FINAL REPORT

Travel Time Estimation Using Cell Phones (TTECP) for Highways and Roadways

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16. Abstract

Across the USA, there has been interest among the State DOTs to investigate alternative technologies to estimate travel time such as the use of cell phones as travel probes. This project "Travel Time Estimation using Cell Phones (TTECP) for Highways and Roadways" was initiated by the Florida Department of Transportation (FDOT) at Florida International University (FIU) in September 2004. This report summarizes our studies and investigations regarding the maturity of cell phone technologies for application as real-time traffic probes for travel time estimations along the highways and roadways. Also, the reliability, accuracy, and reproducibility of the travel speed and travel time computations based upon the cell phones as travel probes have been investigated and compared with other methods such as the 511-based operations and Global Positioning System (GPS) - based measurements.

The FIU TTECP team has found by virtue of their investigations that the cell phone technology is viable and mature under the normal conditions of free traffic flow, for the travel time estimations. However, the team has also found that the cell phone technology is not accurate in congested traffic conditions, where the data is more important than in the free-flow traffic conditions, and the accuracy decreases rapidly as the congestion increases. The details are provided in the executive summary and the conclusion sections. Additional issues remain such as: (1) privacy of the cell phone users whose phone transmissions are being probed by the cell companies for location data, (2) irregular and transient cell data for travel time and speed computations, especially during congested traffic and severe weather conditions, (3) limited capabilities of the travel time providers to follow changes by the cell companies in their data formats and structures, and (4) incompatibility of data when switching from one travel time provider to another (with different affiliations with the cell phone companies). These issues should be addressed and viable solutions should be found.

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Executive Summary

Across the USA, there has been interest among the State DOTs to investigate alternative technologies such as cell phones as travel probes to estimate travel time. Traditionally the State DOTs obtain the traffic flow information on roadways and highways through cameras, sensors, matching license plates, toll booth traffic flow records, etc. While these operations provide valuable information, the operational costs are very high, and so are the maintenance costs of the equipment, software upgrades, and dissemination of the information to the end drivers. The present "Travel Time Estimation using Cell Phones (TTECP) on Highways and Roadways" project has been initiated by the Florida Department of Transportation (FDOT) at Florida International University (FIU) in September 2004. This report summarizes our studies and investigations regarding the maturity and practical application of cell phone as real-time traffic probes to estimate travel time along highways and roadways. Also, the reliability, accuracy, and reproducibility of the travel speed and travel time computations based upon the cell phones as traffic probes have been investigated, and compared with methods such as 511-based operations and Global Positioning System (GPS) - based measurements.

Nearly 30 companies and organizations have claimed that they have capabilities, resources, and activities in providing travel speeds and travel time estimations in real time environment. The FIU TTECP team has investigated the operations, data, and result deployments of all these organizations regarding travel time estimations on roadways, with particular emphasis on the cell probe technology. All these companies obtain positional information of cell phones from the cell service providers on an anonymous basis. Then their systems aggregate this information, map the cell positions on the roadways and highways,

and compute the travel times and the speeds. The FIU TTECP team assessed and evaluated the travel time estimation methodology of the companies based on the following criteria:

- Travel time and speed extraction methodologies from the cell data.
- Data filtering and aggregation schemes to provide reliable travel time data.
- Potential to grow and deploy the traffic information on a continuous basis, without interruptions.
- Reliability of the data when compared against other methods.
- Willingness of the traffic information providers to provide non-classified information to the FIU TTECP team to be shared with the Florida DOT.

With these criteria, the list was narrowed down to five travel time providers. These companies are, in alphabetical order: AirSage, Cellint, Delcan, Globis Data, and IntelliOne.

The following summary of projects provides a glance of the potential of the cell phone technology to estimate travel time:

AirSage	Location: Norfolk, VA Network partner : Sprint Project coverage: 90 miles Date: 2005-2006 I. December 2005 Test • University of Virginia conducted an independent study on the Hampton Roads, VA, to compare AirSage's data and GPS data from vehicles used as traffic probes • In its final report, University of Virginia concluded that as of December 2005, AirSage could not provide data of sufficient quality to support operations within VDOT. Among the conclusions: o In severe traffic congestion condition (0-30 mph), the average absolute error was 24.69 mph. o In free-flow to moderate traffic congestion condition (higher than 30 mph), the average absolute error was less than 10 mph, but susceptible to large errors, 20% or higher.

	II. October 2006 Test
	• In severe congested traffic conditions, AirSage reported an average absolute error of approximately 15 mph, 68.2% percent difference, with respect to ground truth data.
	• The FIU TTECP observed that:
	  o There was no independent validation.
	  o The average absolute error of 15 mph (68.2%) in severe congestion condition was significant.

AirSage	Location: Salt Lake City, UT
	Network partner : Sprint
	Project coverage: n/a
	Date: 2006- in production
	
	• AirSage provided two graphs for comparison, which showed color-coded speed information. One displayed AirSage's speed data and the other speed from Salt Lake City road sensors. AirSage claimed:
	  o Its system had more coverage than the sensor-based system.
	  o Its system accuracy was good enough for DOTs.
	• After analyzing the AirSage's graphs, the FIU TTECP concluded:
	  o There was no indication of independent validation.
	  o The graphs displayed color-coded speed information in green, yellow, and red. This method does not provide accurate speed information.
	  o AirSage's system covered more roads, but since there was no sensor data, the accuracy of AirSage's data could not be determined on these roads.
	  o Roads segments where comparison were possible were mostly during non-congested traffic conditions (green). The matching on these roads between AirSage and the sensor system did not necessarily indicate an accurate AirSage's system because the comparison was during non-congested traffic conditions, and it did not provide accuracy information in heavy traffic and congested areas.

AirSage	Location: Fresno, CA Network partner : Sprint Project coverage: 90 miles (private contract) Date: 2006- in production • AirSage is providing traffic data to a TV Station in Fresno, CA. AirSage claims that it needed only 5% of phones in an area to provide good information.

	• The FIU TTECP team did not get any traffic information data of this project from AirSage. Traffic data for TV is generally color-coded speed information, which does not provide accurate information for variation and errors.
Cellint	Location: Tel-Aviv, Israel Network partner : Orange Israel Project coverage: 12 miles Date: 2004- in production Cellint's data was compared with road sensors data. There was no indication that it was an independent study. The FIU TTECP team's analysis of data provided by Cellint reached the following findings: • The average of the absolute error for all six segments were: 4.1 mph (5.4%), 4.9 mph (6.1%), 5.2 mph (9.9%), 5.4 mph (9.4%), 6.2 (11.3%) mph, and 7.4 mph (12.3%).
Cellint	Location: Kansas City, KA Network partner : n/a Project coverage: n/a Date: 2006 • Cellint's data was compared with the Kansas-Missouri SCOUT system. • The average absolute error was less than 5 mph. • The average delay (slowdown), as defined by Cellint, was 4.2 minutes. • The FIU TTECP observed that there was no analysis about Cellint's system accuracy during congested traffic conditions. A general average is not enough to evaluate a travel time estimation system.

Delcan	Location: Tel-Aviv, Israel
	Network partner : n/a
	Project coverage: 12 miles
	Date: 2005
	
	• Delcan's data was compared with the roadways sensors data.
	• The study was partially funded by Estimotion, now owned by ITIS, Delcan's partner.
	• The average absolute error between Delcan's system and a loop sensor system was:
	    o 1.46 minutes for non-congested traffic conditions.
	    o 2.82 minutes for congested traffic conditions.
	• The FIU TTECP Team observed that the error between Delcan's system and the sensor system was 2.82 minutes, but the error in percentage was not calculated in the study. Since raw data was not available, a more accurate evaluation by FIU TTECP team was not possible.

Delcan	Location: Baltimore, MD
	Network partner : Cingular
	Project coverage: 1000 miles
	Date: 2005
	
	• Delcan's data was compared with GPS data from vehicles used as traffic probes.
	• The independent study by University of Maryland, showed mixed conclusions:
	   o Delcan's system was good in most of the studied expressways.
	   o Delcan's system over-predicts speed calculation significantly on arterials.
	   o The accuracy diminished with traffic congestion.
	   o University of Maryland recommended more studies.
	• The FIU TTECP observed:
	   o The University of Maryland stated that the study was performed with far less vehicles probes that the recommended number.
	   o The average absolute error on the I-985 highway was 10.3 mph (42%), and during congested traffic condition, the average absolute error was 20.2 mph on the highway I-395.

Globis Data	Location: Ottawa, Canada Network partner : Bell Mobility Project coverage: 15 miles Date: 2004 • A comparison was conducted between the Globis Data's method and Ottawas's D.R.I.V.E.S. traffic information system. The results matched 100% except for one case which was 75%. • The comparison used the color-color method to display speed data. The used method that displayed color-coded speed information in green, yellow, and red did not provide accurate speed information. • Globis Data has not conducted additional tests.
IntelliOne	Location: Tampa, FL Network Partner : Cingular Project coverage : 96.8 miles Date: 2005 • IntelliOne provided to FIU TTECP team real-time access of their test data during their operations with cell probes in 2005. The FIU TTECP team analyzed data along 96.8 miles. • The FIU TTECPP team analyzed IntelliOnes's travel time estimation data on six segments along I-275 and compared it with Tampa 511 system. The average absolute differences between the two systems were between 5.5 to 34.4%.

	• The FIU TTECP team observed correlation in travel time estimation between the two systems on some segments and significant differences on others. Some of IntelliOne's inconsistencies, such as speed calculations far beyond the speed limits were later minimized using additional filters.
IntelliOne	Location: Tampa, FL Network Partner : Cingular Project coverage : 175 miles Date: 2006 • IntelliOne's data was compared with GPS data from vehicles used as traffic probes. • In a comparison to GPS readings: o IntelliOnes's readings were a match 18% of the time. o IntelliOnes's readings were less than 3 mph 34% of the time. o IntelliOnes's readings were less than 10 mph 82% of the time. • The FIU TTECP team observed: o The test was an IntelliOne's demonstration. There was no independent validation. o The data used were from the IntelliOne's phones, which were in use all the time. The calculations should have been done with data collected from other phones that happen to be in vehicles traveling on the same road as the test vehicles. Some phones may be in use and others not, but that is the real traffic condition.

The FIU TTECP team by virtue of their investigations found that the accuracy of the cell probe technology depended on the level of traffic conditions of the road. Good results were observed in free-flow conditions but there was no conclusive evidence that the travel and speed estimation are accurate enough in heavy congested traffic conditions. There were no independent validations in the US that the technology is mature enough to provide travel time information in arterials, and the findings were mixed when evaluating highways in heavy traffic conditions where the information is more important than in free-flow traffic.

However, the technology has good potential for the travel time and speed estimations and more studies are necessary, especially in highways where the findings were mixed.

The FIU TTECP team also recommends FDOT to establish a criterion for cell phone travel time estimation to prove accuracy of results prior to investing in technology for roadway network. For instance, a requirement may be made that computed speed with cell probes be at least 95% accurate (absolute error < 5%), at least 95% of the time, at all levels of traffic conditions.

Other issues associated with application of cell phone technology to estimate travel time include:

1. Privacy of the cell phone users whose phones are being probed by the cell companies for location data.
2. Capabilities of the travel time providers to follow the changes by the cell companies in their data formats and structures.
3. Incompatibility of switching from one travel time provider to another (with different affiliations with the cell phone companies) should be addressed and viable solutions should be found.

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List of Abbreviations

3G	3rd Generation
AOA	Angle of Arrival
BSC	Base Station Controller
CFVD	Cellular Floating Vehicle Data
CTS	Center of Transportation Studies
DEX	Data Extraction
DoD	Department of Defense
DOT	Department of Transportation
E911	Enhanced 911
ETT	Estimated Travel Times
FCC	Federal Communications Commission
FCD	Floating Car Data
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FVD	Floating Vehicle Data
GIS	Geographical Information Systems
GPS	Global Positioning System
GSM	Global Mobile System
GTD	Ground Truth Data
HD	High Definition
INRET	Institut National de Recherche sur les Transports
ISD	Intelligent Systems Design
ITS	Intelligent Transportation Systems
IVR	Interactive Voice Response
LBS	Location Based Service
LOS	Level of Service
MPS	Mobile Positioning System
NATO	North Atlantic Treaty Organization
PDA	Personal Digital Assistants
RFID	Radio Frequency Identification Technology
RDS	Radio Data System
RF	Radio Frequency
SMS	Short Message System
TAG	Traffic Alert Generator
TDE	Traffic Determination Engine
TMC	Traffic Management Center
TOA	Time of Arrival
TTECP	Travel Time Estimation Using Cell Phones
TTID	Transportation Technology Innovation and Demonstration
VLSI	Very Large Scale Integration
VPN	Virtual Private Network
WAP	Wireless Application Protocol
WI-FI	Wireless Fidelity

1 Introduction

The TTECP project at Florida International University (FIU) started in September 2004, with a primary objective of conducting research and investigations on the maturity, applicability, and reliability of using cell phones as travel probes for travel time estimation.

Acknowledging the importance of reducing travel time, the US government has established the nationwide 511 system to inform travelers about road conditions and travel time estimates between two locations. Cities, counties, and states have also tried to provide travel time estimations by installing a variety of sensors on main roadways. These sensors identify vehicles and/or measure the speed of vehicles. Then, the results from the computations of these data are transmitted to drivers as travel time information. Unfortunately, these traditional methods are very expensive. Only main roads are equipped with these sensors because economically it is close to impossible to install and maintain sensors for entire cities.

In this report, section 2 summarizes the literature review of research efforts in the past several years on travel time estimation using cellular phones as probes in the US and some cities around the world.

Section 3 includes an overview of the cell phone network architecture. A cellular phone network needs to locate its mobile cell phone users as well as to time the calls. Since the wireless network is tracking the phones, and many of them are in vehicles traveling the roads, it would seem to imply that travel time and speed calculations of any road would be an easy task. However, factors such as errors in radiolocation and bandwidth to carry the data reduce the viability using this technology for travel time estimation.

The FIU TTECP team investigated several companies and organizations which have technologies, methodologies, and patents related to travel time estimations and computations and identified the following five organizations, in alphabetical order: AirSage, Cellint, Delcan, Globis Data, and IntelliOne. They have responded to the team's request for publications, projects reports, patents numbers, and/or data. Section 4 includes a profile of each organization, their architecture, and data analysis.

In section 5, the FIU TTECP team summarizes the study findings. Conclusions and recommendations are also included.

2 Literature Review

An extensive study was conducted by INRET, a French transportation research organization, in the Rhone Corridor, near Lyon, France in 2000. The study extracted data from the interfaces between the base station and the base station controller (interface Abis) and between the base controller and the Mobile Switching Center (interface A) of a Global System Mobile (GSM) cellular network. The travel time estimated by the cellular network was compared with the travel time estimation by an inductive loop sensor system. The study concluded that within a location error of 150 m and 5% of cell users on the roads, the average absolute error in travel time estimation would be 10%. It also found a relationship between the volume of calls and the number of incidents on the roads [1], [2].

In 2000, the Virginia Department of Transportation, Maryland State Highway Administration, and US Wireless Corporation participated in a wireless location technology test and concluded that the technology was able to produce speed estimates of moderate quality, due to problems in generating the necessary sample size and map matching. The average mean absolute speed error in miles per hour was between 6.8 and 9.2 [1].

In 2003, Randall Cayford and Tigran Johnson investigated the parameters that could influence the effectiveness of a cell phone-based traffic monitoring system. The study concluded that a network-based location technology could provide measurements on 85% of the roads using approximately 5% of the location capacity of a single carrier, in every 5 minute interval. It also mentioned that with handset-based location technologies, using 5% of the location capacity of a single carrier can generate measurements for over 90% of the roads in every 5-minute interval [3].

In 2004, Michael Fontaine and Dr. Brian Smith studied the possibility of using a wireless network as a traffic monitoring tool instead of inductive loop sensors. The study provided guidelines for implementation of a wireless location technology-based system, and it supported the deployment of this kind of system for field tests, but it suggested the use of the study findings for preliminary evaluation of the vendor's system before funding the project [4].

In November 2005, the University of Virginia released its Probe-based Traffic Monitoring report that reviewed 16 planned or completed deployments of wireless location technology. The report stated the lack of performance requirements by the DOTs, insufficient information to determine the quality of the data, and inadequate sample sizes for accurate travel time estimations. It also recommended further research [5].

The Center of Transportation Studies (CTS) of the University of Minnesota is conducting a project titled "Evaluation of Cell Phone Data Traffic" for the Minnesota Department of Transportation. The CTS will compare data provided by the traffic information provider that uses cell phones as probes with data from inductive loop detectors, instrumented probe vehicles, and ground truth travel time calculated by matching the vehicles license plates through recorded video. This research is being conducted by Henry Liu, Senior Research Associate [6].

3 Technology Evaluation

3.1 Introduction

An overview of cell phone technology suggests that data collected and tracked by cell networks could easily and readily be used to calculate travel times on roadways. Cell phone carriers periodically probe cell phones, which may be in use or not, to obtain user identification as well as the cell phone location. This probing can be done because the area serviced by the network was divided into many sectors called cells, and each cell is serviced by a base station. To communicate with the cell phone and select the proper base station, the network must know in which area the cell phone is. Moreover, as a cell phone moves from one sector to another, the call must be handed off to the appropriate base station, as shown in **Figure 1**. Therefore, the network is continually identifying and tracking the cell phones to perform the handoffs, when necessary. Given the number of motorists traveling with cell phones, it is expected that sufficient data would be available to estimate traffic conditions along most roads. To understand the reasons why this problem is not that simple, it is necessary to comprehend the cell phone network architecture and the cellular phone methodology used to calculate the travel time on the roads.

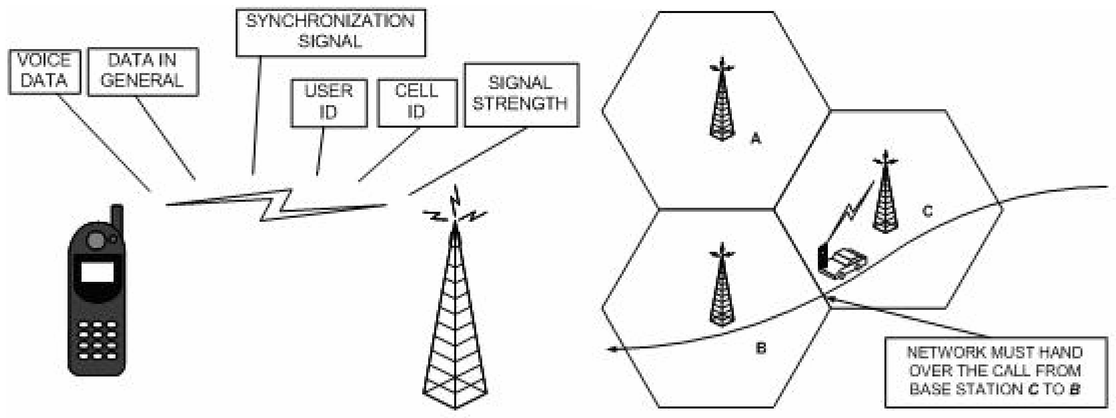

Figure 1 Cell Phone Communication and Handoff

3.2 Cellular Phone Network and Travel Time Estimation

A network consists of many base stations that serve nearby cell phones. The service area is called a cell. The base stations are controlled by the Base Station Controller, which in turn is controlled by the Switching Center. The Switching Center routes the calls between cell phones or between a cell phone and a fixed telephone. The Switching Center also stores files with identification and location of the cell phones for billing purposes, as shown in **Figure 2**. These identification and location files may also be used for speed and travel time calculations.

A network cell may have a radius of a few hundred meters in cities to a few kilometers in rural areas. The base station usually serves the phones inside its cell. The farther the phone is from the base station, the greater the attenuation of the signal. If the signal strength from the phone decreases to a predetermined threshold level, the network has to look for a closer base station to hand off the call. The location procedures for the handoff do not need to be precise. For handoffs, an error location of 500 m in a large cell area and 100 m in a small cell area would be acceptable. Therefore, the location techniques that are good enough to hand off phones in a wireless network may not be enough for other applications.

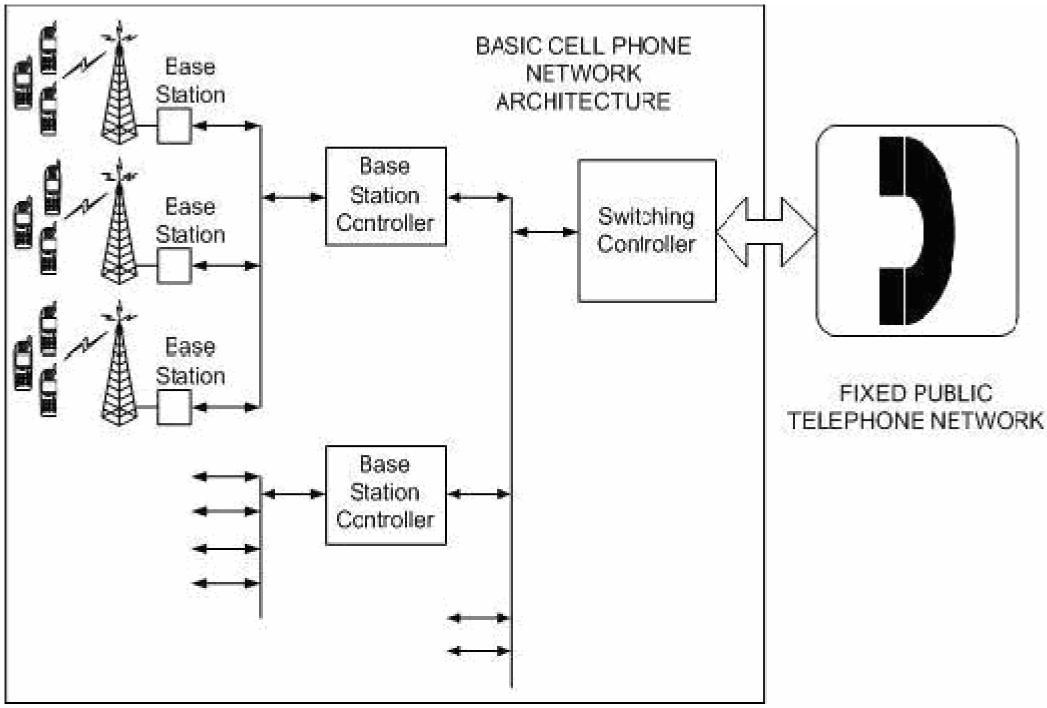

Figure 2 Basic Cellular Network Architecture

3.3 Cell Phone Location Calculation Methods and Limitations

In free space, the distance between a point in space and a radio frequency source, like the cell phone signal, can be calculated if the attenuation of the signal is known. The cell phone network measures the transmitting power and the receiving power of the signal at its towers. Therefore, the attenuation, which is the transmitting power minus receiving power, is known. However, there is no ideal free space condition, especially in cities where the paths of communication include not only direct sight, but reflection, refraction, and diffraction. Even phones that are close to each other may have different signal strength receptions. As shown in **Figure 3,** the signal path may pass close to a building and reach the phone, but a signal bound to a nearby phone may be reflected. The attenuation to each phone may be quite different, but the technology makes possible communication to both phones. Statistic methods have to be used to calculate the attenuation in these cases and automatic gain controls make the user unaware of these changes. However, the estimated distance from the base station to the phone calculated using these very different attenuation values may result in large errors.

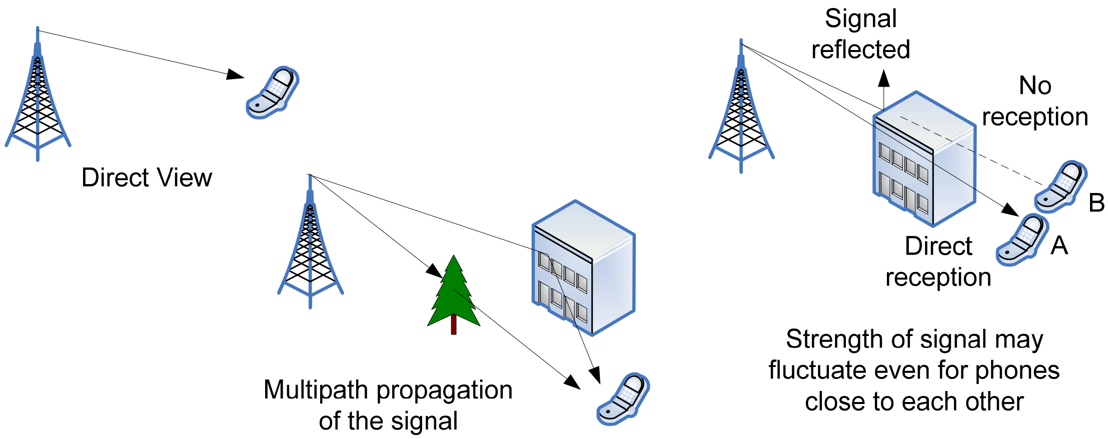

Figure 3 Propagation of Cell Phones signals

Ideally the exact cell phone position could be calculated using the triangulation method with computed distances at three nearby stations, as shown in **Figure 4.**

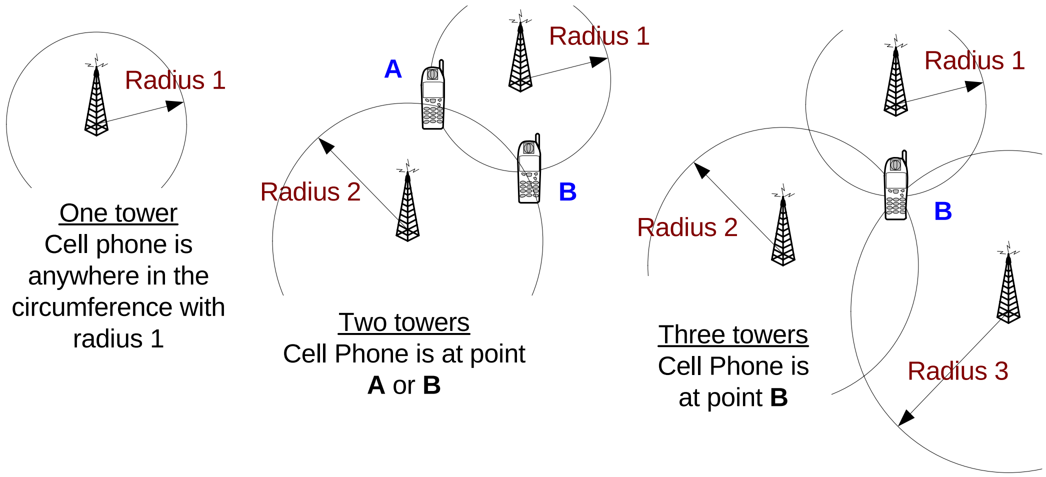

Figure 4 TOA Location Method

Unfortunately, in real situations the computed distances are dependent on the reflections, diffractions, and multipath occurrences of the phone signal. Taking into account the errors of the calculated distances, the triangulation method result is an area instead of a point, as shown in **Figure 5.** The typical accuracy of this method is about 50-200 m [7].

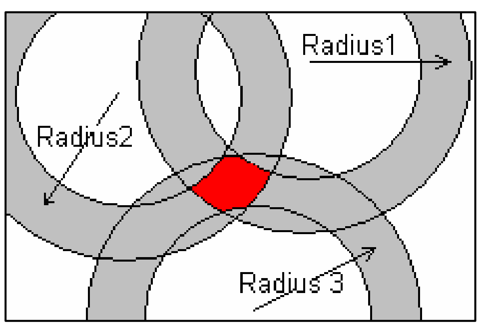

Figure 5 Error in Triangulation

In another method used by cellular networks to locate a phone, special antenna arrays are installed at the base stations to calculate the direction the signal is coming from. In this method two stations are enough to calculate of what direction the cell phone signal is coming from, as shown in **Figure 6**.

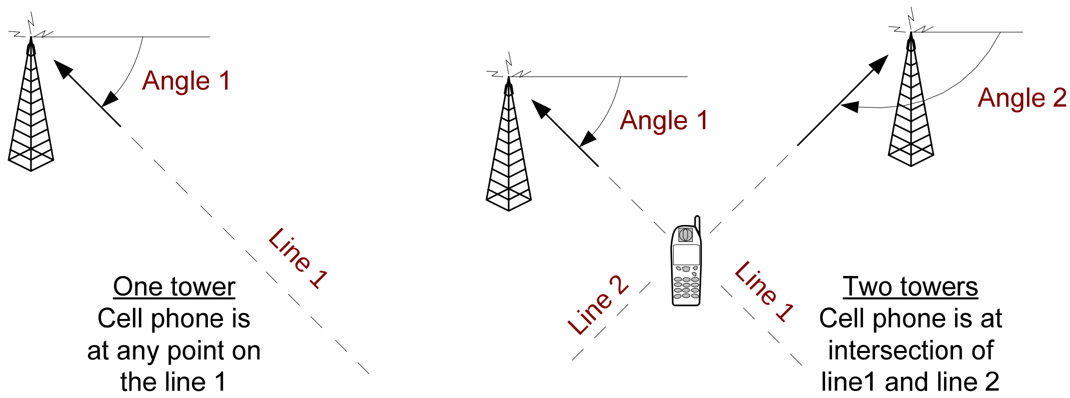

Figure 6 AOA Location Method

The effects of multi-propagation are illustrated in **Figure 7.** This method has an accuracy of about 50-300 m [7].

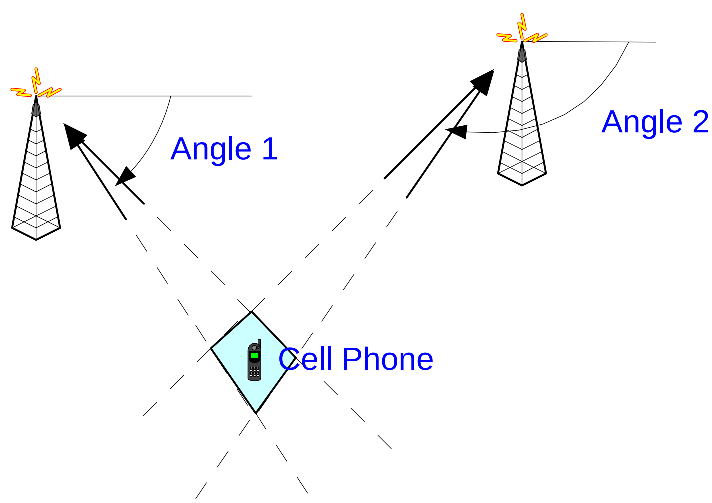

Figure 7 Errors in AOA Method

Some networks also use GPS to locate a phone. This method uses the GPS satellite system to calculate the position of the cell phone. The accuracy is between 5-30 m [7]. The accuracy is affected by factors such as the ionosphere, troposphere, noise, clock drift, ephemeris data, multipath, etc. Another problem is the heavy computation performed by the cell phone that may take minutes to calculate its position. In addition, the computations drain the battery of the phone. In the assisted-GPS method, the wireless network uses a server to perform the calculations, which are transmitted to the phone. That solves the delay and power consumption. To reduce the errors, the wireless network can use the differential-GPS method. In this method, a tower with a known position is equipped with a GPS receiver to estimate the total error. The error is the GPS reading minus the known position of the tower. Since the GPS reading errors are roughly the same in nearby areas, the estimated error can be transmitted to the phone for compensation. Therefore, the corrected location in a nearby area is the non corrected GPS location minus the estimated error. See **Figure 8.** The accuracy is improved to 15 m or less.

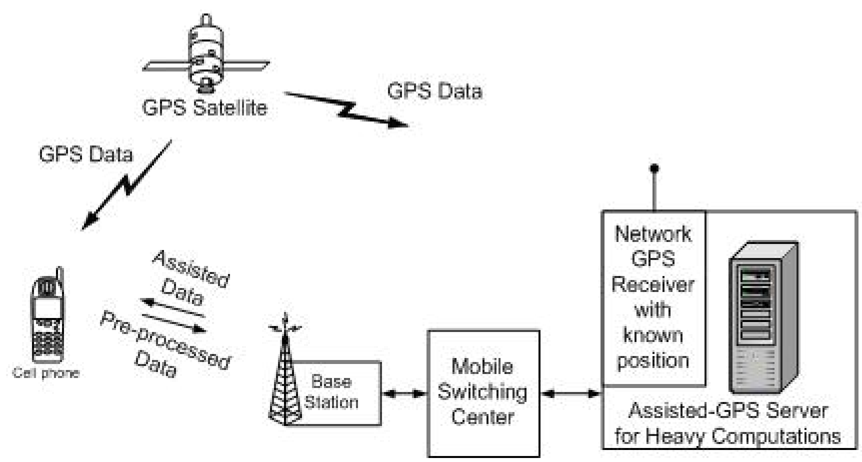

Figure 8 Assisted and Differential GPS Location Methodology

The method depends on the satellite data, which belong to and are maintained by the Department of Defense (DoD). The FIU TTECP team considers highly unlikely that the DoD will discontinue the maintenance of these satellites due to widespread civilian use.

3.4 Traffic Information Providers Architecture

A typical network architecture of a traffic information provider is shown in **Figure 9.**

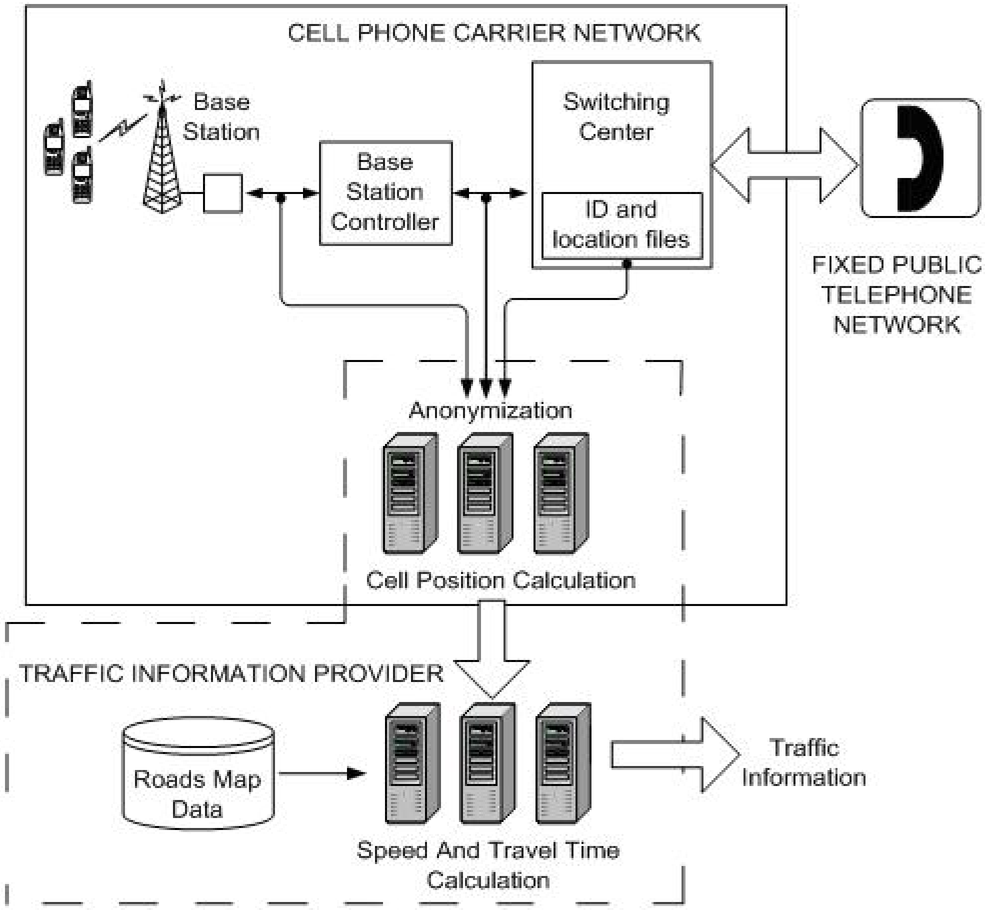

Figure 9 Typical Traffic Information Provider's Network

The cell phone providers' network is tapped for data or files containing the identification of the users and the positions of their phones [8]. Therefore, it can be concluded that if no wireless provider is interested in lending its network in a certain area, the traffic information provider cannot use cell phones as probes in that area to calculate travel time.

The next step of the process is anonymization of the data, which is performed in the wireless provider's premises, to protect the privacy of the users [8] and lessen concerns of identity theft. Then a log of the vehicle positions is obtained, as shown in **Figure 10**.

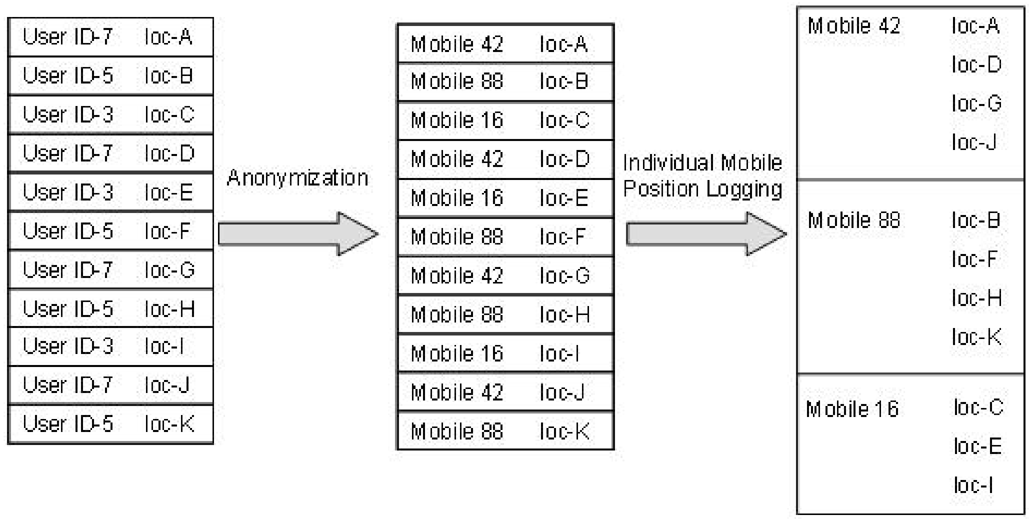

Figure 10 Cell Phone Position Tracking [9]

Next, the data is sent through secure channels to the traffic service provider's premises for more processing.

The obtained positions are then correlated to a map and assigned to segments of roads. The map data is usually provided by a third party company. The difficulty of assigning a location to a road depends on the source that provides the location [10]. A location given by a differential-GPS method may have an accuracy of 15 m, 50 m for a 911 call, and 200 m for a TOA-AOA radiolocation method. Therefore, depending on the method used to obtain the mobile position, there may be many possible road segments where the mobile really is. For example in **Figure 11** the black triangle indicates the position given by the cell phone network, which is not necessarily the actual cell phone position. If the position was obtained by differential-GPS, the cell phone is on 2nd St. or 11th Ave. If it was obtained by the network and it is a 911 call, it is on 10th Ave., 11th Ave., or 2nd St. But if the position is not a 911 call and the network used the TOA-AOA method to obtain it, the cell phone could be on any road except 13th Ave [10].

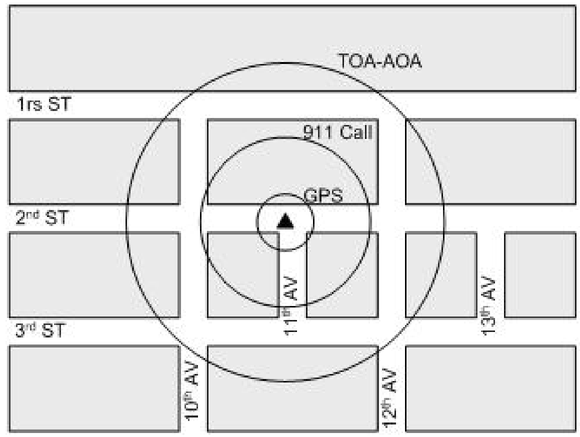

Figure 11 Cell Phone Position Range [9]

Furthermore, even if its position were accurately established and associated to a road, there may be many possible routes between two consecutive position readings for a mobile, as shown in **Figure 12**. The network locates a cell phone two times per second if a call is going on and, in order to save bandwidth, two times per minute if not. So, if a cell phone that is not on a call is moving at 60 km/h, it would travel 500 m between two readings 30 s apart.

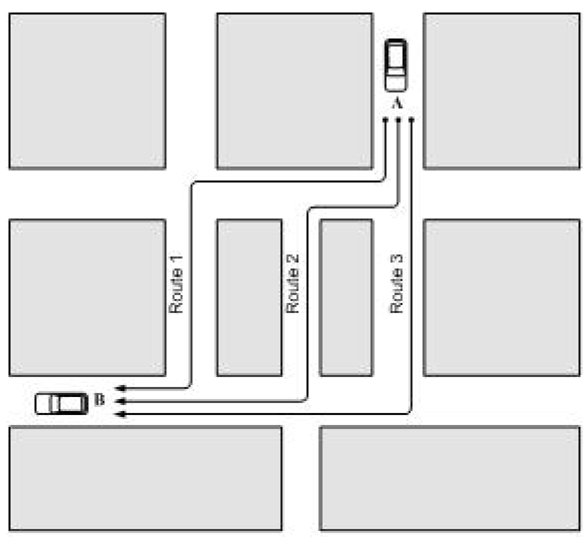

Figure 12 Possible Routes Between Two Location Readings [9]

During a call, the phone is located twice per second, the traveled distance would be 10 m, so its route can be more easily determined.

To estimate the traffic conditions on the roads, information traffic providers using the cell phone method use complex algorithms, statistical methods [11], driver behavior models [12], and data from many cell phones.

Some traffic information provider's systems estimate travel time using the handoff data. A handoff is produced when a cell phone moves to a cell that is serviced by another base station, as shown in **Figure 13.** The time between handoffs depends on the speed and direction of the mobile phone and the size of the cell.

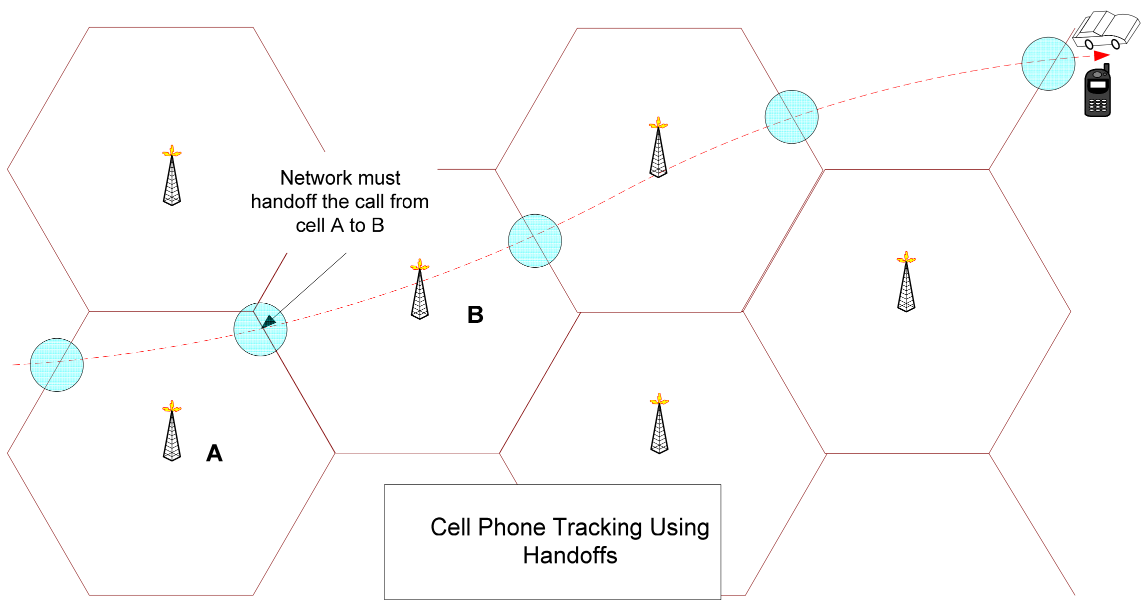

Figure 13 Tracking Using Handoffs

4 Organizations Contacted

Five organizations responded to the request for information about their travel time estimation methodology. In alphabetical order, they are: AirSage, Cellint, Delcan, Globis

Data, and IntelliOne. See Appendix A for the list of organizations identified by the FIU TTECP team at the start of the project, and Appendix B for profiles of Inrix and Traffic.com, whose traffic data were used as comparison data in some studies of this chapter.

4.1 AirSage

AirSage, based in Atlanta, GA, is in the business of providing travel time estimation for major roads. AirSage is privately held with lead investment by Constellation Partners, a global private equity firm based in Zurich, Switzerland [13].

AirSage has its system in production at Salt Lake City, UT; Fresno, CA; Atlanta-Macon, GA; and Norfolk, VA, and it is projecting to have its system installed in Atlanta, GA in November 2006 and in Minneapolis, MN in January 2007.

TV station KFSN, Channel 30 (affiliated with ABC) recently began using AirSage's system as part of its morning traffic report. The station is the first news organization to use the AirSage system. AirSage is providing speed and flow information in real-time on highways and backcountry roads in Fresno, CA [14].

The new system has been in use for two weeks, and AirSage claims that viewers have responded favorably. Also, AirSage claims that it doesn't take many cell phones for the system to work. AirSage officials said they only needed about 5% of the cell phones in use in an area to be on or in use to get good information [15].

AirSage’s architecture is typical. See **Figure 14.** It extracts data from a cell phone network, anonymizes the data in the wireless network operator, processes the data to calculate location, maps the position, and calculates speed and travel time.

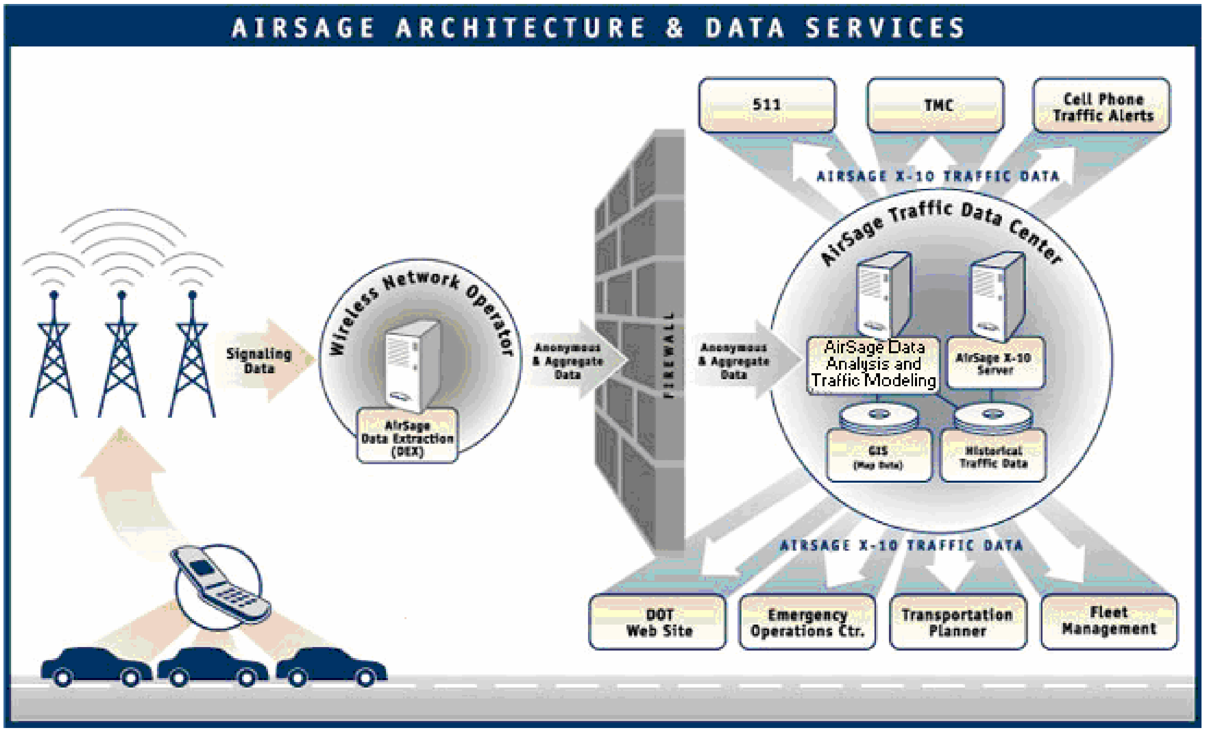

Figure 14 AirSage's Architecture [15]

AirSage has conducted in-house tests on 90 miles of the Hampton Roads in Virginia, and these tests included urban freeways, rural freeways, and urban arterials. The length of the tested roads was divided into 299 segments. A total of 612 ground truth measurements were taken and compared to AirSage's calculated results. AirSage provided the following observations in a March 2006 publication [16]:

- The average absolute error for all 299 segments was 8.7 mph.
- 145 segments (48.5%) had an average absolute error of less than 5 mph.
- 78 segments (26.1%) had an average absolute error between 5 mph and 10 mph.
- 76 segments (25.4%) had an average absolute error greater than 10 mph.

AirSage expects to quadruple the volume of their data to greatly improve accuracy. One of the additions includes an interface to access GPS data from cell phones. According to AirSage, they soon will be able to provide accuracy data within 5 mph for any type of road.

Another document handed out to the FIU TTECP team by AirSage on October 27, 2006 [17], indicates that at speeds over 35 mph the average difference between AirSage data and the baseline (reference) is less than 10 mph, as shown in **Figure 15**. During heavier traffic conditions, 22 mph, the average difference was approximately 25 mph, 113% error. Because the test was performed using only 25% of the expected data, these results were anticipated by AirSage.

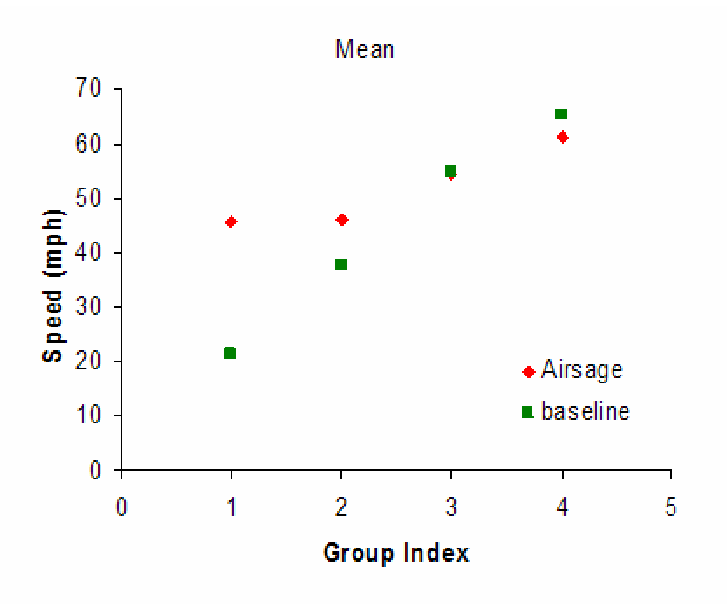

Figure 15 Initial Hampton Roads Results [17]

In October 2006, AirSage conducted another test, apparently an in-house test, using a greater flow of data from Sprint. The results indicate average absolute error was less than 10 mph for traffic conditions where the speeds were over 45 mph. During heavier traffic conditions, 22 mph, the average error was approximately 15 mph, 68.2% [17]. See **Figure**

16. However, the FIU TTECP team does not know if the tests were validated by a third party.

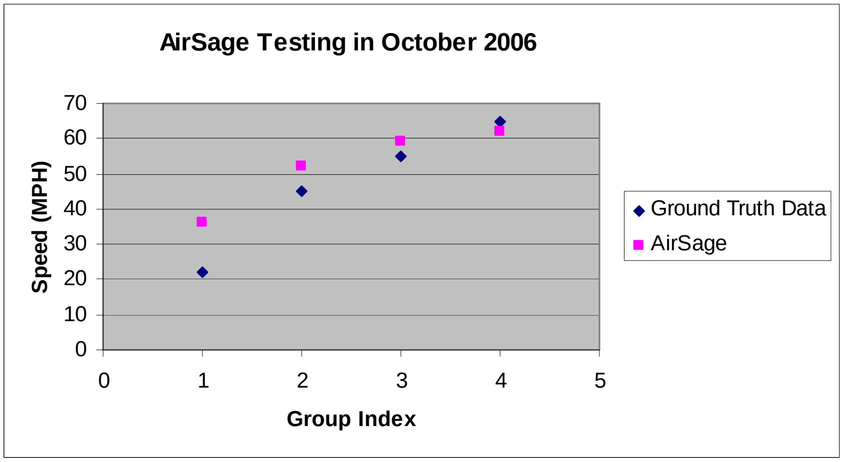

Figure 16 October 2006 Hampton Roads Test Results [17]

The type of analysis used by AirSage in this test provides more valuable information about a system than that from the lone average provided in other studies by different organizations. These lone averages are informative but not complete because they usually take into account long periods of non-congested traffic conditions that result in low and sometimes deceptive values.

AirSage has also provided a comparison between their system and the sensor system already in place in Salt Lake City, UT. According to AirSage, the information shown in **Figure 17** not only provides accurate information, but it also displays data on more roads than the sensor system, and that AirSage "have improved their product accuracy and coverage to a point where DOTs should now consider this a viable alternative to traditional systems [17]."

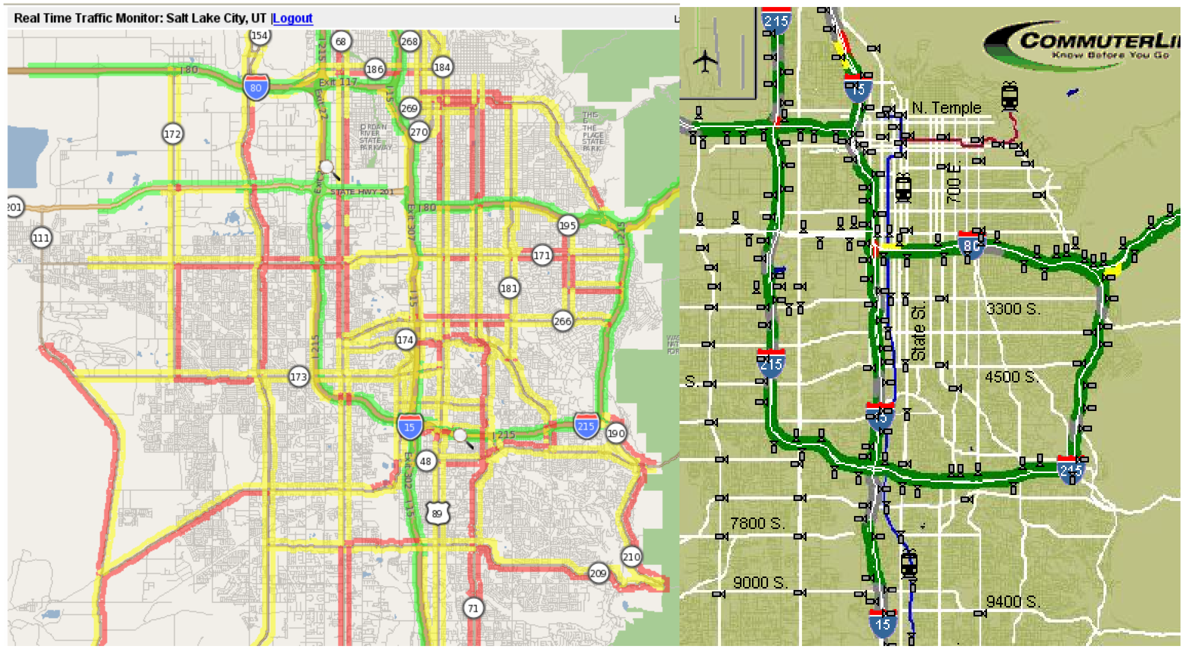

Figure 17 Graphical AirSage (left) – Sensors (right) Comparison [17]

Analyzing the illustrations, the FIU TTECP team observed the following. First, the color-coded method employed only provided coarse values. Second, the AirSage's system covered more area, but its accuracy was unknown because there was no sensor data to compare with. Finally, comparing the information on roads where sensors existed, the colors matched on most parts of the roads. However, on the compared roads, the predominant color was green, meaning non-congested traffic. During non-congested conditions, sensors, cell phone, and GPS methods provided small errors all the time. Therefore, the comparison in the illustration did not provide crucial information about the accuracy of the AirSage's system.

4.1.1 Independent Hampton Roads Final Evaluation

The test was conducted in the Hampton Roads region in December 2005. The final evaluation report "Wireless Location Technology-Based Traffic Monitoring Demonstration and Evaluation Project," was published by Smart Travel Lab of the Center for Transportation Studies, University of Virginia on May 26, 2006 [18].

The report concluded that as December 2005 AirSage could not provide data of sufficient quality to support operations within VDOT [18].

The report revealed a significant difference at severe traffic congestion, as shown in **Table 1.**

Table 1 Average Absolute Speed Difference Between AirSage and Baseline Data [18]

Group Index	Baseline Speed Range	Average Speed Difference (mph)
1 – Severe Congestion	0-30 mph	24.69
2 – Moderate Congestion	30- 45 mph	8.52
3 – Light Congestion	45- 60 mph	8.65
4 – Free Flow	>60 mph	9.49

University of Virginia also provided the following evidence:

- AirSage produced traffic speed estimates within 10 mph of true speed when traffic was higher than 30 mph. However, the system was susceptible to large errors, 20% or higher.
- AirSage could not produce reliable travel time on arterials or on congested freeways. Under congested conditions, there were errors greater than 15 mph in 84% of the measurements.
- AirSage could not produce data on the reversible HOV facility on I-64
- AirSage could not produce a confidence measure for traffic data records.

4.2 Cellint

Cellint, an organization with headquarters in Tel-Aviv, Israel, is a provider of cellular-based detection solutions. Cellint's systems have been deployed during 2005 on more than

5000 km and included numerous base station controllers (BSCs) in the US, Europe, and Middle East [19].

Cellint's architecture, illustrated in **Figure 18,** is a typical one. It taps data from the Base Stations and the Switching Center of a cellular network, anonymizes the data, and calculates travel time. These calculations are performed inside the wireless provider premises. Finally the data is sent through secure channels to its Central Traffic Server for more processing.

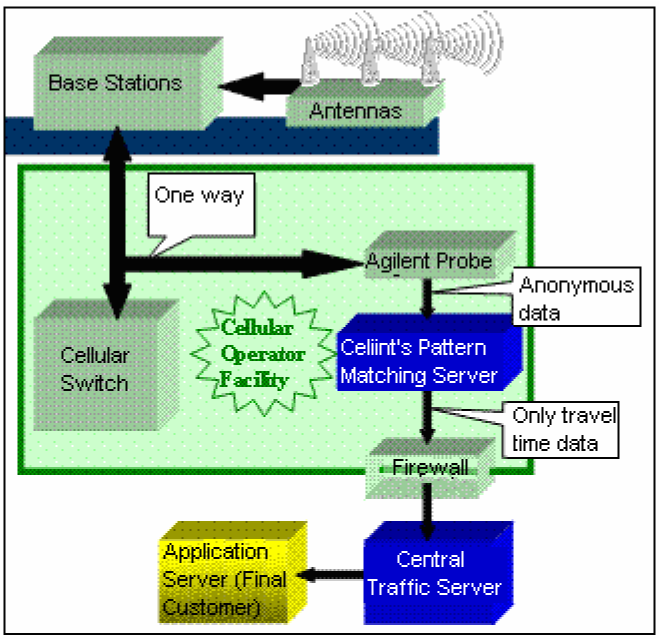

Figure 18 Cellint's Architecture [19]

Cellint was awarded a contract to provide travel time information during a construction period on road GA-400 during which the road sensors have to be disconnected from the traffic information system. Including roads that are in proximity to GA400, Cellint monitored 140 miles of road [20]. Cellint is also providing traffic information in Missouri along I-435 and I-69 under the management of Kansas DOT, and the data is being benchmarked by SCOUT, the joint traffic management project of the States of Kansas and Missouri [20].

4.2.1 Tel-Aviv, Israel Test

The test was performed on the Ayalon Expressway, Israel, for a period of three months in 2004. Cellint's speed calculations were compared with those obtained from loop sensor data. The inductive loop sensors were located on average every 500 m. The loop sensor system computed an average speed value every 5 minutes for each sensor. The computed speed value was the average of all instantaneous speeds given by the sensor during the previous five minutes. On the other hand, the Cellint's system monitored 200-m segments, with a loop sensor located on the segment geometric median. The system computed an average value every 2.5 minutes for every segment. To calculate speed, Cellint must locate the same phone at least twice in the 200 meter segment to calculate the travel distance. Then the speed value was calculated as the travel distance divided by the elapsed time [21]. Cellint averaged all speeds computed by its system on a road segment during 2.5 minutes, assigned this computed speed to this period of time, and continued the process for the next 2.5 minute interval.

Cellint provided the FIU TTECP team with the speed comparison between their system and the loop sensors on six segments of the Ayalon Expressway. The data were taken between May 09, 2004 and May 13, 2004 [21].

The FIU TTECP team's analysis of Cellint's data reached to the following findings:

- The average of the absolute errors for all six segments was 5.5 mph.
- Two segments (33.3%) had an average of the absolute error less than 5 mph (4.1 mph and 4.9 mph).

- Four segments (66 .7%) had an average of the absolute error between 5 mph and 10 mph (5.2 mph, 5.4 mph, 6.4 mph, and 7.4 mph).
- No segment (0.0%) had an average of the absolute error greater than 10 mph.

4.2.2 Kansas City, KS Test

In February 2006, a contract for testing TrafficSense, Cellint's solution for traffic information, was signed between KDOT and Cellint to compare Cellint's system with the existing SCOUT roads sensors system in Kansas City. The study was conducted between June 18 and July 31, 2006 [22].

Cellint placed special emphasis on slowdowns. A slowdown was defined by Cellint as the decrease of speed by at least 10 mph during less than 10 minutes, where the speed before the slowdown was higher than 50 mph and the speed during the following 10 minutes drops below 50 mph. The slowdowns were taken into account only if they were detected by both the sensors and TrafficSense within 30 minutes. The delay was calculated as the time difference between TrafficSense and the sensor system.

The speed obtained by SCOUT averaged the data from all lane sensors at a specific sensor station, including sensors at entry and exit lanes. Since entry and exit sensors may introduce errors in the speed calculation of the road, comparisons were done with and without the influence of these sensors.

Cellint has provided the following results [22]:

- The average error between the TrafficSense and the SCOUT system was less than 5 mph.

- The average latency (delay) detecting slowdowns by TrafficSense in comparison to the SCOUT road sensors system is approximately 4 minutes, as shown in **Table 2**.

Table 2 Slowdowns in Cellint's System[22]

	Without filtering entry/exit influence			After filtering extreme entry/exit influence		
Sensor #	number of	total delays	avrg. delay	number of	total delays	avrg. delay
#	slowdowns	(minutes)	(minutes)	slowdowns	(minutes)	(minutes)
59	2	-7.5	-3.8	2	-7.5	-3.8
61	10	60	6.0	10	60	6.0
62	14	117.5	8.4	14	117.5	8.4
64	22	107.5	4.9	22	107.5	4.9
69	34	230	6.8	34	230	6.8
77	19	67.5	3.6	19	67.5	3.6
80	6	37.5	6.3	6	37.5	6.3
82	5	47.5	9.5	5	47.5	9.5
135	15	-35	-2.3	15	-35	-2.3
136	23	-142.5	-6.2	23	-142.5	-6.2
138	4	35	8.8	4	-5	-1.3
139	24	130	5.4	24	130	5.4
140	15	220	14.7	15	117.5	7.8
141	7	62.5	8.9	7	62.5	8.9
142	7	75	10.7	7	75	10.7
143	13	122.5	9.4	13	122.5	9.4
144	12	55	4.6	12	55	4.6
147	16	-12.5	-0.8	16	-12.5	-0.8
	246	1177.5	4.8	246	1035	4.2

* KDoT/SCOUT may use different criteria for slowdowns, so their final results may be different.

Figure 22 shows a comparison between Cellint's system and loop sensors.

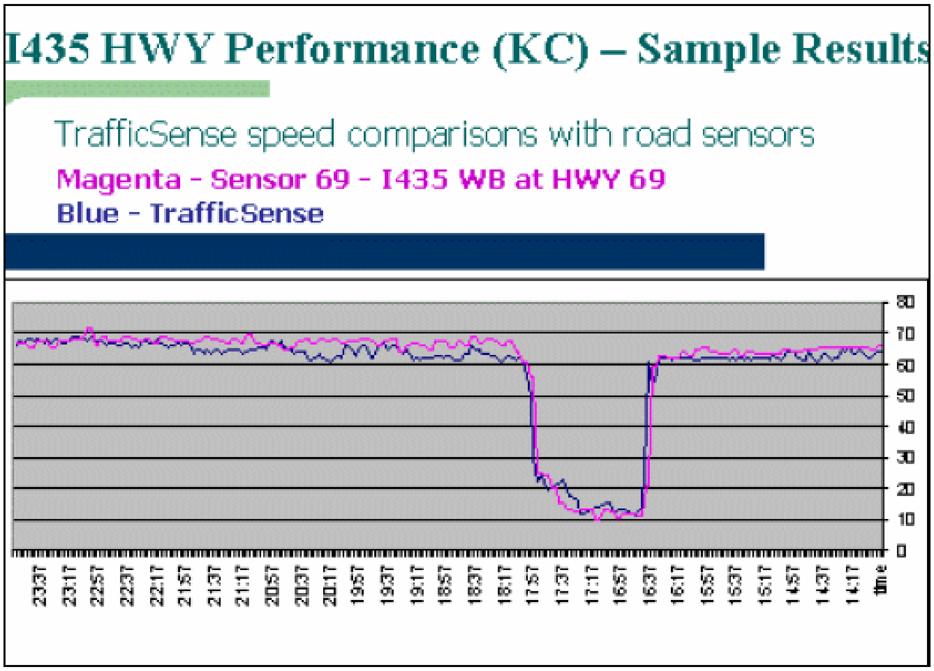

Figure 19 Cellint – Sensors Comparison [22]

According to Cellint, the trial was a "blind test" because they submitted their data during June and July 2006 and received the corresponding sensor data in August 2006 [22].

After analyzing the Cellint's report, The FIU TTECP team concluded:

The estimation of the delay response of the system to slowdowns provided extra information about the performance of the Cellin's system.

The sole difference average, 5 mph in this study, is not enough to evaluate the accuracy of the system. Usually this average is calculated over many hours of non-traffic conditions that may lower the average. A lone average is informative, but it does not provide complete information of a travel time estimation system.

4.3 Delcan

Delcan is a multi-disciplinary engineering company, including Intelligent Transportation System (ITS). It has a presence in more than 50 countries, including the USA and more than

50 years of experience. It is in partnership with ITIS, one of the leading companies within the United Kingdom in travel time estimations. Delcan and another partner, National Engineering Technology (NET), have integrated their global services under one common name of Delcan.

The state of Missouri has a contract with Delcan for statewide traffic information that will make it one of the biggest traffic information systems in the USA. Also, the State of Maryland has a contract to obtain 1000 miles of traffic information in Baltimore from Delcan [23].

Delcan's architecture, shown in **Figure 20,** illustrates that cell phone data is complemented by GPS data and incident data.

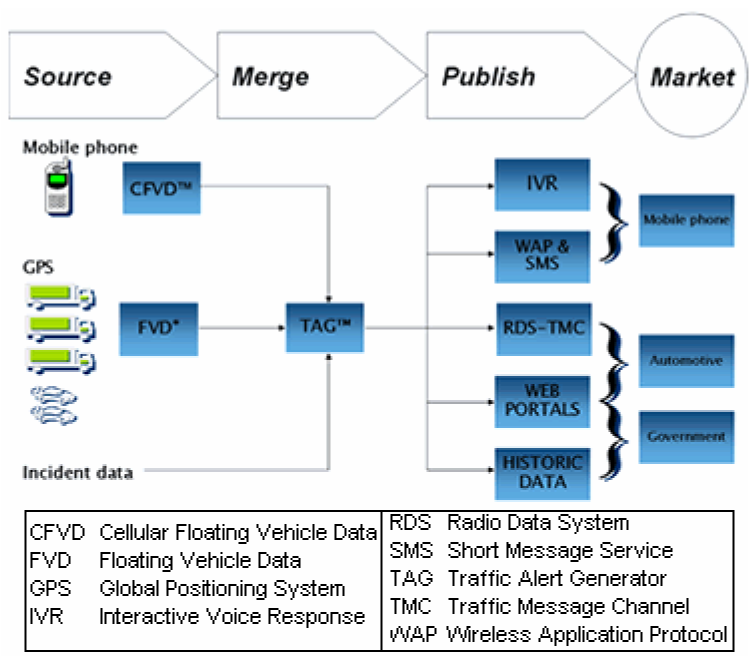

Figure 20 Delcan's Architecture [24]

ITIS's patent shows an architecture [11] that accepts different sources of data, putting them together in its fusion module. The interesting part of this architecture is its Predictor module, as shown in **Figure 21**. All organizations offering travel time information have algorithms to estimate travel time in near real-time. The FIU TTECP team believes that forecasting travel time enhances the real-time information.

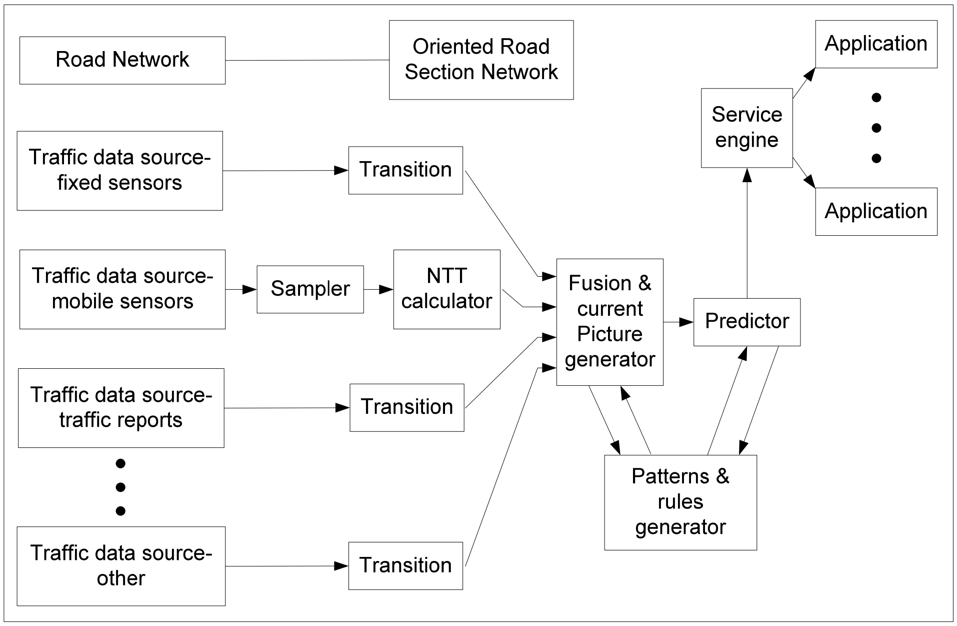

Figure 21 ITIS's (Delcan's Partner) Patent [11]

4.3.1 Tel-Aviv, Israel Test

The road segment chosen for testing was a 12 km section of the Ayalon freeway, the busiest road in Tel-Aviv, Israel. The test was performed from January to March 2005, between 7:00 AM and 12:00 PM [25]. Delcan's data, obtained from anonymous cellular phones, was compared with those obtained from dual magnetic loop detectors. The cellular data was also compared to the one obtained from dispatched vehicles, which were driven using the recommended "floating car" technique [26].

Data from cellular phones were assigned to 1-2 km road segments that start and end at either a diverge of an off-ramp or at a merge of an on-ramp. The travel time for the entire 12 km freeway was calculated by adding the travel times of all these 1-2 km segments, during the same time interval.

The dual magnetic loop detectors on the Ayalon freeway were approximately spaced 500 m apart. The speed data associated with the location of a loop sensor were computed as the average of all instantaneous speed values obtained from this detector in a five minute interval. For the graphical presentation, these calculations were associated with a section of roadway 500 m in length centered at the detector location.

The evaluation also consisted of 25 travel time measurements from dispatched cars traveling the freeway using the floating car technique as additional comparison.

According to **Table 3**, after evaluating the data of 5186 observations, the average of the error between the cell phone data and the loop detectors data was 1.2 minutes, and the average of the absolute error was 1.40 minutes. These calculations were also performed in congested and non-congested traffic conditions for better evaluation. The data were classified according to the travel direction and the traffic congestion level. One group contains travel times shorter than 10 minutes, as measured by loop detectors, and the other group contains all travel times equal to or greater than 10 minutes, as measure by loop detectors. The three statistical calculations performed were:

$$\Delta_1 = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)$$ Average of the error

$$\Delta_2 = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - y_i\right|$$ Average of the absolute error

$$\Delta_3 = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - y_i - \Delta_1\right|$$ Average of the absolute error, Δ_1 compensated (normalized)

where

- N is number of data taken.
- x_i is the data value of cell phone method corresponding at time i.
- y_i is the data value of reference method corresponding at time i.

- $(x_i - y_i)$ is the difference (error) of values between cell phone data and the reference at time i, with emphasis on the sign; positive is higher than the reference, negative is less than the reference.
- $\Delta_1 = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)$ is the average of the error of all reading, taken into account its sign.
- $|x_i - y_i|$ is the absolute value of the error between the two methods at time i; it does not matter if it is higher or lower than the reference.
- $\Delta_2 = \frac{1}{n}\sum_{i=1}^{n}|x_i - y_i|$ is the average of absolute values of the error of the two methods for all readings. It averages the absolute error, no matter the data was higher or lower than the reference data.
- $|(x_i - y_i) - \Delta_1|$ is the difference between the error of the two readings at time i and the average Δ_1, without taking into account the sign (absolute value). It tells, at time i, how much higher or lower the error of reading are from the average. In other words, it is the variance.
- $\Delta_3 = \frac{1}{n}\sum_{i=1}^{n}|x_i - y_i - \Delta_1|$ is the average for all readings of $|(x_i - y_i) - \Delta_1|$, and it gives an indication of the level of fluctuations of the signal.

The following table shows similar values for travel time shorter than 10 minutes. However, for >10 minutes, Δ_1, Δ_2, and Δ_3 were 1.69, 2.82 and 2.49 for NB; -0.13, 0.90 and 0.90 for SB. The values, although not large, do not show consistency. The northbound (NB) errors are much closer for any type of traffic than the southbound (SB) differences.

Table 3 Comparison between Cellular Phones and Loop Detectors Data [26]

	Total	Southbound		Northbound	
Travel time according to road detectors (min)		<10	≥ 10	<10	≥ 10
Number of observations	5186	1848	696	2459	183
Average loop cellular error Δ_1 (min)	1.20	1.46 >14.6%	1.69 < 16.9%	1.03 >10.3%	-0.13 < 1.3%
Average absolute error Δ_2 (min)	1.40	1.46 >14,6%	2.82 < 28.2%	1.07 >10,7%	0.90 < 9.0%
Average absolute error compensated for average error Δ_3 (min)	n/a	0.58 >5.8%	2.49 < 24.9%	0.52 >5.2%	0.90 < 9.0%

Congested traffic increases the travel times, as well as associated errors.

The results of this test showed small errors between the cell data and the data from the loop sensors. However, the percentage of the errors may be significant since the average travel time in no traffic conditions was approximately 8 minutes. Since the FIU TTECP team did not have the raw data, the team could not calculate the percentages.

The project was partially funded by the traffic information provider, Estimotion, which is now owned by ITIS, Delcan's partner.

4.3.2 Baltimore, MD Test

The state of Maryland has a contract with Delcan to obtain traffic information for 1000 miles in Baltimore.

In a 2006 conference in Montana, Delcan provided the following Validation Test Drives Summary [27]:

- GPS drives data was taken as a reference ('Ground Truth'). The average difference was under 10%.
- On 83% of the links Delcan's speed calculation category matched exactly the one from the test vehicles, and the remaining 17% were within 5 mph.

The University of Maryland published its draft final report on the Baltimore Multimodal Travel Information System in October 2006 [28]. The FIU TTECP team noticed two important findings by the University of Maryland on this report:

- On most freeways the evaluation results are consistently good while on arterials the cellular probe data tends to over-predict the travel speeds significantly [28], as shown in **Figures 22-23.** I-70, I-95, I-395, and I-695 are freeways and the graph indicates smaller travel time differences than on US-1, MD-40, MD-45, and Martin Luther King Boulevard, which are arterials.

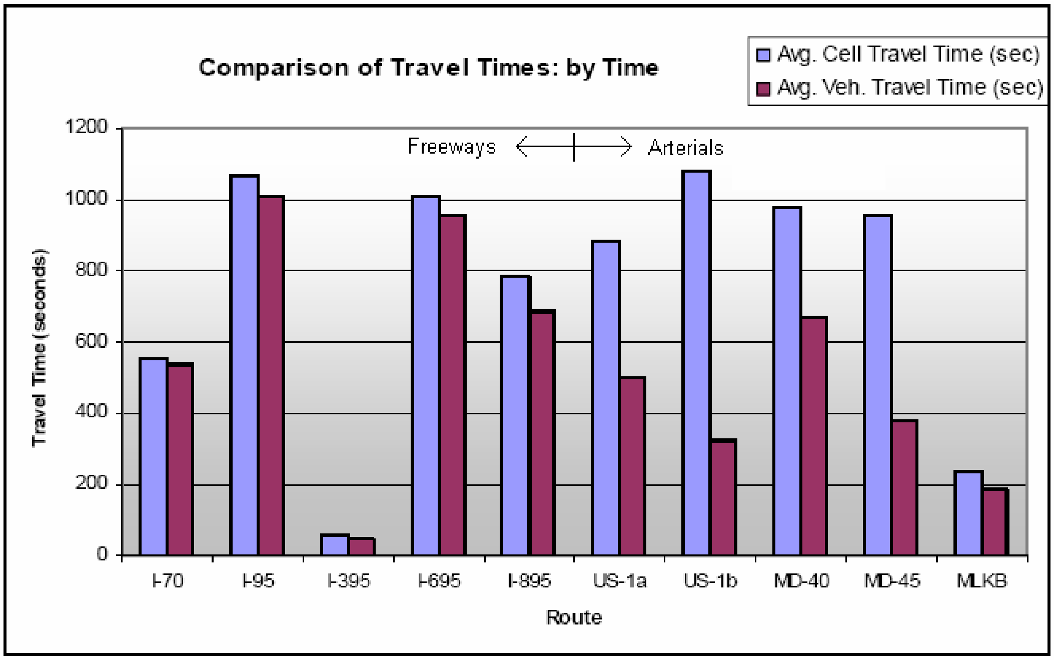

Figure 22 Comparison of Average Travel Times [28]

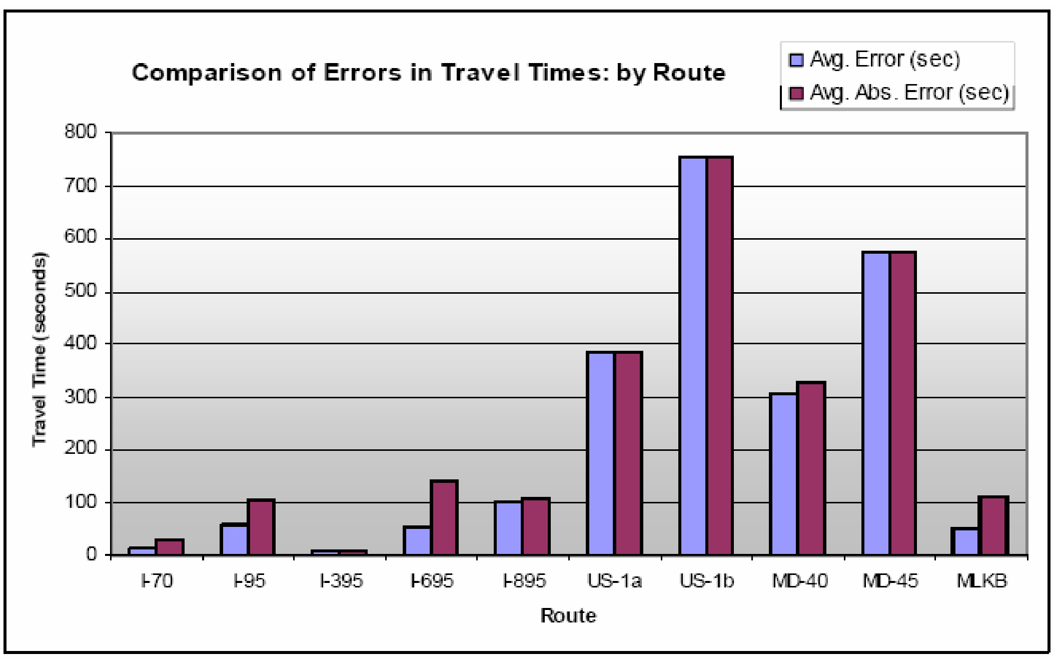

Figure 23 Comparison of Errors in Travel Times [28]

- The University of Maryland reports also indicated the effect of congestion on data quality, as shown in **Figures 23.** The level of service (LOS) was reported by the probe vehicle drivers according to their personal experience in traffic, being Level A the best and level F being the worst [28]. The graph shows that at level A 57% of the errors were less than 10% while at level F 84% of the errors were greater than 100%. **Figure 24** shows the findings as absolute speed differences. According to **Figure 25**, at level A 49% of the errors were less than 5 mph while at level F 80% of the errors were greater than 20 mph.

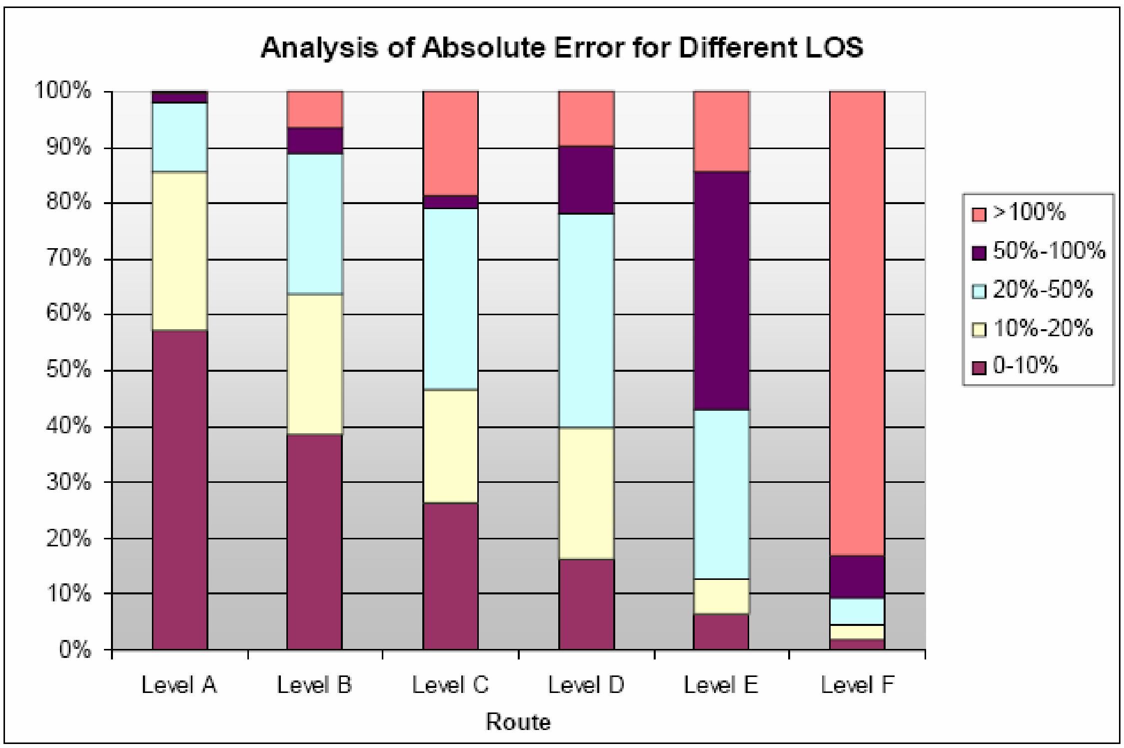

Figure 24 Analysis of Errors for Different LOS [28]

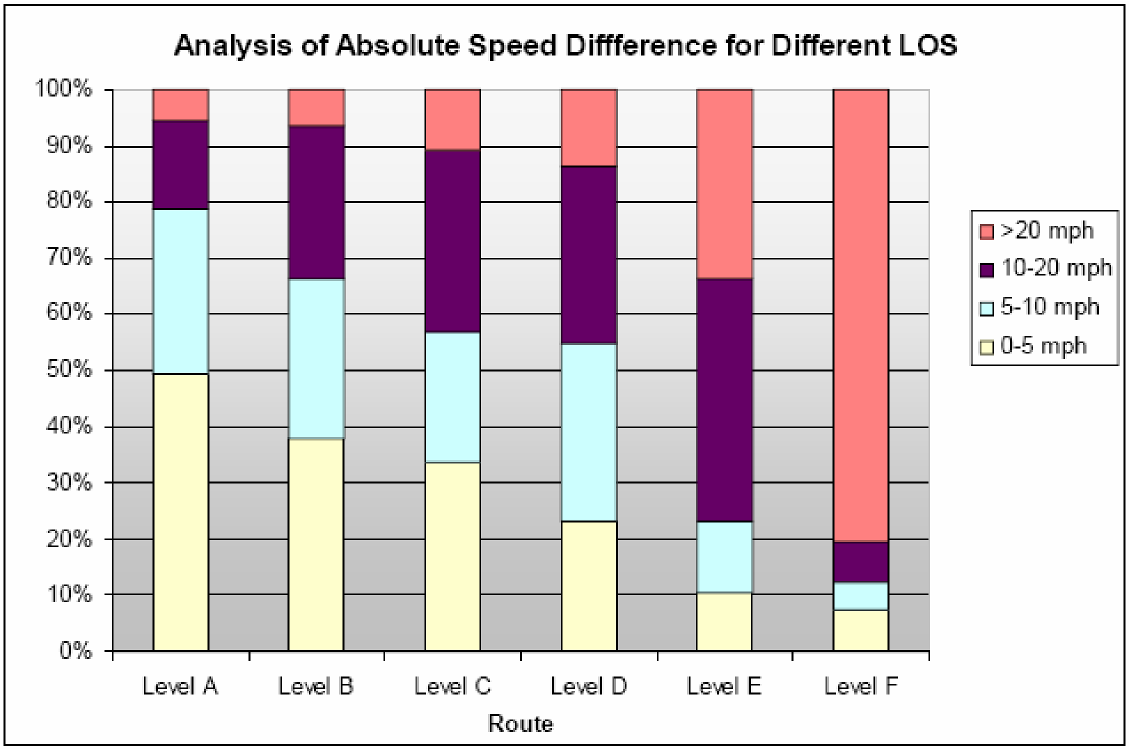

Figure 25 Analysis of Absolute Speed Difference of Different LOS [28]

4.4 Globis Data

Globis Data provides real-time traffic information in Montreal and Toronto, Canada. They have teamed up with Bell Mobility, a mobile service provider, for a project that evaluated built-in GPS cell phones as traffic probes to estimate travel time.

Globis Data processed data obtained from its project partner Bell Mobility, whose users own cell phones with built-in GPS. Bell Mobility sent the phones location data through a firewall, a secured Virtual Private Network (VPN), and the Internet to Globis Data's VPN router, as shown in **Figure 26**. Globis Data used its D.R.I.V.E. Ottawa, Canada infrastructure to associate the location data to a road segment on a map, calculate the speed, and display color-coded speed information of the roads under test.

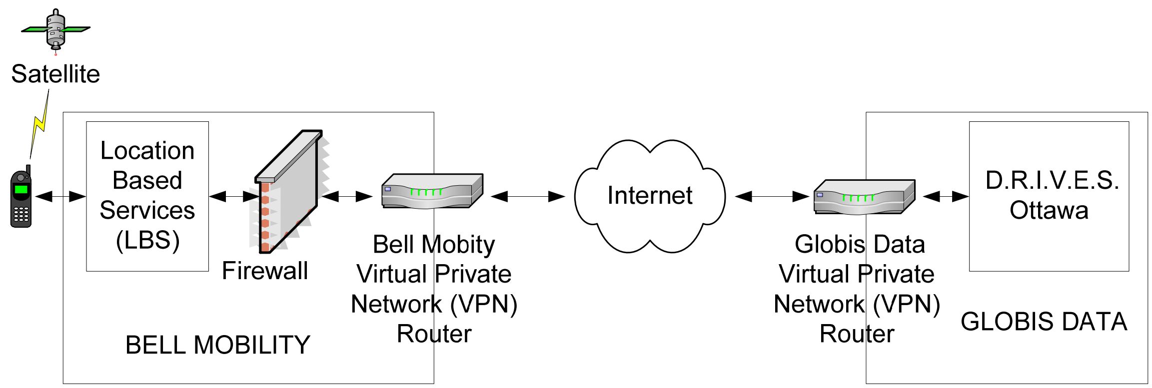

Figure 26 Globis Data's Architecture

4.4.1 Globis Data Test

The tests were conducted on an 18 km portion of Highway 417, Ottawa, Canada, on October 8, 2005, with normal traffic conditions, and October 12, in morning rush hour [29].

The calculated speeds were classified and displayed in one of three colors:

- Green (normal) for speeds greater than 80% of the posted speed limit.
- Yellow (somewhat slow) for speeds between 40-80% of the posted speed limit.
- Red (very slow) for speeds less than 40% of the posted speed limit.

The *observed speed* in a zone was provided by the drivers and observers in the vehicles looking at the car speedometer. The *calculated speed* was computed by dividing the travel distance, calculated using the car odometer, by the elapsed time.

4.4.1.a Preliminary Accuracy Measurements

The objective of this test was to measure the accuracy of the location data from the cell phones with Assisted-GPS used in the project. A marker with a known position to ± 1 mm was chosen as a reference. Four phones were placed at this mark and 250 data location readings were collected. The average difference from the reference mark was 7 m, and over 99% of the data had less than 20 m difference [29], as shown in **Figure 27.**

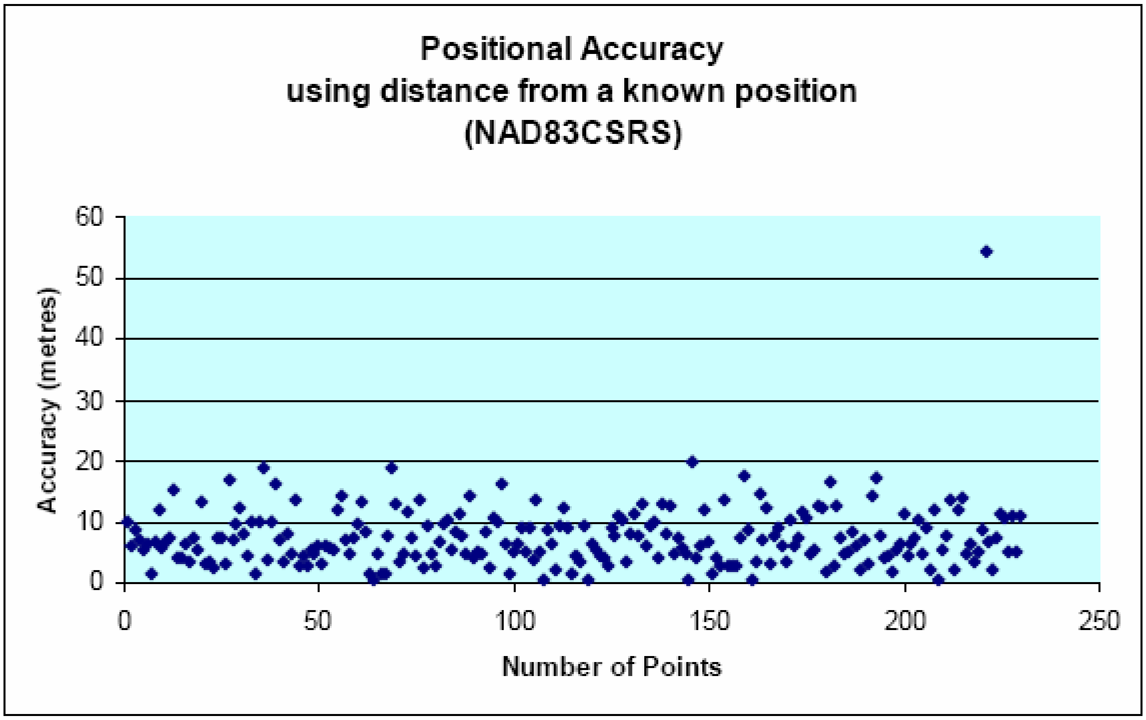

Figure 27 Globis Data's Positional Accuracy Test [29]

The location errors are reflected in the speed calculations by D.R.I.V.E.S - Globis Data software, as shown in **Figure 28.** The test was conducted driving a car at constant speed, according to the vehicle's speedometer, which was previously calibrated. The speedometer readings were corrected by a factor calculated during its calibration. The speed errors were up to 10.5% at 45 km/h and up to 3.2% at 100 km/h.

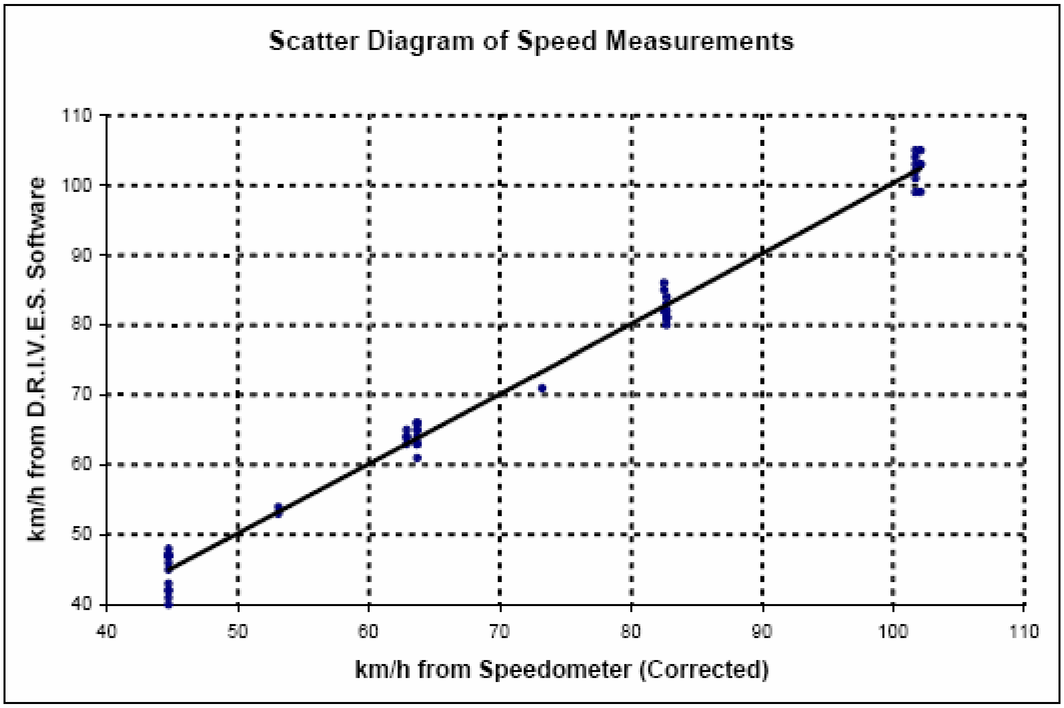

Figure 28 Globis Data's Speed Accuracy Test [29]

4.4.1.b Final Test Results

The test gave the following results:

The D.R.I.V.E.S. green, yellow, and red speeds were 100%, 75%, and 100% in agreement with their respective *Observed Speeds* respectively, as shown in **Figure 29.**

Globis Data D.R.I.V.E.S. Ottawa

		Green 42	Yellow 4	Red 2
Observed Speed	Green	42 100.0%	1 25.0%	0 0.0%
	Yellow	0 0.0%	3 75.0%	0 0.0%
	Red	0 0.0%	0 0.0%	2 100.0%

Figure 29 Globis Data's Observed Speeds Final Test (Highway Only)

The final results comparing D.R.I.V.E.S. speeds with the *Calculated Speeds* were even better. Although there was not always a *Calculated Speed* per every D.R.I.V.E.S. speed, all of them, 34 greens, 4 yellows and 1 red, matched D.R.I.V.E.S., as shown in **Figure 30.**

Globis Data D.R.I.V.E.S.
Ottawa

Calculated Speed		Green 34*(42)	Yellow 4	Red 1*(2)
	Green	34 100.0%	0 0.0%	0 0.0%
	Yellow	0 0.0%	4 100.0%	0 100.0%
	Red	0 0.0%	0 0.0%	1 100.0%

Figure 30 Globis Data's Final Test Results (Highway Only)

Although these results were encouraging, the tests had their limitations. The number of readings was only 48, with 42 greens, and only 6 non-greens. Furthermore, the green, yellow, and red classification is a coarse classification. On a 100 km/h limit, a color red is given for speeds of 40 km/h or less. That would mean that a D.R.I.V.E.S. 40 km/h and an *Observed* or *Calculated Speed* 10 km/h had to be counted as red, even when the first reading is four times that of the second one. Similar cases may happen on green and yellow results. Therefore, a more sophisticated evaluation is needed.

Team FIU TTECP has not found evidence that these results were validated by an independent third party. Globis Data has informed the FIU TTECP team that even though they are involved in travel time estimations, they have not performed further tests.

4.5 IntelliOne

IntelliOne is based in Atlanta, GA. It converts ordinary mobile phone network reports into speed information on all highways and surface streets - wherever cell phone coverage exists [30].

IntelliOne monitors the network and extracts the data, which is processed to calculate speeds and travel time on roads, as shown in its architecture in **Figure 31.** The positioning server calculates the phone position, and the traffic server maps this position on an actual road. The FIU TTECP team finds this architecture to be appropriate, reliable, and applicable to travel time estimations.

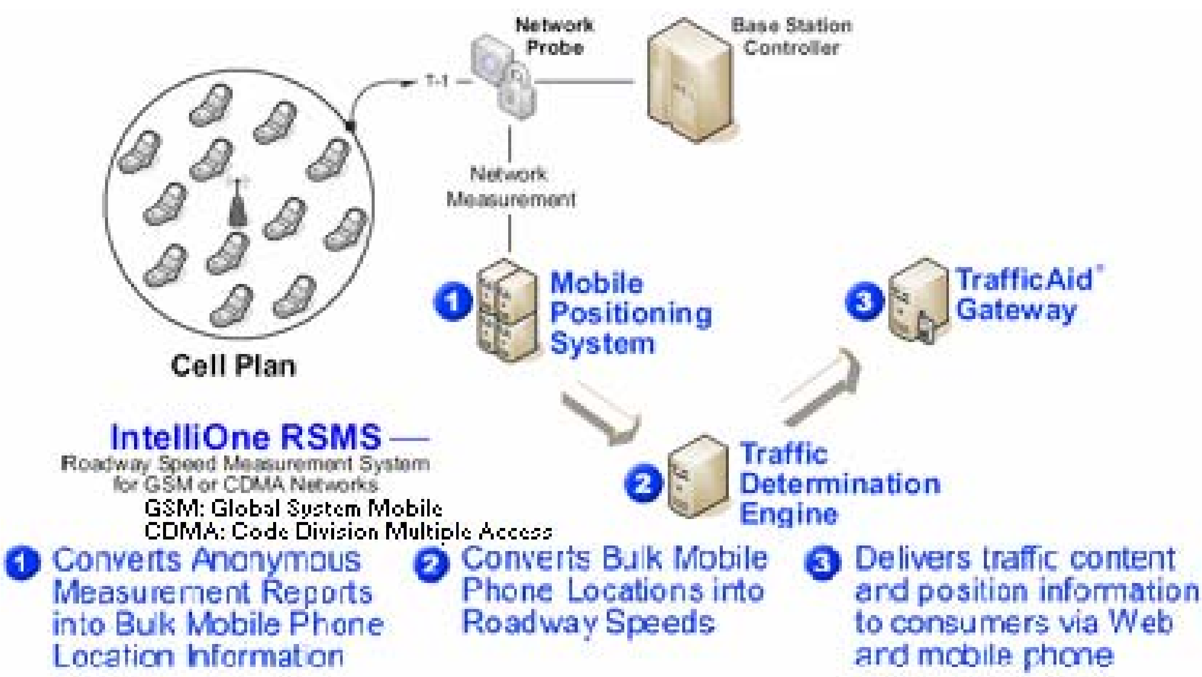

Figure 31 IntelliOne's Architecture [30]

IntelliOne uses US patent No. 6,560,532, *Method and System for Electronically Determining Traffic Information*, assigned to the Regents of California. IntelliOne claims to have exclusive and perpetual license to this patent.

IntelliOne provided to FIU TTECP team real-time access of their test data during their operations with cell probes in Tampa, FL in 2005. The FIU TTECP team analyzed 96.8 miles data along I-275. The FIU TTECPP team compared IntelliOnes's travel time estimation data on six segments along I-275 with Tampa 511 system. The average absolute difference between the two systems was between 5.5 to 34.4%. The FIU TTECP team observed correlation in travel time estimation between the two systems on some segments and significant differences on others. Some IntelliOnes's inconsistencies, such as speed calculations far beyond the speed limits were later minimized using additional filters.

IntelliOne carried out their Need4Speed demonstration in Tampa Bay, FL, during a two week period, during August 8-18, 2006. Due to confidentiality issues, The FIU TTECP team could not obtain the data of this demonstration. Therefore, the team could not perform its own data evaluation

During the demonstration, the positions of the cell phones were placed over the mapping data provided by TeleAtlas, a company that gathers raw data for use in navigation systems, and mobile and online maps. The position was represented by a blue dot so that all calls made during a small amount of time could be displayed on a website graph [31], as shown in **Figure 32.**

The following observations have been made:

- Heavy clusters show traffic congestion. These clusters provided congestion information using graphical display that may help government officials in charge of evacuations.
- There is no direct quantitative relation between the clusters, the speed of travel, and the time of travel.

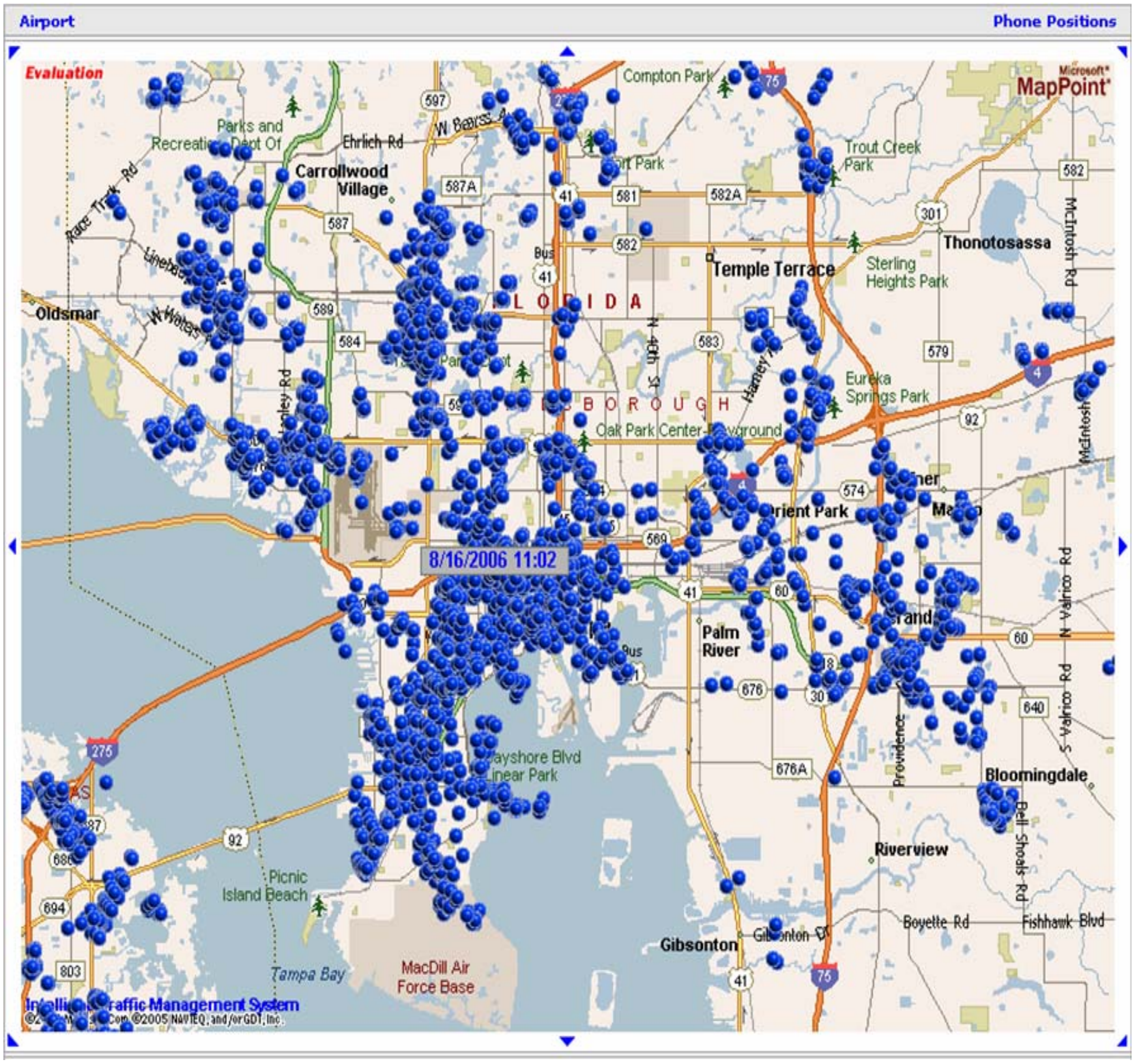

Figure 32 Cell Phone Calls Positions Shown by the IntelliOne's System [31]

IntelliOne's system collects data from the network every 30 s if the phone is not in use or two times a second if the phone is in use. The roads are sliced into segments and averages are calculated for each segment. The estimated speed and travel time are expected to be delivered to the users within two minutes [31]. IntelliOne updates the data and the associated results every minute.

The data were compared with Global Positioning System (GPS) information and the Florida Department of Transportation 511 system, which includes data from video cameras, roadside radar, and in-pavement monitors [31]. The reported accuracy was within 3-5 mph at any given location [31]. The following analysis comes from an IntelliOne's self-report [31]:

Two tests plans were conducted: Test Plan A comprised approximately 23 miles along Hillsborough Avenue, US-41 (Tamiami Trail), and I-4. Test Plan B consisted of 35 miles of freeways along I-75, I-275, and I-4.

For the tests, two vehicles equipped with GPS provided vehicles' location, speed, and heading one per second. The vehicles' drivers were provided with two standard GSM mobile phones

The drivers placed a cell call to another within the vehicle, allowing the cellular network Mobile Positioning System (MPS) to create a location file and the IntelliOne Traffic Determination Engine (TDE) to compute speeds from the cellular network data.

IntelliOne compared:

- GPS location versus MPS location
- GPS speed versus TDE speed

Figure 33 shows a histogram, which has been taken from IntelliOne's report, and it displays a GPS-MPS comparison. The histogram shows in percentage the absolute difference between the MPS and GPS locations. The MPS was tuned for throughput (speed), not accuracy. In its analysis, IntelliOne writes "The MPS positions are within 50 m of the GPS positions approximately 24% of the time. The MPS positions are within 100 m approximately 24% of the time. The MPS positions are within 100 m approximately 45% of the time, 150 m 60% of the time and within 250 m approximately 85% of the time." This histogram basically shows the accuracy of a MPS, which is located inside the cell phone carrier premises, to locate a phone. This data is processed to obtain speed and travel time data. The analysis of this final data reveals the performance of the traffic information system.

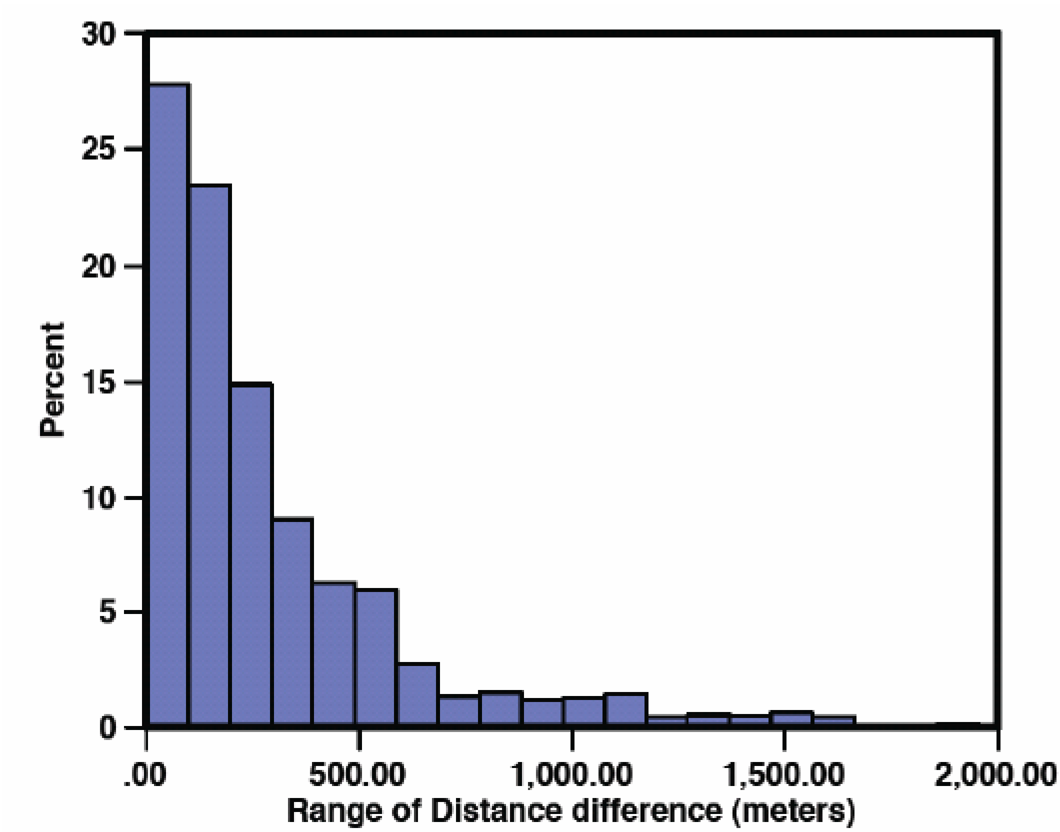

Figure 33 Errors in Radiolocation (percent values) Histogram [31]

The MPS data was processed by IntelliOne's Traffic Determination Engine (TDE) to obtain the road speeds. IntelliOne has provided the histogram shown in **Figure 34,** plotting the speed differences between the TDE and the GPS. The speed calculated by IntelliOne matched the GPS 18% of the time, the difference between them was within 3 mph approximately 34% of the time, and within 10 mph approximately 82% of the time.

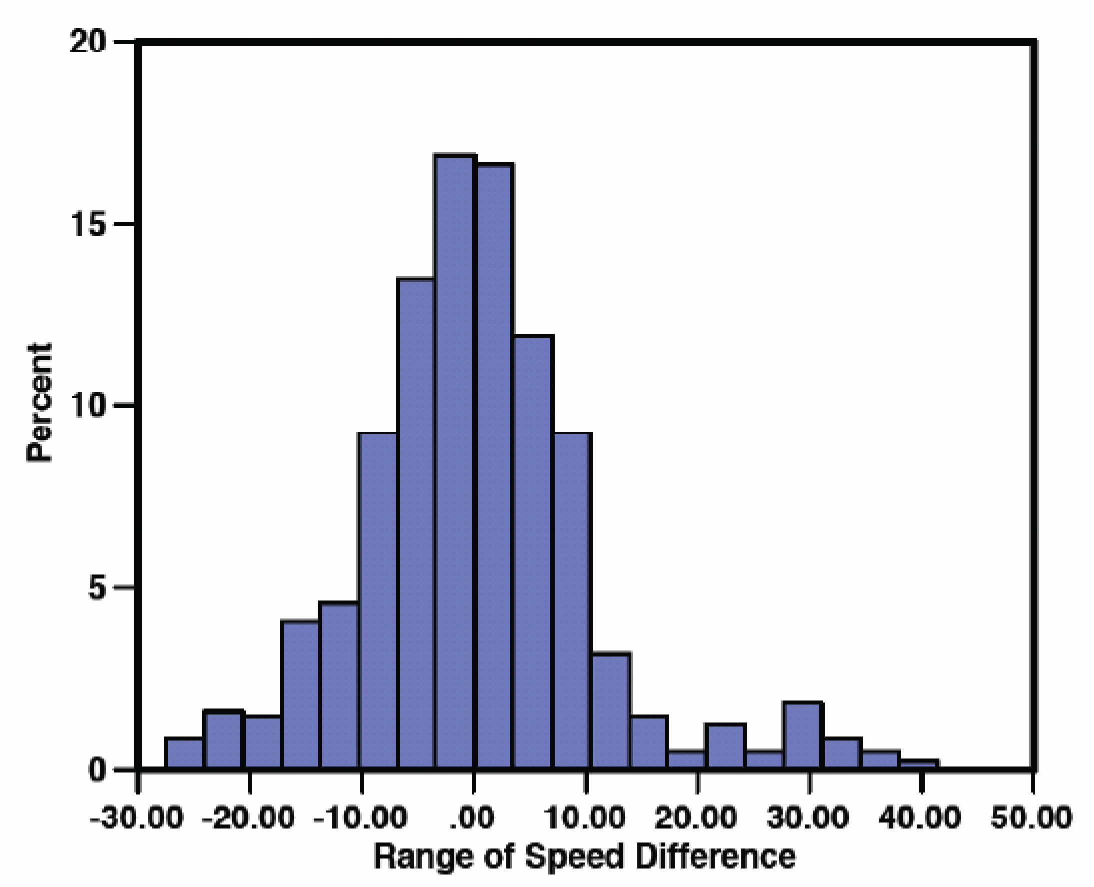

Figure 34 Difference Speed Histogram [31]

The FIU TTECP team observes that although the study is illustrative, it may not reflect real traffic conditions. In the study the phones were in use. IntelliOne did not test its system when the phones were not in use, which is the case most of the time. The FIU TTECP team considers that the calculations should have been done with data collected from other phones that happen to be in vehicles traveling on the same road as the test vehicles. Of course, some phones may be in use and others not, but that is real traffic condition.

Since the FIU TTECP team has not had access to the raw data and all the details about the test, the team cannot validate IntelliOne's result.

4.6 Summary of Projects and Contracts

Table 4 Summary of Projects

COMPANY	NETWORK PARTNER	LOCATION	MILES	DATE
AirSage	Sprint	Salt Lake City, UT		2006-In production
AirSage	Sprint	Fresno, CA (Private contract)	90	2006-In production
AirSage	Sprint	Atlanta-Macon, GA	65	2006-In production
AirSage	Sprint	Norfolk, VA	90	2006-In production
AirSage	Sprint	Atlanta, GA		Projected by Nov. 06
AirSage	Sprint	Minneapolis, MN		Projected by Jan. 07
Cellint	Orange Israel	Tel-Aviv, Israel	12	2004
Cellint	N/A	Kansas City, KA	N/A	2006
Cellint	N/A	GA 400, GA	140	2006
Delcan	N/A	Antwerp, Belgium	N/A	N/A
Delcan	N/A	Tel-Aviv, Israel	12	2005
Delcan	Cingular Wireless	Baltimore, MD	1000	2005-In production
Delcan	N/A	Missouri (statewide)	5500	In progress
Globis Data	Bell Mobility	Ottawa, Canada	15	2004
IntelliOne	Cingular Wireless	Tampa, FL	175	2005, 2006

4.7 Privacy Concerns

All traffic information providers get anonymous data from their cellular carrier partners to protect the cell phone user's personal information. However, there are privacy advocates who are against the use of personal information without consent, and some publications have already addressed these concerns [32], [33], [34], [35].

These privacy concerns are fueling calls to Congress to ban the sale of cell phone records. Privacy advocates say that even with the anonymous data, consumers should have a choice about their information. The San Francisco Bay Area is taking into account these privacy concerns, as explained in the next section.

The San Francisco Bay Area project has rejected cell phones to obtain data to calculate travel time information. One of the primary reasons was the concern for privacy [23]. For a project that costs $35 million over several years, they decided to install an electronic toll pass system to collect data for traffic information. These passes are scanned using Radio Frequency Identification (RFID) technology. The scanners capture anonymous and encrypted information that is later destroyed daily. To ease the concerns of being monitored at other places, the Bay Area Toll Authority mailed metal bags to users. Metal bags shield RF signals so the driver would have to take the pass out of it when approaching a toll booth. Also, drivers who do not want to participate for any reason have the alternative of using traditional toll payments. There are no such alternatives in the cell phone method to collect data for traffic information.

5 Findings and Conclusions

Findings

The FIU TTECP team found by virtue of their investigations that the cell phone technology is viable and mature under the normal conditions of free traffic flow, for the travel time estimations. However, the team has also found that the cell phone technology is not accurate in congested traffic conditions, where the data is more important than in the free-flow traffic conditions, and the accuracy decreases rapidly as the congestion increases. The University of Maryland was the only independent study to conclude that the technology was good for freeways, measuring averages absolutes errors of 7-13% for different highways. However, in their report the average absolute error for the I-985 highways was 10.3 mph (42%), and during congested traffic conditions the average absolute error was 20.2 mph for the highway I-395. There was also the issue that the study was conducted with far less probe vehicles than the recommended values due to budget limitations.

The accuracy of travel time estimation using cellular phones depends on the traffic conditions on the road. Therefore, the accuracy of the estimated travel and speed time must specify the level of the traffic congestion on the roads during the test. Some organizations are claiming to achieve speed measurements within ± 3 to 5 mph. However, the averages have been taken in long intervals of time. For example, if the interval has four hours of traffic congestion per day, and the system error is 20 mph during congested traffic, and 3 mph during non-congested traffic for 20 hours, the average error per day of the interval would be 5.83 mph [(4*20 + 3*20) / 24]. Sometimes these averages are misleading and give an impression of better accuracy. Therefore, these average errors should be taken with caution.

The FIU TTECP has analyzed many report studies and each presented their results in different ways: sole average, average according to two or three levels of traffic congestion, average and standard deviations, etc. Some studies measure travel time, others speed time. Some studies used vehicles probes data and other used loop sensors as reference. As a result, the different methods used to analyze the data complicated the comparison of these studies.

Traffic information providers using cell phones as probes depend on the wireless cell phone networks. This dependency is very critical, since the cell phone companies are not necessarily interested in the traffic information business. The cell companies already use their allocated bandwidth to the limit in their established, competitive, and profitable services such as the multi-customer conference calls, webbing, etc. Therefore, if the public in general is not willing to pay for additional services, the cell phone companies are not likely to be interested in lending their networks. That is why traffic information providers put effort into loading the network as little as possible.

All the companies have implementation requirements to secure the privacy of the cell phone users. Wireless Service Providers already encountered problems protecting the private information of their users. This has been prompting concerns and complaints from privacy advocates. The tapping of network data by third party organizations (like traffic service providers) has already increased the level of concerns about privacy. These concerns are further expected to increase, with law makers getting involved in possible legislation regarding the security and privacy issues. Therefore, security measures by the wireless companies, such as replacing the user identification data (ID) with coded numbers before leaving wireless network premises, firewalls and secure channels, data encryption and trans-positioning schemes, etc, are becoming necessary to gain the acceptance of the public to use their cell phone services, especially when the cell companies are selling user related information to third party organizations. As such, using the anonymous cell data for travel time estimations may not have free ride and may not provide the needed accuracies, especially under the congested traffic conditions. In addition, incidents such as the accidents and construction bottle necks can not be obtained from the anonymous cell data.

Conclusions and Recommendations

FIU TTECP did not find indisputable evidence that travel time estimation using cell phones as probes is accurate enough in heavy traffic conditions. As such, it recommends independent evaluations, in which the data can be analyzed to corroborate previous findings, especially if mixed results were obtained.

To assess the technology, FDOT should select the criteria that the study results must meet. For instance, a requirement may be made that computed speed with cell probes be at least 95% accurate (absolute error < 5%), at least 95% of the time, at all levels of traffic conditions.

Travel time providers using cell phones as traffic probes depend upon the wireless cell companies to obtain the anonymous positional data of the cell users in order to allow them to compute the travel time estimations on the highways and the roadways. The traffic information providers should demonstrate the involvement of the wireless cell network companies in the cell probe-based travel time estimation activities.

The travel time companies should also demonstrate their ability to interface with more than one cell carrier, and adapt to the changes in cell data activity. This is particularly true as the cell phone companies are changing their affiliations and scope of activities, and their system architectures and cell data extraction methodologies.

There should be continuous evaluation of the cell travel time data by other means such as the 511, toll center computations, and road sensors, and initially floating car techniques, to develop a dynamic working model of variances of the speed and travel time data, and probable extrapolation for predictability of these entities.

Cell technology is improving rapidly with cell companies providing video conferencing capabilities on cell platforms. Perhaps, participating cell customers can provide the real time video information directly to the travel time providers regarding incidents, accidents, construction zones, and other traffic slow down scenarios. The travel time providers can further analyze this information to provide the most needed information to travelers regarding the travel times, alternate routes, and possible predictions.

All these issues need to be further investigated.

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Appendices

A Studied Companies

Table 5 Studied Companies

Company	Comments
AirSage	• Uses existing cellular network infrastructure. • Provides traffic information (speed and travel time) for highways and arterials. • No road-side equipment (hardware) installation and maintenance needed. • Data Extraction can be obtained inexpensively from carrier networks. • To obtain secondary data or incident locations, it must use LBS and E911 technologies.
Andrew (Geometrix)	• Network solution. • Supports all phone technologies. • Claims to meet and surpass the FCC requirements. • Private network with five sites that covers approximately 18 square miles.
Cellint (VirtualSensor)	• Provides real-time travel time. • Provides traffic speed data, and immediate incident alerts. • Works with DOTs. • Successful when compared to road sensors and FCD (Floating Car Data). • Simulates road sensors at an average distance of 200 m. • It uses wireless network provider's infrastructure. • From Israel.
CloudBerry	• 100% nation coverage. • Designed for vehicle fleets.

Company	Comments
Decell (AutoTraffic)	• Provides location-based traffic solutions to mobile network operators and application service providers. • Recommends driving routes. • Alerts members of travel problems. • Uses existing mobile network infrastructure. • Random Probing to protect privacy. • Based in Israel. • Error (ETT) < 10%. • At least 1 millions users needed for network data.
Delcan (ITIS)	• Based in England. • Leader in England. • Uses cell phone and GPS data. • Tracking and travel time services.
Globis Data	• Provides current traffic information (updated every 3 minutes). • Collects information from a sensor network in Canada.
IntelliOne	• Rapid deployment. • No additional load on the mobile network. • Cover major and minor roads. • Real-Time data. • It uses a wireless network provider.
Intrinsic	• Provides travel time for all roads. • Records trips to analyze travel time (Commute Advisor). • Provides faster routes using real time data. • Focus on GPS data from fleet vehicles.
IT2Me	• Extracts accurate information from GPS. • Exclusive service to Nextel Wireless Network. • No traffic information provided.
LADSnet	• Tracking system with speed capabilities. • Works with Nextel phones. • Designed for dispatchers.

Company	Comments
LogicaCMG	• Provides journey times instead of length of traffic jams. • Covers entire network of highways, as well as regional and urban roads. • Provides comparable travel-time estimates for road alternatives. • Equipment must be implemented in road-side. • Company based in The Netherlands. • Not clear if service needs partnership of wireless service provider.
Networks in Motion	• 1st Place in 2004's Wireless LBS Challenge. • Accurate global positioning of software users. • Works with GPS-enabled phones only. • Extremely focused on user location (AtlasTrack). • Traffic-tracking capabilities unstipulated.
Open Motion	• Updates based on historical conditions, weather, construction, incidents, and special events. • Provides driving directions. • Comprehensive mobile platform. • Limited information on its website.
Quarterscope Solutions (WPS-Net)	• No GPS required. • Accuracy of 10 - 20 m. • No line of site requirements. • Tested to be 95% as accurate as GPS. • Miami coverage. • Only for Laptops and PDAs with Wi-Fi capabilities (no phones). • Devices usually off on the road.
ReachEverywhere	• Research for solutions as consultants.
RoDIN24	• No road-side infrastructure (equipment) installation and maintenance needed. • Mobile network vendor independent. • High-Quality and Accurate Data. • Full Road-Network coverage. • Data Extraction depends on Wireless Network Switching Centers from carriers' networks. Then, raw data is processed by RoDIN24.

Company	Comments
Televigation	• Detailed directions on how to reach a requested destination. • Searches for a requested point of interest. • Traffic alerts along the user's path. • Software Platform.
TrafficCast	• Updates based on historical conditions, weather, construction, incidents, and special events. • Supports value-proposition for commuters, business travelers, and fleets. • Driving direction demonstration. • Color-coded real-time and predictive traffic speed map. • Dynamic Routing (with Construction and Incident). • Needs a hand-held computer with network connections to display offered information.
ULocate	• Location positions are updated every two minutes. • Uses government's GPS. • Works only with certain Motorola phones and certain carrier networks. • Gives geographical location of those phones listed on their account.
Zip Dash	• Provides map with listed average speeds on roads. • Work with Nextel phones. • Limited to regions.

B Other Organizations in Traffic Services

B.1 Inrix

Late in the project, the FIU TTECP team came across another company in the traffic information market: Inrix.

Inrix, with headquarters in Kirkland, WA delivers real-time and predictive traffic services nationwide. It was founded in July 2004 by former Microsoft executives Bryan Mistele and Craig Chapman [36]. Its main source of data comes from GPS devices.

Inrix claims to be the exclusive beneficiary of years of research and millions of dollars of development by Microsoft Research into the statistical inference of traffic patterns, predictive analysis and mobile-based visualizations of real time systems [36].

Inrix aggregates data from anonymous, real-time GPS probe data from more than 500,000 commercial fleet, delivery and taxi vehicles across the U.S. with toll tag data, occupancy and speed measurements from Department of Transportation sensor networks, and other real-time traffic flow information, such as construction and road closures, real-time incidents, sporting, and entertainment events, weather forecasts, and school schedules [36].

Inrix offers real-time and predictive travel time estimation, predictive dynamic routing, incident data, and free-flow speed by road segment. **Figure 35** shows some answers that Inrix is able to provide to its customers.

Predictions

- How long will it be before traffic starts to back up at the I-5/I-90 interchange?
- How long before the congestion there now clears up?
- Is this congestion normal or an anomaly?

Forecasting

- How long will it take me to get to the airport tomorrow morning?
- What will traffic be like at 6:00PM tonight? How long will it take me to get home?
- What is the optimal time for me to leave for work in the mornings?
- When I arrive at JFK airport at 3:00PM in two weeks, how long will it take me to get to my hotel in Manhattan?

Predictive Dynamic Routing

- What is the quickest route to get downtown right now?
- What will be the quickest route for me to get to my hotel in New York when I fly there in two weeks?

Figure 35 Questions that Inrix's System is able to answer [37]

Inrix targets a broad range of markets: regional and federal government agencies, automobile manufacturers, personal navigation device manufacturers, satellite radio and high-definition (HD) radio service providers, location-based services, mapping application providers, mobile phone application developers, wireless operators and telematics service providers, and fleet management solution providers.

In Florida, Inrix covers Fort Myers-Cape Coral, Jacksonville, Miami-Fort Lauderdale-Miami Beach, Orlando-Kissimmee, Palm Bay-Melbourne-Titusville, Sarasota-Bradenton-Venice, Tampa, St, Petersburg-Clearwater, and West Palm Beach-Boca Raton.

B.2 Traffic.com

Traffic.com is mentioned in this report as the organization whose sensors are used to compare cell phones as probe technology. It is also mentioned in the next section as an inexpensive alternative for the DOTs to obtain traffic information. Therefore, the profile of this organization is also included in this report.

Traffic.com is based in Wayne, PA, and it is one of the leading providers of travel time estimation. Their main source of data is their own digital roadside sensor networks. The company has recently signed an agreement with Caltrans to construct a digital sensor network in San Jose, CA and Sacramento, CA. As part of the Federal Highway Administration (FHWA)-funded Transportation Technology Innovation and Demonstration (TTID) program, Traffic.com will pay for the construction, operational costs, and ongoing maintenance of the sensors and will also reinvest a portion of the revenue to expand the system.

Their market includes government agencies, broadcast media, in-vehicle navigation, consumer, advertising, and web content. Customers include more than 100 independent radio stations and over 70 television and cable stations. They deliver real-time, highly personalized, on-demand traffic information to drivers [37]. Traffic.com currently serves 50 metropolitan areas throughout the U.S. covering approximately 100 million drivers of which 70 million are daily commuters.

Traffic.com integrates data from a proprietary network of digital roadside sensors, agency data shared by government partners, state-of-the-art event and accident information gathered through Traffic.com's local operations centers based across the country, and probe data, defined as anonymous, location-based data delivered from GPS-enabled vehicles, toll tags, and cellular signaling. **Table B1** summarizes Traffic.com's data sources [38]. Traffic.com is able to combine and analyze various factors and apply high-end algorithms to billions of data points to predict traffic trends before they happen.

Table 6 Traffic.com's Data Sources [38]

<table>
<tr><th colspan="4">TRAFFIC.COM'S DATA SOURCES</th></tr>
<tr><th>Own Sensors</th><th>Government Sensors</th><th>Cell Phone</th><th>Toll Data</th></tr>
<tr><td rowspan="2">Boston, MA
Chicago, IL
Oklahoma City, OK
Philadelphia, PA
Pittsburgh, PA
Providence, RI
San Diego, CA
St. Louis, MO
Tampa, FL
Detroit, MI
Los Angeles, CA
San Francisco, CA
Phoenix, AZ
Washington, DC
Baltimore, MD (*)
Salt Lake City, UT(*)
Seattle, WA(*)
(*) Pre-construction</td><td rowspan="2">Atlanta, GA
Chicago, IL
Baltimore, MD
Dallas, TX
Denver, CO
Detroit, MI
Houston, TX
Los Angeles, CA
Milwaukee, WI
Minneapolis, MN
New York, NY
Phoenix, AZ
Sacramento, CA
Salt Lake City, UT
San Diego, CA
San Francisco, CA
Seattle, WA
Washington, DC</td><td>Salt Lake City, UT</td><td>Houston, TX
San Francisco, CA
New York, NY</td></tr>
<tr><td colspan="2">Miscellaneous
• GPS from some of their vehicles
• Incident Data
• Event Data</td></tr>
</table>

Traffic.com usually provides traffic services to radio and TV in exchange for advertisement slots, which Traffic.com sells to third party companies [34], as shown in **Figure 36.**

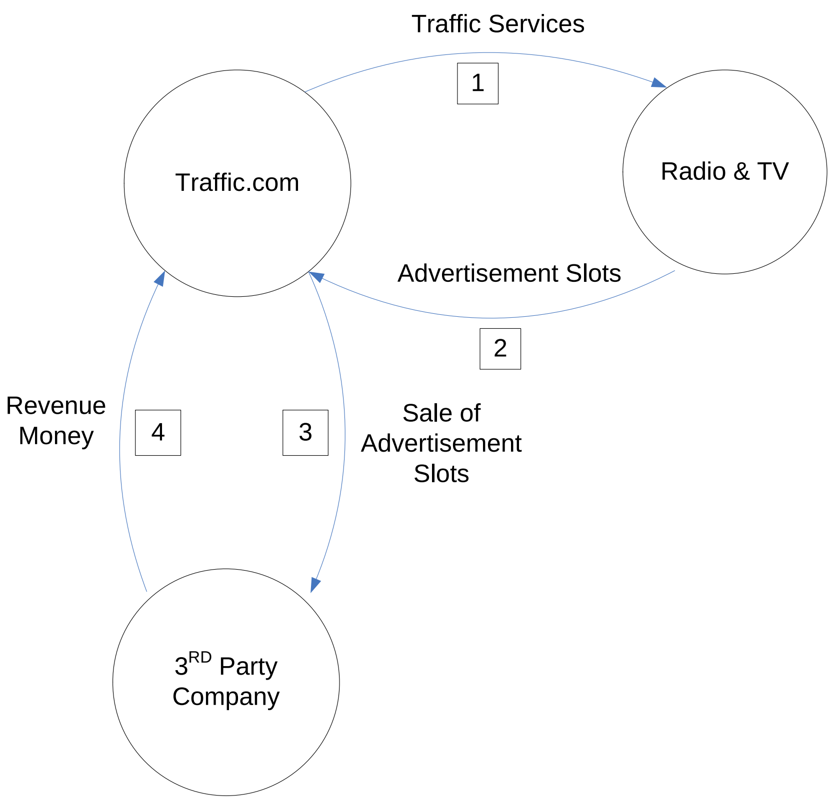

Figure 36 Main Source of Revenue of Traffic.com

Currently, Traffic.com is focusing on its growth by selling advertisements on their website. To attract advertisers, Traffic.com is trying to increment the visitors to their web site by offering free personalized traffic services, as well as making agreements with other companies trading its services in exchange for more exposure to their traffic.com website.

C Statistical Analysis

When comparing two measurements, generally one of them is designated as a reference and the other as the measurement under test. The difference between them is usually called the *error*, as shown in **Figure 37.** Obviously, zero error is the ideal measurement.

Every calculation has an error when compared to the reference values. The analysis of these data has to deal with the data themselves and the errors. **Figure 38** shows at the top two series of data: one taken from the system under comparison and the other from the reference system. At the bottom, the errors, respective to the reference, are illustrated. For example, at 1 s, data-1 shows a value of 16 mph and the reference gives 14 mph, so the error is 2 mph.

Figure 37 Error of a Measurement

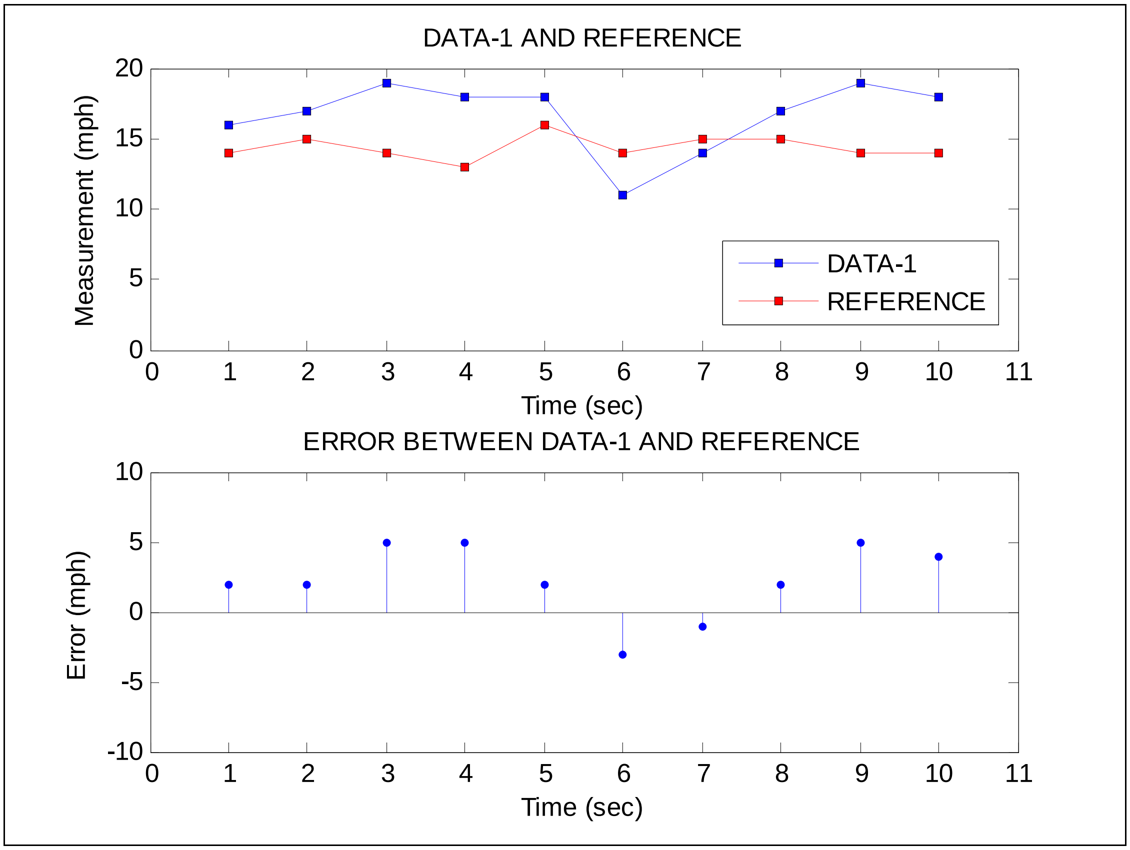

Figure 38 Error Between Two Data

C.1 Average Error (Δ_1)

An important aspect of the system is the expected error, which is the *average* of the errors,

$$\Delta_1 = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)$$

Figure 39 shows the system error of a system respective to a reference system. The average of this error is 2.3 mph, enhanced with a dashed red line in the figure. Therefore, the expected error of the system under test is 2.3 mph.

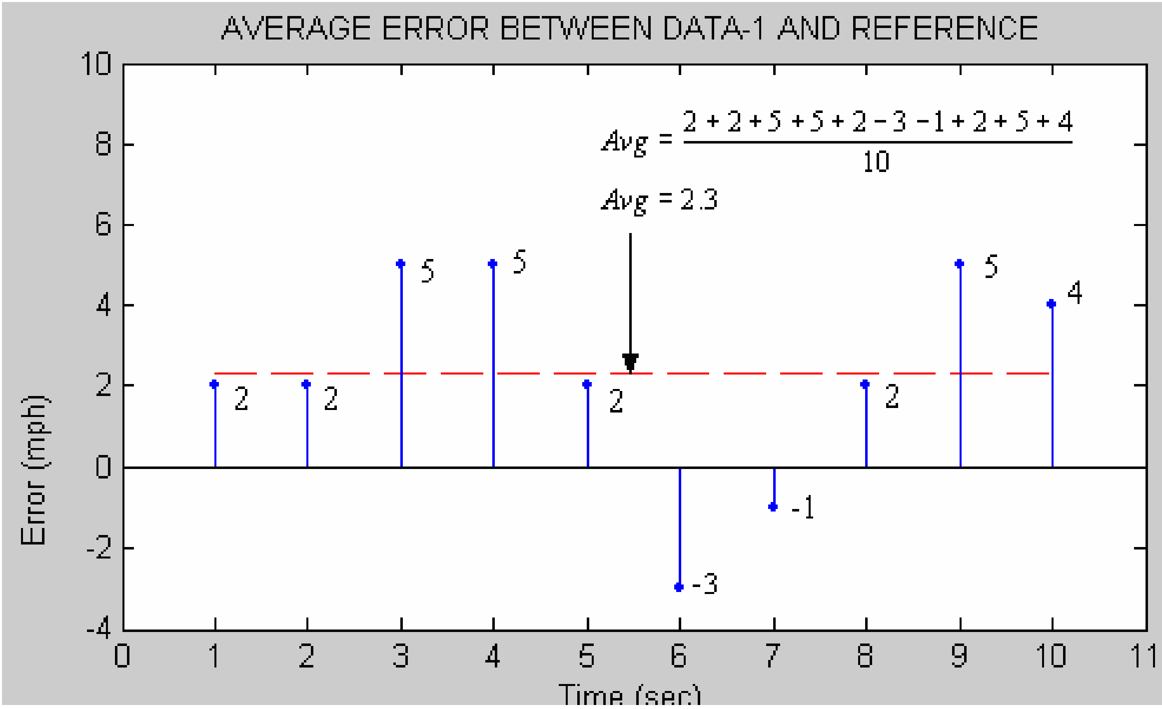

Figure 39 Average Error of a system (Δ_1)

Although the average calculation provides important information about the system under test, it could be misleading. **Figure 40** shows a system which is suppose to measure 10 mph at all times, but the system under test gives up to 10 mph error, a 100% error. However, the average error Δ_1 is zero, because the errors have different signs and cancel each other. To solve this limitation, another calculation is performed: the average of the absolute of the errors.

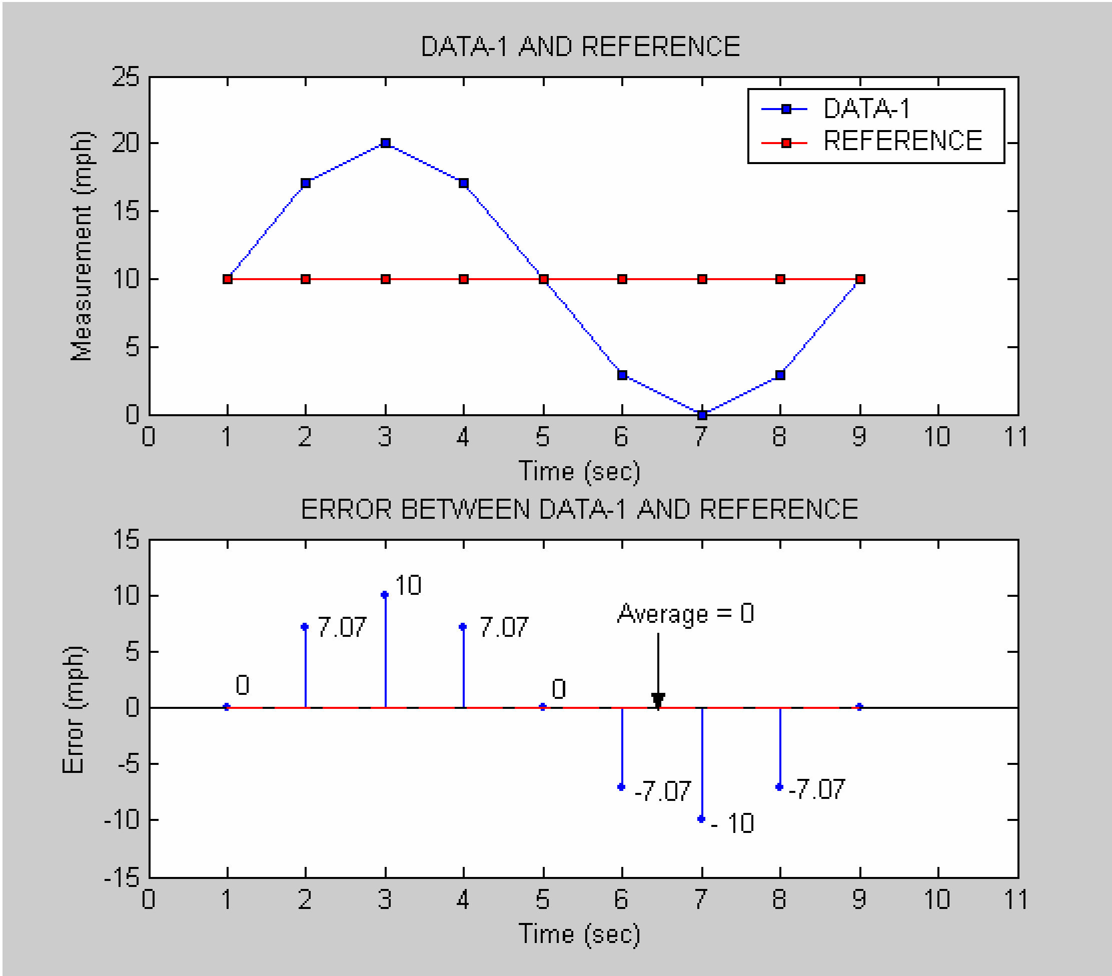

Figure 40 **System With Zero Average Error (** $\Delta_1 = 0$ **)**

C.2 Average of the Absolute Errors (Δ_2 *)*

The average of the absolute errors of a system provides the expected average error, with respect to the reference, without taking into account whether the individual errors are over or under the respective reference. For this calculation, the absolute value of each error is taken before calculating the average,

$$\Delta_2 = \frac{1}{n}\sum_{i=1}^{n}|x_i - y_i|$$

Figure 41 shows the same measurements for the system under test as in the previous section. In this case only positive numbers are averaged. The system is expected to have an average error of zero and an average absolute error of 5.36, which is a better description of the system. However, other calculations may still be needed for an adequate analysis, such as the calculation of the average of the absolute difference between the errors and its average.

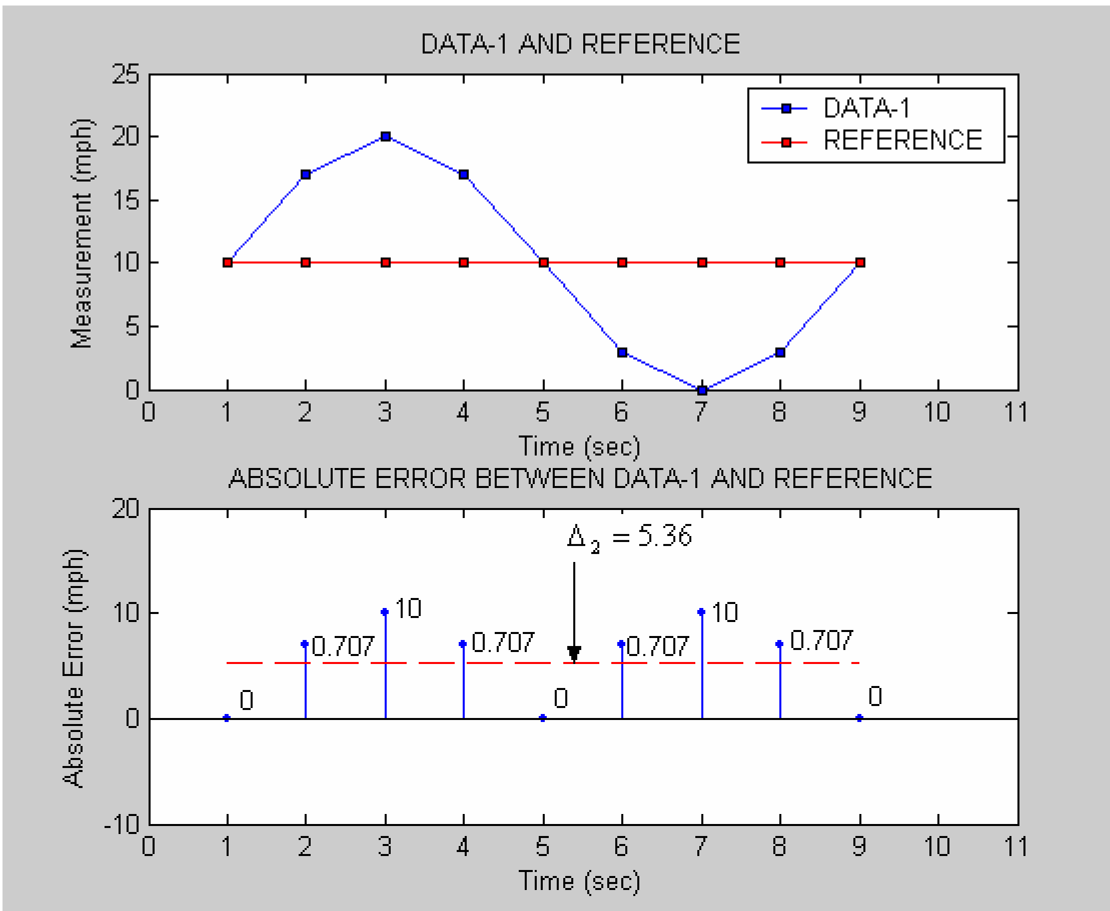

Figure 41 **Average of the Absolute Error (Δ_2)**

C.3 Average of the absolute of the errors, Δ_1 compensated (Δ_3)

This average gives an indication of the smoothness of the system. A zero value indicates that the error is constant, and the higher the value, the more fluctuations in the errors. To calculate this value, the mean value, Δ_1, is subtracted from the error. Then, the average of the absolute of these values is calculated,

$$\Delta_3 = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - y_i \quad - \Delta_1\right|$$

Figure 42 compares two data sets, data-1 and data-2, against the same reference. In this particular case data-1 is smoother than data-2, as shown in **(a)** and **(b)**. The averages Δ_1 and Δ_2 happen to be 3.0 mph for data-1 and data-2-2, illustrated in **(c)** and **(d)**. Because data-2 is noisier, its Δ_3 = 1.6 is higher than data-1, which has Δ_3 = 1, as shown in **(e)** and **(f)**.

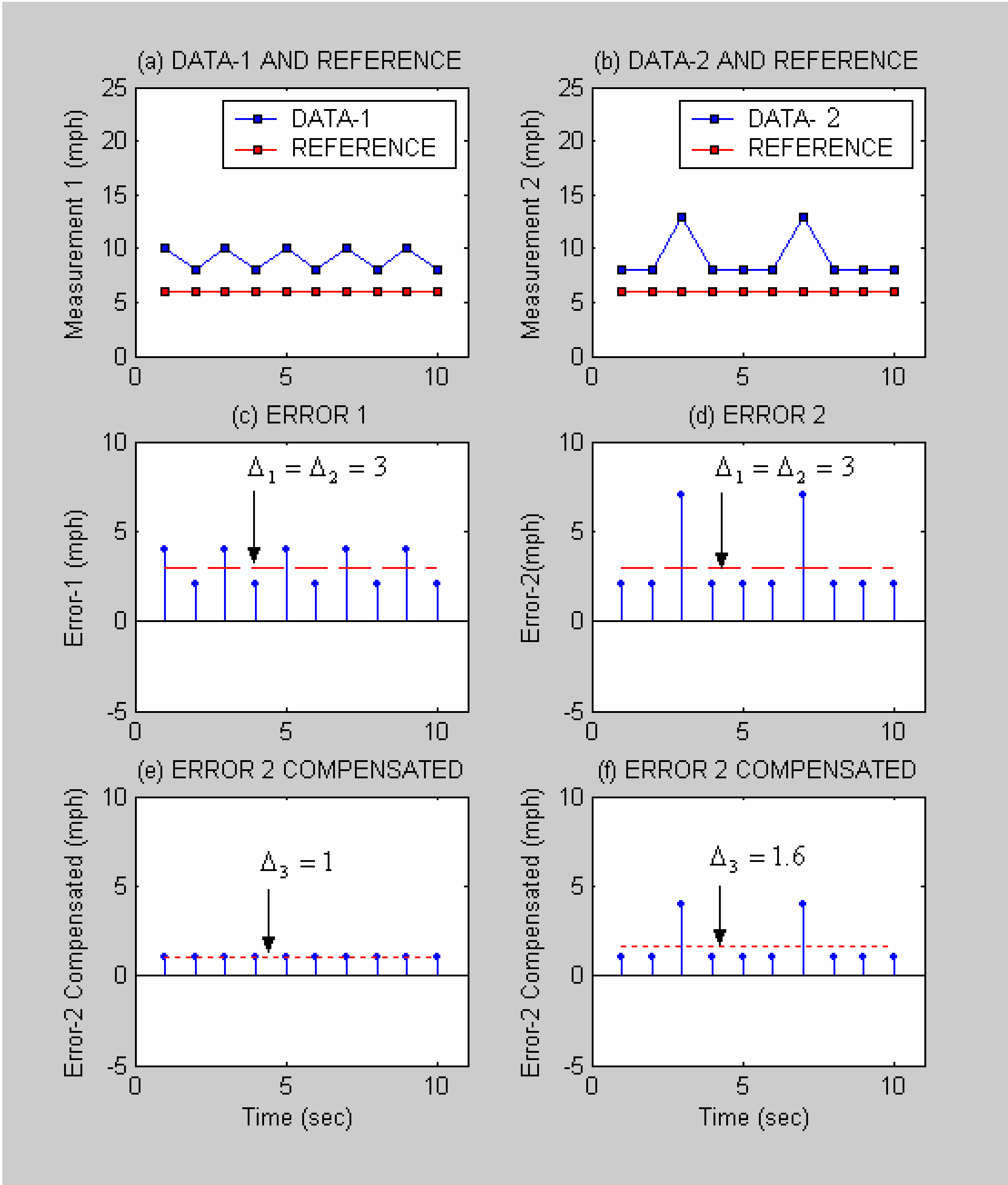

Figure 42 **Average of the Absolute of the Difference, Mean Compensated**