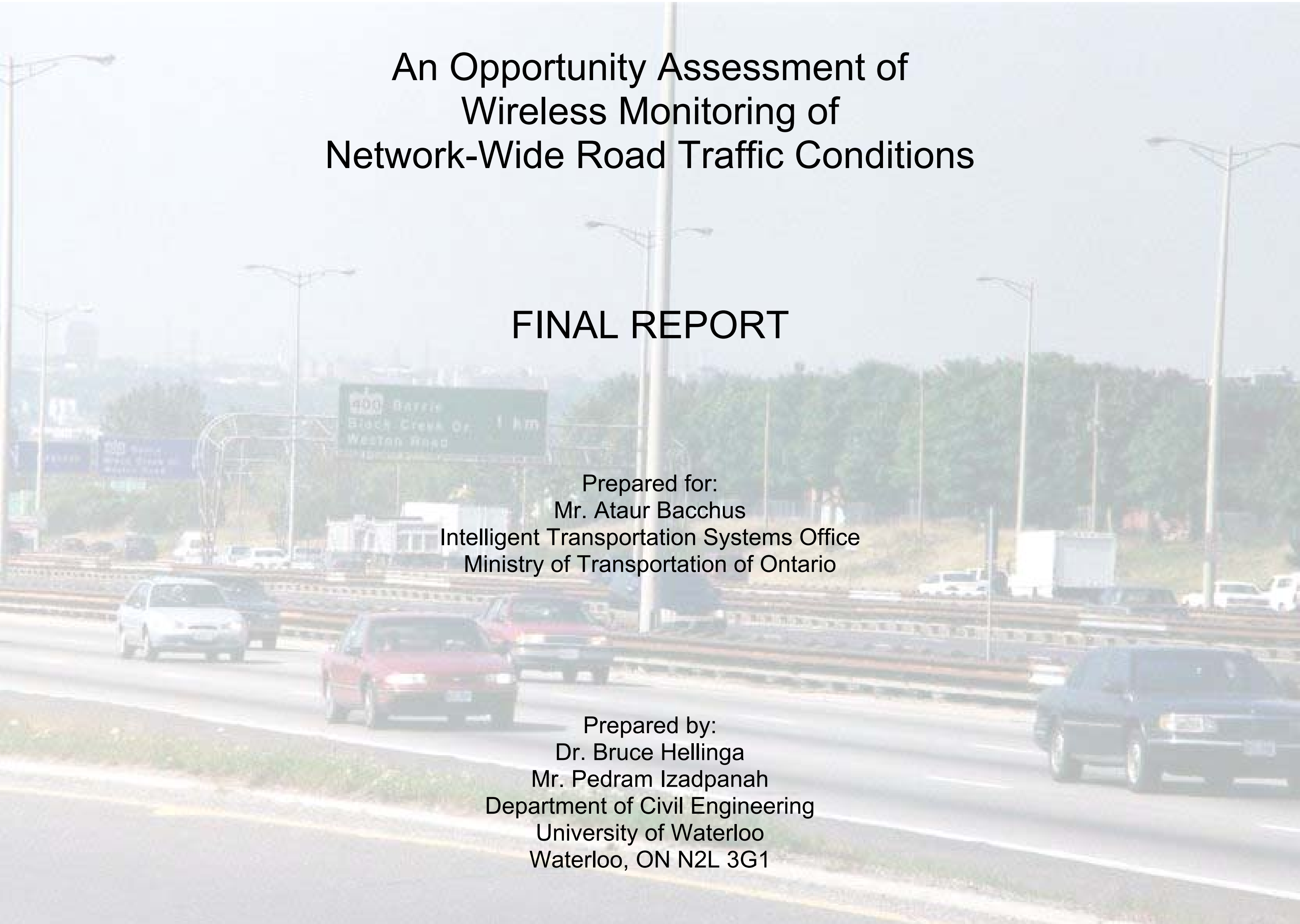

An Opportunity Assessment of Wireless Monitoring of Network-Wide Road Traffic Conditions

FINAL REPORT

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EXECUTIVE SUMMARY

INTRODUCTION

One of the most significant challenges to more effectively using the existing transportation infrastructure is the lack of accurate, up to date traffic condition data for the entire road network. In large urban centres, dedicated traffic sensors are deployed on major freeways (i.e. COMPASS and RESCU) enabling traffic operators to collect high quality road condition information in near real-time. However, almost no real-time information is available for all other roadways. Consequently, travellers are unable to make informed decisions about the best travel mode, departure time, and route and traffic managers are unable to predict or monitor the effect of management strategies for roadways outside of the instrumented freeway corridors. The lack of information causes frustration on the part of travellers and transportation system managers and often results in poor decisions.

The wide spread deployment of dedicated traffic sensors is cost prohibitive. However, new developments within the wireless communication field provide the opportunity to obtain traffic condition information over a wide spatial area in near-real time without the deployment of dedicated traffic sensors. These developments, originally instigated in response to Federal Communications Commission (FCC) requirements that wireless carriers be able to provide an estimate of the location of a mobile phone in the event of a call to 911, are now maturing to the point where the accuracy of the estimated position is sufficient to support the estimation of speeds and travel times on roadway segments.

Traffic management and monitoring has relied primarily on the same types of location specific traffic sensors (e.g. loop detectors) for over 40 years. And while control algorithms, such as automatic incident detection algorithms and algorithms to automatically generate messages for changeable message signs have been developed and improved, the concept of building systems that rely on dedicated location specific traffic sensors has remained virtually unchanged. The recent developments in the wireless communication field hold the potential to change that and open a wide range of possibilities to significantly enhance traveller information and traffic management capabilities in both urban and rural areas.

PROJECT GOALS AND OBJECTIVES

The goal of this project was to determine whether or not current or emerging wireless technologies have the potential to be successfully used for the wide-area monitoring of road traffic conditions.

To achieve this goal, 3 specific objectives were defined:

1. Identify decision support and management capabilities enabled by wireless monitoring of wide area road traffic conditions.
2. Perform a technology scan to identify and assess existing and emerging technologies for obtaining wide area road network traffic conditions with respect to the operations identified in objective 1. Recommend the technology(ies) that MTO should focus on for wide-area monitoring.

3. Identify gaps in the current technology or supporting applications that require further research to meet MTO operational needs. This would include answering key questions regarding operational characteristics, performance evaluation, uncertainty and reliability, and use of data from a wireless road network traffic condition monitoring system.

POTENTIAL OPERATIONAL CAPABILITIES

This part of the project identified transportation related activities of potential interest to MTO and associated opportunities and challenges for which wireless monitoring of network conditions may be suitable for providing some or all of the required data. In other words, this part of the report identified how wireless network monitoring could support existing MTO activities as well as identifying how the data obtained from wireless monitoring could support new activities that may be of interest to MTO. A number of possible activities were identified as follows:

1. In the field of traffic management:
    1. Automatic incident detection
    2. Congestion balancing
    3. Integrated freeway/arterial management
2. In the field of traveller information:
    1. Pre-trip route planning
    2. Roadway travel times
    3. Boarder crossing travel times
3. In the field of transportation planning:
    1. Identification of O/D demands
    2. Identification of routes
    3. Historical network travel times
    4. Mobility monitoring
    5. Public transit planning

There are a range of technical, institutions, and legal (i.e. privacy) issues associated with each potential activity. Information obtained from a number of US DOTs currently involved in field trials of wireless traffic conditions monitoring systems suggests that the primary activity of focus is traveller information (i.e. roadway travel times or average speeds).

WIRELESS TRAFFIC CONDITIONS MONITORING SYSTEMS

Wireless traffic conditions monitoring systems can be divided into three categories:

- Dedicated vehicle probe systems
- Anonymous cell phone tracking systems
- Vehicle infrastructure integration (VII) systems

It appears that in the long term, VII systems have the greatest potential to provide accurate, timely, reliable and detailed road conditions data. However, VII is still in its infancy and VII-based systems cannot be expected to become commercially deployed in sufficient numbers for at least 7 to 10 years and possibly longer.

Dedicated probe-based systems, which have been shown to be commercially viable ventures in Europe, have not experienced the same level of success in North America. It remains to be seen if a road traffic conditions acquisition system based on dedicated probes will emerge in North America. The key challenge facing such a system will be enrolling a sufficient number of probe vehicles to provide adequate accuracy, reliability, coverage and timeliness.

The technology required for cell phone based systems has been developed and several different approaches are currently being marketed as commercial systems. Though the performance of these systems has not yet been adequately demonstrated, several systems are sufficiently mature that the product vendors have entered into demonstration and/or deployment contracts with public sector agencies.

CONCLUSIONS

1. Wireless road monitoring systems have the potential to significantly improve real-time knowledge of road traffic conditions and to radically alter the way MTO/DOTs manage, maintain, and plan the road network.
2. Dedicated probe systems may be able to provide travel time data suitable for freeways, particularly rural freeways. However, the minimum lag time inherent within these systems may prevent their use for real-time applications.
3. A number of wireless road monitoring systems are being marketed and are being, or have been, field demonstrated. These include:
    a. D.R.I.V.E.S developed by Globis Data.
    b. NETWorks™ developed by Delcan.NET in partnership with *iTIS* Holdings.
    c. RoDIN24 developed by Applied Generics (now part of the TomTom Group).
    d. TrafficSense developed by CellInt.
    e. X-10 developed by AirSage.
4. Traffic.com obtains traffic data via a combination of fixed, dedicated traffic sensors, and wireless road monitoring system (i.e. dedicated probes and cell-phone probes). The company is the largest commercial provider of traffic data in North America.
5. The quality of data that can be obtained from cell phone based systems has not yet been sufficiently demonstrated in North American deployments.

   There are only two systems that have to-date undergone field trials in North America which were evaluated by a third party and for which the reports are publicly available. These evaluations are (i) the AirSage system trial in Hampton Roads, Virginia completed in 2006 in which the evaluation team concluded that the data from the AirSage system were not of sufficient quality to support operations within VDOT; and (ii) the Delcan.NET trial in Maryland completed in 2007 in which the evaluation team concluded that the system was able to estimate speed and travel time on freeways with sufficient accuracy to meet the functional needs of Traveler Information Systems but they also concluded that the system is not yet able to estimate traffic information for arterials with adequate accuracy (Note that an evaluation report from the CellInt trial in Kansas City is expected to be finalized in late spring of 2007).

6. The cell phone based systems that have been field evaluated in North America are systems that rely on network based location determination. This approach permits rapid and (relatively) inexpensive location tracking of a large number of cell probes; however, location accuracy is generally poor. Systems that make use of handset location determination methods, such as assisted GPS (i.e. Globis Data system), typically are able to obtain higher location accuracy but generally must contend with a smaller number of probes in the sample.
7. Recently completed field trials suggest that cell probe systems which rely on network based location determination methods cannot provide sufficiently accurate traffic conditions data for arterials. The more accurate handset based location determination systems are expected to be more successful for arterials, however, this has not yet been tested in a comprehensive field trial.
8. Participation of wireless carriers is necessary to operate cell phone based systems. However, the level of commitment of wireless carriers to participate in road conditions monitoring projects is not clear.
9. The costs associated with cell phone based systems are not yet well defined.
10. Currently, the majority of wireless monitoring systems provide data primarily for traveller information purposes in the format of average link speed or travel time for freeways and major arterials. The data have generally not yet been used as input to other decision support functions such as incident detection, identification of routes and O-Ds for planning purposes, etc.

SIGNIFICANT ISSUES

It is apparent from limited field results available and the views expressed by the DOT personnel associated with the pilot projects in the US that wireless monitoring of road traffic conditions is technically feasible and holds significant potential. However, there appears to be five key outstanding issues that need to be resolved before MTO can realistically make a decision whether or not to adopt this approach to acquiring road conditions data.

First, is the issue of whether or not the private sector firms can establish long term relationships with wireless carriers. This is critical as without the participation of at least one wireless carrier the systems can not operate. The onus is on the private sector firms to develop these relationships and demonstrate that the wireless carrier partners are committed to participating.

Second, is the issue of data quality. The system must be able to provide accurate, reliable, and timely data for the road network of interest and must be able to do so for 24/7. Naturally, the quality of the data is particularly important during periods when congestion exists on parts of the network as it is particularly under these conditions that network condition information is most valuable.

Several demonstration projects have been or are currently being conducted in North America. However, the evaluation methodologies and the conclusions from these projects are not always consistent. Furthermore, given the unique and varied nature of the road transportation network in Ontario (e.g. express/collector facility on Hwy 401 in Toronto; location and importance of the international border crossings; high density of network in major urban centres and low density along rural corridors, etc.) it may be difficult to translate the results from a demonstration in the US to the Ontario context.

Third, is the issue of cost. It appears that at the current level of commercial development of these systems, the cost structure is not well defined and the cost structure for deployment in the US may be different than for deployment in Ontario. Furthermore, the cost structure likely depends on the required quality of data, network coverage, etc. It is also anticipated that the costs will change as one or more of the system vendors develops a larger commercial deployment base in North America.

Fourth, is the issue of development and evaluation of decision support tools. It appears that at the current time, system vendors are focusing their efforts on developing and field demonstrating the capabilities of their systems to provide accurate and reliable average link travel time and speed data. While there is clearly value in these data, MTO may be able to utilize the road network conditions data for a much wider range of decision functions. MTO needs to give careful consideration to what contractual arrangements would permit the development and evaluation of the use of data for other decision functions.

Fifth, is the issue of privacy of cell phone users. From a technical perspective, the privacy of individual cell phone users can be protected by the design of the system and disseminating only aggregate traffic data (e.g. link speed or travel time). Additionally, in the current systems a firewall is used to assign a random number to cellular phone IDs being tracked, preventing the association of cell phone ID with an individual. Nevertheless, there may remain the perception by the public that their individual movements are being tracked without their consent.

RECOMMENDATIONS

The current trend in technology development suggests that the derivation of traffic conditions information from wide-area wireless monitoring techniques is approaching the level required to meet (some) of the operational requirements of MTO. Nevertheless, at this time, it appears that no one wireless monitoring technology has been field proven to clearly outperform all others over a wide range of applications. Consequently, the following recommendations are made to enable MTO to establish on the basis of field performance which solutions are best suited to support specific MTO operational activities:

1. It is recommended that MTO conduct a demonstration/evaluation project in Ontario. The only recent field evaluation of a cell probe system in North America was conducted in Maryland. The final evaluation report concluded that cell phone probes are able to provide traffic information for freeways that is of sufficient quality to satisfy the operational needs of traveller information systems. However, the Maryland evaluation did not explicitly consider the data quality requirements associated with other operational activities. Furthermore, the evaluation suffered from several constraints including; limited data for comparison due to withdrawal of the wireless carrier from the project; and analysis results are aggregated limiting the ability to interpret the reliability of the speed and travel time estimates for different traffic conditions.
2. It is recommended that MTO retain an independent and objective party (not the system vendor) to conduct the system evaluation. The system should be evaluated in both the urban and rural context for a variety of traffic conditions. Particular emphasis should be placed on evaluating the system for conditions that are not “free flow”. Furthermore, “ground truth”, against which the cell probe data will be compared, must be established using spatial techniques (i.e. dedicated probe vehicles or travel times obtained via automated license plate matching from video images) as it is not possible to compare the accuracy of cell probe link travel time estimates using data from dedicated traffic

sensors such as loop detectors. Particular care must be exercised in designing the evaluation to avoid problems such as those encountered in the Maryland evaluation.

3. Given the existing uncertainty regarding the operating costs and quality of data associated with cell-phone tracking and the relatively long period of time before VII can be expected to be deployed, it is recommended that MTO:
    a. Evaluate opportunities for obtaining speed/travel time data from dedicated probe systems for major freeway corridors (such as Highway 401). This effort should focus on three aspects of the data, namely (1) the quality of the data (paying particular attention to bias); (2) the time lag that exists in obtaining the data; and (3) the costs associated with obtaining these data.
    b. Determine the likelihood of existing commercial traffic data providers, such as Traffic.com, expanding operations into Canada and specifically Ontario. The Traffic.com system appears capable of providing consumer grade level traffic information over a wide variety of dissemination platforms (though no information was found during the literature review that quantifies the accuracy and reliability of the data provided by Traffic.com). This level of traffic information may meet the data needs of several of the operational activities identified in this report, particularly now that Traffic.com is reported to be obtaining traffic data from multiple sources, including dedicated sensors, cell-phone probes, and dedicated commercial probes.

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CHAPTER 1:

INTRODUCTION

The safe and efficient operation of our nation's transportation systems, and in particular our roadways, is vital for the nation's economic well-being. Unfortunately, many urban and even key rural roadways are congested during significant portions of each day, resulting in increases in delays to commuters and freight carriers, decreased reliability of trip travel times, increased fuel consumption and tailpipe emissions, and decreased safety.

In the past, the solution of choice was to increase capacity through the construction of new infrastructure. Today, however, with rising construction costs and increasing public concern over environmental degradation, there is mounting pressure on transportation agencies to implement management strategies and policies that make more efficient use of existing infrastructure, while at the same time, providing reliable travel options and explicitly considering the safety, energy and emission impacts.

One of the most significant challenges to more effectively using the existing transportation infrastructure is the lack of accurate, up to date traffic condition data for the entire road network. In large urban centres, dedicated traffic sensors are deployed on major freeways (i.e. COMPASS and RESCU) enabling traffic operators to collect high quality road condition information in near real-time. However, almost no real-time information is available for all other roadways. Consequently, travellers are unable to make informed decisions about the best travel mode, departure time, and route. And traffic managers are unable to predict or monitor the effect of management strategies for roadways outside of the freeway corridors having dedicated traffic monitoring equipment. The lack of information causes frustration on the part of travellers and transportation system managers and often results in poor decisions.

The wide spread deployment of dedicated traffic sensors is cost prohibitive. However, new developments within the wireless communication field provide the opportunity to obtain traffic condition information over a wide spatial area in near-real time without the deployment of dedicated traffic sensors. These developments, instigated in response to the CRTC and FCC requirements that wireless carriers be able to provide an estimate of the location of a mobile phone in the event of a call to 911, are now maturing to the point where the accuracy of the estimated position is sufficient to support the estimation of speeds and travel times on roadway segments.

Traffic management and monitoring has relied primarily on the same types of location specific traffic sensors (e.g. loop detectors) for over 40 years. And while control algorithms, such as automatic incident detection algorithms and algorithms to automatically generate messages for changeable message signs have been developed and improved, the concept of building systems that rely on dedicated location specific traffic sensors has remained virtually unchanged. The recent developments in the wireless communication field hold the potential to change that and open a wide range of possibilities to significantly enhance traveller information and traffic management capabilities in both urban and rural areas.

1.1 PROJECT GOALS AND OBJECTIVES

The goal of this project is to determine whether or not current or emerging wireless technologies have the potential to be successfully used for the wide-area monitoring of road traffic conditions.

To achieve this goal, 3 specific objectives were defined:

1. Identify decision support and management capabilities enabled by wireless monitoring of wide area road traffic conditions.
2. Perform a technology scan to identify and assess existing and emerging technologies for obtaining wide area road network traffic conditions with respect to the operations identified in objective 1. Recommend the technology(ies) that MTO should focus on for wide-area monitoring.
3. Identify gaps in the current technology or supporting applications that require further research to meet MTO operational needs. This would include answering key questions regarding operational characteristics, performance evaluation, uncertainty and reliability, and use of data from a wireless road network traffic condition monitoring system.

1.2 ORGANIZATION OF DOCUMENT

This document is organized as follows:

Chapter 2, which addresses objective 1, identifies potential capabilities and describes to what extent wide-area road traffic conditions monitoring could support these opportunities.

Chapter 3 provides a description of the technologies that support wireless wide-area traffic conditions monitoring. Specifically, this chapter describes three technologies categories namely, cell phone systems, dedicated vehicle probe systems, and vehicle infrastructure integration (VII) systems. For each technology category, the chapter describes the underlying technology and highlights the most significant characteristics.

Chapter 4 identifies five commercial systems for obtaining wide-area traffic conditions data, namely systems developed by iTIS Holdings, Applied Generics, AirSage, and Globis Data. The chapter describes the basic characteristics of each system, status of the system development, and any performance evaluation results that have been made publicly available.

Chapter 5 assesses each of the three wireless traffic conditions monitoring technologies for ten specific operational activities relevant to MTO (as identified in Chapter 2) and identifies which application areas can be viewed as most likely early successes.

Chapter 6 identifies knowledge gaps with respect to the performance of individual commercial systems and in terms of the use of wireless wide-area network conditions monitoring to support various transportation activities.

Chapter 7 summaries the findings of this study, identifies issues that remain to be addressed, identifies a path forward in terms of wireless traffic monitoring, and provides several specific recommendations.

CHAPTER 2:

POTENTIAL OPERATIONAL CAPABILITIES

2.1 INTRODUCTION

This chapter identifies transportation operational activities of interest to MTO that could potentially benefit from the availability of network-wide road traffic conditions. In many instances, the range of activities currently conducted by MTO, and the manner in which these activities are conducted, have been defined and/or constrained by the type, quantity, and quality of data available to support these activities. The purpose of this chapter is to explore what transportation related activities (existing as well as new) could be supported (in whole or in part) by data obtained via wireless road network conditions monitoring systems.

2.1.1 Scope

It is necessary at this stage to define the scope within which the opportunities listed in this chapter have been generated and several broad assumptions that have been made with respect to the functional capabilities assumed to be provided by the wireless network monitoring technology.

The scope of this chapter is confined to identifying transportation related activities of potential interest to MTO for which wireless monitoring of network conditions may be suitable for providing some or all of the required data. Thus, this chapter identifies how wireless network monitoring could support existing MTO activities as well as identifying how the data obtained from wireless monitoring could support new activities that may be of interest to MTO.

There is no attempt at this stage to prioritize the identified activities in terms of which are of greater importance to MTO or in terms of which would benefit most from the data obtained via a wireless monitoring system. This level of evaluation and assessment is addressed in Chapter 6 after examination of the technology capabilities (Chapter 4) and knowledge gaps (Chapter 5).

2.1.2 Assumptions

The following assumptions have been made regarding the general capabilities of the wireless monitoring technologies. These assumptions are consistent with the capabilities of current systems and the recently conducted research at University of Waterloo (Takada, 2006). A more specific assessment of the wireless monitoring technologies is provided in Chapters 4 and 5.

1. Network conditions are characterized by either average travel time or average travel speed.

2. Data obtained from individual probe vehicles are aggregated to provide estimates of the average conditions for a defined length of roadway (referred to as a link).
3. Road conditions data are available for a road segment as a whole and it is not possible to differentiate between individual lanes on that road segment.
4. Data are obtained in near-real time and therefore reflect roadway conditions over the past *N* minutes, where *N* is of the order of 5 – 30 minutes.
5. The prediction of future road traffic conditions on the basis of data obtained from probes may be possible, but this capability is not inherent to wireless monitoring and is not expected to be available in the near term deployment of such systems.
6. The upper bound of the accuracy of travel time estimates is likely to be on the order of 5% for freeways and 20% for arterials. The actual accuracy will vary depending on a number of factors, including the sampling rate, locationing technology, traffic conditions, road network topology, etc.
7. The wireless monitoring system is able to select a random (unbiased) sample from all vehicles on the road network (e.g. not a designated sub-group such as taxis or buses) for purposes of extracting road network conditions data.

2.2 IDENTIFICATION OF OPPORTUNITIES

Table 1 provides a listing of the activities that could potentially benefit from data obtained via wireless network conditions monitoring. These activities have been associated with five broad categories of transportation activities, namely traffic management, traveller information, transportation planning, winter maintenance, network performance monitoring, and public transit. Some specific activities can contribute to more than one of the six categories and there undoubtedly exists overlap between some of these categories.

In the subsequent sections the nature of the opportunity, the expected benefits, and the general constraints are described for each activity listed in Table 1.

Table 1: List of transportation activities that potentially could be supported by wireless network conditions monitoring data

	Automatic incident detection	Freeway congestion balancing	Integrated freeway/arterial management	Origin/destination demands	Identification of routes	Pre-trip planning	Current travel times	Road surface conditions	Historical network travel times	Border crossing travel times	Travel time prediction
Traffic Management	X	X	X								X
Traveller Information						X	X			X	X
Transportation Planning				X	X				X		
Winter Maintenance							X	X			
Network Performance Monitoring									X		
Public Transit									X		

2.3 TRAFFIC MANAGEMENT

2.3.1 Automatic Incident Detection

The detection of incidents (i.e. unexpected events such as collisions, spilled loads, debris, stalled vehicles, etc.) has been viewed as a critical component of a traffic management system. Automatic detection of incidents on freeways has been the subject of extensive research for over 40 years. The majority of this research has focussed on the development of automatic incident detection algorithms (AID) that rely on induction loop detector data for input, as this is the traffic monitoring technology that is predominately deployed in North America and overseas. However, despite this effort, AID performs at levels much less than required with false alarm rates higher than acceptable and detection rates lower than desired. Consequently, most freeway traffic management systems rely on ad hoc methods of incident detection, including calls from motorists and police, and real-time visual monitoring by traffic management centre personal of freeway video surveillance feeds.

Incident detection on roadways without surveillance infrastructure (i.e. in Ontario outside of COMPASS and RESCU) is restricted to relying on reports from motorists and police services. Relying solely on reports from motorists and police provides almost no centralized traffic management operational capability as information quality is unknown, there is no means to automatically measure the impacts of the incident once notified, and there is no means to inform drivers of the incident or its impacts.

Consequently, given the surveillance infrastructure requirements of current AID methods, no centralized incident detection capabilities exist for all rural roads and urban arterial roads.

Opportunities:

The wireless monitoring of road conditions provides the opportunity to conduct automatic incident detection on urban arterials and on rural roadways – locations at which currently no AID capability exists. It also has the potential to improve current AID capabilities on instrumented freeways by supplementing loop detector data with probe data.

Some research has been conducted to explore the opportunities of AID based solely on probe data (e.g. Hellinga and Knapp, 2000; Hongtu, 2002) and based on combined fixed sensor and probe data (e.g. Sethi et al., 1995). However, the literature review did not reveal any field operational systems employing probe data for AID.

VII (vehicle infrastructure interchange) based wireless network monitoring systems are expected to be able to provide event specific information, such as notification that an airbag has been deployed. These detailed data may support the direct identification of an incident.

Challenges:

Conducting AID on the basis of data collected via a wireless road conditions monitoring system faces several challenges, some of which are a function of the nature of the wireless monitoring system:

1. Event confirmation is a key operational capability of freeway traffic management systems. In conventional systems, when an incident is detected, the event is visually confirmed by an operator using the system's CCTV infrastructure. Wireless road conditions monitoring systems will not provide video capabilities and therefore event confirmation may not be possible. To what extent can/should MTO respond to an incident alarm if there is less than 100% certainty an incident has occurred?
2. Existing AID methods that rely on loop data typically operate using lane specific data. This level of resolution is not yet possible with wireless road conditions monitoring systems and therefore new AID algorithms will need to be developed.
3. Incident detection on arterial roadways has received much less attention than incident detection on freeways, largely as a result of the lack of traffic surveillance infrastructure deployed on arterials. However, AID is much more challenging on arterials than freeways due to the impact of traffic signals, etc. Even if adequate data were available developing a successful AID method for arterials would pose a significant technical challenge.
4. The extent to which wireless road conditions monitoring data could improve existing freeway AID is not known.

2.3.2 Congestion Balancing

Highway 401 through Toronto is somewhat unique in that it consists of an express and collector facility in each direction. This characteristic provides MTO with the opportunity to influence driver behaviour to balance congestion on the two facilities. Currently, the COMPASS system provides congestion messages on dynamic message signs (DMS) upstream of transfer roadways reflecting the average travel speeds on the two facilities. These average speeds are estimated on the basis of spot speeds obtained from loop detectors.

The DMS messages express downstream traffic conditions in terms of one of three congestion levels (moving well; moving slowly; moving very slow). These categories of congestion are associated with specific average speed thresholds.

Opportunities:

A wireless network conditions monitoring system has the potential to improve the existing average speed estimates used within the COMPASS system due to the ability to directly measure travel times. This capability is particularly important during periods of construction and road maintenance when the loop detector data often are not available.

Challenges:

The most significant challenge is the necessity to distinguish between vehicles in the express lanes and vehicles in the collector lanes. Wireless monitoring systems that rely on data with relatively low location accuracy will not be able to distinguish between vehicles in the express versus the collector lanes and therefore will not be able to reliably estimate travel times separately for the two facilities.

2.3.3 Integrated freeway/arterial management

The integration of freeway and arterial control and management is an area of traffic management that has not yet seen significant progress. One reason for this limited progress is the lack of real-time road condition information for the arterial road network. In most jurisdictions in North America, arterial control primarily consists of traffic signal control (fixed time, actuated control, or adaptive control such as SCOOT), and in some instances directional lane control. However, for the most part, these arterial control systems operate independently from any freeway traffic conditions or control. Furthermore, even for areas operating advanced traffic signal control systems, such as SCOOT, there is often little or no data available that informs traffic management personnel about the traffic conditions on the arterial road network.

Opportunities:

Wireless road conditions monitoring systems present the opportunity to obtain road conditions data in near real-time. These data are not restricted to freeways or selected major arterials, but to almost the entire road network. Consequently, there is the potential to use these data to support more integrated freeway/arterial control than is currently possible.

The scope of possible integrated control strategies is rather wide and a complete description within this document of all potential strategies is not possible. However, several candidate strategies can be identified:

1. The existing congestion balancing strategies for the express and collector facilities on Highway 401 could be expanded by also informing drivers of the associated congestion on parallel arterial routes.
2. Signal control strategies could be enhanced to consider conditions on nearby freeways. If an incident occurs on the freeway causing significant congestion, then signal timings on the off-ramp and surrounding arterial roads could be altered to more effectively accommodate the increased traffic demands resulting from vehicles diverting from the freeway.

Challenges:

There is a lack of field proven methods and algorithms for integrated freeway/arterial control, even those based on loop data. Consequently, there is the challenge of developing field ready methods that are based on data obtained from wireless road conditions monitoring systems.

2.3.4 Travel time prediction

Most existing and emerging traffic monitoring techniques attempt to measure existing, or near-historical, traffic conditions. However, though this information is of significant value, the ultimate goal is to be able to predict near-future traffic conditions. These predictions would be of value for traffic managers as it would enhance their ability to assemble efficient response strategies. The predictions would also be of value for travellers as it would enable them to make more efficient choices with respect to travel mode, departure time, and route.

Despite the substantial value associated with predicting near-future traffic conditions, techniques for making accurate and reliable predictions have not yet been developed. The majority of research in this area has focused on near-term prediction of freeway traffic conditions on the basis of data obtained from dedicated traffic sensors (e.g. loop detectors). Little is available in the literature describing travel time prediction techniques associated with cell probe data.

Opportunities:

Wireless monitoring of road network traffic conditions provides the opportunity to compile a real-time and historical data set of measured travel times. A rich historical database provides the opportunity to utilize data mining and statistical pattern recognition techniques as a means of predicting near-future traffic conditions. These techniques would need to control for weather, time of day, day of the week, time of year, special events, incidents, planned events such as construction zones, etc., in order to find a set of historical travel time patterns that suitably match the current conditions. Predictions for the near-future would be made on the basis of the selected historical travel time patterns.

Challenges:

The most significant challenge associate with travel time prediction is that the underlying techniques required to obtain accurate and reliable predictions have not been developed and disseminated. Consequently, even if a cell probe system was deployed in Ontario, the algorithms necessary to predict near future traffic conditions would need to be developed.

2.4 TRAVELLER INFORMATION

From the perspective of road users, travel time typically is the single most important measure of road network performance. Unfortunately, most traffic sensors are not able to measure travel time and therefore typically, there are little or no empirical travel time data available.

Travellers make origin, destination, route, mode, and departure time choices, in part on the basis of their personal prediction of what the travel time for their trip will be. Choices of origin and destination are typically long term choices, such as location of home and work. The other choices are shorter term choices and made on a trip basis. For a trip between any given origin and destination, the expected trip time is a function of not only the average trip time but also the distribution (variability) of travel times. Travellers who frequently make a specific trip gain an understanding of the mean and distribution of trip travel times based on personal experience. However, this experiential data is:

- restricted to the route(s) taken (i.e. drivers don't know what their travel time would have been if they had taken a different route),
- subjective and qualitative (i.e. drivers generally do not objectively measure their travel times. Rather they form qualitative or approximate impressions such as the trip was "much longer" today than expected),
- not easily disseminated to other travellers.

Wireless network conditions monitoring systems provide the capability to compile a real-time and historical data set of measured travel times and to use these data to support various pre-trip and en-route traveller decisions (i.e. traveller information) and infrastructure planning (i.e. transportation planning) activities.

2.4.1 Pre-trip route planning

In the context of traveller information, the most common pre-trip planning choices are those associated with travel mode (e.g. transit, auto, walk, etc.), route, and time of departure. Time of departure is dictated almost exclusively by the expected mean and variance of trip travel time while route and mode may be influenced by other factors (e.g. car ownership, out of pocket cost, perceived convenience, etc.).

Pre-trip planning tools have already been implemented with respect to specific modes, such as transit (for example Mississauga Transit's "Click n' Ride" web-based trip planner: http://www.mississauga.ca/portal/residents/publictransit). These tools enable travellers to identify appropriate routes and determine the expected trip travel time.

Route planning tools also exist (e.g. Google maps: http://maps.google.com/) for the auto mode, however, these tools do not consider current or historical link traffic conditions.

Opportunities:

There exists the opportunity to create a true multi-modal (e.g. public transit, active modes such as walk and bike, and auto) trip planning tool that has the ability to estimate journey times. Such a tool would also be very valuable as a component of a 511 traveller information service. It is anticipated that the first phase of developing such a tool would be the development of the tool for auto trips as tools for transit already exist.

A demonstration tool has been developed by the Scottish Executive in partnership with *iTIS* Holdings (Figure 1) which provides travellers with the normal average travel time, the current travel time, and the historical variability of journey times between a selected trip origin and destination by time of day.

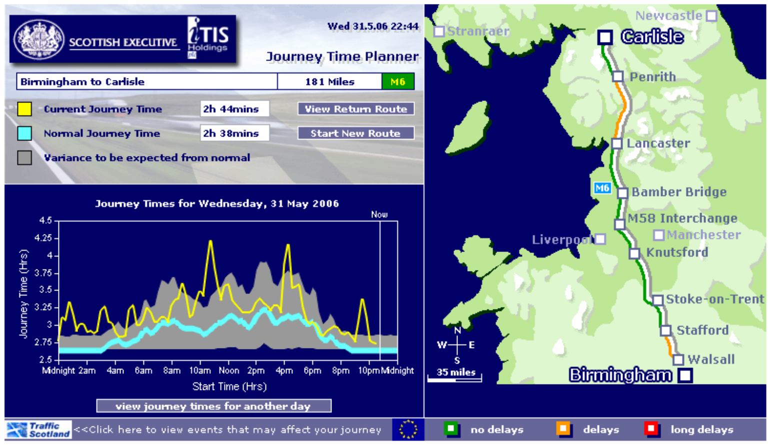


Figure 1: Journey time planner. (Source: http://scottishexecutive.itisholdings.com/)

Challenges:

There appear to be relatively few challenges associated with developing the proposed multi-modal travel planning tool that have not already been encountered in other applications. For example, issues with network representation, interface design, routing, etc., have already been addressed by developers of transit route planning tools. Assuming the wireless network conditions monitoring technology can provide sufficiently accurate and reliable link travel times, then developing such a tool should be possible.

2.4.2 Roadway travel times

Opportunities:

Perhaps one of the most significant opportunities presented by wireless wide-area network conditions monitoring systems is the ability to obtain travel time information for the majority of the road network in near real-time.

This information is not currently available and cannot be obtained in a cost effective manner using fixed point traffic sensors. Furthermore, travellers value this kind of information, as evidenced by the existence of commercial traffic data subscription services (such as the one offered by iTIS Holdings in the UK).

Once travel time (or average speed) data are obtained, they can be disseminated through a variety of means, including dynamic message signs, the internet, radio, text messaging, portable web enabled handheld devices, in-vehicle navigation systems, etc.

Challenges:

There are four significant challenges that must be addressed, namely accuracy, reliability, coverage, and timeliness. For the data to be valuable to traveller and to system managers, the reported network conditions must reflect the actual current conditions on the road. If data are outdated or based on very few observations, then they are unlikely to reflect the current actual conditions and decisions made on the basis of faulty data may be worse than decisions based on no data at all.

The most appropriate methods to meet these challenges will vary depending on the wireless monitoring system under consideration and the level of accuracy, reliability, coverage, and timeliness required.

2.4.3 Border crossing travel times

The issue of delays at international border crossings is of particular relevance to the Province of Ontario due to the high volumes of commercial truck and private auto traffic traversing the Ontario/US border crossings on a daily basis.

Opportunities:

Wireless monitoring of road network traffic conditions provides the opportunity to specifically target the travel times on roadway approaches to and through the international border crossings. This information would be of high value to commercial carriers (although some large carriers may already obtain similar information on the basis of internal company fleet tracking systems) as well as private motorists.

Challenges:

The challenges faced with obtaining border crossing times are similar to those for obtaining travel times. However, an additional challenge faced when attempting to estimate border crossing times is the possibly large discrepancy in crossing times for commercial vehicles versus private vehicles. Depending on the monitoring system under consideration, this problem is extremely difficult to solve (i.e. for cell phone based systems) or relatively easy to solve (e.g. dedicated probe systems or VII-based systems).

2.5 TRANSPORTATION PLANNING

A wireless network monitoring system provides near-real time road condition data which are of prime importance for traffic management and traveller information. However, these data can also be archived to build a rich historical database that can be mined in support of various off-line activities, including transportation planning. Five specific activities that relate to transportation planning have been identified:

- Identification of origin/destination demands
- Identification of routes
- Historical network travel times
- Mobility monitoring
- Public transit planning

2.5.1 Identification of O/D demands

Opportunities:

Transportation planning is focussed on the identification of long range future transportation infrastructure needs. These needs are identified through the use of regional planning models that estimate the future travel (O-D) demands as a function of the future land use and estimated future O-D travel times. The relationships on which these estimates are based are determined through calibration to existing conditions. One of the most significant challenges in calibrating these regional planning models is obtaining enough quality data describing existing travel patterns. Typically, census type data (e.g. from Federal Census or from Transportation Tomorrow surveys) are used to establish household and employment characteristics aggregated to the level of a traffic zone. Relationships are determined for estimating total trip attractions and productions for each zone on the basis of the socio-economic zonal data. Then screen line traffic volume count data are used to calibrate the trip distribution models from which the O-D demands are estimated.

However, it has long been recognized that there are typically many different O-D demand patterns that can produce the same screen line volumes, and therefore, in general, closely matching the measured screen line volumes does not guarantee a similar level of accuracy in the estimated O-D demands. Furthermore, these models rely on equations to estimate travel time as a function of traffic volume. In most planning applications, no data exists with which these travel time functions can be calibrated or validated.

Wireless network conditions monitoring may provide an opportunity to obtain a direct sample of trip origins and destinations. If trip trajectories of individual vehicle probes are recorded, then it may be possible to infer the trip origin and trip destination. These individual trips could then be aggregated over a period of months or even years to compile a dataset of O-D interactions.

There are several potential applications for such an O-D dataset.

> First, the data could be used within the calibration of regional planning models, likely as a supplement to the data and methods currently used.
>
> Second, the data could be used in the development of O-D demands for micro-simulation models. Micro-simulation modelling is being used more and more frequently for assessing operational traffic management strategies and geometric improvements. However, one of the key input data required for the use of these models is the time varying O-D traffic demands. Currently these O-D demands are either extracted from planning model output, directly estimated on the basis of manually obtained O-D data (e.g. license plate survey), or indirectly estimated on the basis of link volume count data. O-D data obtained from wireless network monitoring may be more cost effective than manually obtained samples, and may be more accurate than data extracted from planning models.

Challenges:

A review of the literature has revealed no reported instances of wireless network monitoring data being used for the purpose of compiling O-D demands.

It is anticipated that several challenges exist in extracting O-D data from a wireless network monitoring system.

- First, the location of the trip origin and trip destination must be inferred because the system anonymously collects data and therefore there is no means for the traveller to define the start and end of the trip. Methods of inference may include defining trip nodes as geographical locations at which the traveller engages in some type of activity for which the trip was made (e.g. place of work, retail centre, home, etc.). Trip node locations could, for example, be inferred on the basis of the amount of time spent at the location. Methods for doing this have not yet been established so there exists uncertainty as to the level of accuracy and reliability of such a scheme.
- Second, one of the characteristics of a wireless network monitoring system is that it samples only a portion of the vehicles within a geographical area. Furthermore, in the case of cellular phone based monitoring, only a portion of phones can be sampled and only a portion of the sampled phones are located within moving vehicles on the road network and not all vehicles are equipped with a mobile phone. Consequently, there is no way to know the fraction of all vehicles (vehicle trips) that are sampled. This presents a challenge when attempting to factor up the sample O-D demand to be representative of the whole system.
- Third, the segment of the population of travellers that carries a mobile phone, or participated as a designated vehicle probe, may not be an unbiased sample of the entire population of travellers. For example, if employees in white collar jobs are more or less likely to carry a mobile phone than employees in blue collar jobs, then an O-D derived from a sample of travellers with mobile phones will be biased.
- Fourth, there is no direct means to extract the trip purpose for each identified O-D trip. In most planning models, estimates are made for a specific trip purpose, such as a "home to work" trip. Directly extracting trip purpose from wireless network monitoring data is not possible.

2.5.2 Identification of routes

Opportunities:

A second opportunity related to transportation planning is directly obtaining information regarding the routes that travellers use to travel between specific origins and destinations. Transportation planning models estimate these routes (an exercise referred to as traffic assignment) by making the assumption that drivers select the route that provides them with the shortest travel time and that travellers have perfect information regarding the travel times on their selected route as well as all other routes.

It is evident that travellers obtain experiential data regarding average travel times on the routes that they select, however, there is some evidence that travellers often have a very poor understanding of travel times on alternative routes. Furthermore, there is evidence that travellers will remain on their habituated route even if they are aware that an alternative route provides relatively minor travel time savings. These issues have generally not been addressed in regional planning models, likely due in part to the lack of empirical data.

The routes developed within planning models are typically not examined in the calibration process and are never validated directly against field data. Consequently, the correctness of the estimated routes is not known. For many planning applications, the validity of the estimated routes is not a significant matter. However, for other applications, particularly when O-D demands are extracted from the planning model for a sub-network, the routes estimated by the model can have a significant impact on the model results.

The opportunity exists, therefore, to assemble an historical database of the routes taken by travellers between specific origins and destinations. These data could be used to refine the calibration of current regional transportation models, and to directly validate the routes generated by the planning models.

These data could also be used to monitor various operational issues such as neighbourhood infiltration by through traffic.

Challenges:

A review of the literature has revealed no reported instances of wireless network monitoring data being used for the purpose of identifying routes used by motorists. Nevertheless, there does not appear to be significant technical challenges to extracting this information.

One area of potential concern is the protection of the privacy of individuals. The dissemination of aggregate (e.g. average or median) link travel times or link speeds inherently protects the identification of individuals. However, when route data is disseminated, even when the identification of an individual is not revealed, it is possible to identify the home and work location for an individual probe by tracing the origin and destination over a number of days. Consequently, there exists a challenge to protect the rights of individuals while maximizing the opportunities provided by the data.

2.5.3 Historical network travel times

Opportunities:

A rich database of historical travel times could be used to support several transportation activities, including those associated with transportation planning, traveller information, and infrastructure maintenance.

Transportation planning applications include the validation and calibration of transportation planning models and the determination of isochrones.

The use of a historical travel time database to support planning applications has been demonstrated. For example, *iTIS* Holdings has developed an historical travel time database on the basis of a dedicated fleet of probe vehicles. They can query the database to extract travel time data by a specific route, day of week, time of day, etc. Figure 2 illustrates travel time contours (isochrones) developed on the basis of their historical travel time database.

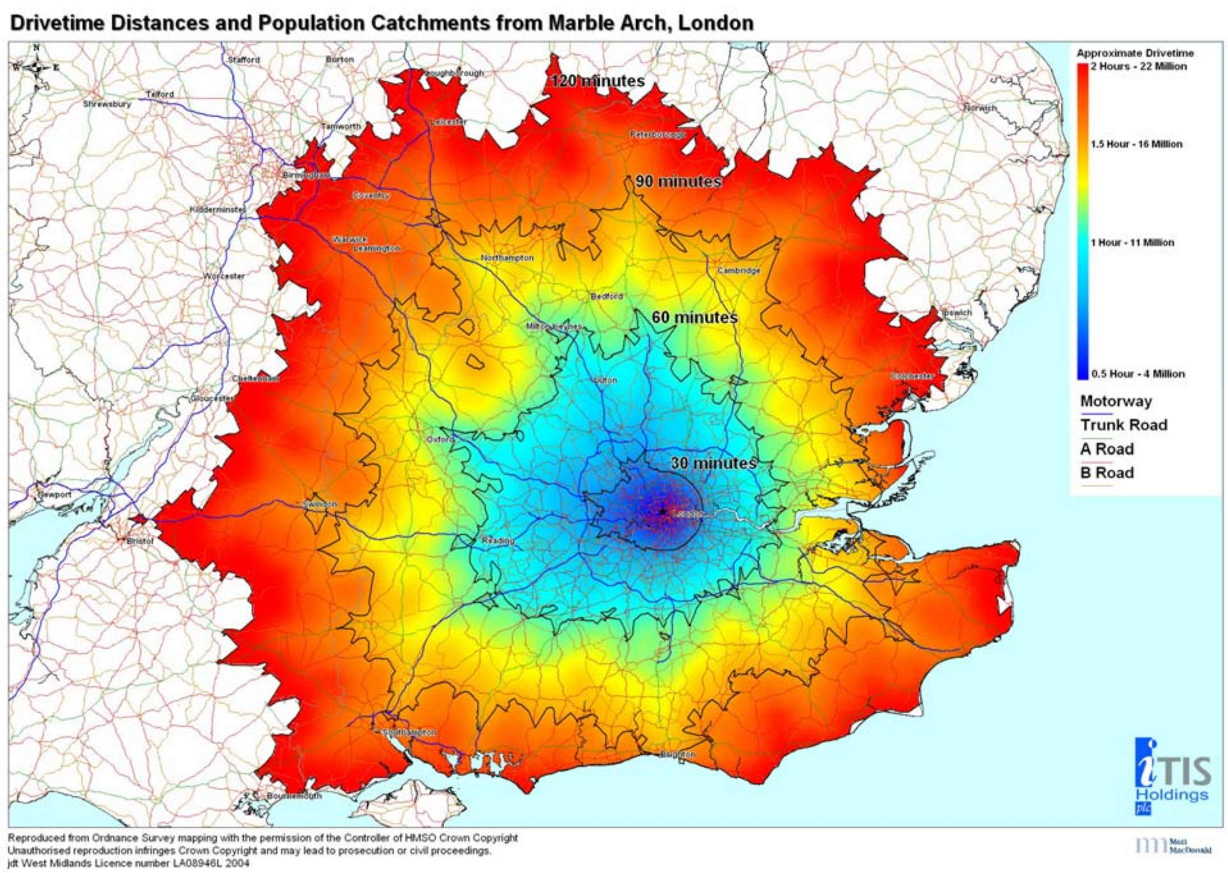


Figure 2: Use of historical travel time database for planning applications.
(Source: Quayle, 2005)

Challenges:

Wireless network conditions monitoring systems directly measure travel times, and therefore are ideally suited to developing an historical travel time database. The most significant challenges are associated with quality assurance of the data and amount of data to be handled by the system.

2.6 WINTER MAINTENANCE

Opportunities:

Wireless wide-area conditions monitoring provides at least three opportunities in the area of winter road maintenance. The first is the direct measuring and reports of road surface conditions. The second is the inference of road surface conditions on the basis of traffic speeds. The third is the use of current travel time data to manage the dispatch of winter maintenance vehicles.

The direct measuring of road surface conditions is only viable for VII-based systems in which the vehicle is able to report data from the traction control system, anti-lock braking system, use of wipers, etc. The data can be used to directly infer road surface conditions.

The inference of road surface conditions on the basis of traffic speeds is also conceptually possible. In general, there is a relationship between traffic speeds and road surface conditions. If the road surface is slippery from falling or drifting snow or from ice, the traffic stream will be travelling more slowly than if the road surface is just wet. Consequently, it may be possible to identify specific roadway sections requiring additional winter maintenance treatments without the need to have patrol vehicles traverse the section.

The use of current travel time data may be of value in optimizing the dispatch of winter maintenance vehicles.

Challenges:

The inference of road surface conditions on the basis of traffic characteristics (either individual vehicle data as from VII-based systems or from general traffic stream characteristics) has not yet been demonstrated. Consequently, appropriate methods and models will need to be developed and demonstrated before such a system could be deployed. It is anticipated that the process of doing so will require several years.

2.7 NETWORK PERFORMANCE MONITORING

The road transportation network represents a very significant financial investment. Continued growth in travel and changes in travel patterns can result in operating conditions on portions of the network degrading to unacceptable levels.

Transportation agencies typically monitor network performance using periodic data collection efforts (e.g. MTO's travel time surveys conducted every two years) or using data from stationary sensors such as permanent vehicle count stations.

The cost of dedicated data collection surveys necessarily limits the frequency at which the surveys can be conducted, the portions of the network included with the surveys, and the number of observations taken for each road segment. As a consequence, these survey methods are constrained in terms of the extent to which they are able to reliably reflect network operating conditions and support infrastructure expansion decisions.

Opportunities:

Wireless wide-area road conditions monitoring systems provide the opportunity to collect and compile network performance data (e.g. travel times) over the majority of the road network on a continuous basis. Such as database would cover a larger portion of the road network, cover a larger portion of the year (and thereby capturing effects of seasonality, weather, etc.), and contain more observations, than is economically feasible using dedicated survey methods.

It is expected that the availability of such a data source would permit the accurate and reliable tracking of road network performance without the need to conduct dedicated travel surveys.

Challenges:

The challenges with conducting network performance monitoring using data from wireless wide-area conditions monitoring systems are restricted primarily to those challenges associated with developing a historical travel time database as defined previously.

2.8 PUBLIC TRANSIT

Opportunities:

One of the inputs to the public transit bus route planning process is an estimate of the roadway travel times. Traditionally, these data have been estimated on the basis of experience or on the basis of dedicated travel time studies. If a travel time database were constructed on the basis of data from a wireless road conditions monitoring system, the transit planners would have available to them a comprehensive set of travel times (by time of day, time of year, etc.) and would be able to use these data to devise appropriate bus routes. This would result in reduced costs as dedicated travel time surveys would not be required, and may also result in cost savings as a result of optimized routes and schedules that more accurately reflect travel times.

Challenges:

There are two challenges that with using wireless wide-area network conditions data to support these transit activities:

1. Transit planners would need to develop methods by which they could incorporate the greater quantity of travel time data within the route planning/optimization process.
2. Travel times obtained from a wireless wide-area monitoring system will not be lane specific and therefore may not be able to accurately reflect differences in travel times between general purpose lanes and dedicated bus lanes or HOV lanes.

CHAPTER 3:

TECHNOLOGY SCAN

3.1 INTRODUCTION

Wireless traffic conditions monitoring systems can be divided into three categories:

- Anonymous cell phone tracking systems
- Dedicated vehicle probe systems
- Vehicle infrastructure integration (VII) systems

The following sections describe each of these technology categories.

3.2 ANONYMOUS CELL PHONE TRACKING SYSTEMS

Cell phones are now used as a regular medium of communication around the world. A cell phone system consists of a set of base stations, located on a cell grid typically depicted as a series of adjacent hexagons (Figure 3). One base station is associated with each cell. The base station consists of a tower and a small building containing the radio equipment to communicate with cell phones located the cell and landline equipment to communicate with a Mobile Telephone Switching Office (MTSO). The MTSO handles all of the phone connections to the normal land-based phone system for several base stations in a region. Consequently, the MTSO knows the cell in which each cell phone currently connected to the network is located.

The cell ID information available at the MTSO represents one source of data for inferring traffic conditions. However, extracting meaningful information requires that:

1. It is possible to determine if the mobile phone is in a vehicle, and
2. The road segments a mobile phone has traversed can be identified from a time series of cell IDs and electronic road map database.

Cells are normally thought of as hexagons on a big hexagonal grid similar to Figure 3. The base station in a cell communicates with cell phones in that cell using a special radio frequency. Adjacent cells must use different frequencies. Consequently, a single cell in an analog system uses one-seventh of the available duplex voice channels. Each cell (of the seven on a hexagonal grid) is using one-seventh of the available channels so it has a unique set of frequencies and there are no collisions. In North America cells typically have a diameter ranging from 1.5 to 3 Km in urban areas (Layton et al., 2006).

Knowledge of the time of hand-off and the geographical region of hand-off provides a second source of data for extracting road conditions data. This source provides more information than just the cell IDs obtained from the MTSO providing the potential for more accurate determination of the mobile phone's position.

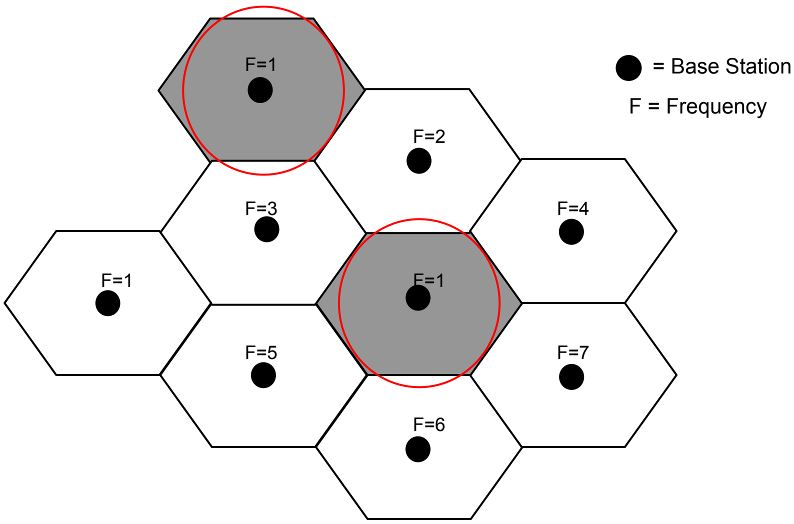


Figure 3: A typical cell grid and associated base stations.

3.2.1 Cell Phone Codes

All cell phones have special codes associated with them. These codes are used to identify the carrier the cell phone is registered with and the cell phone's owner. When a cell phone is turned on, it obtains a System Identification Code (SID) via a control channel. The SID is a unique 5-digit number that is assigned to each carrier by the CRTC (Canada) or FCC (USA). The control channel is a special frequency that cell phones use to communicate with the base stations. If the cell phone can not find any control channel to listen to, it concludes that it is out of range and a "no service" message appears on the phone.

When the cell phone receives a SID, the phone compares it with the SID already programmed inside the phone. If the two SIDs are identical, then the phone understands that it is communicating with the "home" wireless carrier system. Meanwhile, the phone transmits a registration request to the base station for the MTSO. If the MTSO approves the eligibility of the cell phone, it is registered to the network through a unique 10-digit number which is called the Mobile Identification Number. In this way, the MTSO finds out the phone number of the cell phone and which cell the phone is in and it can properly route a call.

As the cell phone is moving toward the edge of a cell, the base station associated with the cell can measure that the strength of the signal from the cell phone is diminishing. At the same time the neighbouring cell notes that the cell phone's signal is strengthening. Consequently, the two base stations communicate with each other through MTSO and at some point, the cell phone gets a message via the control channel that tells the cell phone to switch to another frequency and thereby begin communicating with another base station. This process is termed "hand-off" and is depicted in Figure 4 (Layton et al., 2006).

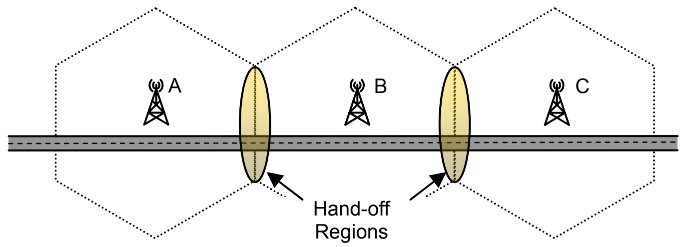


Figure 4: Hand-off mechanism of a moving cell phone.

3.2.2 Mobile Phone Locationing - Requirements

In order to improve quality and reliability of 911 emergency services, the Federal Communications Commission (FCC) in a series of orders and through a few phases, mandated all wireless carriers to automatically provide information about the location and identification number of emergency wireless callers to 911. The new emergency service is called E911. The evolution of requirements established by these orders and rules can be summarized as follows (FCC, 2001):

2. Phase 0: All cell phones manufactured for sale in United States must include a special method for processing 911 calls. "When a 911 call is made, the handset must override any programming that determines the handling of ordinary calls and must permit the call to be handled by any available carrier, regardless of whether the carrier is the customer's preferred service provider" (FCC, 2001).
3. Phase I: All the carriers are required to provide to the Public Safety Answering Point (PSAP) the phone number of the wireless 911 caller and the location of the cell site or base station receiving the call. This rule has been effective since April, 1, 1998 (FCC, 2001).
4. Phase II: All carriers are required to provide Automatic Location Identification (ALI) to the PSAP effective October, 1, 2001. The FCC mandated accuracy to be within 100 meters for 67 percent of calls and within 300 meters for 95 percent of calls. Wireless carriers were unable to meet those requirements by the deadline; however, currently carriers have satisfied the requirements in most jurisdictions in North America.

3.2.3 Mobile Phone Location Identification Techniques

The E911 location performance specifications could not be satisfied by carriers using only the cell ID. The cellular phone system was not designed originally to provide more accurate handset locations and therefore, carriers have had to develop new modules and deploy additional hardware to determine the locations more accurately.

Location identification techniques can generally be divided into one of 3 categories (Laitinen et al., 2001):

- Network-based
- Handset-based (GPS)
- Assisted- GPS

3.2.4 Network-based Techniques

In network-based implementations, one or several base stations are involved in locating a mobile phone. Moreover, all required measurements are conducted at the base stations and the measurement results are sent to a location centre where the position is calculated. In this type of implementation, there is no requirement to make any changes to the current handsets. However, the mobile phone must be in active mode (i.e. in "talk" mode or sending a signal through the control channel) to enable location measurement.

Cell Identification Technique

This is a preliminary and simple technique to roughly estimate the location of a mobile phone. Since this is an intrinsic characteristic of a cellular phone system, there is no need for network hardware enhancements. Based on phase I of E911, all wireless carriers are able to report the cell ID in which each cell phone is located. In this technique, the location of the mobile phones is approximated by the location of the base station. Relatively minor software changes enable these cell IDs to be obtained continuously over time rather than only when a 911 call is initiated. Obviously, the accuracy of this technique is dependent on the size of the cell; the accuracy in rural areas, where the sizes of cells are substantially bigger than urban areas, is much lower.

Time of Arrival Technique

Since radio waves between base stations and mobile stations travel at a constant speed equal to the speed of light, the distance between a mobile phone and a base station is directly proportional to the time of arrival of the wave (Zhao, 2000). Consequently, if at least three base stations identify the time of arrival of a signal from a specific handset, then the location of the handset can be estimated as the intersection of the three circles centered on these base stations (Figure 5-a).

Time Difference of Arrival Technique

Another technique, termed "time difference of arrival" is based on the characteristic that the locus of time difference of arrival of a signal between two base stations and a mobile phone forms a hyperbola. Thus, the mobile phone's location lies at intersection of two hyperbolas associated with two pairs of base stations (Figure 5-b).

Angle of Arrival Technique

The location of a cell phone can also be determined by measuring the angle of arrival of the radio wave. In this case, the intersection of two directional lines of bearing defines a unique position (Figure 5-c) (Takada, 2006). This technique requires at least two base stations and also requires directional antennas or antenna arrays to be installed at the base stations to measure the angle of arrival. Since the angle of arrival technique requires line-of-sight propagation conditions to accurately estimate the location of a mobile phone, this technique is not appropriate in dense urban areas (Zhao, 2000).

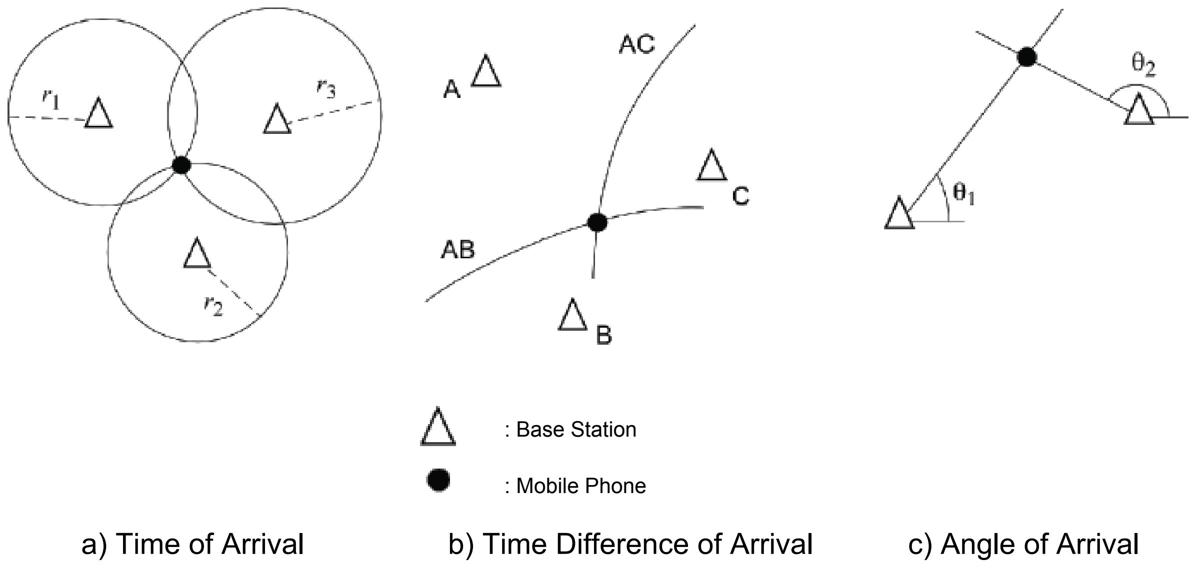


Figure 5: Network-based methods of estimating handset locations.

Timing Advance

Timing Advance (TA) is a Time Division Multiple Access (TDMA) term used in Global System for Mobile communications (GSM) networks. GSM uses the TDMA technology for sharing one frequency between several users in order to avoid interference. The TA value is normally between 0 and 63 and each step represents an advance of one symbol period (approximately 3.69 microseconds). Since the radio waves travel at the speed of light (300,000,000 m/s), each TA step represents 550 m from the base station (Eberspacher et al., 2001). In the urban areas, the maximum TA step is usually 2 (i.e. cell diameter ≤ 2 Km) while in rural areas it could even be 20 (i.e. cell diameter ≤ 20 Km). Consequently, TA can be used to identify the location of a cell phone with maximum error of approximately 550 m.

3.2.5 Handset-based Techniques

In the handset-based implementation all the measurements and calculations are performed in the handset and the results are transmitted to the base station. In this category of implementation, handsets must be able to measure their own locations, typically through the use of GPS.

Global Positioning System (GPS) uses satellites orbiting the earth to determine position, speed, and time anywhere around the globe. The system is developed and maintained by the US Department of Defence. Civilian access is available through an agreement with the US Department of Transportation (Zhao, 2000). The GPS receiver determines the position of itself based on time of arrival technique.

The use of GPS in mobile phone as a locationing device, suffers from three main disadvantages (Zhao, 2000): First, the time required to obtain a GPS position is relatively long, ranging from 60 seconds to a few minutes due to the long acquisition of the satellite navigation message. Second, GPS signals are too weak to detect indoors and in urban canyons especially with small cellular sized antennas. Third, due to long signal acquisition time, GPS power dissipation is very high.

3.2.6 Assisted GPS Techniques

Assisted GPS (AGPS) is a technique devised to overcome the limitations of GPS based locationing can be used. In an Assisted GPS system, a network of fixed GPS receivers (often located at the base stations) is deployed. These receivers are located to have a clear view of the sky and can operate continuously. The reference network is also connected with the cell phone network and continuously monitors the real time satellite constellation status and provides precise data. At the request of the mobile phone, the data derived from the GPS reference network are transmitted to the cell phone's GPS receiver to "bootstrap" the position acquisition process (Zhao, 2000). Through this technique, acquisition time is reduced due to the fact that the search space is limited by reference network and therefore power consumption is reduced and sensitivity of the receiver is increased when the signals are weak (Zhao, 2000). Obliviously, legacy cell phones can not be used in this system.

3.3 DEDICATED VEHICLE PROBES

Another method of obtaining traffic conditions data is use of instrumented vehicles as dedicated probes. Vehicles are typically equipped with a GPS receiver and a communication link. The vehicles periodically send position data to a central data processing facility. *iTIS* Holdings, a company based in London in the UK has adopted the approach in their commercial Floating Vehicle Data system. In the *iTIS* Holdings' system (Figure 6), several commercial vehicle fleets are equipped with GPS. The fleet disseminates location and time data to a cellular operator and then after analysis of data, the traffic information is sent to the subscribers through the cell phone network. Consequently, they are using the concept of "dedicated probes".

Since these probes are chosen from a particular category of vehicles, the traffic information could be biased and may not be representative of the whole population. Bias could arise either because of characteristics of the vehicle (e.g. heavy trucks travel more slowly on up grades); different operating constraints (e.g. trucks are not permitted in the median lane or are required to enter weight station); or travel patterns (taxis likely exhibit very different origin-destination patterns than entire vehicle fleet). Nevertheless, the use of dedicated probes may be both cost effective and accurate for specific applications. For example, speed and travel time data obtained from commercial vehicle probes operating on rural freeways may reflect with sufficient accuracy the near real-time operating conditions of the roadway.

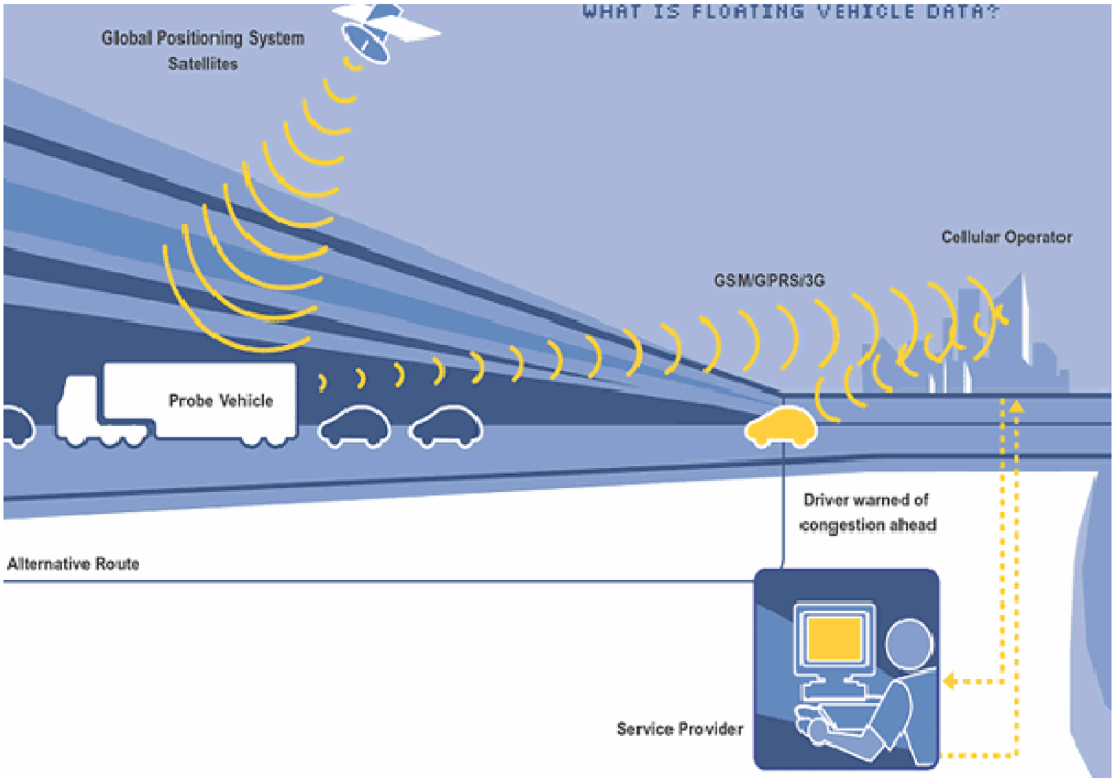


Figure 6: FVD® technology used by *iTIS* Holdings. (Source: *iTIS* Holdings, 2006)

Another method that can potentially use "dedicated probes" is General Motors OnStar technology. The OnStar system, introduced by GM in 2004, is a vehicle assistant and vehicle diagnostic service provided to subscribers. All OnStar subscribers' vehicles are equipped with GPS and also cellular wireless connection. The OnStar system every 30 days checks engine, airbags, antilock breaks, and OnStar system itself and sends an email to the subscriber with odometer readings and remaining oil life of the vehicle (GM, 2006). Moreover, the drivers can communicate with OnStar advisory center if they have any problem with their vehicles. In case of emergency, the drivers can request for emergency crews by pressing the emergency button installed in the vehicle and the OnStar operators dispatch the emergency crews to the scene by locating the vehicle through GPS.

Currently, OnStar service has more than four million subscribers in North America. If the system were to regularly query each OnStar equipped vehicle for the vehicle's position, the system would be able to collect traffic information through these dedicated probes. Unlike most of the dedicated probe fleets (e.g. taxis, trucks, transit buses, etc) the OnStar probe fleet would likely introduce much smaller bias.

3.4 VEHICLE INFRASTRUCTURE INTEGRATION

Vehicle Infrastructure Integration (VII) is another approach that potentially can be used to acquire traffic information dynamically. This approach enables vehicle-to-vehicle and vehicle-to-roadside communication (US Department of Transportation, 2006). The VII prospect is that every car manufactured would be equipped with Dedicated Short Range Communication (DSRC) and a GPS unit so that data could be exchanged with a nationwide, instrumented roadway system (US Department of transportation, 2006). Currently, most of the vehicles being manufactured in North America have a large array of sensors required for maintenance and operation of the vehicles. These vehicles have the ability to measure outside temperature near the surface of the pavement, they can determine whether it is raining or not, they can also know when traction control or the antilock braking system (ABS) is activated. If this information is coupled with traditional GPS information (to provide a spatial reference), then these data can be of benefit to a broad range of stakeholders in the transportation industry. For example, in addition to obtaining traffic information necessary for maximizing capacity of the network, maintenance crews could operate more efficiently by receiving real time information regarding the pavement surface conditions. This might result in cost saving for winter maintenance in the Province. Furthermore, many improvements regarding safety of the roadways are expected through this approach.

The concept of vehicle to infrastructure or vehicle to vehicle communication was first introduced for intersection collision avoidance systems in the mid 1990's. In 2001, ITS America and the US DOT started the development of a strategic document, the *National ITS program plan: A ten-year Vision.* "This plan outlined an enabling path to collision avoidance through the use of dedicated short range communications to support infrastructure – vehicle and vehicle – vehicle communications" (ITS America, 2005). In 2003, the historical Integrated Network of Transportation Information workshop gathered automotive manufacturers and US state transportation officials which paved the way for the US DOT to launch the VII initiative. The American Association of State Highway and Transportation Officials (AASHTO) organized the early meetings. In these meetings, Minnesota DOT, Florida DOT, Caltrans, and Michigan DOT participated as well as representatives from DaimlerChrysler, General Motors, Toyota, and Nissan.

The VII initiative was one of the nine new programs of the US DOT that was formally announced in 2004, at which time the VII Coalition was formed. The general organization of the VII Coalition is illustrated in Figure 7.

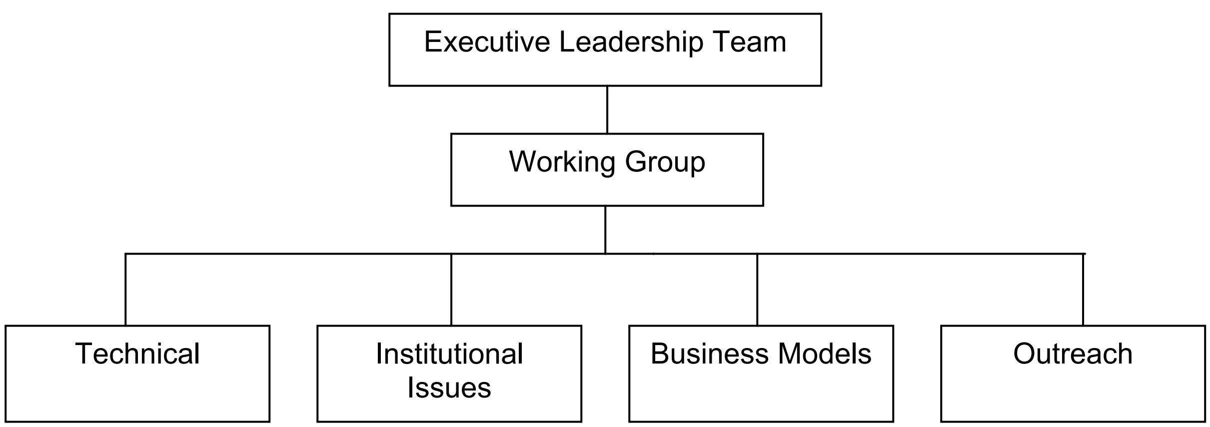


Figure 7: General Organization of VII Coalition.

The VII Coalition members include:

1. US DOT (FHWA, FMCSA, ITS JPO, and NHTSA)
2. Automotive Manufacturers (BMW, DaimlerChrysler, Ford, General Motors, Honda, Nissan, Toyota Motor North America, and Volkswagen)
3. State/Local Agencies (CALTRANS, Florida DOT, Idaho DOT, Indiana DOT, Maryland State Highway Administration, Metropolitan Transportation Commission -San Francisco Bay Area, Michigan DOT, Minnesota DOT, New York State DOT, Utah DOT, Virginia DOT, and Washington State DOT)
4. Associations (AASHTO, Alliance of Automobile Manufacturers, Association of International Automobile Manufacturers, IBTTA, ITE, and ITS America).

3.5 ISSUES ASSOCIATED WITH DEPLOYMENT OF VII[1]

Before any VII implementation attempt, the following issues need to be resolved:

1. Technical issues
2. Institutional issues
3. Business model.

3.5.1 Technical Issues

To help address the technical issues associated with VII, the FHWA introduced the VII national architecture (FHWA, 2005). This national architecture represents a summary of all of the efforts of the VII Coalition since 2003. Figure 8 illustrates an overview of the VII architecture.

[1] The majority of the information in this section is extracted from (FHWA, 2005)

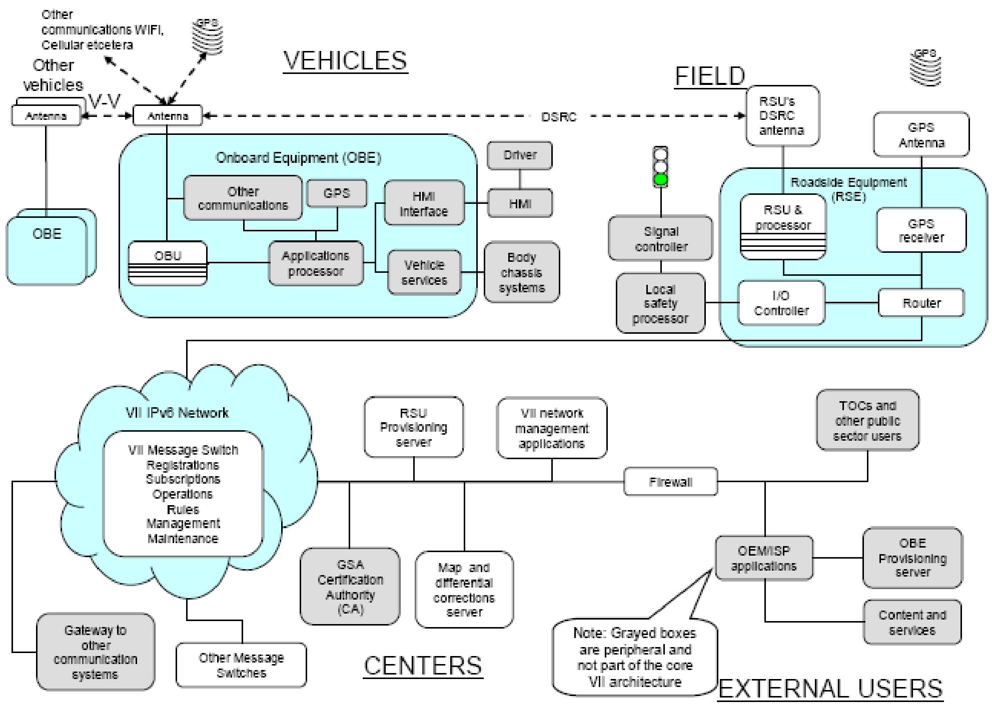


Figure 8: VII Architecture Overview (Source: FHWA, 2005).

Some of the terminology used in Figure 8 and in the VII Architecture is defined in the following paragraphs:

1. Roadside Equipment (RSE): The RSE may be installed at any location in the road network (e.g. highway interchanges, arterial intersections, etc.) to communicate with vehicles in range. An RSE would typically be composed of a GPS unit, a DSRC (dedicated short range communication) receiver, an application processor, and an interface to the VII communications network. An RSE also should be equipped with an input/out controller to communicate with local traffic control devices (e.g. traffic signals).
2. On-Board Equipment (OBE): The OBE represents all devices installed in vehicles in order to facilitate the VII system. The OBE collects data from different sensors installed in the vehicle and has the capability to store (some of) the data. Moreover, the OBE includes a GPS receiver and DSRC transmitter/receiver to communicate with the RSE and other OBE in vehicles in range.
3. Network Users: Seven general categories of public users have been identified:
   - National users such as the US DOT monitoring major evacuations.
   - State Transportation Operation Centers collating data across their interstate system.

- Regional Transportation Operation Centers providing data sharing across jurisdictional boundaries.
- Individual City or State Transportation Operation Centers providing speed maps to web sites and using weather inputs for maintenance activities.
- Local Safety Systems (LSS) at the roadside using precise vehicle data to warn of collisions.
- Controllers and processors to provide input to adaptive signal control algorithms.
- Other vehicles for vehicle-to-vehicle safety applications.

4. VII Message Switch: The VII Message Switch is a pass-through for all of the data needed to support the network applications. Each Message Switch is connected to multiple RSE (possibly up thousands of individual RSE). Data from each of the RSE are received by the VII Message Switch. The subscribed Network Users can access the VII Message Switch according to their permission. The VII Message Switches are not responsible for storing the data. The data is overwritten once it is published to the authorized Network Users. The Network Users are accountable for data storage. It is expected that the VII Message Switches will be connected to each other and VII Operation Center(s) will control all of them.
5. VII Network Operations Entity: It is envisioned that this non-profit entity will be composed of representatives from the US DOT and other federal or regional bodies involved in transportation operations. This entity will be responsible for management of the design, implementation, expansion, operations, and maintenance of the VII network. Furthermore, this entity will determine access privilege of different Network Users.

In the VII Network introduced above, vehicles will disseminate two types of data namely periodic data and event data. Periodic data are the information that is changing over time such as speed and position. This kind of data will be disseminated frequently. Event data describe events that occur much less frequently, such as the deployment of a vehicle's airbag.

It is anticipated that vehicles will store "snapshots" of event and periodic data along with the GPS co-ordinates at the time of the recording and the time at which the data were recorded. When the vehicle comes within the range of a RSE or another suitably equipped vehicle, all of the stored "snapshots" of data are transmitted to the RSE and RSE immediately sends them to the corresponding VII Message Switch. The VII Message Switch publishes the data to the appropriate subscribers. When a vehicle has successfully transmitted a snapshot of data, those data are deleted from the digital storage device in the vehicle and this storage capacity becomes available for the storage of future snapshots.

The operation and deployment of a VII system requires development of numerous standards, including several communication standards. The process of developing those standards has already begun. For instance, DSRC standard is under study by the Institute of Electrical and Electronic Engineering (IEEE), the American Society for Testing and Materials (ASTM), and the Society of Automotive Engineers (SAE).

3.5.2 Institutional issues

A number of institutional issues ought to be studied prior to any VII deployment including:

1. Customer requirements: The VII system should be able to provide services to a wide range of customers for wide variety of applications. Also, customers and applications should be prioritized so that when demand for system resources exceeds system capacity, the system can postpone requests from lower priority demands in order to satisfy higher priority demands.
2. Security: All users must obtain authorization to access the system. Moreover, the VII system must ensure security of data transmission through encryption techniques and all messages must be digitally signed to be trusted by the precipitants.
3. Privacy: It should be ensured that the data being made available to public can not be reverse-engineered to identify an individual driver or vehicle.
4. Data ownership: The VII system will support public and private data. It remains to be determined who will have access to which kinds of data.
5. Certification and registration: There is a need to ensure that the devices communicating on the system are authorized to do so.

3.5.3 Business Model

The VII is a unique participation of several private and public entities in transportation industry. Consequently, it requires a unique business model to be defined in order to finance the deployment and operation of the VII system. The model should be able to allocate the costs of the system to the participants in line with their expected benefits (Shladover, 2005).

3.6 APPLICATIONS OF THE VII

Since the fall of 2003, a cooperative effort led by AASHTO has been underway to identify and prioritize public sector application areas of VII. Some of these areas are as follows:

Safety

1. Infrastructure-based Signalized Intersection Violation Warning Infrastructure-based Signalized Intersection Turn Conflict Warning Vehicle-based Signalized Intersection Violation Warning Infrastructure-based Curve Warning
2. Crash Data to Public Service Answering Point
3. Crash Data to TOC
4. Advance Warning Information to Vehicles
5. Highway Rail Intersection
6. Commercial Vehicle Safety Data
7. Commercial Vehicle Advisory
8. Commercial Vehicle Electronic Clearance
9. Emergency Vehicle Pre-emption at Traffic Signals

Operations

1. Vehicles as Traffic Probes
2. Travel Time Data to Vehicles
3. Transit Vehicle Priority at Traffic Signals
4. Public Sector Vehicle Fleet/Mobile Device Asset Management Electronic Payment

Maintenance

1. Vehicle Probes Provide Weather Data
2. Vehicle Probes Provide Road Surface Conditions Data

The Vehicle Safety Consortium (formed by the auto manufactures) has identified 8 VII safety applications that they believe could provide substantial safety benefits:

1. Traffic signal violation warning
2. Curve speed warning
3. Emergency electronic brake lights
4. Pre-crash warning
5. Cooperative forward collision warning
6. Left turn assistant
7. Lane change warning
8. Stop sign movement assistance

The VII Working Group, the Society of Automotive Engineers (SAE), and the US DOT are working on the definition, prioritization, and refinement of various network wide and local applications and also their engineering needs.

3.7 VII PRESENT AND FUTURE

There are many research projects that have been defined in academic and research institutions which address different aspects of VII. For instance one of the research teams that has been actively working on VII is the University of California at Berkeley PATH program. Caltrans funded PATH and its DiamlerChrysler subcontractor to investigate a slippery road warning system. The investigation was called “Expedited VII”. In this experiment some equipment was installed on probe vehicles. The probe vehicles could communicate with the sensor installed on an instrumented highway. The vehicles could categorize the level of slipperiness of the highway as well as roughness of the pavement (Minsener et. al., 2006). Researchers in Oklahoma State University created a testbed to experiment with collision avoidance systems (Sheng et. al., 2006).

PATH with collaboration of Caltrans, San Francisco Bay Area Metropolitan Planning Organization, the Metropolitan Planning Commission (MTC), DaimlerChrysler Research and Technology North America, Volkswagen of America Electronics Research Laboratory, Toyota InfoTechnology Center, and Parsons Brinckerhoff – Farradyne are planning to deploy a VII testbed in Northern California.

The testbed will be in a corridor consisted of ten-mile segments of three routes north of Palo Alto and south of the San Francisco Airport along Route 82, Interstate 280, and US 101. The objective of the study is "supplementing the Federal VII effort with a regional effort in order to better understand the research and deployment issues with VII" (Misener et. al., 2006).

According to the above brief description of the VII architecture, it seems that VII has a great potential in a broad range of applications. It has a great potential in improving safety, providing accurate data for traveler's information systems, improving highway management system, and many other commercial applications. However, based on the VII targeted milestone timing shown in Table 2, feasibility of the VII deployment is expected to be determined in 2008.

Table 2: VII Targeted Milestone Timing
(Source: Cops, 2006).

Activity	Year
DSRC frequency allocation	2003
USDOT adopted VII as major initiative	2004
VII Coalition founded	2004
USDOT/VIIC[1] Cooperative Agreement	2005
Michigan DOT Local Test Bed	2006-2007
VIIC[2] Proof-of-concept testing	2006-2008
Field Testing	TBD
VII Deployment Feasibility Determination	Dec 2008

Even if VII is determined to be feasible, the deployment of VII infrastructure within even a small portion of the in-use vehicle fleet is likely to take a number of years. The level of penetration of VII equipped vehicles within the in-use vehicle fleet required to support various applications has not yet been determined. Consequently, it appears likely that VII can be expected to not provide substantial enhanced capabilities for MTO over the near-term (e.g. the next 5 years). However, in the longer term, VII provides the potential to enable a range of exciting capabilities. The extent, to which VII can deliver on these potential capabilities, and the length of time before these capabilities become commercially viable, remains unknown.

3.8 SUMMARY

It appears that in the long term, VII systems have the greatest potential to provide accurate, timely, reliable and detailed road conditions data. However, VII is still in its infancy and VII-based systems cannot be expected to become commercially deployed in sufficient numbers for at least 7 to 10 years and possibly longer.

Dedicated probe-based systems, which have been shown to be commercially viable ventures in Europe, have not experienced the same level of success in North America. It remains to be seen if a road traffic conditions acquisition system based on dedicated probes will emerge in North America. The key challenge facing such a system will be enrolling a sufficient number of probe vehicles to provide adequate accuracy, reliability, coverage and timeliness.

The technology required for cell phone based systems has been developed and several different approaches are currently being marketed as commercial systems. Though the performance of these systems has not yet been adequately demonstrated, several systems are

[2] Vehicle Infrastructure Integration Coalition

sufficiently mature that the product vendors have entered into deployment contracts with public sector agencies. These systems are described in detail in the next Chapter.

CHAPTER 4:

COMMERCIAL CELL PHONE BASED SYSTEMS

Several wireless area-wide road conditions monitoring systems have been developed into commercial products and are now available world wide. Unfortunately, due to commercial confidentiality reasons, there is little or no detailed information publicly available regarding the specific models and algorithms used within these systems. In this report systems from five vendors are described.

4.1 CELLINT

CellInt is a private company headquartered in Israel and started in 2001 (http://www.cellint.com/default.htm). The company has developed a system for extracting road traffic information (speed, travel time, incident alerts) via cell phone tracking which they market under the name of "TrafficSense". Very little information is publicly available regarding the techniques used by the system to determine the road traffic conditions. The authors of this report contacted the company to obtain additional information, but the company did not respond.

CellInt has entered into an arrangement with the Kansas City DOT to pilot the TrafficSense product. The pilot is a proof of concept and is being undertaken by CellInt with no funding from Kansas City DOT.

The Kansas City evaluation is limited to evaluating the accuracy of average speeds provided by CellInt for a 5 mile (9km) long segment of Interstate 35 between I-435 and the Missouri-Kansas border. This section of interstate is an urban freeway and one of the most heavily travelled corridors in the state.

Kansas City DOT operates a freeway traffic management system, called SCOUT, that uses conventional traffic sensors including loop detectors spaced approximately every half mile (800m), CCTV cameras, variable message signs, etc. The data from these sensors are used to generate a colour coded network conditions map (Figure 9).

Figure 9: Existing Kansas City Scout highway conditions map.
(Source: http://www.kcscout.net/kcatis/index.asp)

CellInt has arranged with Kansas City DOT to provide average speed data in a similar format to that available from the Scout system. Kansas City DOT will evaluate the performance of the CellInt data by comparing it to the Scout data and to floating car runs. According to a member of the Kansas City DOT, the DOT anticipates doing approximately 50 floating car runs.

As of the end of June 2006, CellInt had completed the system setup phase in which they calibrated their estimates to the Scout data. The CellInt system was scheduled to begin providing Kansas City DOT with estimates of average speed as of July 1, 2006. An evaluation report is expected to be finalized by Kansas City DOT by the end of March 2007.

There is no plan to evaluate estimates of travel times as part of this demonstration project.

4.2 DELCAN.NET/*ITIS* HOLDINGS

iTIS Holdings was founded in 1997 in the UK to provide dynamic and predictive traffic information for both business and leisure users of the British road and transport system (*iTIS* Holdings, 2006). They are the UK's leading road traffic information and data specialist, with customers in four areas: automotive, government, logistics, and mobile telephone companies (Quayle, 2005). In the UK, *iTIS* Holdings obtains traffic information from two sources: Floating Vehicle Data[3] (FVD) and journalistic information. In December 2003, they acquired an Israel-based company, Estimotion Ltd., which had developed a commercial application for acquisition of traffic information through cellular phones. Estimotion Ltd., which was founded in July 2000, patented a method for extracting traffic conditions data from the movement of cellular phones.

[3] *iTIS* Holdings acquires traffic information mostly via commercial vehicles that are equipped with GPS and disseminates traffic information to a cellular operator who will inform subscribers of travel time and incidents.

They termed this system CFVD (Cellular Floating Vehicle Data) technology and tested it in the Tel Aviv area in Israel.

The Estimotion system can be classified as a network-based implementation. This technology uses “hand-offs” (i.e. the process by which the mobile phone system transfers communications of the mobile phone from one base station to the next) of cellular phones to identify the locations of mobile phones (Figure 10).

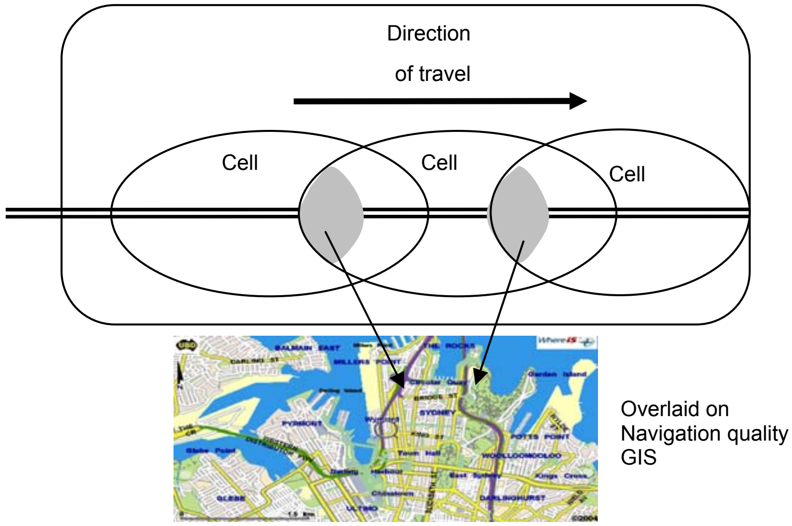


Figure 10: "Hand-off" events in *iTIS* Holdings system.
(Source: Quayle, 2005)

Figure 11 shows the path of a handset found by map matching and route tracking algorithms incorporated into the CFVD technology. In this figure the shaded areas are associated with possible locations of the handset at each hand-off.

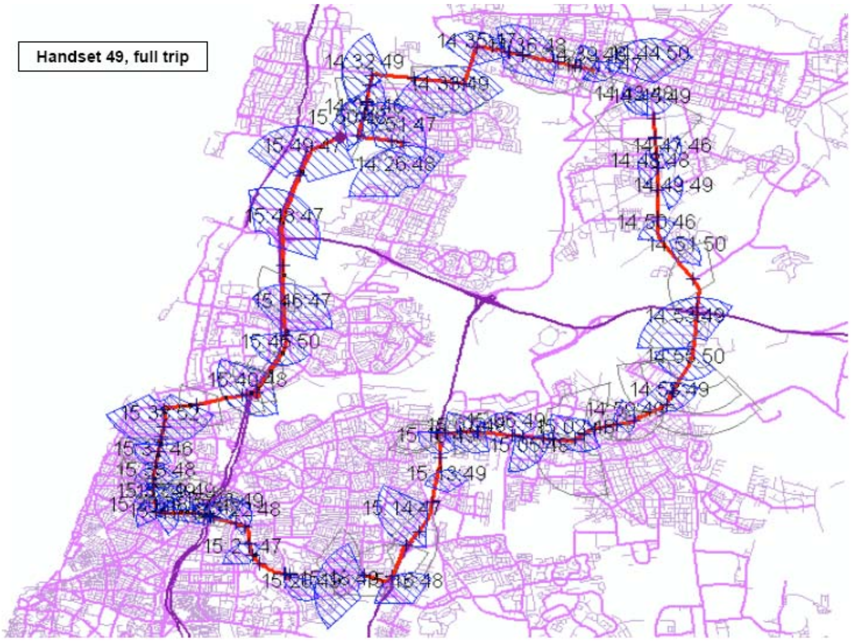


Figure 11: Locations and route of a handset identified using CFVD® technology.
(Source: Mudge, 2005)

iTIS Holdings has used GPS equipped vehicles to validate the quality of information derived from the CFVD® technology. *iTIS* Holdings believes that "The results of test drives have shown that the path finding algorithms are extremely accurate with an accuracy of between 95 to 97% on interstate roads and at least 85% on urban roads" (Quayle, 2005). Figure 12 illustrates a comparison of speed obtained from tracking cellular phones and vehicles equipped with GPS in the same route. Based on this figure the difference is less than 10 Km/h between speeds estimated according to the two techniques. It must be cautioned that these results are for a specific freeway location and should not be interpreted as a typical level of accuracy provided by this system. In particular, wireless based technologies are likely to provide best performance on freeways in low density road networks. Accuracy on dense roadways and arterials is likely to much lower.

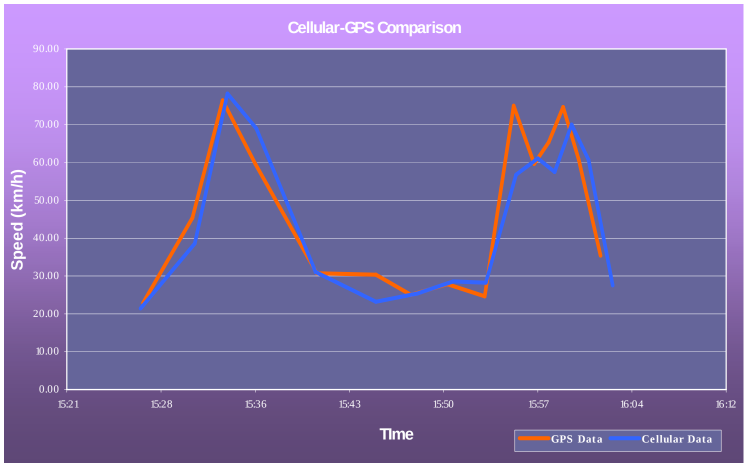


Figure 12: Published comparison of speed accuracy.
(Source: Quayle, 2005)

An example interface of the *iTIS* Holdings' application is shown in Figure 13. As can be seen in this figure, speeds associated with almost all major highways and arterials of the region have been shown with different colours on a digital map.

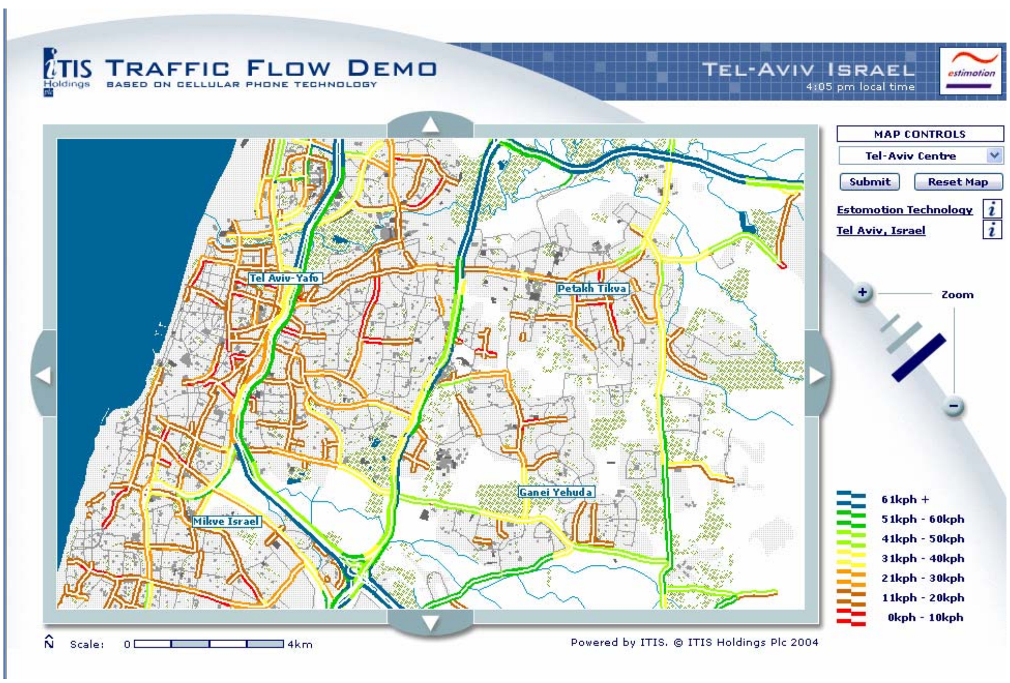


Figure 13: *iTIS* Holdings CVFD® technology interface for Tel Aviv, Israel.
(Source: *iTIS* Holdings, 2006)

There are a number of projects in which the CFVD® technology has been or is being implemented to acquire dynamic traffic information including Tel Aviv (Israel), Antwerp (Belgium), Baltimore (Maryland, USA), Scotland (UK), London (UK), and Missouri (USA).

In September 2004, *iTIS* Holdings started implementation of the Estimotion technology in Antwerp, Belgium and Baltimore, Maryland (*iTIS* Holdings, 2006). *iTIS* Holdings has developed full working sites in these two cities and the Estimotion model has been calibrated against simulation models and loop detector data (Delcan, 2006). According to the *iTIS* Holdings corporate website, the Baltimore contract was awarded to *iTIS* Holdings for a period of two years and worth approximately US$1 million.

In April 2005, Delcan.NET and *iTIS* Holdings entered into a formal partnership to deliver real time traffic information through CFVD® technology to public agencies in North America. Their partnership led to a US$6.2 million contract with Missouri Department of Transportation to supply traffic information through cellular phone tracking. This is a two year period contract and covers 5400 miles of roadways in the state of Missouri (*iTIS* Holdings, 2006).

Representatives from the Maryland Department of Transportation and the Missouri Department of Transportation were contacted to determine the status of these two Delcan.NET projects. As of mid-June 2006, both projects were on hold because the wireless carrier which had partnered with Delcan.NET to deliver the location data withdrew from the project. The Maryland project began in Sept. 2004 and data began to flow as of March 2005. However, in February 2006, the wireless carrier involved in the project (Cingular Wireless), withdrew from the project. Though the reasons for the withdrawal could not be confirmed, it is suspected that the carrier was concerned about potential impacts of privacy concerns raised in the popular press. As of late summer 2006, Delcan.NET was attempting to re-start the project by entering into arrangements with several wireless carriers (rather than just one) and to made arrangements to secure data from fleets that can act as dedicated probes (much as *iTIS* has done in the UK).

The University of Maryland had been contracted to perform an evaluation of the data produced by the Delcan.NET system. In January 2007 the final report of the evaluation was published (Haghani *et. al.*, 2007). The evaluation was conducted using data collected over a three week period in January and February 2006 (presumably prior to the withdrawal of Cingular Wireless from the project).

The main objective of the evaluation was to assess the quality of traffic data obtained through anonymously tracked cellular probe vehicles for use in the Baltimore metropolitan area traffic control and management and traveller information systems. The cell probe system, developed in partnership by *iTIS* Holdings and Delcan.NET, provided speed and travel time information for the area under study. Dedicated probe vehicle data were used in this study as “Ground Truth”. Traffic sensor data (i.e. loop detector and RTMS) provided by the Coordinated Freeways Action Response Team (CHART) were also tested against cellular probe and dedicated probe data. The dedicated probe data were used for obtaining travel time and average speed of the links. The fixed sensor data, however, can only be used to obtain spot speeds and are incapable of providing travel time information.

In this study, another contractor (MotionMaps) collected dedicated probe vehicle data from January 26th 2006 to February 3rd 2006. Dedicated probe vehicles were scheduled to traverse different routes on different days. In some cases, data were collected for the same route on two different days.

The researchers were provided with fixed sensor data and cellular probe vehicle data by the CHART and *iTIS* Holdings/Delcan.NET systems respectively. It should be noted that the cellular probe data was provided from January 26th, 2006, 12:00 AM to February 16th, 2006, 11:55 PM but due to budget constrains the evaluation was performed for a shorter period of time. For the same reason, the proportion of dedicated probe vehicles was much less than the desired proportion of 4% to 5%. Two to three dedicated probe vehicles were used to survey pre-determined routes in the study area. These probes collected data throughout the survey time period (from 6 AM to 9 PM), but the majority of the data collection occurred during the morning and afternoon peak periods.

Table 3 illustrates an example of the cellular probe data provided by the *iTIS* Holdings/Delcan.NET system. Speed and travel time were provided for each link and direction every 5 minutes. In every 5-minute interval, data from all probe vehicles that traversed the link during the interval were averaged and the aggregated information was given to the researchers. Timeliness of data dissemination, which is an important factor in some applications (e.g. automatic incident detection, travel time prediction, etc.), could not be determined using the aggregated information. An interesting finding from this study is that whenever the *iTIS* Holdings/Delcan.NET system was not able to provide real time data, default values for speed and travel time (which is normally the speed limit and associated travel time) are reported. It is obvious that the default values might some times generate enormous error in estimation of speed and travel time.

Table 3: An Example of Cellular Probe Data
(Source: Haghani *et. al.*, 2007)**.**

timestamp	LinkID	Direction	Speed(kph)	Journey Time(secs)	Length(m)
1/26/2006 12:05:00 AM	4368	1	80	129.96	2888
1/26/2006 12:10:00 AM	4368	1	80	129.96	2888
1/26/2006 12:15:00 AM	4368	1	80	129.96	2888

The evaluation was performed to compare traffic information obtained through cellular probes (CFVD) with "Ground Truth" values for a number of links and paths separately.

The following two error terms were used to quantify the accuracy of the cell probe data at the link level:

$$E = \hat{S}_i - S_i \tag{1}$$

$$E_i^{\%} = \frac{E_i}{S_i} \times 100\% \tag{2}$$

where:

E_i: Difference between average speed obtained from cell phone probes and the average speed estimated from the ground truth (i.e. dedicated probe or dedicated sensor) data for 5-minute time interval *i* (km/h),

$E_i^{\%}$: Estimation error for time interval *i* measured as a percent of the average ground truth speed,

$\hat{S}_i$: Average speed as estimated from the cell phone probe data for time interval *i*,

S_i : Average speed as estimated from the ground truth data (i.e. dedicate probes or dedicated sensors) for 5-minute time interval *i* (km/h),

Based on the above error terms, four measures of error were calculated for comparison scenarios which are evaluation by route, by time of day, and by level of service:

1. Average Error,
2. Average Percentage of Error,
3. Average Absolute Error,
4. Percentage of Average Absolute Error.

The researchers were not able to compare average travel times obtained from cell probes with corresponding dedicated probe vehicle values at the individual link level due to discrepancies between the definition of link boundaries (and consequently link lengths) in the GIS maps used by *iTIS* Holdings and MotionMaps. It was found that these differences could be relatively large, especially at highway interchanges.

The researchers evaluated 9 routes and found the average estimation error on each route ranged from 0.3 km/h to 37.8 km/h. Furthermore, they observed that the average estimation errors were much smaller for routes that traversed freeway links than those that traversed arterial links.

One limitation of these aggregate finding is that they are based on data collected over different time periods and different roadways and therefore encompass a wide range of traffic conditions. Some of the collected data represent uncongested traffic conditions when most vehicles travelled at a speed near to the speed limit. Under these conditions, it is expected that the cell probe system estimates contain relatively small estimation error. However, when traffic conditions transition from the un-congested regime to the congested regime, it is anticipated that speed estimates from the cell probe system may be less accurate. However, these transition periods, and periods of congestion, occur relatively less frequently during the day than do periods of near free flow speeds. If estimation errors are averaged over the entire day (or even from 6 AM to 9 PM as in this study) then the effects of these high errors are masked.

This effect can be confirmed by observing the reported average estimation errors by route and time of day (Table 4). The results in this table show that the estimation errors on freeway routes are generally lower than the errors on arterial routes. Moreover, on freeways (for instance I-695) errors associated with AM and PM peaks are higher than off-peak time intervals.

Table 4: Average Absolute Error (km/h) by Time of Day on Different Routes
(Source: Haghani *et. al.*, 2007).

Time	Freeway Routes					Arterial Routes			
	I-70	I-395	I-695	I-895	I-95	US1	MD40	MD45	MLKB
6:00-7:00			16.1		11.8				
7:00-8:00		12.5	14.0		16.3	36.3	29.6		41.7
8:00-9:00		16.0	13.9		19.4	38.2	26.4		37.4
9:00-10:00		13.2	11.3		16.8	40.0	28.5		42.8
10:00-11:00			8.9		6.6	41.4	34.4		
11:00-12:00		5.8	7.3		16.7	39.9	32.6		39.2
12:00-13:00		22.9	9.0		15.5	37.0	37.7	38.0	38.8
13:00-14:00		29.2	10.6		14.0		28.8	37.2	36.8
14:00-15:00			15.2	19.6	11.3		28.9	36.9	
15:00-16:00	9.9	14.9	14.9	29.8	13.0		26.1	40.2	24.4
16:00-17:00	15.0	25.4	14.9	17.1	15.6		26.8	37.5	29.8
17:00-18:00	11.0	22.9	16.6	12.6	18.3		22.8	40.9	21.4
18:00-19:00		32.3	15.2	12.9	19.6	22.0			

In this study, drivers of dedicated probe vehicles were asked to report level of service of traffic based on their own perceptions from A (the best) to F (the worst). The results of this analysis confirmed that the more congested links incur higher errors.

The length discrepancy is no longer an issue when the analyses are performed for path traffic information evaluation purposes. Consequently, travel time was used as a comparison index to evaluate path traffic information. In this part of the study, the same error terms and error measures were defined. However, travel time was used in the error terms instead of speed. In this part of analyses the authors only reported aggregate values of travel time (Table 5). They found that "cellular data can provide very good estimation on freeways with an average absolute error around 10%, which is smaller than the recommended error range of 20% for traveler information system" (Haghani *et. al.*, 2007). Average absolute relative errors for arterial routes are much larger ranging from 33 to 69%.

Table 5: Comparison of Travel Time in Path Traffic Information Evaluation
(Source: Haghani *et. al.*, 2007).

Route Name	Avg. Vehicular Travel Time (sec)	Avg. Cellular Travel Time (sec)	Avg. Abs. Error (sec)	Avg. % of Abs. Error (%)
I-70	550.31	539.17	29.56	6.81
I-95	1065.39	1007.17	105.53	9.78
I-395	55.35	48.99	6.80	11.59
I-695	1009.61	955.40	139.40	11.06
I-895	787.50	685.95	106.75	12.63
US-1a	885.78	501.68	384.10	39.99
US-1b	1079.95	323.43	756.52	69.41
MD-40	974.05	669.45	325.56	33.54
MD-45	955.52	381.10	574.42	58.56
MLKB	239.11	186.78	109.81	47.55

The last part of the Maryland evaluation study compared spot speeds obtained from sensor data with the average link speed as established from dedicated vehicle probes ("Ground Truth") and from the cellular probe data. It is expected that even without any measurement error, spot speeds may differ significantly from average link speed, especially when the link or path is partially congested. Figure 14 and Figure 15 illustrate speed profiles at two different locations along Freeway I-695. In Figure 14, the average link speeds estimated from the cell probes dedicated probes decrease (at approximately 16:48) but the spot speeds obtained from the traffic sensors do not. This suggests that the probe vehicles experience congestion on a portion of link but this congestion does not spill over the traffic sensor.

Figure 15 provide a similar comparison. However, in this case, the speeds from the sensor data do follow the decline exhibited by the probe speeds.

These figures serve to illustrate the inherent difficultly that arises when trying to evaluate data that spatially based (i.e. data from vehicle probes) with data that are location specific (e.g. dedicated traffic sensors).

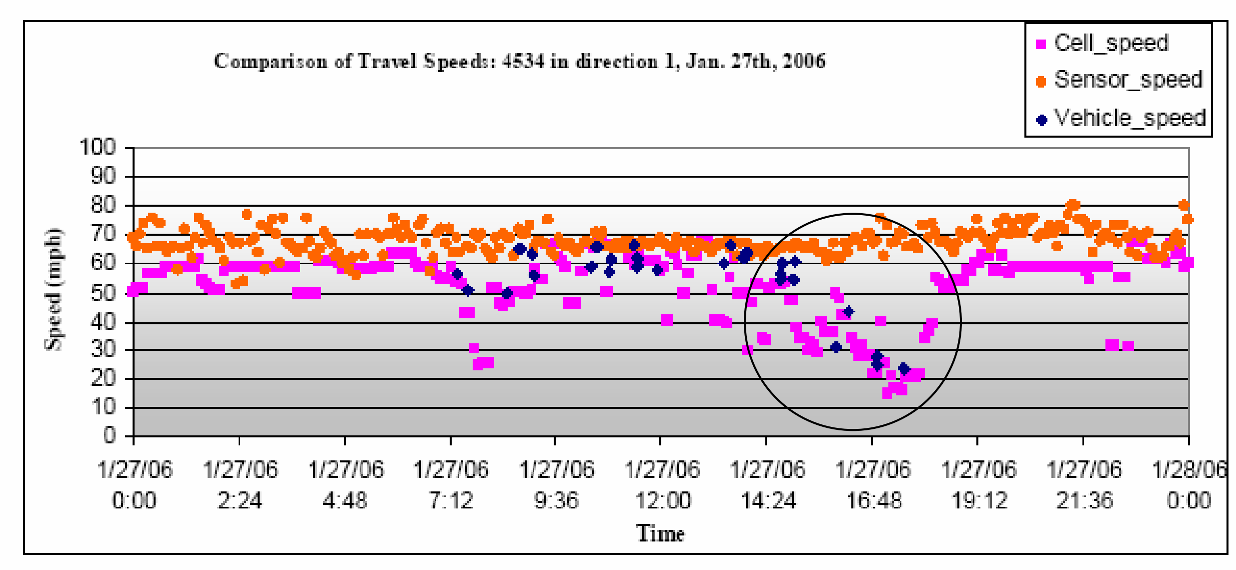


Figure 14: Comparison of Travel Speed Profile Obtained from Three Sources in I-695 @ Joppa Rd. (Source: Haghani et. al., 2007).

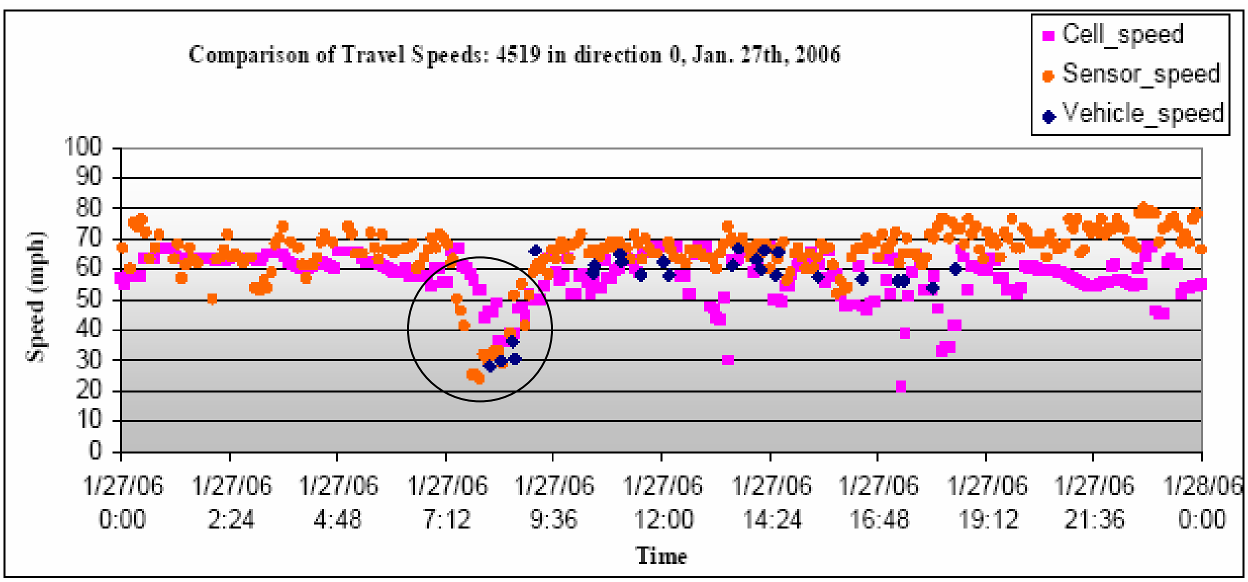


Figure 15: Comparison of Travel Speed Profile Obtained from Three Sources in I-695 @ US 40 West (Source: Haghani *et. al.*, 2007).

The authors of the Maryland evaluation make the following conclusions:

1. “The accuracy of travel time data obtained from cellular probes on freeways is quite good (around 10% error terms) for immediate ITS applications. The accuracy for travel speed data obtained from the cellular probes on freeways is acceptable (around 20% error terms)”.
2. “On arterials, the cellular probe data can not provide accurate travel speed and travel time information at this time”.
3. “The average absolute errors on freeways are about 10 mile per hour”.
4. “The statistical tests results show no significant difference between cellular link speeds and vehicular link speeds [dedicated probe speeds] on all freeway routes except I-70”.
5. “On arterials, on the other hand, the results of statistical tests on link speeds show that there are significant differences between cellular probe speeds and vehicular probe speeds”.
6. “Travel time evaluation showed the same trend in link travel speed evaluation. That is, cellular probe data provides good estimations of path travel times on freeways”.
7. ” Cellular phone tracking, at least the one implementation we examined, shows promise and would benefit from additional technology improvement".
8. “On the positive side, it promises very large numbers of probes and better spatial and temporal coverage than conventional loop detectors”.
9. “On most freeways, the evaluation results are consistently good”.
10. “In addition to improving the underlying algorithms, other avenues to correct this problem include: 1) not using speed limits as default values for speed when data is not available; 2) working with a wireless carrier that can provide greater market penetration; and 3) using additional available data, for example GPS data from local fleets, in estimating the speeds”.

The project in Missouri has experienced the same delay as the project in Maryland. The Missouri project had involved the same wireless carrier as the Maryland project. When Cingular withdrew their participation from the Maryland project, they also withdrew from the Missouri project. However, in the Missouri project, no data stream had been established before Cingular withdrew. Consequently, the Missouri project has not yet produced any data on which to perform an evaluation. The Missouri DOT had arranged for HNTB to conduct the evaluation, but given the lack of data, no new timeline for the completion of the evaluation had been established by early June 2006.

The Missouri DOT are still expecting Delcan.NET to secure arrangements with other wireless carriers and to continue the project but were unable to provide a timeline.

Missouri DOT had intended to use the data for the following purposes:

- traveller information
- planning tool: to track road performance as an input to long range infrastructure planning

- incident management: identify the occurrence of incidents and determine appropriate responses
- work zone management: track the delays caused by work zones and manage the activities at the work zone to minimize delay (i.e. if delays become too large, direct he contractor to re-open a lane, etc.)

Specific details on how the data would be used to support these last two traffic management activities were not available.

4.3 APPLIED GENERICS

Applied Generics is a software company based in Edinburgh, Scotland, founded in 1999. In January 2006, a Dutch satellite navigation group, TomTom, purchased Applied Generics and now this company is a part of the TomTom Group Company (Applied generics, 2006).

Applied Generics has developed software called RoDIN24 to provide real time traffic information obtained from cellular phones. RoDIN24 uses the Timing Advance (TA) of the handset from the serving call. As described in Chapter 3, each TA in the GSM system is equal to approximately 550 m distance from the handset to the cell base station. The Applied Generics system uses this data to estimate the location of the phone within an area between two circles centred on the base station, one with a radius equal to TA×550m and one with a radius of (TA+1)×550m. By tracking the movement of the location regions over time, the system is able to estimate the trajectory of the mobile phones. Figure 16 illustrates this procedure.

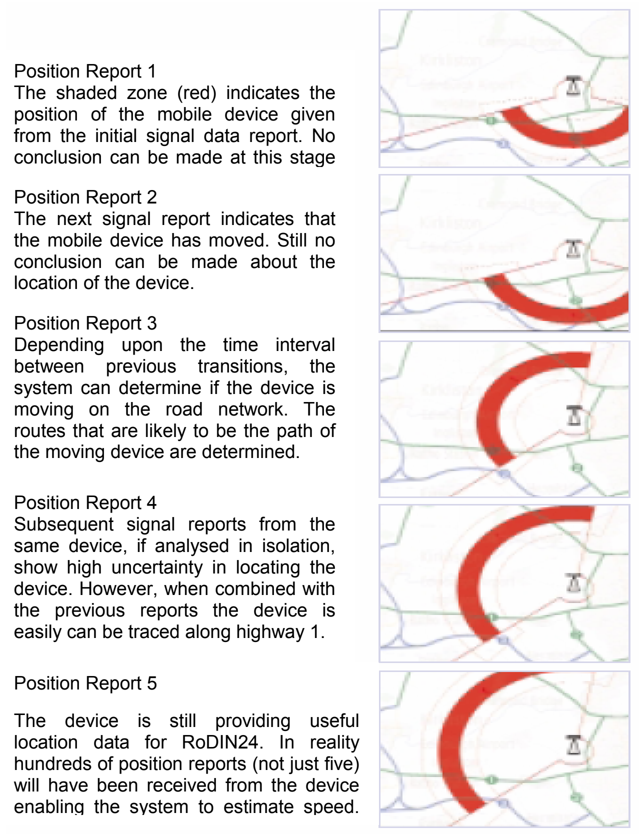


Figure 16: Route identification procedure in RoDIN24.
(Source: Applied Generics, 2006)

The first large scale commercial implementation of RoDIN24 took place in Noord Brabant, Holland in mid 2003 (Applied Generics, 2006). The system was tested on A16, A58, A59 and N261 roadways. These roadways represent highways, urban arterials, and rural roadways (NCHRP, 2005).

Figure 17 shows the user interface of RoDIN24 displaying the Noord Brabant network. As can be seen in this figure, the roadways are coloured based on estimated speed acquired through cell phones.

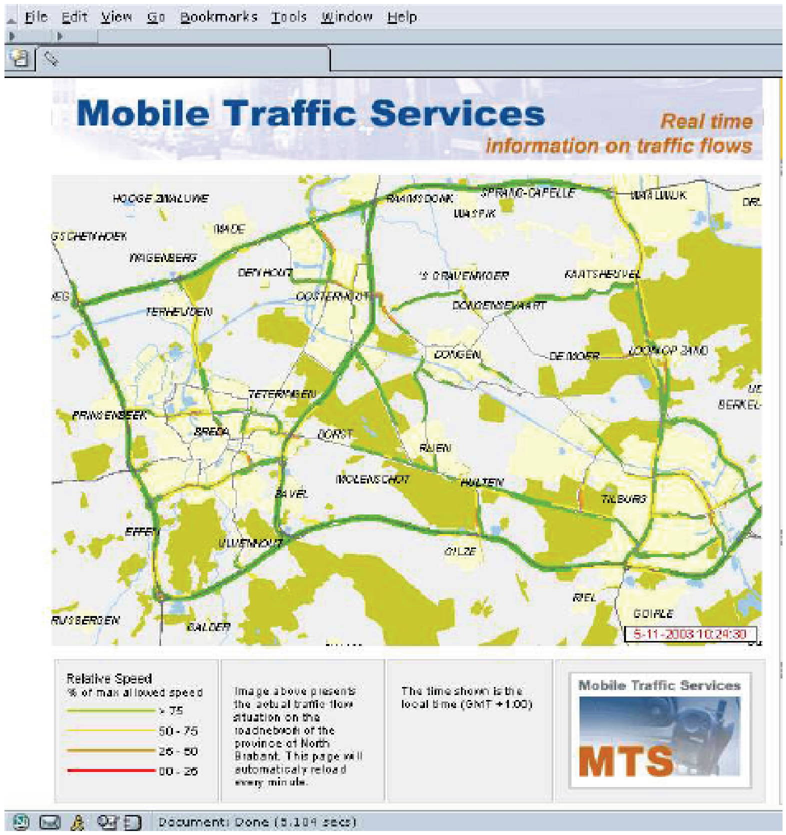


Figure 17: RoDIN24 user interface for Noord Brabant, Holland.
(Source: Applied Generics, 2006)

A Dutch transport consulting engineering company, Goudappel Coffeng, used a variety of mechanisms to validate speed information obtained from RoDIN24 over different routes in the Noord Brabant area. The validation data included (Applied Generics, 2006):

- loop detector data where available,
- speed obtained from vehicles equipped with GPS,
- speed data obtained from a number of licence plate tracking tests.

The evaluator of the Noord Brabant deployment of RoDIN24 reported that the accuracy of information for highways was excellent. Moreover, they concluded that RoDIN24 was reliably able to estimate travel time on congested highways when average speed was less than 20 km/h, conditions under which loop detectors tended to be inaccurate. Figure 18 provides an illustration of accuracy of travel times estimated by RoDIN24 for a short section of highway A27. Again, these results should not be interpreted to apply generally to all traffic and roadway conditions. As noted by the system developers, the RoDIN24 system, similar to the cellular phone tracking technologies developed by other vendors, estimates travel times in rural areas and dense urban areas less accurately in comparison with highways (Applied Generics, 2006).

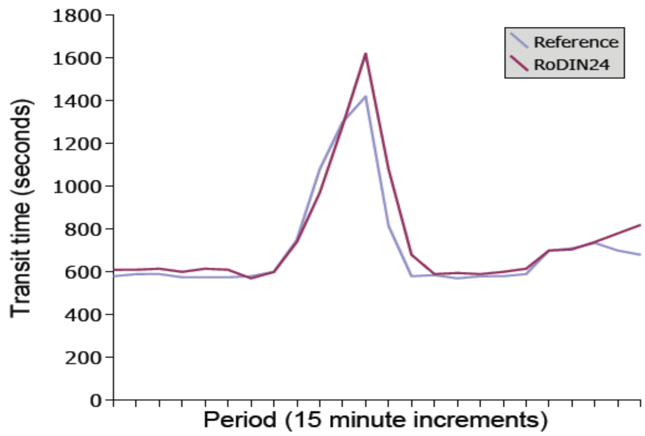
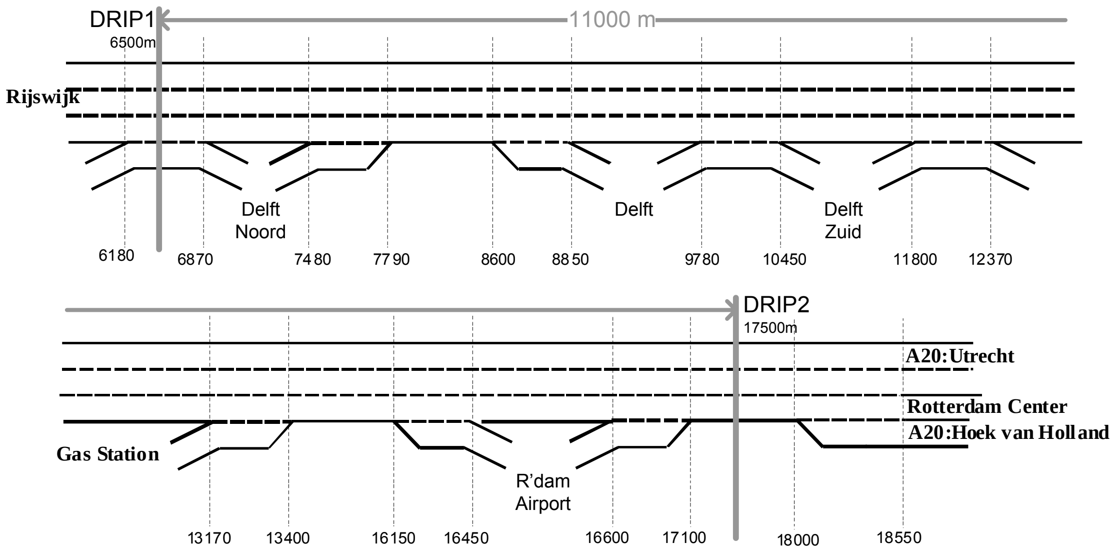


Figure 18: Reported accuracy of travel times estimated by RoDIN24.
(Source: Applied Generics, 2006)

A more recent European study, completed in October 2006, compared the quality and cost of road segment travel times obtained from cellular probes with travel times estimated from loop detector data. Delft University of Technology was contracted by the Directorate General for Public Works and Water management to evaluate the quality of data obtained from loop detectors and cellular probe vehicles on a freeway in the Netherlands. The evaluation had two main objectives (Van Lint, 2006):

1. Off-line and real-time comparison of travel time obtained from cellular probes and loop detectors with "Ground Truth".
2. Comparison of the price/quality ratio of each of the cell-probe and loop detector systems.

The study examined data from an 11km section of the A13 (from Delft-Noord to Rotterdam Overschie), one of the busiest motorway (freeway) segments in the Netherlands (Figure 19). This section includes several ramp junctions and frequently experiences significant recurrent and non-recurrent congestion.



Motorway A13:Rijswijk->Rotterdam

Figure 19: Study area.

Cell probe travel times were estimated every 5-minutes by the Applied Generics cell-probe system. The system made use of only handsets in "Active" mode (i.e. phone being used for either voice communication or text messaging) and only phones associated with a single carrier. These constraints limited the number of cell probes within each 5-minute sample.

Travel times can not be measured directly by loop detectors rather they must be estimated. This study estimated travel times from spot detector measurements using three techniques:

1. The PLSB (piece-wise linear speed based) method estimates the vehicle trajectory between two loop detector stations by assuming that the vehicle speed at locations between the loop stations is a linear combination of the spot speed measured as the loop station (Van Lint *et. al.*, 2003).
2. The CDMS (Central DRIP Management System) is the method currently used to estimate the travel times that are displayed on the Dynamic Route Information Panels (DRIPs) near Delft-Noord in the Netherlands.
3. Monibas is similar to the PLSB method but develops travel time estimates on the basis of both measured spot speeds and detector occupancy.

"Ground truth" travel times were determined on the basis of video cameras and licence plate recognition software. A database containing more than 9,600 average five-minute travel times was developed on the basis of individual travel times measured between March 15 and April 13, 2006.

The evaluation study showed that:

1. Off-line travel times (i.e. travel times not estimates in real-time) estimated from loop detector data were more accurate than travel times estimated from cell probes for all traffic conditions (i.e. free flow, recurrent and non-recurrent congestion).
2. On average, for off-line analysis, the travel time estimation error was found to be less than 8 seconds/km for loop detector data based methods and less than 13 seconds/km for cell probes.
3. During congestion (average speed <80 km/h) in the offline state, the travel time estimation error per kilometre ranges from -9 to +12 seconds and between -12 to +19 seconds for loop detector data based methods and cell probes respectively. During serious congestion (average speed < 26 km/h), the corresponding errors increase to -29 to +18 seconds and -54 to +30 seconds.
4. The cellular data has a latency of 5 minutes to 15 minutes in real time analyses.
5. Purchase of cellular data is estimated to cost 17% less than loop detector data. Note that researchers at Delft University state that they did not have accurate information about the costs. Furthermore, they mention that in congested traffic conditions the quality of cellular data is 40% to 45% worse than loop detectors.

It is important to interpret these conclusions within the context of the constraints that existed on the quantity of cell probe data available for the evaluation and to note that this study was restricted to an urban freeway application and did not consider arterial applications.

4.4 AIRSAGE

AirSage is an Atlanta, Georgia based company founded in 2000 to develop a system to derive traffic information through tracking cell phones (AirSage, 2006a). The AirSage product to extract traffic information is called X-10 and its system architecture is illustrated in Figure 20.

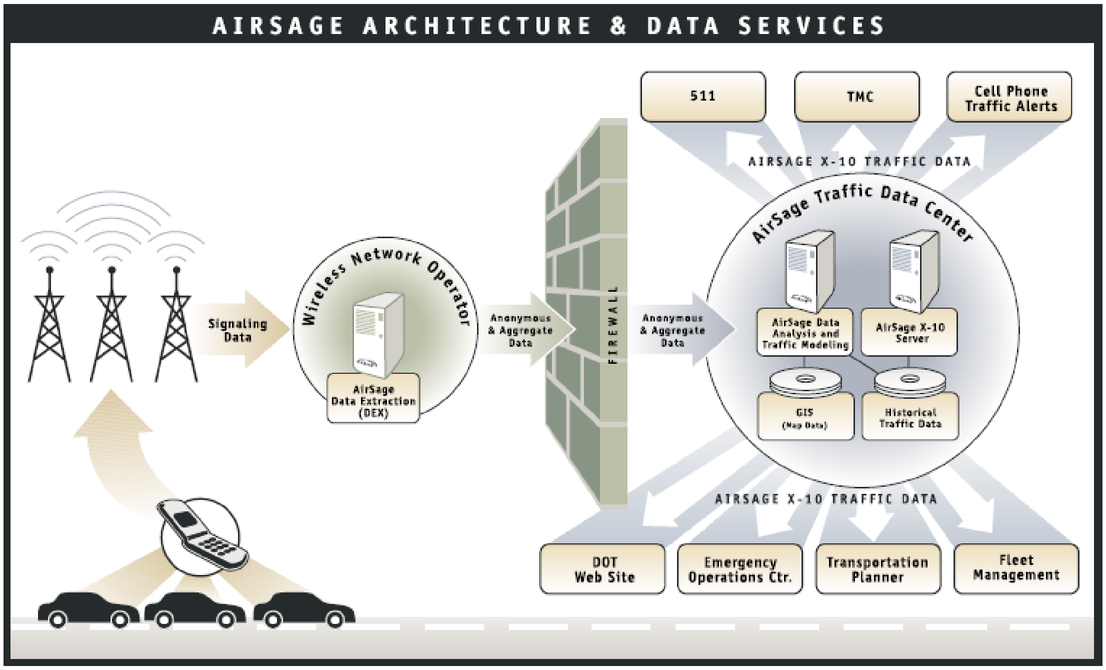


Figure 20: AirSage X-10 system architecture.
(Source: AirSage, 2006b)

The X-10 system consists of two subsystems – the Data Extraction Subsystem (DEX) which resides within the wireless carrier's computer systems, and the Data Analysis (DAN) Subsystem, which resides in AirSage's Traffic Data Center.

The DEX system obtains data from the wireless carrier's signalling system (though AirSage does not reveal explicitly what data is used for the locationing) which is used to track cell phones to find their locations. The location data is sent to the DAN for processing into traffic information. To ensure privacy, the DEX allocates an arbitrary ID to each handset being tracked instead of the unique Mobile Identification Number and only forwards the arbitrary ID to the DAN (AirSage, 2006b).

The X-10 Data Server retrieves the data from the DAN and provides it to application clients through the internet via an Application Program Interface (API).

In 2003, AirSage was awarded a contract by the Virginia Department of Transportation to estimate location, speed, travel time, and other performance measures on the basis of cell-phone probes. The test was conducted in the Hampton Roads region of Virginia. Funding for the project was provided jointly by the Virginia Department of Transportation and the Federal Highway Administration. The University of Virginia participated as an evaluator of the data provided by the AirSage system. The final evaluation report (Smith, 2006), which was very recently released, states that "…it can be concluded that the Hampton Roads Airsage system, as of December 2005, cannot provide data of sufficient quality to support operations within VDOT." The report also states that:

- "Airsage cannot produce reliable segment travel time or average speed estimates on arterials or on congested freeways. Under congested conditions, 84% of the Airsage speed estimates have an error greater than 15 miles/hour."
- "Airsage cannot produce data on the reversible HOV facility on I-64."
- "Airsage cannot produce a confidence measure for traffic data records."

It is important to note, that the evaluation report also states that "…the results should not be considered to be definitive in describing the capabilities or potential of wireless location technology-based traffic monitoring in general. Rather, they reflect the capabilities of the Airsage system in Hampton Roads as of December 2005 – a system described by the company as 'interim'."

It is also worth noting that in November 2005, the Georgia Department of Transportation contracted with AirSage to provide the DOT with traffic information however further details on the status of this project were not available.

4.5 GLOBIS DATA

Unlike the other commercial systems, Globis Data Inc., a company based in Ontario, Canada, has developed a system that relies on assisted handset based locationing. The system uses handsets equipped with assisted GPS technologies and periodically polls the handsets to obtain their position. On the basis of two consecutive location measurements, the distance travelled and the elapsed time are used to compute speed (i.e. speed = distance/time). The actual speeds are then converted to one of three congestion values, which are displayed as colour-coded zones on a real-time traffic map.

A prototype system was developed and the feasibility of the concept was demonstrated in a field trial funded by Transport Canada and held in Ottawa, Ontario in 2004 and 2005 (Globis Data, 2005). In the field trial, a set of dedicated phones (up to 14) were tracked as they traversed a fixed road route. The route consisted of arterial, freeway, and ramp links.

The evaluation of the system performance was conducted by the system developer. In their final report, Globis Data (2005) concluded that the system performed successfully for the freeway road segments, but that more sophisticated algorithms were required for application to arterial roadways.

4.6 TRAFFIC.COM

Traffic.com was incorporated in 1998. It is based in Wayne, PA, USA and operates locally based traffic centers across the US. It has 600+ employees. In November 2006, NAVTEQ a leading global provider of digital maps for vehicle navigation and location-based solutions announced it has agreed to acquire Traffic.com for $179 million. The acquisition was expected to be completed in the first quarter of 2007.

Traffic.com provides real time traffic information for 50 metropolitan areas throughout the US covering approximately 100 million drivers of which 70 million are daily commuters. Figure 21 shows the coverage of the company. At present, the company does not operate outside of the continental United States.

Figure 21: Coverage of Traffic.com across the US.
(Source: www.traffic.com)

Traffic.com provides travel time, speed, delay, and congestion level. The traffic information can be accessed through www.traffic.com web site, toll free phone number 866 MY-TRAFC, in-vehicle navigation systems and hand-held wireless devices such as phones and PDAs. The services for individual consumers are free of charge but commercial users are charged for the subscriptions. The customers can be categorized into media (radio and television stations), data services clients (AOL, Microsoft, Comcast, etc), and automotive industry (XM NavTraffic for Acura RL and Cadillac CTS).

Figure 22 illustrates a typical report from the Traffic.com web site. This figure shows an inquiry for I-405 San Diego Freeway – Southbound between 118/Ronald Reagan Freeway and 101/Ventura Freeway. In this figure the colour of each link demonstrates real time speed of the vehicles in those links. Figure 23 also shows delay, average travel time, average speed, and speed associated with the slowest section for the same section shown in Figure 22. Furthermore, Figure 23 shows that an incident has occurred in this section of the freeway.

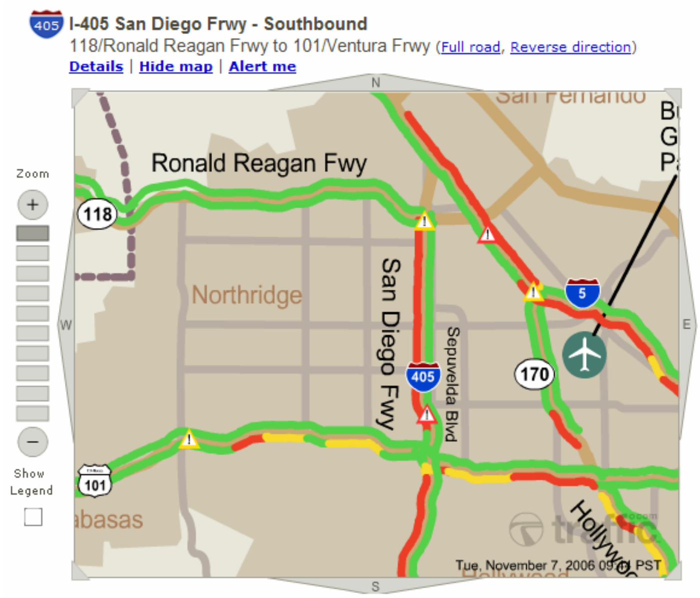


Figure 22: A typical web report from traffic.com. (Source: www.traffic.com)

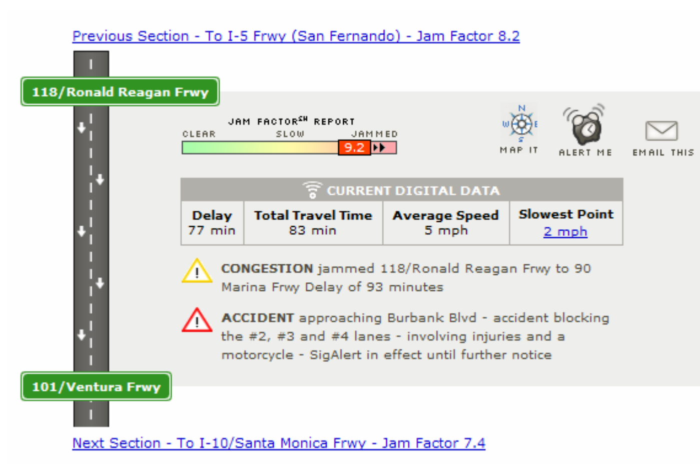


Figure 23: Travel time, delay, speed, and incident report from Traffic.com. (Source: www.traffic.com)

The data disseminated by Traffic.com is obtained from various sources including its own dedicated traffic sensor network (installed on heavily travelled roadways in the major metropolitan areas) and government agency sensors. More recently, Traffic.com has incorporated data obtained from dedicated vehicle probes equipped with GPS, vehicles equipped with electronic toll tags, and from anonymous cell-phone probes.

The success of Traffic.com in securing contracts with US DOTs seems to be due, in part, to the company's business model, in that the company pays for the deployment, operation, and maintenance of the traffic sensors, and provides individual travellers with free access to the traffic information. Revenues are generated from commercial users.

Currently, Traffic.com does not operate in Canada, or anywhere else outside of the United States. Consequently, the feasibility and costs associated with Traffic.com coverage in Ontario is not known.

CHAPTER 5:

MATCHING TECHNOLOGIES WITH MTO OPERATIONS

The purpose of this section is to provide an initial assessment of the suitability of the different wireless traffic monitoring technologies (i.e. dedicated probes; cell-phone probes; and VII) for the range of MTO operations identified in Chapter 2.

Table 3 provides an assessment of the likely suitability of each of three wireless traffic monitoring technologies for each of the 12 operational activities. In each case, the technologies have been rated using the following scale:

A = Likely to provide high level of functionality and reliability.

B = Likely to provide adequate level of functionality.

C = May not provide adequate level of functionality.

D = Likely cannot support this operational activity.

\- = Insufficient information available to make an informed assessment.

For the majority of the assessments, brief comments have been provided to justify or qualify the assessment. In all cases, these assessments have been made by the authors on the basis of the material described in Chapter 2, 3, and 4. Given that VII does not yet exist, and cell-phone based systems are just now emerging, the assessments in Table 3 represent a forecast of *anticipated* performance rather than a reflection of existing documented performance and should be viewed primarily as an indication of each technologies relative potential to satisfy the data needs of the associated operational activity.

It is expected that as more data reflecting system performance (particularly for cell phone based systems) becomes available, more accurate ratings of the technologies can be made.

Table 6: Assessment of most suitable technologies by operational activity

Operational Activity		Technology					
		Dedicated Probes		Cell-Phone Probes		VII	
		Score	Comments	Score	Comments	Score	Comments
Automatic incident detection	Arterials	D	Given limited number of probes, potential bias, and lag times, not likely to support this function.	C	Ability has not yet been demonstrated in the field or technical literature	A	Direct reporting of airbag deployment, engine status, etc.
	Freeways	C	May be suitable for rural applications but lag times may be long.	B	Not yet demonstrated, but likely to be able to perform rural AID		
Freeway congestion balancing		C	Lag time; bias due to commercial vehicle O-D patterns	C	Accuracy of location (i.e. express vs. collector)	B	Sample size
Integrated freeway/arterial management		C	Required short lag time; possible bias especially on arterials	B	Can obtain travel times network wide.	C	Performance may be constrained by number and placement of RSU.
Origin/destination demands		D	Bias due to use of dedicated commercial vehicles	B	Will require development of specific algorithms.	-	Uncertain that this would be supported by VII
Identification of routes		D	Bias due to use of dedicated commercial vehicles especially for arterials. Valuable for determining commercial vehicle fleet movements.	B	Will require development of specific algorithms	-	Uncertain that this would be supported (privacy issues)
Pre-trip planning		B	Suitable for freeways and major roads	A	Wide area coverage enables large historical databases	C	Likely RSU located only on major freeways.
Current travel times		B	Likely suitable for rural freeways assuming lag time is small. Cannot provide travel times on a lane basis.	A	Evaluation data not yet available, but it is highly likely that systems will be able to provide travel time data especially for major roads (not for individual lanes)	B	Spatial coverage may be limited to freeways.
Road surface conditions		C/D	Not likely to be able to infer from vehicle speeds.	C/D	Not likely to be able to infer from vehicle speeds.	B	Likely to be able to infer from various sensors, including wipers, traction control, etc.
Historical network travel times		B	Suitable for freeways and major roads	A	Wide area coverage enables large historical databases	C	Likely RSU located only on major freeways.
Border crossing travel times		C	Bias due to different processing requirements for commercial vehicles	B	May suffer from bias due to different processing times of commercial vehicles, but bias will be much smaller than from dedicated (commercial) probes	A	May be able to directly report wait time and separate by vehicle type (i.e. commercial vs. non-commercial).
Travel time prediction		B	Data latency may be an issue. Requires adequate fleet size.	A	Frequency of location referencing and accuracy of positions are quite important and will require development of specific algorithms.	A	Will require development of specific algorithms.

On the basis of the ratings provided in Table 3, it would appear that VII can likely provide the highest level of resolution of data (e.g. specific event based data such as air-bag deployment, etc.) and consequently is likely the most promising wireless technology for incident detection applications. However, it is much less clear how well VII will perform in terms of other operational activities, such as providing near real-time estimates of current arterial link travel times. In part, the performance of VII in these operational activities will be dictated by the number and spatial distribution of the VII road side infrastructure. Given the cost to deploy the road side units, it is likely that deployment of VII roadside hardware will begin with heavily travelled freeway corridors and then migrate to arterials and less heavily travelled roads.

On the basis of the ratings in Table 3, and the expected deployment timelines for the technologies, the most likely early successes are:

1. The use of cell-phone based systems for developing area-wide link speeds/travel time. Note that this technology will not provide estimates on a lane basis and therefore is not suitable for distinguishing between the travel times of an HOV lane and an adjacent general purpose lane.
2. Compiling an historical database of travel times estimated from a cell phone based system for use in pre-trip planning. This database could be integrated with transit service scheduled or actual travel times (if available) to make the pre-trip planner multi-modal.
3. The use of dedicated probe systems to obtain link travel times for rural highways. The success of this application depends primarily on the time lag being sufficiently small.

First efforts should be focussed on obtaining traffic conditions data for roadways for which no data is currently available rather than obtaining data from freeway sections on which dedicated traffic sensors are already deployed.

CHAPTER 6:

KNOWLEDGE GAPS

While wireless techniques appear to be quite appealing to obtain traffic information, a number of issues still need to be addressed. These issues can be categorized as:

- Institutional
- Privacy
- Data Ownership
- Data Quality
- Decision Support Tools
- Costs

The issues in each of these categories and the associated gaps in knowledge are described in the following sections.

6.1 INSTITUTIONAL

The primary institutional issue that has, or is likely, to arise is the relationship with the wireless carriers. In all of the wireless traffic monitoring schemes, except for those that rely solely on dedicated probes, the core handset signalling and/or location data resides with the wireless carrier. Consequently, the participation of at least one wireless carrier is necessary for any system to operate. In practice, it would be highly desirable to have partnerships with more than one wireless carrier to (a) increase the number of potential mobile probes; and (b) increase robustness of the system by ensuring that the withdrawal of one carrier would not render the system inoperable.

The business case incentive for the wireless carriers is not known and likely varies depending on the partnerships. However, it seems clear that the wireless cell phone business is very competitive and wireless carriers are sensitive to participation in activities that could be viewed negatively by current or potential customers. On the other hand, the information required to support cell phone based systems (e.g. hand-offs) are produced in all wireless networks as a requirement of cellular networks. So, this information can be thought of as a by-product that could generate additional revenue to the wireless carriers.

6.2 PRIVACY

The issue of privacy is important from a marketing issue rather than from a technical issue. All of the systems reviewed include technical solutions to ensure personal information is not disseminated by the wireless carrier. Furthermore, the road network conditions data are aggregated to the level of average link speed or travel time and thus the information disseminated to DOTs or publicly to travellers cannot be reverse-engineered to identify specific vehicles or individuals.

Nevertheless, concerns about privacy have appeared in the public press and wireless carriers are quite sensitive to any potential negative perceptions.

Concerns about privacy may increase if/when wireless road conditions monitoring systems are used to determine dis-aggregate data such as route information, trip origins and destinations, etc. It is likely that practical technical solutions to these issues can be implemented, but it is not clear to what extent the public will remain concerned about their privacy.

6.3 DATA OWNERSHIP

In most of the projects to-date, and the existing commercial systems (i.e. *iTIS* in the UK; Traffic.com in the US), the data are owned by the data provider and data are provided in specific formats for use by the clients (e.g. MTO/DOT). In existing systems, these data are typically in the form of average link speeds updated at a pre-defined interval (say 5 minutes). The agreements with the data provider specify how the data may be used (e.g. used to drive DMS, disseminated on web site, etc.).

This model changes the traditional role of the DOT/MTO from a data generator (i.e. the DOT/MTO owns and operators the sensor network, owns the data, and can manipulate the data for whatever decision support functions it wishes – such as incident detection, travel time prediction, etc.) to a data user. In the role as a data purchaser, the DOT/MTO has much more limited ability to develop decision support tools (such as incident detection algorithms, etc.) as they do not have the ability to manipulate the aggregation interval, sample size, etc., of the data.

6.4 DATA QUALITY

There are four main attributes associated with data quality, namely:

- accuracy,
- reliability,
- spatial coverage, and
- timeliness of the data.

Accuracy is referred to as the level of error, on average, of the estimated link travel time or speed. Error is typically quantified as the absolute difference or squared difference between the true and estimated quantity (e.g. speed).

From the user's perspective, reliability is the degree of confidence that can be placed in the correctness of the data. In statistical terms, reliability is related to the variation of the error. If sometimes the error associated with the estimated travel time (or speed) is very small, but sometimes it is very large, then these estimates are less reliable then a system that has the same average error, but the errors are more consistent (i.e. less variable).

Spatial coverage refers to the proportion of the network for which data are available. Spatial coverage is clearly a function of the number of probes, how quickly data from probes becomes out of date, and the distribution of probes on the road network. Availability of data might not be a major obstacle in urban highways during the day time. However, this can be an issue for rural areas and for systems using dedicated probes if the probe fleet is not sufficiently large.

Timeliness of the information is somewhat of a new consideration for traffic engineers. Traffic engineers are accustomed to using data from loop detectors which report traffic counts every 20 or 30 seconds. For these traffic sensors, timeliness is not an issue, as the reporting frequency is fixed. However, it is not clear what time lag is associated with the data acquired through the wireless systems and whether these systems can provide data that can to be used in real time traffic applications such as incident detection or they can only provide near real time traffic information that have other usage such as route advisory (Rose, 2004).

A number of studies have been conducted in order to examine one or more of these data quality issues. These studies can be categorized as field tests or simulation/analytical studies. The following sections describe the most relevant studies conducted within each category.

6.4.1 Field Test Studies

In field studies locations and corresponding time stamps of each probe are received from wireless carriers. The locations are subject to errors and therefore a process is required to match these locations to the street network. There are a number of map matching algorithms in the literature (Takada, 2006). Some of them are simple such as point-to-point or point-to-curve map matching in which every single reported location is matched with the closest point on the overlaid network. However, more sophisticated probabilistic and heuristic map matching techniques are also described in the literature (Takada, 2006). Typically there is a trade-off between accuracy and computation intensity of map matching algorithms.

As can be seen in Figure 24, there might be more than one route between two consecutive estimated locations. Consequently, a method is required to select the most likely route taken by the probe vehicle. This procedure is usually termed “trajectory estimation” or “path identification”.

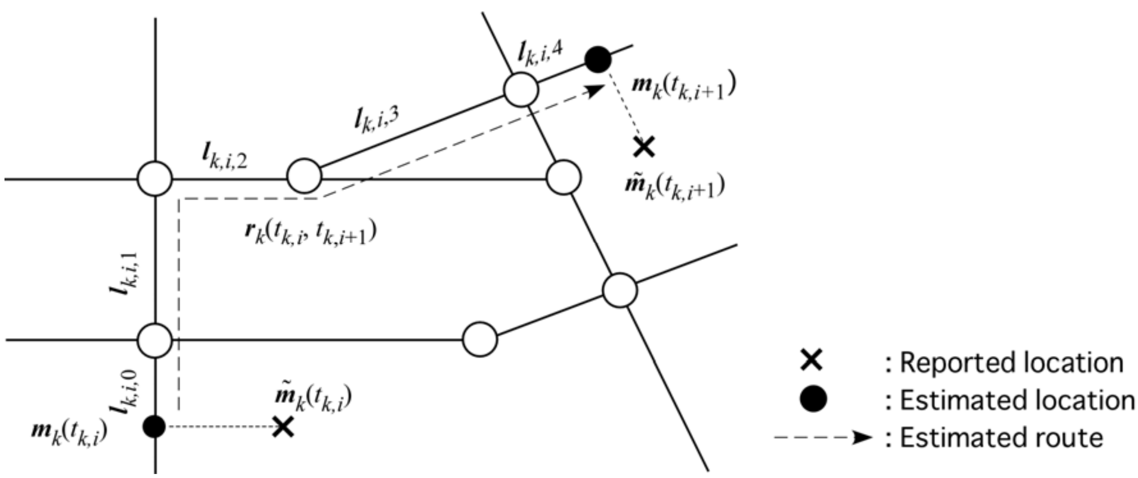


Figure 24: Map Matching and Trajectory Estimation Processes
Source: (Takada, 2006)

Having the estimated locations, corresponding time stamps, and route of travel, traffic information associated with the route can be calculated.

The first major field test study to evaluate performance of cellular tracking systems was conducted in the Virginia suburbs of Washington, D.C. in 1994 and ran for 27 months. The Federal Highway Administration, Virginia Department of Transportation, Maryland State Highway Administration, Raytheon E-Systems, Farradyne Systems Inc., Bell Atlantic NYNEX Mobile, and the University of Maryland participated in this project, called CAPITAL (Cellular Applied to ITS Tracking And Location). They found that the system was able to determine location of the cell phones within an average of 107 meters of their actual position during the final static accuracy evaluation (NCHRP, 2005). The accuracy of the position estimates improved considerably as the number of cellular towers providing directional information increased. The evaluators noted that accuracies on the order of 5 to 25 meters might be needed to perform accurate speed estimation for a network (University of Maryland, 1997).

In order to calculate speed, at least four position estimates had to be identified for each phone, and this occurred only 20 percent of the time. As a result, link speed estimates could not be generated for the network. This was due to the small number of data points, as well as a lack of well-developed algorithms to match vehicles to links (Takada, 2006).

Since the CAPITAL test showed that mobile phone tracking system could not provide reasonably accurate positional data, it was unsuccessful in producing traffic information.

In 2000, researchers at the University of California - Berkeley were provided with 44 hours of data collected by US Wireless (no longer in business). They studied a small area in the San Francisco Bay region. These researchers planned to measure the accuracy and reliability of speed or travel time estimation of vehicles tracked by cellular phones and compare the results with GPS equipped vehicles.

The University of California developed the Travel Information Probe System (TIPS) software that estimated probe location and travel times based on wireless location data. For those phones that could be matched to locations on the road network, the location estimates were regularly accurate within 60 meters. However, 66 percent of the tracked probes had at least one reported location with an error of more than 200 meters (NCHRP, 2005).

In 2001, the only field test study in Canada was deployed in Calgary, Alberta. The objective of the research was to study the technical feasibility of using vehicles equipped with cellular phones as traffic probes which was implemented by Cell-Loc Inc. and Transport Canada. Two types of data were gathered in this study: tracking of predetermined vehicles that were equipped with both cell phone and GPS and also anonymous tracking of cell phones (Cell – Loc, 2002).

The authors found that GPS receivers in the probe vehicles performed well as a benchmark with an accuracy of 5 to 20 meters, providing a very realistic view of vehicles' path and velocity. Data acquired by cellular phone system was within 100 meters for 67 percent of the time and within 300 meters 95 percent of the time. They claim that this level of accuracy gives a very good view of a vehicle's path and velocity when the sample size of reported locations is large enough. However, no information was provided regarding the required sample size (Cell – Loc, 2002).

In Southern Germany, Vodafone deployed a pilot study to access viability of cell phone tracking systems in 2003 for a major multilane autobahn North of Munich. They used cell phone hand-offs to determine locations of the cellular phones and also they gathered loop detector and probe vehicle data as a benchmark. They found that the mobile phone data had a larger variance than probe vehicle data. This could have been due to bias of data caused by using taxis as probe vehicle while the mobile phone data is from variety of vehicles (Alger, 2005).

Perhaps the most comprehensive published field study (called STRIP) was conducted on the Rhone Corridor in Lyone, France as part of the European SERTI project. The aim of the SERTI project was to manage the heavy traffic flow from Germany through Switzerland, France, and Spain to Italy during summer and winter holidays, using Intelligent Transportation Systems. The objectives of STRIP project were to estimate highway travel times and locate emergency calls on highways (Yim, 2003).

From August 1st to September 30th 2000, the cell phone data including volume of incoming and outgoing calls were recorded 24 hours a day and they were aggregated into 12 minute intervals. Furthermore, traffic volume, speed, loop detector occupancy and incident data were collected by the department managing this freeway (Ygnace, 2001).

The researchers also examined the relationship between the volume of cell phone calls and traffic conditions. Statistical analysis revealed that the number of outgoing calls and incidents are highly correlated and they concluded that people tend to make more phone calls in congested roadways to either friends and family or to inform their associates about the incident. The researchers suggested that this correlation might be useful for inferring traffic conditions. Furthermore, a survey of vehicles along this showed that 77.4% of travellers had at least one mobile phone in their vehicles.

This field study showed that data collected for cellular probes could result in good speed estimations in both directions of the Lyon rural freeway. The Southbound and Northbound average speed acquired through mobile phones were 100.5 Km/h and 99.4 Km/h respectively while average speed obtained from loop detectors were 107.9 Km/h and 111.25 Km/h associated with Southbound and Northbound respectively. It is notable that these conditions reflect near free flow speed. Performance under congestion is not known.

In the same study researchers found that for a stretch of urban freeway southwest of Lyon, the mean speed of the mobile probe vehicles were 24% lower than the mean speed obtained from inductive loop detectors on the Northbound direction and 32% lower than on the Southbound direction (Yim, 2003). It is assumed that the higher error for the urban freeway is caused by inaccuracies in the map-matching algorithms.

In late June 2005, a traffic monitoring system became fully operational in Tampa, Florida. In this project, the University of California at Berkeley in cooperation with a Tier 1 US telecommunications carrier and IntelliOne Technologies deployed the traffic surveillance system. An improved version of a software package called TIPS (Travel Information Probe System) that had been developed for a pilot study in the San Francisco Bay Area by the University of California at Berkeley was used in the Tampa deployment.

To identify locations of cell phone probes, they used Network Measurement Report (NMR) records. NMR records, which are generated as part of the cell phone system, consist of information about the strength of signals from all the cell towers seen by the phone. NMR records are generated when a cell phone changes cells or a call activity is made. In this project the NMR records were converted to cell phone location data in two stages. In the first stage the distance between the cell phone and the tower is determined using Timing Advance technique.

In the second stage, the signal strength data to neighbouring towers is processed to refine the position of the cell phone (Cayford et al., 2006).

The study area included 255 kilometres of freeway and 1,352 kilometres of major surface streets. The location system processes all the NMR records that pass through the carrier's center. Obviously the number of NMR records depends on the call volumes. Approximately 33.4 million records per second were processed in the peak period.

To examine the distribution of measurable phones across the study area, the travel time measurements were aggregated over 5-minute intervals and the number of road segments providing at least one observation per the 5-minute interval was calculated as a percentage of the total number of roads in the study area (Cayford et al., 2006). These researchers found that, as expected, the percentage of freeways covered in each 5-minute interval is substantially higher than the percentage of the surface streets covered due to higher volume of vehicles on the freeways. On average, 76% of freeways were covered (i.e. at least one observation during a 5-minute interval from 10:00 am to 10:00 pm. Moreover, this coverage was achieved by tracking phones from a single carrier, constituting only 15% of all cell phones in the area of study. The researchers also determined that the system could generate average speeds accurately within 5 mph with 95% confidence for 38.1% of freeways and within 10 mph with 95% confidence for 71.5% of freeways in every 5-minute interval for a 12 hour period between 10:00 am and 10:00 pm.

Recently, the evaluation report of the Hampton Roads field study has been published by the University of Virginia. As already mentioned, AirSage company began implementing a wireless traffic monitoring through tracking cell phones in the area in 2003. Originally, it was a 12-month contract but it was extended at Airsage's request. In December 2005 the baseline data were collected by the University of Virginia to compare with AirSage data. To obtain baseline data (i.e. position and time) floating vehicle runs using GPS devices were conducted (University of Virginia, 2006).

The evaluators found that the AirSage system is not able to produce reliable segment travel time or average speed estimate on arterials and congested freeways. Under congested conditions (i.e. speed less than 30 mph), 84% of the AirSage's speed estimations have an error larger than 15 mph. Furthermore, the AirSage system is unable to provide data in facilities with HOV lanes (University of Virginia, 2006).

A number of projects have been deployed to acquire traffic information using dedicated probes. A system similar to *iTIS* Holdings FVD was tested in Germany in a project termed Vehicle Relayed Dynamic Information (VERDI). In this study approximately 850 probe vehicles were used to collect traffic information. The vehicles were equipped with a GPS receiver and a GSM telephone line. The position data and associated timestamps were determined by the GPS and the data is disseminated to the managing servers. The system was able to detect 45% of the traffic disturbances, which were confirmed by the police. The VERDI system was able to detect about 25% of the incidents an hour earlier than they were broadcasted on the radio (NCHRP, 2005).

6.4.2 Simulation Studies

Researchers have used simulation studies to estimate the expected accuracy and effectiveness of wireless traffic monitoring systems and to evaluate the performance of specific algorithms.

General simulation studies are described first followed by the work that has been done to develop and evaluate specific system algorithms.

Estimating System Performance:

In simulation studies, the desired network and traffic conditions are simulated, and then the actual positions of probe vehicles are obtained at a specific frequency and probe vehicle sample size. Typically, the location data extracted from the simulation model is degraded to emulate real world situations. These data are then used as if they had been generated by a real system. The degraded locations (reported locations) are matched with street network through a map-matching algorithm and a trajectory is chosen as the most likely routes of the probe vehicles. The next steps would be calculation of travel time/speed, allocation of the estimated travel time/ speed to the network links, and aggregation of the estimated traffic information over a desired time interval. In simulation studies, the accuracy of the estimated information is examined by comparing the estimated metrics with corresponding metrics directly derived from the simulation package.

In 2000, researchers at the French transportation research organization, INRETS, conducted a simulation study prior to the field test in Rhone corridor in order to identify the sample size requirements and accuracy of a hypothetical wireless system. In this study they tested three configurations of a stretch of a freeway and a parallel arterial. They simulated a 15 kilometre freeway consisting of ten links of equal links. In the next step, they added a 3 kilometre arterial parallel to and 200 meters offset from the freeway and as the last step it was assumed that the length of the arterial is equal to the freeway. Furthermore, in the last step an underpass was included in the midpoint of the freeway.

In this study, the impact of different levels of probe vehicle penetrations on the accuracy of travel time was studied assuming a location error of 150 metres. The simulation results illustrated that freeway link travel times could be calculated to within 10 percent of their actual values when probe vehicles composed at least 5% of the traffic stream (NCHRP, 2005).

The networks used in this study were relatively small and were geometrically simple with the result that the study results may be optimistic when compared to actual field performance. The researchers stated that they have used a simple map matching algorithm which matched each reported location with the nearest point on the links. Furthermore, they did not address issues such as mobile phones in non-moving vehicles, frequency of location inquiries, and allocation of travel time to the links of the network.

In 2004, researchers at the University of Virginia conducted a simulation study to investigate the relative significance of system design and roadway network characteristics on the overall performance of wireless based traffic monitoring systems. They addressed several issues such as the impact of map-matching algorithms on the performance of the wireless traffic monitoring systems; identification of problematic situations where these systems do not perform well; the impact of different roadway characteristics on speed estimations; and sampling requirements for these systems (Fountain et al., 2004).

A test bed was developed to evaluate different scenarios. The test bed was a combination of the microscopic traffic simulation model VISSIM and a model that emulated a wireless location technology system. Exploratory testing was performed on simple hypothetical networks and the results were applied to case studies on three simulated networks from Virginia.

The results showed that a reliable and accurate map-matching algorithm leads to statistically significant improvements in the number and accuracy of speed estimates. Furthermore, they found several system parameters that have direct impact on the accuracy of the speed estimates including location error and sampling frequency. Larger errors in position estimation translate into larger errors in speed estimation and using a relatively infrequent mean time between samples generally improves speed estimation over frequent sampling intervals. Moreover, they found that satisfying the central limit theorem criteria does not guarantee the desired level of accuracy and recommended that sample sized two to three times those specified by central limit theorem limit be used (Fountain et al., 2004).

Development and Evaluation of System Algorithms:

A comprehensive simulation study was conducted recently at the University of Waterloo (Takada, 2006). In this study a test bed was developed that emulates wireless carriers' location identification technology through locations provided by the traffic simulation package INTEGRATION. Furthermore, this study offers a scheme to filter out mobile phones that are not in a moving vehicle. Another feature of this study is the travel time assignment procedure which allocates travel times experienced by the vehicles in a trajectory to the individual links along its path. In the proposed scheme, travel time along a trajectory is decomposed into three components namely free flow travel time, additional travel time caused by traffic congestion, and stopping time caused by traffic control devices. Then they introduced a probabilistic model to distribute additional travel time caused by congestion and control devices to the links of the trajectory.

A hypothetical mixed arterial/freeway grid network was used to evaluate the proposed scheme. Temporally varying demands were derived to create a moderately congested network. Transit buses were also included in the demands and also pedestrian probes were generated by assuming an average walking speed of 4 km/h.

In this study the standard deviation of location referencing was assumed to be 30 metres. They assumed two penetration rates of the probe vehicles, 5% and 10% and tried different aggregation time intervals. They found 20% error in travel time on average for freeway and arterial links. Moreover, they found that accuracy of travel time estimates is much lower for short links than longer links. The results of this study showed that pedestrians and cell phones in the non-moving vehicles a have significant adverse impact on the accuracy of travel times and consequently, an effective filtering scheme is of great importance. They also found that as the aggregation time intervals increases from 5 to 30 minutes, the accuracy increases. However, long aggregation time intervals are undesirable when traffic conditions change rapidly.

More recently, researchers at the University of Waterloo (Hellinga et al., 2007) have developed an improved algorithm for solving the problem of decomposing the traversal time reported by individual cell-phone probe vehicles to times taken to traverse individual road segments on the route. The algorithm, referred to as the Probabilistic Based Method (PBM), assumes minimal information about the network, namely network topography (i.e. links and nodes) and the free flow speed of each link. Unlike existing deterministic methods, the proposed solution algorithm defines a likelihood function that is maximized to solve for the most likely travel time for each road segment on the traversed route.

The proposed scheme is evaluated using simulated data and compared to a conventional deterministic method. The performance of the proposed algorithm is quantified using Equations 3 and 4.

$$E_{l(n_a,n_b)} = \frac{1}{ATT_{l(n_a,n_b)}} \sqrt{\frac{\sum_{r=1}^{N} (TA_r - TT_r)^2}{N}} \tag{3}$$

$$\overline{E} = \frac{1}{|\mathbf{L}|} \sum_{j \in \mathbf{L}} E_j \tag{4}$$

where:

$E_{l(n_a,n_b)}$:	Average normalized error associated with travel time allocation for link $l(n_a, n_b)$,
$R_{l(n_a,n_b)}$:	Observation set for link $l(n_a, n_b)$,
r :	Index denotes any individual observations in $R_{l(n_a,n_b)}$,
N :	Number of observations in $R_{l(n_a,n_b)}$,
TA_r :	Allocated travel time of observation r, which is calculated based on either the proposed probabilistic method or the free flow travel time allocation scheme (base scenario),
TT_r :	True travel time of observation r.
$ATT_{l(n_a,n_b)}$:	Average travel time of all observation in $R_{l(n_a,n_b)}$ i.e. $ATT_{l(n_a,n_b)} = \frac{1}{N}\sum_{r=1}^{N} TT_r$
$\overline{E}$:	Average error for the network,
L:	Links set,
$\lvert\mathbf{L}\rvert$:	Dimension of the links set, **L**,
E_j:	The error obtained for link j using Equation 3.

Figure 25 depicts the relationship between aggregate travel time estimation error ($\overline{E}$) and polling interval duration for both the proposed probabilistic based method (PBM) and the benchmark method (free flow travel time based or FBM). As can be seen in these results, the proposed PBM is superior to the FBM for all polling interval durations examined. Furthermore, the results show that estimation error is smallest for very short polling interval duration, but increases rapidly as the polling interval duration increases until a maximum error plateau is reached ($\overline{E}$ ≈ 0.75 for FBM at a polling interval duration of 60 seconds; $\overline{E}$ ≈ 0.65 for PBM at a polling interval duration of 100 seconds).

The relative improvement in estimation accuracy provided by the proposed PBM can be computed as $\left(\overline{E}_{FBM} - \overline{E}_{PBM}\right)/\overline{E}_{FBM}$. The results in Figure 25 suggest that the proposed PBM provides a reduction in overall estimation error of approximately 40% for polling interval durations of 35 and 60 seconds. The improvements are smaller for other polling interval durations (25% for a polling interval duration of 15 seconds; 14% for 90 seconds; and 9% for 100 seconds).

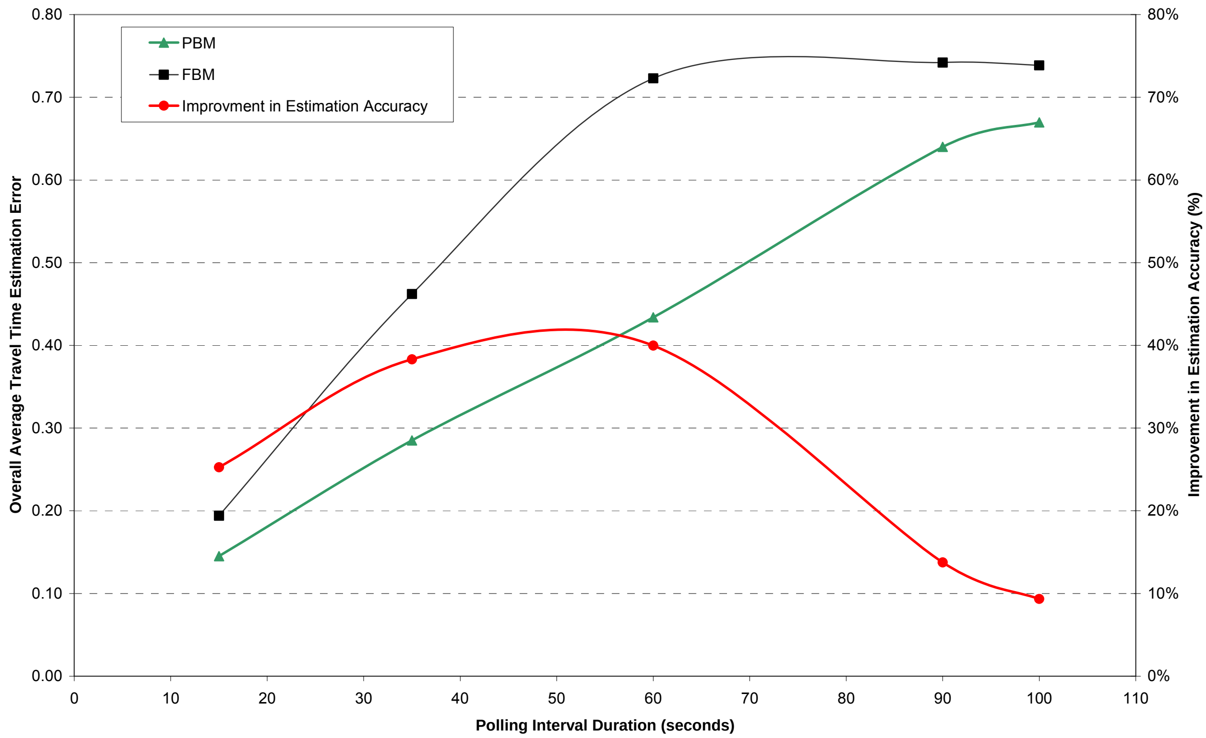


Figure 25: Overall average travel time estimation error
(Source: Hellinga et al., 2007)

The study by Hellinga et al., also examined the relative improvement in link travel time estimation accuracy that could be achieved using the proposed algorithm as a function of link class (i.e. arterial links controlled by a traffic signal and arterial links not controlled by a traffic signal) and the ratio of the polling interval duration to the free speed travel time of the link. The numerator of this ratio is a function of the cell-phone probe system. The denominator is a function of the level of spatial resolution (and roadway class) of the road network for which travel times are to be obtained. The results from Figure 20 indicate that for a short polling interval duration or for long links, when compared to the FBM the proposed PBM provides a reduction in estimation error of approximately 90% for links that are controlled by a traffic signal and approximately 70% for links not controlled by a traffic signal.

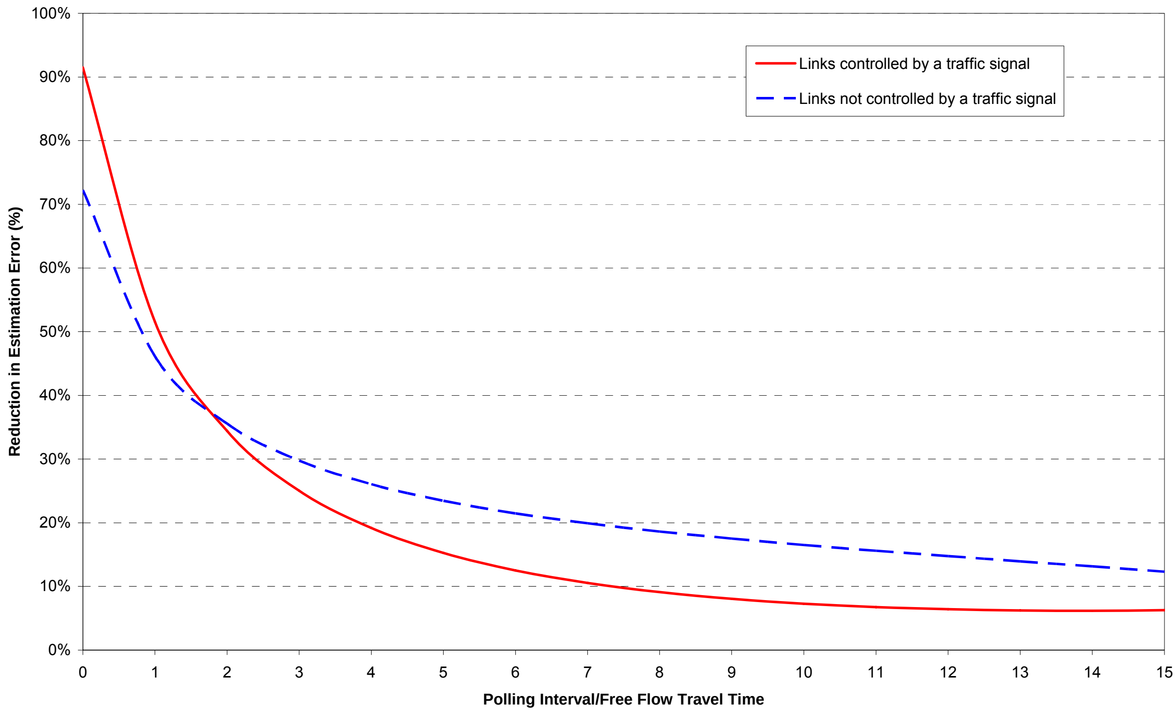
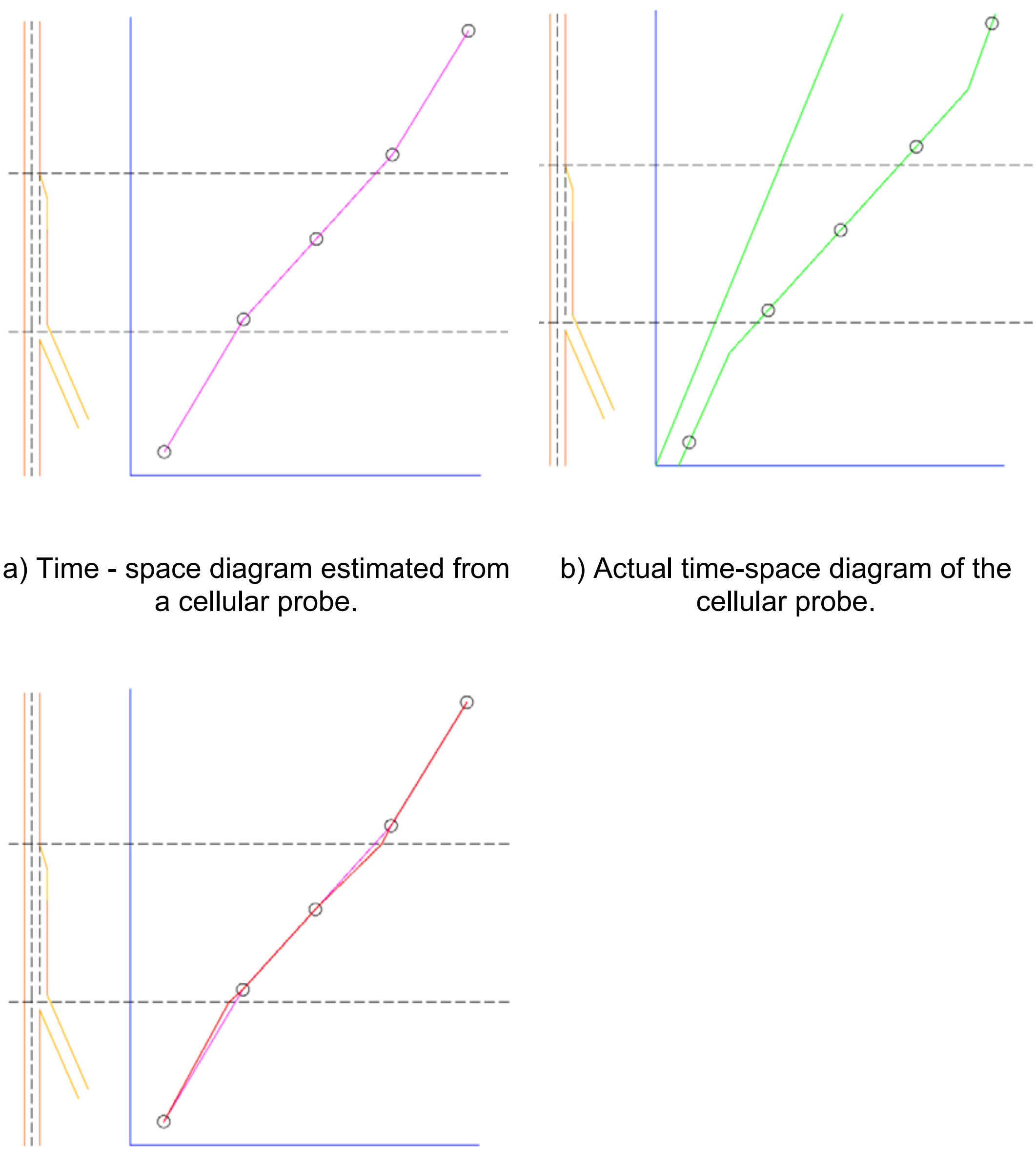


Figure 26: Relative improvement in estimation accuracy provided by the proposed probabilistic based travel time allocation method
(Source: Hellinga et. al., 2007)

Prediction of travel time is an important piece of information that can be used by managers of a network to respond to congestion (recurrent and non-recurrent) more efficiently. Recently, a research project has been defined at the University of Waterloo to utilize time and space information of individual cellular probes in order to predict near future travel time. Figure 27 shows a procedure to develop time - space diagram (vehicle trajectories) using data obtained from cellular probes. In this figure the x-axis depicts time and the y-axis depicts position of the probe along a section of freeway. The circles in Figure 27 (a) represent the estimated position of the cell probe vehicle at corresponding times and the segmented line connecting them is a rough estimate of the probe's trajectory along the freeway section. If the polling interval (i.e. time between consecutive location references) is reduced, the trajectory can be more accurately estimated. The actual trajectory of the probe is illustrated in Figure 27(b) and can be compared with the estimated trajectory depicted in Figure 27(a). Travel time allocation techniques such as PBM described previously can be utilized to make the estimated trajectory more accurate as illustrated in Figure 27(c).

When an estimate of a cell probe trajectory is available, it is possible to make use of a number of existing heuristic techniques and theories to predict travel time. Continuum models of traffic flow, such as that proposed by Newell (Newell, 1993) and heuristic methods such as neural networks, Genetic Algorithms, etc may be useful for modeling travel time prediction. It is hypothesized that best results will be obtained by combining traditional approaches based on traffic flow models with statistical pattern recognition techniques that make optimal use of the historical travel time data.



a) Time - space diagram estimated from a cellular probe.

b) Actual time-space diagram of the cellular probe.

c) Revised time -space diagram using PBM.

Figure 27: Developing time - space diagram using cellular probe data.

6.5 DECISION SUPPORT TOOLS

Wireless monitoring of wide-area road traffic conditions provides the opportunity to acquire data of a type and quantity not possible with conventional sensors. The availability of these data provides the opportunity to enhance existing transportation and traffic management capabilities and to support new capabilities.

However, the existing monitoring systems being tested have focussed on providing average link speeds and/or travel times primarily for use in traveller information systems. They have not explored the much wider range of possible decision support tools. Consequently, there remains a rather large knowledge gap related to what decision support tools could be developed to make use of these data and how well these tools would perform.

6.6 COSTS

The steady-state costs for the wireless monitoring of wide-area road traffic conditions are not well defined. The projects that have been initiated in North America to-date have typically been pilot projects of a fixed duration. In several cases, including the Delcan.NET projects in Maryland and Missouri, the private sector partners contributed a significant portion of the project costs. However, it is believed that these arrangements are likely limited to pilot projects for demonstrating the technology and that commercial rollout of these technologies will have different costing arrangements.

CHAPTER 7:

FINDINGS AND RECOMMENDATIONS

The primary findings of this project are as follows:

1. Wireless road monitoring systems have the potential to significantly improve real-time knowledge of road traffic conditions and to radically alter the way MTO/DOTs manage, maintain, and plan the road network.
2. Dedicated probe systems may be able to provide travel time data suitable for freeways, particularly rural freeways. However, the minimum lag time inherent within these systems may prevent their use for real-time applications. Furthermore, these systems are not likely to be sufficient for obtaining reliable data for arterials or for obtaining planning level data such as origins and destinations.
3. A number of wireless road monitoring systems are being marketed and are being, or have been, field demonstrated. These include:
    a. D.R.I.V.E.S developed by Globis Data.
    b. NETWorks™ developed by Delcan.NET in partnership with *iTIS* Holdings.
    c. RoDIN24 developed by Applied Generics (now part of the TomTom Group).
    d. TrafficSense developed by CellInt.
    e. X-10 developed by AirSage.
4. Traffic.com obtains traffic data via a combination of fixed, dedicated traffic sensors, and wireless road monitoring system (i.e. dedicated probes and cell-phone probes). The company is the largest commercial provider of traffic data in North America.
5. The quality of data that can be obtained from cell phone based systems has not yet been sufficiently demonstrated in North American deployments.

   There are only two systems that have to-date undergone field trials in North America which were evaluated by a third party and for which the reports are publicly available. These evaluations are (i) the AirSage system trial in Hampton Roads, Virginia completed in 2006 in which the evaluation team concluded that the data from the AirSage system were not of sufficient quality to support operations within VDOT; and (ii) the Delcan.NET trial in Maryland completed in 2007 in which the evaluation team concluded that the system was able to estimate speed and travel time on freeways with sufficient accuracy to meet the functional needs of Traveler Information Systems but they also concluded that the system is not yet able to estimate traffic information for arterials with adequate accuracy (Note that an evaluation report from the CellInt trial in Kansas City is expected to be finalized in late spring of 2007).

6. The cell phone based systems that have been field evaluated in North America are systems that rely on network based location determination. This approach permits rapid and (relatively) inexpensive location tracking of a large number of cell probes; however, location accuracy is generally poor. Systems that make use of handset location determination methods, such as assisted GPS (i.e. Globis Data system), typically are able to obtain higher location accuracy but generally must contend with a smaller number of probes in the sample.
7. Recently completed field trials suggest that cell probe systems which rely on network based location determination methods cannot provide sufficiently accurate traffic conditions data for arterials. The more accurate handset based location determination systems are expected to be more successful for arterials, however, this has not yet been tested in a comprehensive field trial.
8. Participation of wireless carriers is necessary to operate cell phone based systems. However, the level of commitment of wireless carriers to participate in road conditions monitoring projects is not clear.
9. The costs associated with cell phone based systems are not yet well defined.
10. Currently, the majority of wireless monitoring systems provide data primarily for traveller information purposes in the format of average link speed or travel time for freeways and major arterials. The data have generally not yet been used as input to other decision support functions such as incident detection, identification of routes and O-Ds for planning purposes, etc.

7.1 VIEWS ON THE PATH FORWARD

It is apparent from limited field results available and the views expressed by the DOT personnel associated with the pilot projects in the US that wireless monitoring of road traffic conditions is technically feasible and holds significant potential. However, to-date the in-field capabilities of cell-phone probe systems have not been adequately demonstrated and documented. Nevertheless, these systems have the potential to provide data that can support a wide range of activities, from real-time traveller information to automatic incident detection, to infrastructure planning and transportation facility monitoring. However, these different activities have associated with them different requirements with respect to data accuracy, reliability and spatial and temporal coverage. Consequently, the suitability of a system is dependent on the activities that the system is expected to support.

There appears to be four key outstanding issues that need to be resolved before MTO can realistically make a decision whether or not to pursue acquiring road conditions data via cell-phone probes.

First, is the issue of whether or not the private sector firms can establish long term relationships with wireless carriers. This is critical as without at least one participating wireless carrier the systems can not operate. The onus is on the private sector firms to develop these relationships and demonstrate that the wireless carrier partners are committed to participating.

Second, is the issue of data quality. The system must be able to provide accurate, reliable, and timely data for the road network of interest and must be able to do so for 24/7. Naturally, the quality of the data is particularly important during periods when congestion exists on parts of the network as it is under these conditions that network condition information is most valuable.

The demonstration projects conducted in North America to date have either not yet produced results; have not included an evaluation by an independent third party; or have provided mixed results. The recent evaluation in Maryland concluded that speed and travel time estimates from cell probes for freeways was of sufficient quality to meet the needs of traveller information systems. However, estimates for arterials were not of sufficient quality. An early evaluation in Hampton Roads found that the estimates from the cell probes did not meet the data quality standard necessary to support DOT/MTO requirements.

Given the unique and varied nature of the road transportation network in Ontario (e.g. express/collector facility on Hwy 401 in Toronto; location and importance of the international border crossings; high density of network in major urban centres and low density along rural corridors, etc.) it may be difficult to translate the results from the Maryland demonstration to the Ontario context.

Third, is the issue of cost. It appears that at the current level of commercial development of these systems, the cost structure is not well defined and the cost structure for deployment in the US may be different than for deployment in Ontario. Furthermore, the cost structure likely depends on the required quality of data, network coverage, etc. It is also anticipated that the costs will change as one or more of the system vendors develops a larger commercial deployment base in North America.

Fourth, is the issue of development and evaluation of decision support tools. It appears that at the current time, system vendors are focusing their efforts on developing and field demonstrating the capabilities of their systems to provide accurate and reliable average link travel time and speed data. While there is clearly value in these data, MTO may be able to utilize the road network conditions data for a much wider range of decision functions. MTO needs to give careful consideration to what contractual arrangements would permit the development and evaluation of the use of data for other decision functions.

7.2 RECOMMENDATIONS

The current trend in technology development suggests that the derivation of traffic conditions information from wide-area wireless monitoring techniques is approaching the level required to meet (some) of the operational requirements of MTO. Nevertheless, at this time, it appears that no one wireless monitoring technology has been field proven to clearly outperform all others over a wide range of applications. Consequently, the following recommendations are made to enable MTO to establish on the basis of field performance which solutions are best suited to support specific MTO operational activities:

1. It is recommended that MTO conduct a demonstration/evaluation project in Ontario. The only recent field evaluation of a cell probe system in North America was conducted in Maryland. The final evaluation report concluded that cell phone probes are able to provide traffic information for freeways that is of sufficient quality to satisfy the operational needs of traveller information systems. However, the Maryland evaluation did not explicitly consider the data quality requirements associated with other operational activities. Furthermore, the evaluation suffered from several constraints including; limited data for comparison due to withdrawal of the wireless carrier from the project;

and analysis results are aggregated limiting the ability to interpret the reliability of the speed and travel time estimates for different traffic conditions.

2. It is recommended that MTO retain an independent and objective party (not the system vendor) to conduct the system evaluation. The system should be evaluated in both the urban and rural context for a variety of traffic conditions. Particular emphasis should be placed on evaluating the system for conditions that are not “free flow”. Furthermore, “ground truth”, against which the cell probe data will be compared, must be established using spatial techniques (i.e. dedicated probe vehicles or travel times obtained via automated license plate matching from video images) as it is not possible to compare the accuracy of cell probe link travel time estimates using data from dedicated traffic sensors such as loop detectors. Particular care must be exercised in designing the evaluation to avoid problems such as those encountered in the Maryland evaluation.

3. Given the existing uncertainty regarding the operating costs and quality of data associated with cell-phone tracking and the relatively long period of time before VII can be expected to be deployed, it is recommended that MTO:

    a. Evaluate opportunities for obtaining speed/travel time data from dedicated probe systems for major freeway corridors (such as Highway 401). This effort should focus on three aspects of the data, namely (1) the quality of the data (paying particular attention to bias); (2) the time lag that exists in obtaining the data; and (3) the costs associated with obtaining these data.

    b. Determine the likelihood of existing commercial traffic data providers, such as Traffic.com expanding operations into Canada and specifically Ontario. The Traffic.com system appears capable of providing consumer grade level traffic information over a wide variety of dissemination platforms (though no information was found during the literature review that quantifies the accuracy and reliability of the data provided by Traffic.com). This level of traffic information may meet the data needs of several of the operational activities identified in this report, particularly now that Traffic.com is reported to be obtaining traffic data from multiple sources, including dedicated sensors, cell-phone probes, and dedicated commercial probes.

REFERENCES

AirSage Company (2006b). *Airsage Product Description.* Received from Airsage Company on May 2006.

AirSage Company Website (2006a). Accessed from http://www.airsage.com on May, 2006.

Alger, M. (2005) *Real-time traffic monitoring using mobile phone data*. Accessed from http://www.maths-in-industry.org/30/01/TrafficMonitoring.pdf.

Applied Generics Ltd. (2004) *RoDIN24 Road Traffic Monitor (GSM Edition)*. Accessed from http://www.appliedgenerics.com on May 2006.

Applied Generics Website (2006). Accessed from http://www.appliedgenerics.com.

Cayford, R. and Y. Yim (2006) *A Field Operation Test Using Anonymous Cell Phone Tracking for Generating Traffic Information*. Transportation Research Board CD-ROM, 85th Annual Meeting.

Cell-Loc Inc. (2002) *Traffic Monitoring Application of Cellular Positioning Technology: Proof of Concepts*. Accessed from http://www.tc.gc.ca/tdc/summary/13900/13936e.htm.

Cops, M., 2006, VII Strategy for Safety and Mobility, vehicle Infrastructure Consortium, Power Point Presentation, Accessed from Internet.

Delcan Company Website (2006). Accessed from Http://www.delcan.com/pood/index.php?id=291.

Eberspacher, J., Vogel. H.J. and C. Bettstetter (2001) *CSM Switching, services, and Protocols*, second edition, John Wiley and Sons (UK), Chapter 5.3 on Synchronization.

Federal Communications Commission (2001) *FCC Wireless 911 Requirements Fact Sheet*. Accessed from http://www.fcc.gov/911/enhanced/releases/factsheet-requirements_012001.pdf.

FHWA (2005) *VII Architecture and Functional Requirements Version 1.1*, ITS Joint Program Office, US Department of Transportation, Accessed from www.vehicle-infrastructure.org/documents/VII%20Architecture%20version%201%201%202005_07_20.pdf.

Fountain, M.D. and B.L. Smith (2004) *Improving the Effectiveness of Wireless Location Technology-based Traffic Monitoring.* Virginia Transportation Research Council, Report 05-17, Charlottesville, VA.

General Motors Company (2006). Accessed from http://www.onstar.com.

Haghani, A., Yang, S. and M. Hamedi (2007) *Cellular Probe Data Evaluation Case Study: The Baltimore Multimodal Traveler Information System (MMTIS)*, Final Report, University of Maryland, College Park.

Hearn, B. (1995) *A Dynamic Freeway Information system for Melbourne*. Proceedings of the International Conference on Application of New Technology in Transport System, Melbourne, Australia, pages 287-306.

Hellinga, B. and G. Knapp (2000) *AVI based incident detection*. Transportation Research Record - Journal of the Transportation Research Board 1727. National Academy Press, Washington, D.C. pages 142 - 153.

Hellinga, B., P. Izadpanah, H. Takda, and L. Fu (2007) *Decomposing Travel Times Measured by Cellular Phone-based Traffic Monitoring Systems to Individual Road Segments*. Submitted for publication in Transportation Research Part C.

Hongtu, Q. (2002) *Expressway incident detection using probe vehicles*. Master of Engineering Thesis, Dept. of Civil Engineering, National University of Singapore.

iTIS Holdings Company Website (2006). Accessed from Http://www.itisholdings.com.

ITS America (2005) Primer on Vehicle-Infrastructure Integration, Accessed from Internet.

Laitinen, H., Ahonen, S., Kyriazakos, S., Lahteenmaki, J., Menolascino, R., and S. Parkkila (2001) *Cellular Network Optimization Based on Mobile Location*, 2001 Cello Consortium, IST-2000-25382-CELLO.

Layton, J., Brian, M. and J. Tyson (2006) *How Cell Phone Work.* Accessed from http://www.howstuffworks.com.

Misener J.A., Shladover, S.E.(2006) PATH Investigations in Vehicle-Roadside Cooperation and Safety: A Foundation for Safety and Vehicle-Infrastructure Integration Research, Proceedings of the IEEE Intelligent Transportation Systems Conference, Toronto.

Mudge, R. (2005) *Real-time Traffic Information and Coming Revolution in Transportation Management and Planning.* Delcan Inc.

National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board (2005) *Probe-based Traffic Monitoring State-of-the-Practice Report.* Centre for Transportation Studies, University of Virginia, Virginia Transportation Research Council.

Newell, G.F. (1993) *A Simplified Theory of Kinematic Waves in Highway Traffic Part I: general Theory*. Transportation Research-B, Vol.27B, No. 4, pp.281-287.

Quayle, D. (2005) *Presentation on GSM based traffic Information services*. A presentation given on Sept. 13, 2005 at the University of Sydney. Accessed from http://www.its.usyd.edu.au/seminars/pastseminars2005.asp on May 15, 2006.

Rose, G. (2004) *Mobile Phones as Traffic Probes*. Working Paper, ITS-WP-04-25, Institute for Transport Studies, The Australian Key Centre in Transport Management, The University of Sydney and Monarch University.

Sethi, V., Bhandari, N., Koppelman, F.S. and J.L. Schofer (1995) *Arterial incident detection using fixed detection and probe vehicle data*. Transportation Research Part C, Volume 3, No. 2 pages 99-112

Sheng, W., Yang, Q., Guo, Yi (2006) Experimental Testbed and Distributed Algorithm for Cooperative Driving in VII Simulation, Proceedings of the IEEE Intelligent Transportation Systems Conference, Toronto.

Shladover, S.E. (2005) Preparing the Way for Vehicle-Infrastructure Integration, California PATH Research Report UCB-ITS-PRR-2005-31.

Smith, B. (2006) *Wireless Location Technology-Based Traffic Monitoring Demonstration and Evaluation Project - Final Evaluation Report.* Smart Travel Laboratory Center for Transportation Studies University of Virginia.

Takada, H. (2006) *Road Traffic Condition Acquisition via Mobile Phone Location Referencing*. Ph.D. thesis, Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, Canada.

University of Maryland Transportation Studies Center (1997) Final Evaluation *Report For The CAPITAL-ITS Operational Test and Demonstration Program Conducted By Raytheon E Systems, Maryland State Highway Administration, Virginia Department of Transportation, Bell Atlantic Mobile Systems and P. B. Farradyne*. Accessed from www.its.dot.gov/jpodocs/rept_mis/2701!.pdf.

US Department of Transportation (2006) *Vehicle Infrastructure Integration Concepts*. Accessed from http://www.its.dot.gov/vii/.

Van Lint, J.W.C. and N.J. Van der Zijpp (2003) *Improving a Travel Time Estimation Algorithm by Using Dual Loop Detectors*. Transportation research Record, 1855, pp. 41-48.

Van Lint, J.W.C (2006) *Evaluation and Analysis of Travel Information.* Delft University of Technology, Faculty of Civil Engineering and Geosciences, Transport & Planning Department.

Ygnace, J.L, and C. Drane (2001) *Cellular Telecommunication and Transportation Convergence.* Proceedings of 4th International IEEE Conference on Intelligent Transportation Systems.

Yim, Y., (2003)*The State of Cellular Phones*. California PATH Program, Inistitute of Transportation Studies, University of California, Berkeley. Accessed from http://www.path.berkeley.edu/PATH/publications/pdf/prr/2003/prr-2003-25.pdf.

Zhao, Y. (2000) *Mobile Phone Location Determination and Its Impact on Intelligent Transportation Systems*. IEEE Transactions on Intelligent Transportation Systems, Vol.1, No.1, pages 55-64.