.

ENABLING APPLICATIONS FOR OPEN INTELLIGENT TRANSPORTATION SYSTEMS (OPEN-ITS)

Online Network Enabled-Intelligent Transportation Systems (ONE-ITS)

ONE-ITS (one-its.net) is a pioneer initiative that exploits modern web, communications, and software technologies to enable collaborative research and development activities among widely dispersed participants specifically focussed on solving problems related to easing traffic congestion, enhancing safety, reducing stress, reducing fuel consumption and pollution, protecting the environment, and promoting urban sustainability. ONE-ITS does this by allowing access to all participating parties to the software, transportation data and knowledge resources that have been acquired and accumulated in the system based on the concept of open innovation discussed in Theme I.

The power of the crowd is what inspired the development of ONE-ITS to provide the means and tools to tap the potential of the many important, but fragmented ideas and views, experts and expertise, data sources, software solutions and applications, communication infrastructure, computing infrastructure, etc. This concept of harnessing the power of participants of many innovators enabled ONE-ITS to integrate the following stakeholders: travellers (through ubiquitous and standard user interface), application developers (through client integration), service developers (through service integration and mashups), data providers (through data integration, security, scalability), system operators and policy makers. This will not only benefit collaborators, who contribute and benefit from the tacit knowledge, technically but creates a social networking dimension to the service innovation platform. In essence, ONE-ITS is designed to establish a Socio-Technical network that transcends fragmentation via connectedness and inclusion.With this structure in place, ONE-ITS successfully enabled a three-prolonged approach via sharing resources, intelligence and services as shown in Figure 6 below.

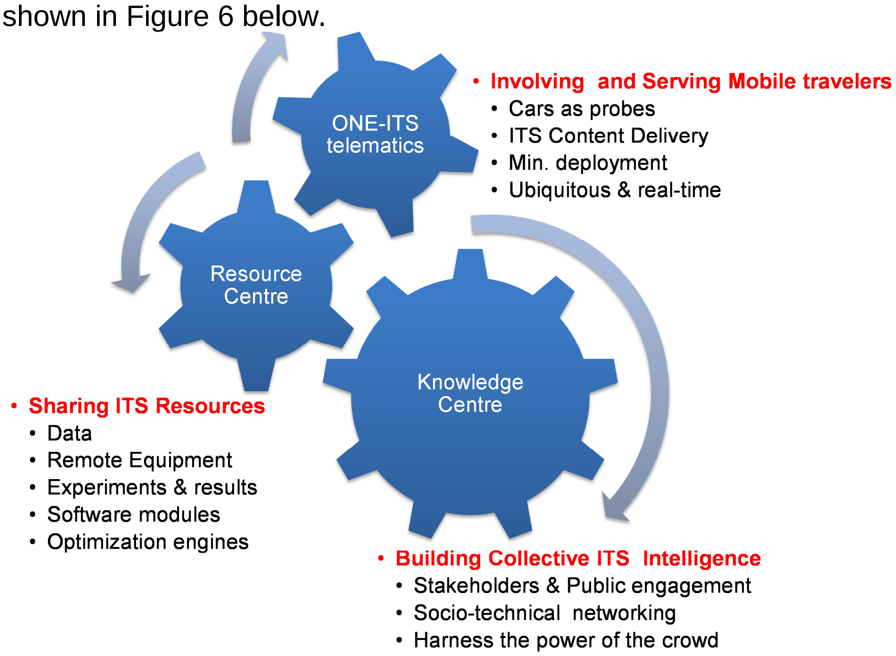


Figure 6: ONE-ITS: A Three-Prolonged Approach

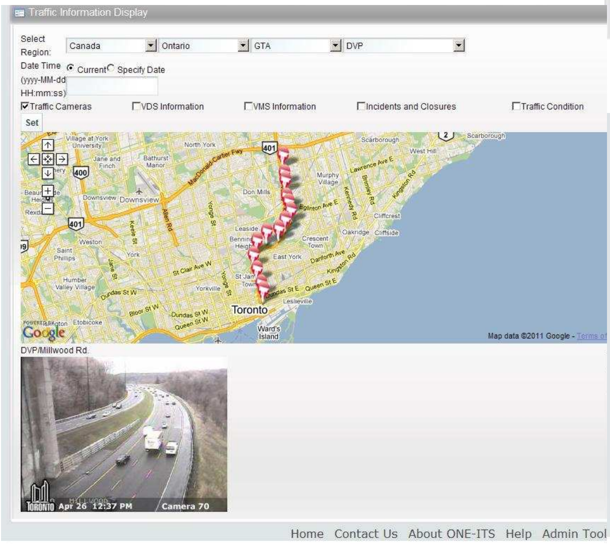
The following sections highlight some of the applications within the ONE-ITS framework and the benefits resulting in each of each sector (public, private, and researchers):

Benefits to the Public Sector

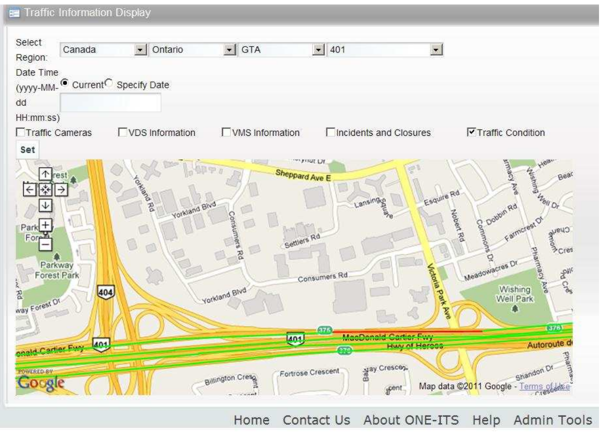
Benefits to the public sector include: multi-agency collaboration (e.g., City Toronto and Ministry of Transportation of Ontario), practitioners & public sector staff can stay on top of the latest developments in the ITS research worldwide and voice their research needs and positive and negative experiences with various ITS products. In addition, it provides web services which means easy implementation with plenty of opportunity for "try-before-you-buy". ONE-ITS examples for potential benefits to the public sector include: incident management (location and routing of emergency vehicles), virtual traffic management centre (customized wall for system operators and agencies staff), geospatial visualization (e.g., color-coded traffic data, freeway camers, etc.) all being integrated from different sources/services as shown in Figure 7.

Customized Virtual TMC Wall

Incident Management Display



Freeway Cameras Display/Customization

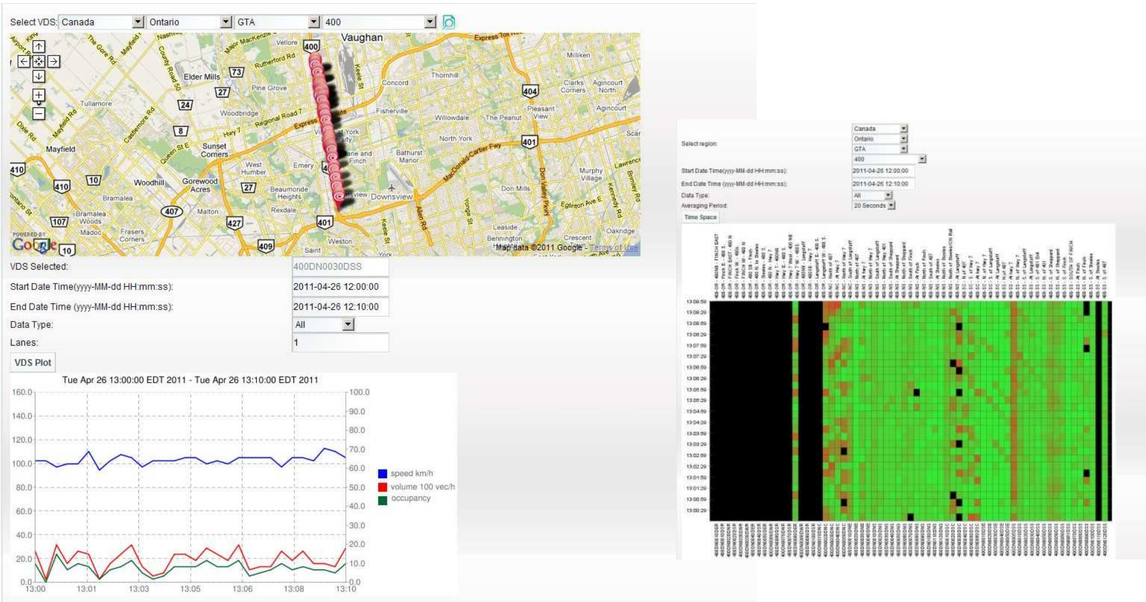


Traffic Data Display

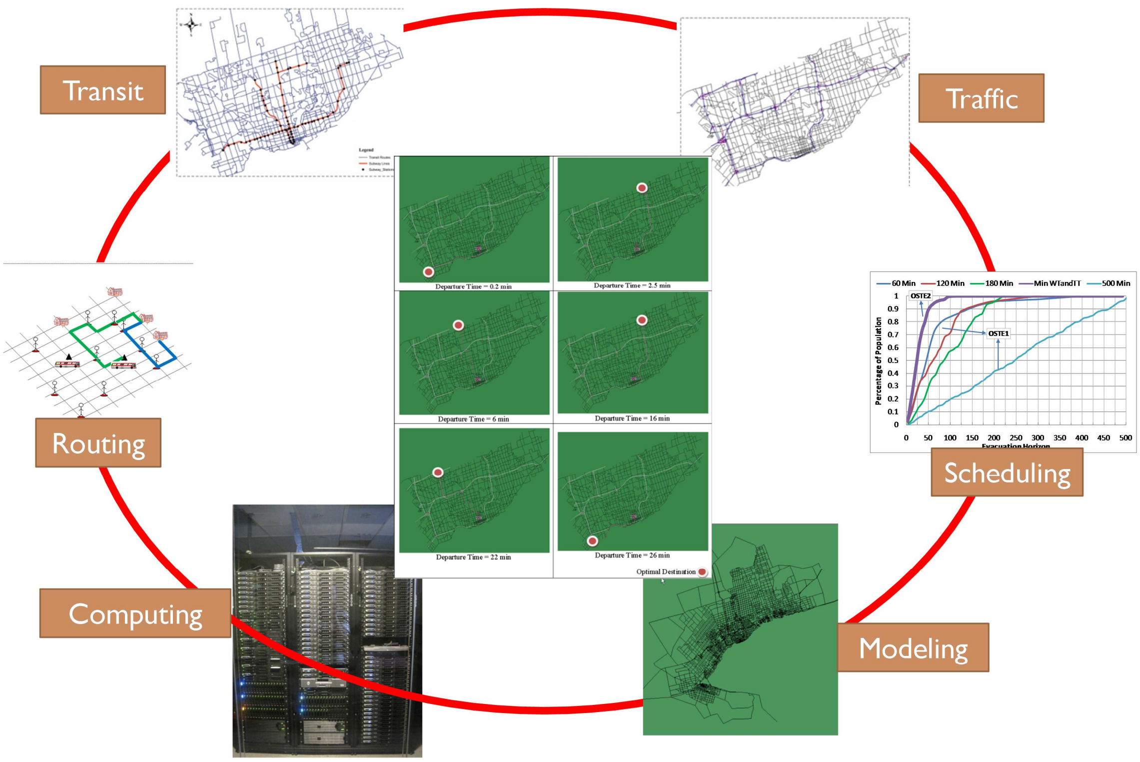
Figure 7: ONE-ITS Applications to Public Sector

Benefits to Researchers

ONE-ITS provide a set of meaningful and rich data for researchers, a virtual online community of researchers who can share their ideas and findings online, web services that can be easily mashed up to develop more complex web services, and web services also means that applications are readily transferable and can easily be implemented in traffic management systems (e.g., multimodal emergency evacuation); all being mashed up using different softwares, engines and artificial intelligence techniques as shown in Figure 8. For example the emergency evacuation platform developed by (Abdelgawad H. and Abdulhai, B., 2010) is built on the following integral components of ONE-ITS: simulation models for traffic and transit, GIS, routing optimization algorithms, and genetic algorithm optimization and high performance computing facility. Each of these services could be integrated and used for other applications; such that researchers can harness the existing technologies and capabilities and use open innovation to create a platform for others to build on perpetually.



Traffic Patterns Plots (Loop Detectors and VDS Plots)



Emergency Evacuation Platform

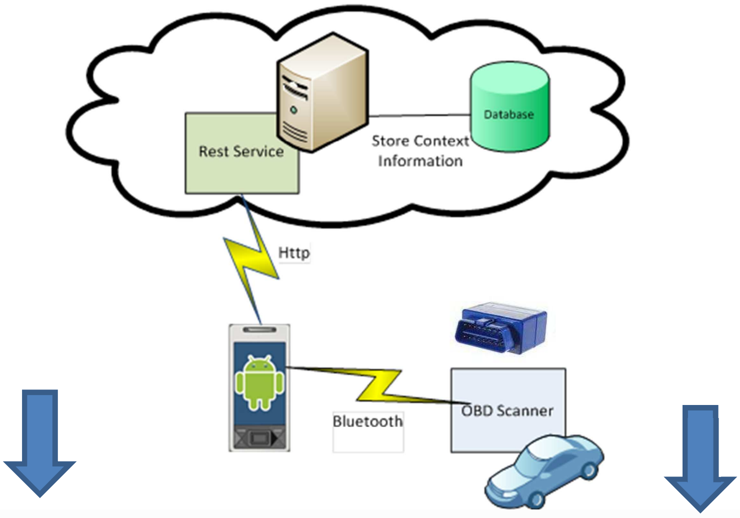
Figure 8: ONE-ITS Applications to Researchers

Benefits to Private Sector

ONE-ITS also provides services and product exposure of private sector and enables working interactively with the research community to take promising research from concept to market. In addition, 'End User' applications can easily be developed using the base web services developed by the researchers as the heart of the system and eventually, structure and regroup these applications to respond to market needs.

A Sensing Platform using Smartphone and On Board Diagnostics Device Application

As part of Theme II objectives, this application is developed to sense vehicles/travellers as they drive anywhere in the network, using OBD scanner and mobile data sensing and telecommunication technology.
In this application, two Android applications were developed and tested: 1) the first application tracks users by periodically sending their GPS coordinates to a central server, 2) the second application, as illustrated in Figure 9, collects the engine diagnostics of vehicles by interacting with an OBD scanner mounted on these vehicles.



Probe Type:OBD
Measured Value Type all
From Date: 2011-08-23 00:00:00 ... To Date: 2011-08-24 00:00:00 ... Cancel
Probe Feeds
Prev Next
Probe Feed Tracking (61 - 80 more)

Update Time	Measured Value	Measured Value Type	Longitude	Latitude
2011-08-23 15:21:16	1.6	FuelEconomyCmdMAP	-79.3651	43.84966
2011-08-23 15:21:16	14.0	ThrottlePosition	-79.3651	43.84966
2011-08-23 15:21:16	0.49	IntakeManifoldPress	-79.3651	43.84966
2011-08-23 15:21:16	0.98	BarometricPress	-79.3651	43.84966
2011-08-23 15:21:16	0.0	LongTermFuelTrim	-79.3651	43.84966
2011-08-23 15:21:16	87.0	AmbientAirTemp	-79.3651	43.84966
2011-08-23 15:21:16	1.314127278E9	ObsTime	-79.3651	43.84966
2011-08-23 15:21:16	2.8	FuelEconomy	-79.3651	43.84966
2011-08-23 15:21:16	4.96	MassAirFlow	-79.3651	43.84966
2011-08-23 15:21:16	47.0	EngineLoad	-79.3651	43.84966
2011-08-23 15:21:16	1.8074E7	EngineRuntime	-79.3651	43.84966
2011-08-23 15:21:16	138.0	Air IntakeTemp	-79.3651	43.84966
2011-08-23 15:21:16	1.0	VehicleSpeed	-79.3651	43.84966

Figure 9: OBD Tracking Application and Sample Results

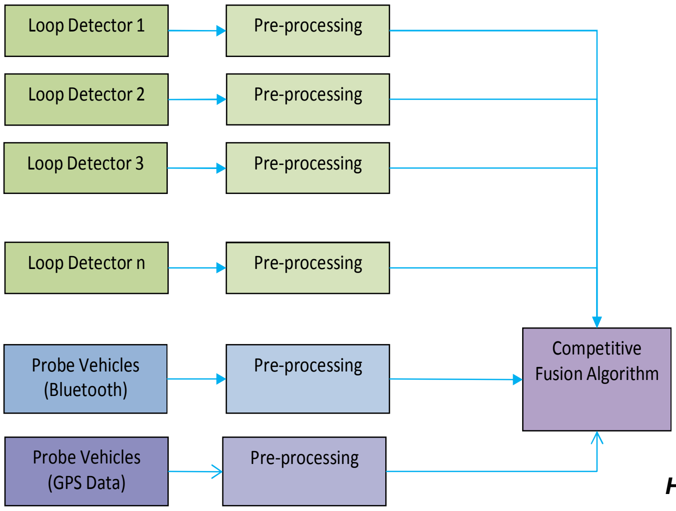
This OBD information is then sent to the ONE-ITS server allowing the platform to keep track of many attributes such as vehicle speed, throttle position, ambient air temperature, etc. With this data stored on the ONE-ITS open service platform, this rich data can then be fused with other data sources or can be used by researchers or agencies internally in their organization, and therefore harnessing the concept of open innovation.

Data Fusion System Application for Speed and Travel Time Estimation

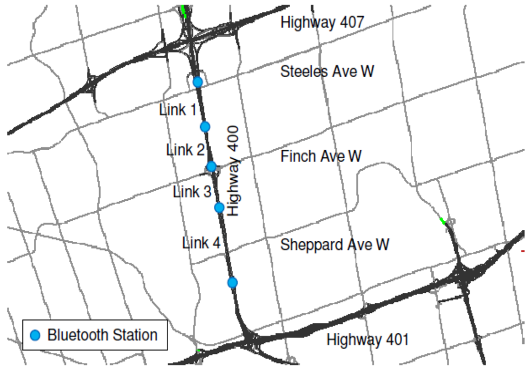
As part of Theme III objectives, this application is conducted to evaluate the effectiveness of each of the data fusion methods discussed above for travel time/speed estimation. The test experiments were conducted on a simulation environment that fused probe vehicle data and loop detector data and compared the fused result to the ground truth traffic conditions (using all vehicle data) as shown in Figure 10. As shown in the figure, the application makes use of competitive distributed data including multiple loop detectors, prob vehicles and GPS data on a simulated freeway (HWY 400) in the City of Toronto. The standard deviation and mean absolute error were used as measures of effectiveness and compared among different data fusion methods to analyse their performances.

The following conclusions can be drawn from the experiment conducted on the simulation environment:

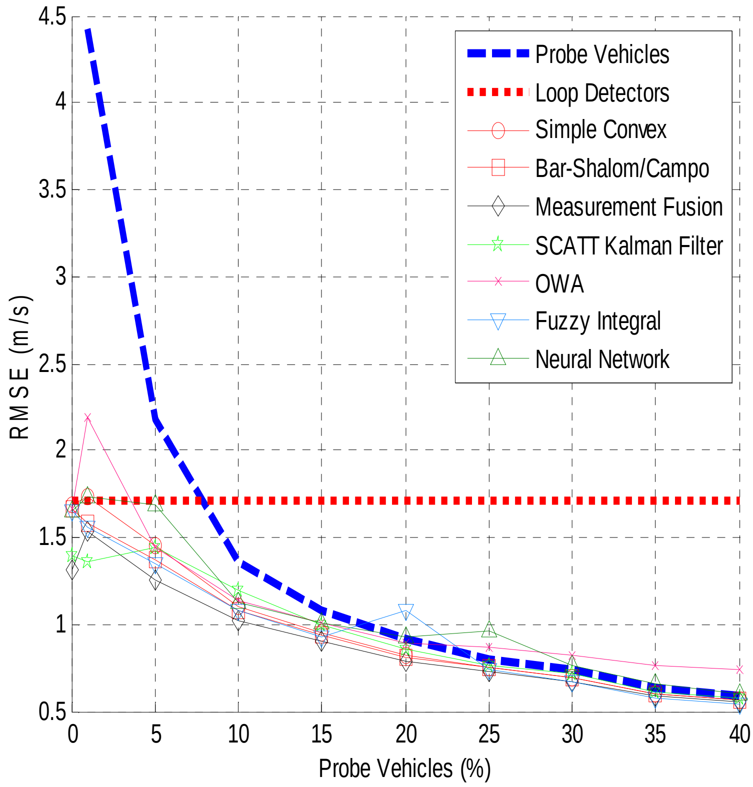
- All data fusion methods realize improvements that are statistically significant in some cases;
- Greatest improvement in accuracy with small numbers of probe vehicles
- Simple convex combination, Bar-Shalom/Campo combination, and the measurement fusion Kalman filter perform best;
- No result is statistically worse than the best sensor used independently (i.e. never loose accuracy).



Competitive Distributed Data Fusion Architecture



Highway 400 Simulation Case Study (AM Peak)



Sample Speed Estimation Error on a Highway Link using Different Data Fusion Methods

Figure 10: Data Fusion Application (Bachmann, C., Abdulhai, B., Roorda, M.J. and B. Moshiri, 2013)

SUMMARY

In this paper we presented the concept of open service innovation for ITS services (Open – ITS) by integrating three intertwined Themes; namely: Open Transport Service Innovation Platform, Sensing Platform for Traffic Monitoring, and Multi-Sensor Data Fusion Framework. The open transport service innovation platform goal is to enable transportation agencies to ‘purposively’ use external ideas as well as internal ideas, and internal and external paths to

market, to create new services, new architectures, and new systems. The sensing platform for traffic monitoring builds on the concept of ubiquitously collecting data from multiple sources while harnessing the emerging technologies and smartphone sensory data. With these rich data and multiple sources of traffic information, the multi-sensor data fusion could not be more empathized as explained in the paper.

The paper also presented three applications that demonstrate the three themes discussed above; namely: Online Network Enabled- Intelligent Transportation Systems (ONE-ITS), A Sensing Platform using Smartphone and On Board Diagnostics Device Application, and Data Fusion System Application for Speed and Travel Time Estimation. This paper forms, to the best of the authors' knowledge, the first attempt to furnish the foundation for open transport service innovation concepts and mass customization for the new generation of ITS by proposing an Open-ITS system.

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