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The State of Cellular Probes

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The State of Cellular Probes

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Task Order 4139

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This paper is prepared to fulfill Caltrans' Task Order 4139. The objectives of Task Order 4139 were to coordinate the joint study between PATH and INRETS, National Transportation Research Institute in Lyon, France, and to report on the cellular probe study conducted by INRETS in Lyon, France. The author wishes to thank Dr. Jean-Luc Ygnace for sharing his field test results of cellular probes in Lyon and reviewing this paper. Thanks to Randall Cayford for his research on cellular probe technologies and for his comments on this paper.

ABSTRACT

Cellular probe technology is one of several potentially promising technologies for obtaining accurate travel time information. In 1996, the Federal Communications Commission (FCC) mandated E911 requirements that cellular location be provided when 911 emergency calls come in to emergency management authorities. The E911 requirements allow 50 –300 meters from the emergency call location, depending on the type of cellular phone technology used and whether handset-based or network-based solutions are deployed. This paper investigates the current state of cellular probe technologies. Recent studies and field tests are reviewed and summarized. As of March 2003, at least four location technologies have been partially or fully deployed. Although these solutions have the accuracy to provide acceptable travel time information, E911 technologies were developed for a different purpose. The use of the E911 infrastructure for probe activities introduces additional concerns such as privacy issues, the need to provide multiple locations on individual phones, and the effects on the carrier networks occasioned by the need to determine large numbers of locations. Further research is recommended in several areas. These include the improvement of cellular geolocation technologies for cellular probes, the establishment of a public-private partnership between transportation agencies and cellular carriers to support probe activities, and the investigation of institutional issues and challenges ahead in order to more effectively deploy cellular probe technologies.

Keywords: Cellular technology, vehicle probes, wireless privacy, institutional issues

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EXECUTIVE SUMMARY

Since the E911 mandate, many studies have investigated the ability of cellular technologies to efficiently and cheaply collect reliable travel time information. In 1996, the FCC (Federal Communications Commission) issued E911. It requires that cell phone locations of 911 emergency calls be reported to appropriate authorities for timely emergency response. To meet the E911 requirements, the FCC permits both network-based and handset-based cellular tracking solutions. The E911 standards are: 67% of calls be identifiable within 100 meters and 95% of calls within 300 meters for network-based solutions; 67% of calls be identifiable within 50 meters and 95% of calls within 150 meters for handset-based solutions. The hypothesis was that the E911 cellular tracking technologies are capable of probing vehicle speeds when cell phones are "on."

The study objectives are to 1) assess the current state of the E911 probe technologies, 2) review recently conducted field tests of cellular probe projects, 3) invite discussions on the feasibility of cellular probe technologies for travel time estimates, and 4) recommend further research on cellular probes.

Cellular phone tracking is one of the potentially promising vehicle-probe methods likely to produce reliable travel time information. Several reports claim that the E911 vehicle location method is feasible in producing acceptable freeway vehicle speeds, yet very few urban regions are considering the deployment of cellular probes for traffic surveillance. One possible reason is that cellular probes have not yet been validated. If cellular probes work, this technology is potentially the best method to collect travel time data in areas where no infrastructure is provided, i.e., rural freeways and local arterials. In addition, cellular probes can augment loop detector data since only about half of the loops are reliable at any given time.

The assertion is that rapid penetration of the cellular market (nearly 55% of the traveling population in the San Francisco Bay Area) makes cellular probes possible by simply working with one or two carriers in order to produce reliable travel time information. Questions are: 1) how far have we come in developing and testing methods of accurately measuring travel times using the cellular technology, 2) what issues still remain for the practical application of cellular technologies for

travel time measurements, and 3) how can the cellular probe method be improved? The paper addresses these issues. Cellular location technologies to date are documented and recent field tests of cellular probes are summarized. Potential privacy issues are identified.

Four of the six largest US cellular carriers use handset-based solutions and the other two use network-based solutions. As of March 2003, three handset-based solutions, Sprint PCS, Verizon and T-Mobile are deployed. Nextel, a handset based solution using IDEN phone technology is partially deployed. Both Sprint and Verizon use an assisted GPS positioning system for their CDMA phone technology. Nextel also uses a GPS positioning system. Table 3 is a summary of the major carriers and their chosen solutions as of March 2003.

The most extensive study of cellular probes to date is the STRIP (System for TRaffic Information and Positioning) project for the Rhone Corridor evaluation in Lyon, France (Ygnace, et al, 2001). In the US, an extensive field test of the RadioCamera™ technology was conducted on the Capital Beltway in Virginia but the project was discontinued for financial and institutional reasons. A small-scale field test was conducted for the Travel Information Probe System (TIPS) in the San Francisco Bay Area by PATH (Yim and Cayford 2000).

The Rhone Corridor study showed that there is a significant relationship between the number of outgoing cellular calls and the level of incidents (correlation coefficient 0.263, pr = 0.001). No significant correlation was found between the incoming calls and the level of incidents. The study concluded that it is possible to detect the level of incidents based on the variation of outgoing call volumes because people tend to call more often when the road is congested. The STRIP project evaluated the feasibility of the location technology called Abis/A Probing for travel time estimates. The evaluation method used in the STRIP project was the comparison of the probe data and the inductive loop detector data taken from the same freeway segments at the same time period. Two sites were field tested: the intercity motorway between Chanas and Tain, south of Lyon (a 32 km motorway was subdivided into eight segments - four Northbound and four Southbound) and the intra-city motorway west of Lyon (a 4km motorway was divided into two segments - one Northbound and one Southbound). The field test done on the intercity motorway segments showed a small variation (6%) between probe and loop detector data. The intra-city motorway showed a larger variation (15%) between probe and loop detector data. The reasons may be sampling inconsistencies and inaccurate cellular positioning due to close proximity to commercial activities along freeways. In addition, a short segment (6 km) of urban freeways does not give any latitude to verify the position of the phones to calculate the speed from two fixes. However, the field tests reported that the values of vehicle speeds from the loops remained within the standard deviation interval of the average speeds obtained from the probes (Ygnace et al, 2001).

Since 1999, PATH has been actively involved with research and development of cellular probe technologies. With Caltrans' support, PATH developed the TIPS software. The initial TIPS capability was to detect 78% of unambiguous freeway segments. The TIPS research continued with support from the National Science Foundation (NSF). Based on the initial TIPS technology research at PATH, the NSF study developed algorithms to detect and correct variations in location accuracy, to identify anomalous probe behavior and to improve the TIPS ability to differentiate routes taken by a cellular probe vehicle when roads are very close together (Cayford, 2002). The study also developed methods of determining which cellular phones to follow and determined the operational parameters for specific location technologies for easily evaluating new technologies. This study was able to improve the software capability to increase the detection of unambiguous freeway segments from 78% in the previous PATH study to 99% with the enhanced algorithm using location accuracies of 100 meters, the lower limit for E911 deployed technologies.

Two basic factors determine the feasibility of cellular probes. One is the cooperation of the wireless carriers to produce cellular locations with the appropriate characteristics and the other is a software that can analyze cellular position data over a large area, correct errors in the data stream and adequately select sample probe phones (Cayford 2002).

Regarding vehicle probe technologies, the consensus (ITS America Forum, 2002) is that: 1) it is too early to pick a single technology as a long-term winner, 2) cellular phone technologies with assisted GPS systems seem to work, at least for E911 requirements, and their potential for vehicle probe is promising, and 3) emerging cellular technologies should be tested and evaluated for their vehicle probe possibility.

Wireless privacy is an important issue in the development and deployment of cellular probe technologies. Recent studies indicate that consumers are consistently concerned with privacy related to wireless technologies. In July 2002, the FCC denied the Cellular Telecommunications and Internet Association's (CTIS) request that the Commission adopt wireless location privacy rules to implement the Wireless Communications and Public Safety Act of 1999 (the enabling legislation for E911). Currently, privacy laws vary considerably by state. Wireless privacy issues related to E911 are yet to be identified. Public concerns with and awareness of wireless privacy issues are potential issues facing the cellular probe projects.

The present study recommended further studies in several areas:

1) Examine the deployed cellular technologies for probe applicability
2) Select promising technologies and develop them further for probe application
3) Conduct field tests of those areas needing traffic information from vehicle probes
4) Investigate privacy issues for using the cellular technologies for vehicle probes
5) Identify institutional issues and challenges associated with using cellular probes
6) Establish a public-private partnership to elicit wireless carriers' participation

Cellular probe technology is one of the most promising technologies for data collection of accurate travel times. Despite years of research on cellular probe potentials, cellular probes are not yet deployed for many reasons. Cellular carriers' research efforts have been focused on the development and deployment of geolocation technologies to meet the E911 requirements. Until recently, very few carriers were interested in collecting and processing travel time data for commercial use. Unlike the toll tag probes, cellular probes need the carrier's cooperation. Public-private partnership is highly desirable to successfully implement cellular probe projects. From the public perspective, cellular probes are beneficial because they will cover areas where no infrastructure is available and augment data in areas where instrumentation is not producing reliable traffic information. From the private perspective, the carriers should be able to get substantial benefits from distributing probe data. The carriers' major concerns are how much capacity they have to give up for vehicle probes and how much return can be expected from probe R&D investment. The field tests of cellular probes have shown that probes take very little capacity. However, a cost recovery and revenue producing business model is recommended. Without a robust business plan to generate a return on their investment of time, resources and effort, the carriers will be reluctant to commit themselves to producing travel time information.

1. INTRODUCTION

In California, 24 million vehicles travel 155 billion vehicle miles each year over 166,000 miles of surface streets and freeways. Inductive loop detectors and airborne surveillance of traffic conditions manage urban freeways and arterials. Since the mandate of E911, cellular probes have shown the potential for efficiently and cheaply collecting reliable travel time information. E911 is an FCC (Federal Communications Commission) mandate issued in 1996 requiring cell phone locations of 911 emergency calls for timely emergency response. The FCC permits both network-based and handset-based cellular tracking technologies to meet the E911 requirements. Three standard technologies used for cellular phones in the US are TDMA for analog phones and CDMA and GSM for digital phones (Cayford 2002). The network-based solutions use the technology installed in the cell towers, thus no change is required in the handsets. The handset-based solutions require both cell tower technology and built-in handset technology.

The revised E911 standards (adopted in September 15, 1999) are 67% of calls be identifiable within 100 meters and 95% of calls within 300 meters for network-based solutions; 67% of calls be identifiable within 50 meters and 95% of calls within 150 meters for handset-based solutions. The hypothesis is that the E911 cellular tracking technologies are capable of probing vehicle speeds when cell phones are "on." This paper summaries a review of recently conducted field tests of cellular probes to obtain reliable travel time information.

The study objectives are to 1) assess the current state of the E911 probe technologies, 2) review recently conducted field tests of cellular probe projects, 3) invite discussions on the feasibility of cellular probe technologies for travel time estimates, and 4) recommend further research on cellular probes.

Over the past several years, many telecommunications carriers, cellular operators, and research organizations have been involved with the development of cellular location technologies to comply with E911 requirements. Consequently, the transportation community is very much interested in extending the E911 research drive for vehicle probe opportunities.

Cellular phone tracking is one of the potentially promising vehicle-probe methods likely to produce reliable travel time information. Several reports claim that the E911 vehicle location method is effective in producing acceptable freeway travel times, yet very few urban regions are considering the deployment of cellular probes for traffic surveillance. One possible reason is that cellular probes are not yet validated. If cellular probes work, this technology is potentially the best method of collecting travel time data in areas where no infrastructure is provided, i.e., rural freeways and local arterials. In addition, cellular probes can augment loop detector data since only about half of the loops are reliable at any given time.

The assertion is that the rapid penetration of the cellular market (nearly 55% of the traveling population in the San Francisco Bay Area) makes it possible for cellular probe activities to be effective by simply working with one or two carriers in order to produce reliable travel time information. Questions are: 1) how far have we come in developing and testing methods of accurately measuring travel times using the cellular technology, 2) what issues still remain for the practical application of cellular technologies for travel time measurements, and 3) how can the cellular probe method be improved? This paper addresses these issues. Cellular location technologies to date are documented and field tests of cellular probes are summarized. Potential privacy issues are identified.

The background of the cellular technology is discussed in Part 2 followed by recent field tests of cellular probe vehicles in Part 3. A review of PATH research on cellular probes is discussed in Part 4. Wireless privacy issues are discussed in Part 5. Further research is recommended in Part 6 and a summary and conclusions are presented in Part 7.

2. BACKGROUND

Accurate travel time information is essential to traffic surveillance and the effective management of traffic conditions, yet reliable methods for traffic data collection are slow in coming. Until recently, inductive loop detectors were the most common traffic data collection method for most urban freeways and some city streets even though loops are not always reliable. Recently, vehicle probe data collection technologies, such as toll tags, cellular phones, and Automated Vehicle Identification (AVL) units have been developed and some are successfully deployed. The deployed toll tag programs include TransGuide Travel Tag in San Antonio, Texas; TransStar Traffic Monitoring System, in Houston, Texas; and the New York/New Jersey TRANSMIT System (Wright and Dahlgren, 2001). The Metropolitan Transportation Commission (MTC) is currently implementing toll tags on the Interstate 80 freeway segment north of the Bay Bridge in the San Francisco Bay Area to collect travel time data for the TravInfo projects, the Bay Area advanced traveler information service.

Cellular probe technologies have not yet been deployed although several of them have been field tested. The cellular field tests include the RadioCamera™ and Abis Probing. Field test reports specifically on the RadioCamera™ technology are not available although a PATH field test was conducted using data collected by U.S. Wireless. The Abis/A Probing technology has been used in a field test, the STRIP project of the Rhone Corridor in Lyon, France. The field test results of the STRIP project are discussed extensively in this paper.

From the implementation perspective, toll tag probes have an advantage over cellular probes, because, in general, toll tags are dependent on government management while cellular probes are dependent on private sector participation. Another reason may be that the cellular probe technology is still in development. Assisted GPS technology has shown promising results with 99% accuracy of vehicle tracking, although a large-scale field test has not yet been performed. The prospects of commercial development of this technology reaching a viable percentage of equipped phones, at least 5 % of the total fleet, remain uncertain.

Cellular Positioning Technologies

Even before the E911 mandate in 1996, the concept of cellular probe technologies had been investigated by transportation agencies and private firms. In 1993 through 1995, the “CAPITAL ITS Operational Test and Demonstration Program” was conducted by a partnership of several public transportation agencies (FHWA, Virginia DOT, Maryland State Highway Administration) and private firms. The probe technology was developed by Raytheon E Systems. The goal of the field test was to "determine the viability of providing real-time, area-wide traffic information through cellular based traffic probes." The test evaluation reported that the geolocation technology was not accurate enough to produce acceptable results.

In the late 1990s and early 2000s, the FCC's E911 requirements brought renewed interest in generating travel time information using cellular probe technologies. To comply with E-911, many cellular location systems have been developed by wireless carriers, location technology providers, and position determining equipment/location platform providers.

In 2000, the firms actively working on the cellular location technologies included U.S. Wireless, Lucent, SnapTrack, and Radix Technologies. In 2002, the firms actively working on the cellular location services included AT & T Wireless, Cingular Wireless, Sprint PCS, Verizon, VoceStream (now T-Mobile), Cambridge Positioning Systems, Grayson Wireless, Nettec, Qualcomm, TruPosition, CellPoint, SignalSoft, and TCS.

In 2000 and 2001, the University of California's PATH Program with Caltrans, the University of Technology in Sydney, Australia, and INRETS in Lyon, France, investigated the feasibility of using cellular probes for travel time information.

Cellular Positioning Technologies in 2000

U.S. Wireless developed the RadioCamera™ cellular location technology which identifies the unique radio signature, or "fingerprint," of the call and matches it to a similar fingerprint stored in its central database. This technology can pinpoint the location of any mobile telephone subscriber anywhere, anytime, with close precision. In 2000 through part of 2001, US Wireless, in association with the University of Maryland, the University of Virginia and the Maryland and Virginia Departments of Transportation, conducted a field test of RadioCamera™ to measure highway congestion speed by tracking motorists talking on cellular phones as they drove the Capital Beltway. The field test was performed for a couple of years, but no report on the test results is available. The University of Maryland and the University of Virginia were involved with the assessment and progress of the field test. The field test was terminated when US Wireless filed Chapter 11 bankruptcy in late August 2001. Trafficmaster , a British firm, subsequently acquired the firm's assets in December 2001. The March 1, 2003, issue of ITS America News reported that "… the pilot test (of the RadioCamera™ technology) up until it was terminated was not yet adequate for its intended traffic analysis and management purposes," although the technology had the potential for producing accurate traffic information.

In 2000, the Bay Area Metropolitan Transportation Commission (MTC) selected U.S. Wireless to collect probe data using the RadioCamera™ technology for the TravInfo project, the regional advanced traveler information system; however, that project did not materialize due to privacy issues, according to MTC. MTC has decided to use toll tags instead. Researchers who developed RadioCamera™ claim that the RadioCamera™ method would not cause any privacy problems. (See Table 1 for company roles and cellular technologies in 2000.)

SnapTrack is handset supported positioning applications and not network solutions. When SnapTrack is activated, the wireless network sends an estimate of the location of the handset to a server. The server informs the handset which GPS satellites are in its area, and the handset takes a "snapshot" of the GPS signal, calculates its distance from all satellites in view and sends this information back to the server. The server software performs complex error correction and calculates the caller's precise latitude, longitude and altitude.

Radix developed a network-based geo-location system designed to locate wireless phones with an accuracy far exceeding the FCC E911 mandate. The initial version of Radix's GeoPhone TDOA/AOA location system was designed for CDMA wireless networks, with later versions being adapted for AMPs, TDMA, and GSM protocols. The system co-locates a low cost sensor at each cell site to gather timing data on the cell phone to be located. The GeoWorkstation, co-located with the MSC, manages the system functionality, gathers all data from the sensors, and calculates the latitude/longitude position data. Radix has gone out of business.

Lucent looked into the feasibility of CDMA positioning and other cellular positioning technologies. It appears that Lucent is no longer actively involved with cellular location technologies.

PATH developed software called “TIPS” (Travel Information Probe System) to analyze positional accuracy using the Global Positioning System (GPS). It maps the positions of probes of arbitrary accuracy to an embedded Geographical Information System (GIS) in order to determine the path the probe took. Once the path has been determined, the software calculates the travel time for each road segment traversed. The preliminary analysis of two Bay Area counties showed that accurate location technologies are capable of producing travel time information for nearly all roads. A technology with a 20-meter accuracy can produce data for 99.2% of road segments and 98.9% of the freeway segments in the two counties studied. This study was continued with support from the National Science Foundation.

The University of Technology, Sydney, Australia, tested a first prototype of a GSM cellular positioning system and carried out field trials on a second prototype. Cambridge Positioning Systems, a company based in England, bought this technology.

Table 1. Company Role and Technology in 2000

Company Organization	Role	Phone Technology	Technology Type	Technology	Status
U.S. Wireless	Location Technology	RadioCamera™	Network		Not deployed
SnapTrack	Location Technology	GPS	Handset		Not deployed
Radix	Location Technology	CDMA	Network		Not Deployed
Lucent	Location Technology	CDMA	Network		Not Deployed
PATH	Location Technology	Any	Any		Not Deployed
University of Technology	Location Technology	GSM	Network	Triangulation	Not Deployed

Cellular Positioning Technology in 2002

A report for the National Science Foundation (Cayford 2002) discusses the cellular positioning technologies up to December 2002 (Table 2). It states that Sprint PCS and Verizon use the CDMA network-based technology with assisted GPS. The preferred technology for CDMA is GPS. The FCC has certified the Sprint PCS and Verizon solutions as meeting the E911 requirements. The FCC has also certified the network-based TDMA solutions used by TruePosition and Grayson Wireless. These two network technologies have demonstrated that location accuracy was achieved 66.7% of the time within 70 meters, which exceeds FCC requirements for the network-based solutions (within 100 meters for 66.7% of the time). The E-OTD (enhanced observed time differential) is the preferred technology for GSM. Cambridge Positioning Systems uses E-OTD for GSM but the FCC has not yet certified this technology.

Table 2. Company Role and Technology (Source: Cayford 2001)

Company Organization	Role	Phone Technology	Technology Type	Status
AT&T Wireless	Carrier	GSM/TDMA	E-OTD/Network	Not deployed
Cingular Wireless	Carrier	GSM/TDMA	E-OTD/Network	Not deployed
Sprint PCS	*Carrier*	*CDMA*	*A-GPS*	*FCC certified*
Verizon	*Carrier*	*CDMA*	*A-GPS*	*FCC certified*
VoiceStream	Carrier	GSM	E-OTD	Not deployed
Cambridge Positioning System	Location Technology	GSM-E-OTD	Handset	Not Deployed
Grayson Wireless	*Location Technology*	*TDMA*	*Network*	*FCC certified*
TruePosition	*Location Technology*	*TDMA*	*Network*	*FCC certified*
Nettec	Location Technology	GSM	Handset	Not deployed
Qualxomm	Location Technology	CDMA-A-GPS	Handset	Not deployed
Cellpoint	Location Technology			Not deployed
SignalFoft	Location Technology			Not deployed
TCS	Location Technology			Not deployed

Cellular Positioning Technologies in 2003

Four of the six largest US cellular carriers used handset-based solutions and the remaining two used network-based solutions. As of March 2003, three handset-based solutions, Sprint PCS, Verizon and T-Mobile are deployed (Table 3). Nextel, a handset based solution using IDEN phone technology, is partially deployed. Both Sprint and Verizon use an assisted GPS positioning system for their CDMA phone technology. Nextel also uses a GPS positioning system. Cayford (2003) reported that AT&T and Cingular are in the process of switching from TDMA to GSM. "They have implemented network based solutions for their legacy TDMA handsets and are in the process of implementing solutions for their new GSM subscribers using variants of the same technologies. Each picked a different vendor for their location technology, AT&T is using a proprietary technology from Grayson Wireless while Cingular is using a different proprietary technology from TruePosition. The minor carriers are following the lead of the major carriers and either implementing matching technology or outsourcing location services to the major carriers." Table 3 is a summary of the major carriers and their chosen solutions as of March 2003.

Table 3. Carriers and Location Technologies in 2003 (Source: Cayford 2003)

Company	Phone Technology	Technology Type	Technology	Status
AT&T Wireless	GSM/TDMA	Network	Grayson Wireless	Partially deployed
Cingular Wireless	GSM/TDMA	Network	TruePosition	Partially deployed
Nextel	IDEN	Handset	A-GPS	Partially Deployed
Sprint PCS	CDMA	Handset	A-GPS	Deployed
T-Mobile	GSM	Handset	E-OTD	Delayed
Verizon	CDMA	Handset	A-GPS	Deployed

In Israel, Decell and Estimotion claim that their software solutions provide accurate and real-time traffic information. Decell's software, called "AutoRoute 1," converts their mobile network billing data into real-time road traffic information. Decell also claims that their AutoRoute 1 does not generate overhead on the mobile network or need any access to its switches or antennas.

Further investigation of their technologies is necessary to validate these technologies for vehicle probe possibilities.

On March 1, 2003, the ITS America News reported that, " the US Department of Transportation and Virginia Department of Transportation are partnering to help fund a feasibility test of what they believe is a promising but risky new approach for deriving traveler information from cell phone usage. If successful, the technology, under development by AirSage, Inc. of Marietta, GA, could help provide travel time information on a wide variety of roadways, including both freeways and major arterial roadways. That information could be immensely valuable, particularly as more and more 511 systems come online nationally." The AirSage technology uses the "data mining" approach; it simply "mines" relevant data about traveler behavior from data already resident in the cellular telephone networks. The AirSage demonstration is planned sometime this summer in Hampton Road, VA. The success of the demonstration depends on the active participation of at least one and up to three cellular carriers. None of the carriers have yet formally agreed to participate in the demonstration. Details of the business model are still unclear although the partners see that there is the potential of revenue from both the public and private sectors. Unlike the earlier U.S. Wireless project, the AirSage demonstration is focused on the feasibility of the technology. The U.S. Wireless project focused on the application of the technology for traffic analysis and management.

3. REVIEW OF FIELD TESTS

The most extensive study of cellular probes to date is the STRIP (System for TRaffic Information and Positioning) project in Lyon, France (Ygnace, et al, 2001). In the US, an extensive field test of the RadioCamera™ technology by US Wireless for vehicle probes has been performed on the Capital Beltway in Virginia, but the field test results are not publicly available and this technology has not been deployed in the US. A small scale field test was conducted using TIPS in the San Francisco Bay Area by PATH (Yim and Cayford 2000). This section reports on the field test results of the STRIP project in Lyon, France.

STRIP Project in Lyon, France

The STRIP project is part of the European SERTI project. SERTI is set up to manage the heavy traffic flow from Germany through Switzerland, France, and Spain to Italy during summer and winter holidays, using Intelligent Transportation Systems.

The objectives of the STRIP project are to estimate highway travel times and locate emergency calls on highways. The participating carrier for the STRIP project is SFR, one of the three cellular French carriers. Other carriers are Bouygues Telecome and France Telecome (Itineris). To estimate travel times using cellular probes, the STRIP system should be able to collect and process the data.

The solution parameters of the STRIP project required that the system should:

1) Be able to locate all the legacy terminals and the location accuracy should meet 100/200 meter requirements.
2) Deliver the location information to customers within 45 seconds in real time.
3) Be able to allow a vehicle flow of 12,000 vehicles per hour.
4) Consider only vehicles traveling on the study corridor.
5) Provide the direction of the vehicle flow.

The *Abis/A Probing* technology was selected for the reason that it can work with the GSM phone technology. This technology reads and processes probe data on the interfaces "*Abis*" and *"A."* Decoding of the collected data is called "probing." The detailed information on the architecture of the STRIP system is provided in the INRETS report (Ygnace et al, 2001).

Abis/A Probing technology was selected based on the following reasons. This technology has: 1) the possibility of locating all mobile phones in idle or communication mode with no impact on the terminal, 2) relatively low impact on the network, i.e., the installation of probes for the reading of the interface Abis, 3) a claimed accuracy of about 100 to 150 meters, and 4) a timely implementation capability of meeting the project schedule.

With STRIP, probe data can be collected only when phones are “on” for travel time estimates. The study estimated that three quarters of the cars traveling on the motorway A7 were valid probes, meaning that these phones were “on.” When considering the SFR carrier only it means that a quarter of the total cars were potentially tracked during the experiment.

Rhone Corridor Field Test

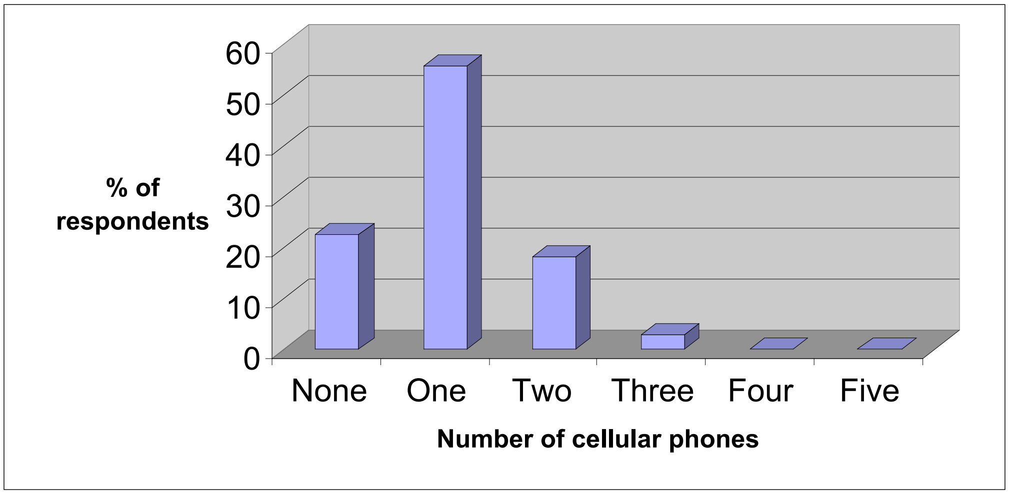
A field test (FOT) of STRIP was conducted on the Rhone Corridor in Lyon, France. The findings of the FOT are as follows:

A survey of corridor users during the peak month (August 2000) was conducted. Peak traffic occurs during the national vacation time in August. The survey purposes were to estimate the number of cell phones in each vehicle traveling on the corridor and to assess the number of probe vehicles needed for estimating travel times on the Rhone Corridor. The survey was conducted at the northbound toll booth on the A7 motorway in Vienne (20 Kilometer south of Lyon).

The survey showed that 77.4% of automobiles had at least one cellular phone (Figure 1). Of the vehicles traveling on the study corridor, 24.5% were considered valid probe vehicles (e.g., belonging to the French carrier SFR involved in the experiment). The valid probe vehicles are defined as vehicles having cellular phones provided by the SFR network with these phones being “on.” Interestingly, the study reported that statistical distribution of “on” cell phone users among other cell phone users was very similar to the distribution of the SFR users.

A quarter (26.7%) of the traveling population with a cell phone has witnessed an incident over the past six months. Transmission of emergency calls to the dispatch center for positional accuracy is in need of improvement.

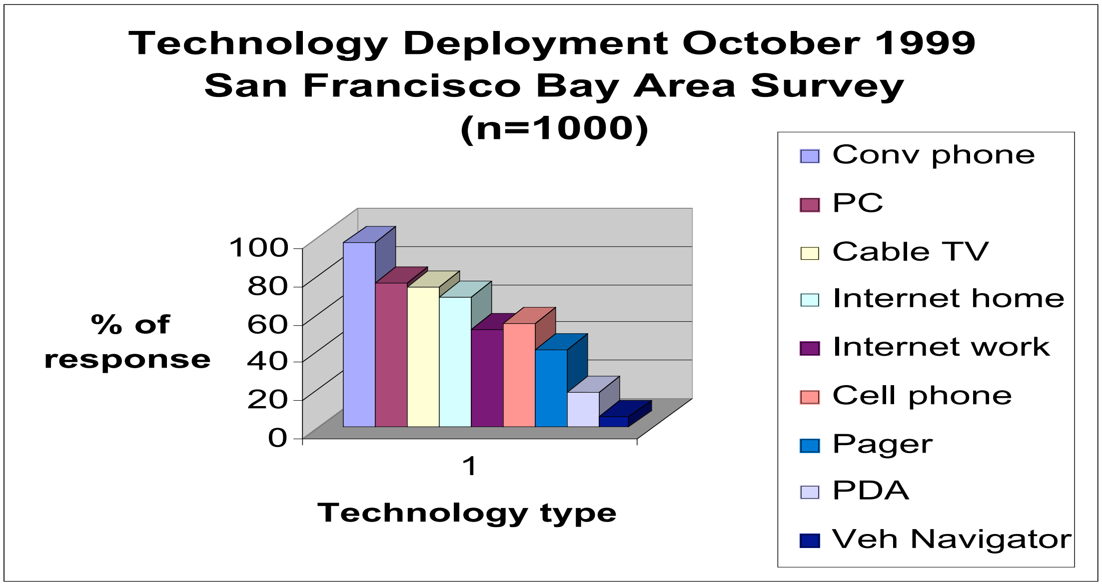
Figure 1. How many cell phones do you have in your car today? (Source: Ygnace et al, 2000)



Note: one cell phone 56%; two cell phones 18.2%; three cell phones 3%; four cell phones 0.2%; five and more cell phones 0.1%.

Figure 2 shows the deployment of communications technologies in October 1999 in the Bay Area. Comparing Figure 1 with Figure 2, the Bay Area technology deployment, the percent (77.5%) of vehicles equipped with cellular phones in the survey of the STRIP study is far greater than the percent (54.7%) of the Bay Area population which is over 18 years old and subscribes to a cellular service (Yim and Khattak, 2000). Note that the STRIP survey was conducted among motorists while the San Francisco survey was conducted among households.

Figure 2. Technology Deployment in the San Francisco Bay Area in October 1999



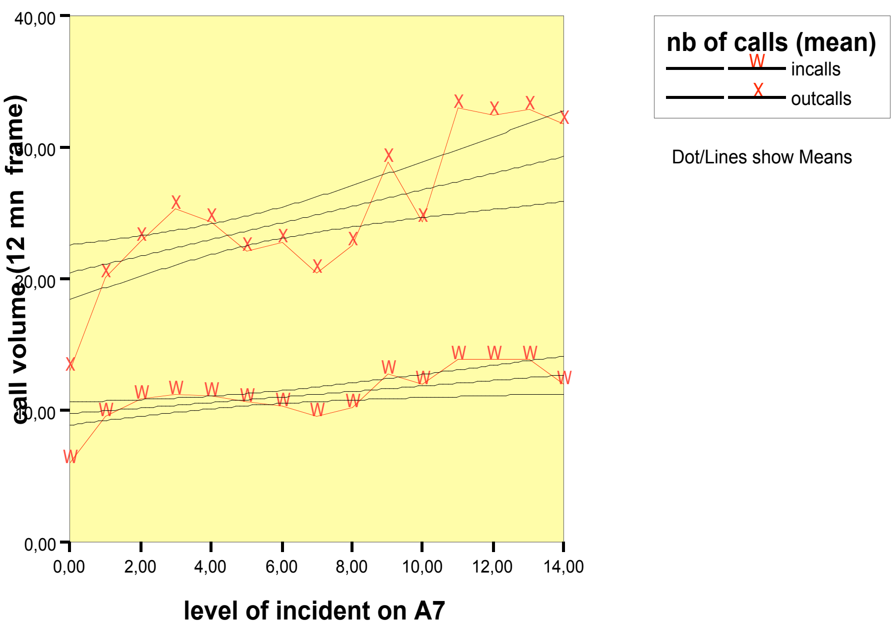
Note: conventional phone 95%; personal computer 76.1%; cable TV 73.5%; Internet at home 67.8%; Internet at work 51.1%; cell phone 54.7%; pager 40.6%; personal digital assistant 17.9%; Vehicle navigator 4.6%

Our hypothesis in the previous study (Ygnace, Drane, Yim, 2000) was that the increasing number of phone calls is indicative of an incident occurring along a given route. The INRETS study looked into the relationship between cellular call volume and incident detection. The assumption is that drivers are inclined to make cellular calls significantly more when they are stuck in traffic. There are various reasons for this, including informing someone they will be late for an appointment, giving instructions to their co-workers, and chatting with friends or family members. Figure 3 shows the relationship between the cellular call volume and the level of incidents on the 80 mile stretch of Route A7 south of Lyon in August and September 2000.

The statistical analysis showed a significant relationship between the number of outgoing cellular calls and the level of incidents (correlation coefficient 0.263, pr = 0.001). No significant correlation was found between the incoming calls and the level of incidents. The study concluded that it is possible to detect the level of incidents based on the variation of outgoing call volumes because people tend to call more often when the road is congested.

Figure 3. Relationship between Cellular Call Volume and the Level of Incidents on Route 7

(Source: Ygnace et al, 2000) Note: Level of incidents: 0 = no incident shown in any inductive loops, 14 = 14 loops out of 21 loops indicate an incident in 12 minute intervals; call volume: average number of incoming and outgoing cellular calls recorded in corresponding 12 minute intervals).



Comment: The report said "our goal is not to suggest the use of the call volume as a means to measure traffic incidents in the near future. The above analysis simply illustrates once again how road traffic changes really interact with cell phone usage. This should open new and promising ways for research in the area of interrelations between cell phone usage and road traffic measurements." The findings of this investigation have shown a promising potential for possible use of cellular call volume counts to qualitatively detect traffic behavior on freeways. Further studies would help to understand the relationships between traffic behavior and cellular call behavior.

Travel Time Comparison between data from Probes and Loops

For the STRIP project, field tests were conducted for inter-city motorways and intra-urban motorways on the ring road west of Lyon. The study results of the four motorway segments are in Appendix A. The feasibility of cellular probes for travel time information was determined by a comparison between the speed data obtained from cellular probes and the speed data obtained from the double loop markings for the same link and the same time period.

Figures 4 through 7 show a graphic comparison between mean speed data obtained from probes and loop detectors. The Abis/A Probing location method was used to collect and process the probe vehicle speed data in the Rhone Corridor freeway network.

Inter-City Motorway Field Test

Loop and probe data were collected from September 15 through October 15, 2001, on the Lyon urban freeway. The average speed data from probe vehicles and inductive loops were compared along the 32.5 km Southbound and Northbound segments between Chanas and Tain. The study showed that cellular probes could produce relatively good speed estimates as shown in Figures 4 and 5. The report said that the speeds between probes and loops were similar in both directions. The Southbound average speed of probe vehicles was 100.5 km/h while of loops was 107.9 km/h. The Northbound average speed of probes was 99.4 km/h while of loops was 111.25 km/h.

Figure 4. Inter-City Motorway Probes vs. Loops:
Mean Speed Comparison of Chanas-Tain road segment Southbound (source: Ygnace et al, 2001)

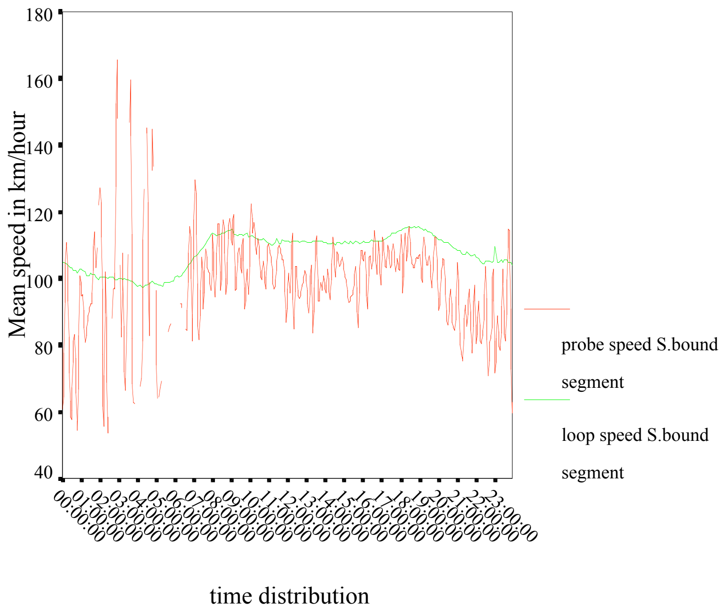
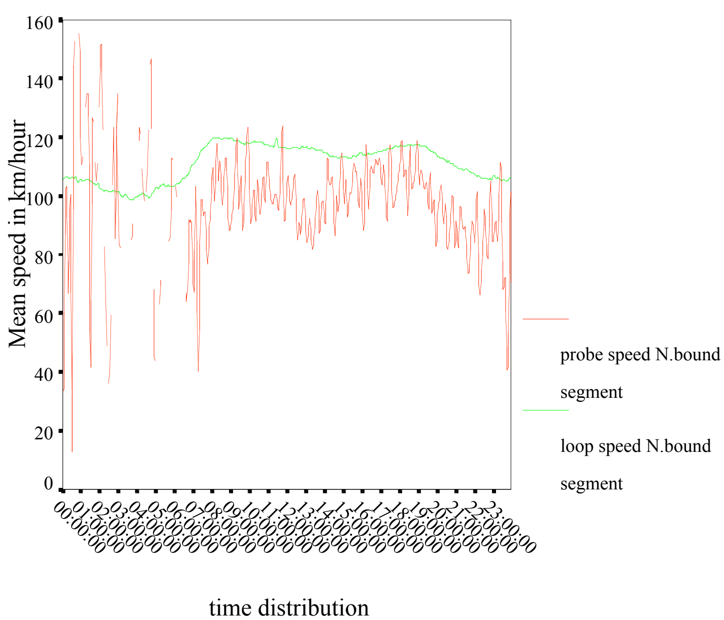


Figure 5. Inter-City Motorway Probes vs. Loops:
Mean Speed Comparison of Chanas-Tain road segment Northbound (source: Ygnace et al, 2001)



Intra-city Motorway Field Test

A field test was conducted in the 4.03 km segment of urban freeway in the southwest of Lyon. This part of the road is equipped with double loops and the SFR network. The mean speed of the probe vehicles was 84.6 km/h on the Northbound and 76 km/h on the Southbound. The mean speeds of the probes were 24% lower than the mean speeds obtained from loops on the Northbound and 32 % lower than on the Southbound. (Figures 6 and 7). However, the report said, "The correlation between the probes and loops speeds is statistically significant, p=0.09, at the 95% confidence interval." (Ygnace et al, 2001) This statistical analysis needs further explanation, considering a large variation between the loop and probe data.

Figure 6 : Intra-City motorway southwest of Lyon; probes vs. loops Southbound
(source: Ygnace et al, 2001)

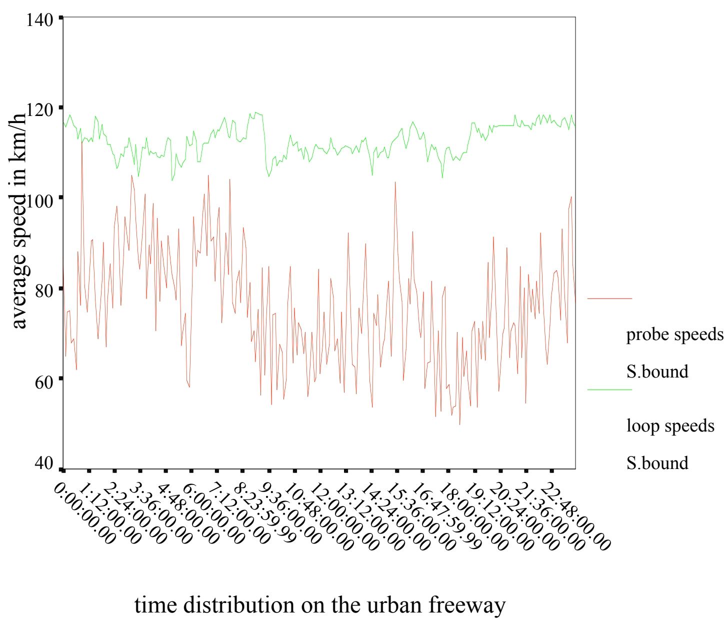


Figure 7 : Intra-City motorway southwest of Lyon; probes vs. loops Northbound
(source: Ygnace et al, 2001)

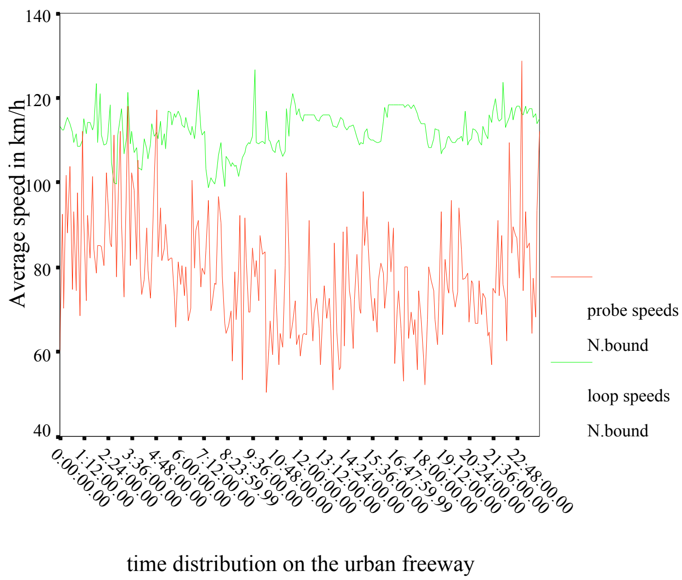
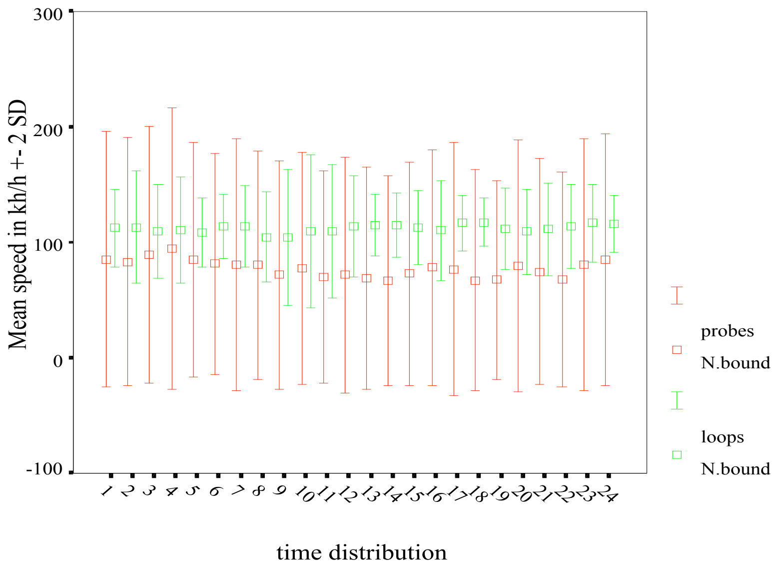


Figure 8 represents the intracity urban ring road, Southbound and Northbound. The figure shows that the mean speed variations from the loops are much smaller than the mean speed variations from the probes. However, the field tests reported, " the speed values from the loops remain within the standard deviation interval of the average speeds obtained from the probes." (Ygnace et al, 2001)

Figure 8: Inter-city Urban Ring Road:
Differences in observed speeds from loops and from probes
(source: Ygnace et al, 2001)



Comment

The Ygnace et al study is probably the most extensive study published to date on a field test of cellular probe vehicles. It presents field operational tests of the *Abis/A Probing* technology and the comparative analysis of data obtained from cellular probes and inductive loop detectors. Some of the study results are promising yet other results suggest further research is needed to validate the cellular technology. The findings of the close relationship between the traffic speed and cellular call volume are suggestive in that there is a potential for predicting traffic congestion using cellular call volume. Further study in this area will benefit the qualitative analysis of traffic flow.

The field test of the Rhone Corridor Study consists of comparative analyses of probe data and loop data in an inter-city motorway segment between Chanas-Tain, south of Lyon, and an urban freeway segment west of Lyon. The inter-city Chanas-Tain study showed little variation between the probe data and the loop detector data. However, the intra-city freeway west of Lyon showed a larger variation between probe and loop data. The loop data showed the vehicle speed 24% greater than the speed indicated by probe vehicles (84.6km/h) (average speed calculated in the six minute intervals) in the Northbound link. The Southbound link also showed loop data were 32% greater than the speed obtained from the probe vehicles (76km/h). When the observed mean speeds obtained from loops and probes were compared, data from probe vehicles had much greater variation than data obtained from loops.

While the inter-city freeway study has shown some promising results, it is too early to say that the Abis/A Probing technology is feasible for all freeway travel situations. The intra-urban segment showed a large variation between the probe and the loop data. The field test showed that a freeway segment with many commercial stops along the way also had a large variation between the probe data and the loop data. Although the present observation is preliminary, the Abis/A Probing technology might be feasible for inter-urban freeway probe activities.

4. PATH RESEARCH ON CELLULAR PROBES

For many years, researchers in the California PATH program at the University of California were interested in developing vehicle probe technologies (Linnartz, et al, 1994; Snawal and Walrand, 1995; Westermen et al, 1996; Moore et al, 1998; Hall et al, 1997, Skabardonis and Chira-Chavala, 1998; Hall et al, 1999; Ygnace et al 2000; Yim and Cayford, 2000). More recently, research interest has been directed to the development and field testing of cellular probe technologies. In 1999, researchers at PATH with researchers at INRESTS investigated the potential use of cellular probes for travel time estimates (Ygnace, Drane, Yim, 2000). This particular study investigated cellular technology options and estimated the volume of active (phones "on") cellular phones to arrive at a reasonably good estimate of travel time information using traffic simulation. The study concluded that approximately 5% of vehicles with active cell phones would give a reasonably good estimate of travel times. The study further concluded that the network capacity needed to collect and process the probe data would require only a small proportion of the total cellular capacity, therefore, it is feasible for cellular operators to commercialize their technologies for vehicle probe services and distribution of travel time data. The simulation study indicates the potential feasibility of using cellular probe technologies for estimating travel time, but more research is needed before a firm conclusion can be made (Ygnace, Drane, Yim, 2000).

Subsequently, two vehicle tracking technologies were evaluated, Global Positioning Systems (GPS) and the cellular phone tracking technology developed by US Wireless. Although GPS has shown great potential for vehicle probes, much of the previous research is theoretical in nature. Very little work has been done in the areas of experimental research, implementation or deployment. Most of the field tests were anecdotal; a systematic approach is highly desired to develop a vehicle probe system that is reliable and efficient for traffic management. If GPS is widely deployed in cellular phones, as GTE in 1998 predicted would happen, GPS technology will become even more attractive and realistic for vehicle probe activities. A custom software package was developed as part of this project in order to conduct the technology evaluation. The software, the Travel Information Probe System (TIPS), maps positions of probes of arbitrary accuracy to an embedded Geographical Information System (GIS) in order to determine the path the probe took. Once the path has been determined, the software calculates the travel time for each road segment traversed. The preliminary analysis of two Bay Area counties showed that accurate location technologies are capable of producing travel time information for nearly all roads. A technology with 20-meter accuracy can produce data for 99.2% of road segments and 98.9% of the freeway segments in the two counties studied (Yim, Cayford, 2000).

Research on cellular probe technologies continued with support from the National Science Foundation (NSF). Based on the TIPS technology research at PATH, the study developed algorithms to detect and correct variations in location accuracy, to identify anomalous probe behavior and to improve the TIPS' ability to differentiate routes taken by a cellular probe vehicle when roads are very close together (Cayford, 2002). The NSF study also developed methods of determining which cellular phones to follow and determined the operational parameters for specific location technologies for easily evaluating new technologies.

Cayford (2002) concluded that two issues basically determine the feasibility of cellular probes. One, the cooperation of the wireless carriers to produce cellular locations with the appropriate characteristics and the other, a software that can analyze cellular position data over a large area and correct errors in the data stream and adequately select sample probe phones. His work improved the software capability to increase unambiguous freeway segments from 78% in the previous PATH study to 99% with the enhanced algorithm using location accuracies of 100 meters, the lower limit for E911 deployed technologies.

How feasible are cellular probes for collecting travel time data?

The feasibility of cellular probes for travel time information was evaluated by several studies and field tests claimed that cellular probes could give a fairly good estimate of travel time. However, the cellular probe technology has not been deployed, at least in the US, except for the ones logged manually. Several urban regions, including the Bay Area, are using cellular phone subscribers to report travel time or vehicle speed at designated locations or between mile post and mile post.

Since the FCC mandates the E911, the use of cellular technologies for travel time estimates becomes more and more probable. In light of the interest in developing reasonably reliable vehicle probe technologies, an ITS (Intelligent Transportation Systems) forum was created to support the National Associations Working Group for ITS. What is presented in this section is a compilation of the concerns and perceptions of the cellular probe technologies in 2002.

The subject of the discussion was, "Which type of probe vehicle makes the most sense?"
It was claimed that the RadioCamera™ technique allows a vehicle with an "on" cellular phone to simply drive the subject blocks or freeway segments and measure the multi-path pattern empirically at each location. The technology is simple and the least costly. The technology works well if muti-path variations are high; if multi-path variations are low, it doesn't work. However, the claim was that there are adequate multi-path variations in urban freeways and major streets because they provide large samples. The failure of the deployment of the RadioCamera™ technology is not because of the technology itself but rather because of financial and institutional barriers. Others surmise, however, that the failure of this technology is due to the technology itself or privacy issues. Until a large scale field test of this technology is verified, it will be difficult to determine the feasibility of the RadioCamera™ technique. Studies conducted by six major telecommunications carriers concluded that the accuracy of the U.S. Wireless technology did not satisfy the FCC E911 mandate requirements.

Privacy is an issue with cellular phone tracking. The privacy issues are more prominent in some cellular technologies than in others. RadioCamera™ technology claims that it operates without knowing the customer of the handset location. The energy emitted by the phone would not necessarily provide the identity of the customer. Even though many cellular probe technologies can prevent the tracking of cell phone callers, call operators know the general location of their customers. The fact that the operators can identify the general location of cell calls coming in or going out can raise privacy issues. A perception of the loss of privacy is a challenge to overcome for the users of cellular probe technologies.

Regarding vehicle probe technologies, the consensus is: 1) it is too early to conclude that a single technology is a long-term winner, 2) cellular phone technologies with assisted GPS systems seem to work, at least for E911 requirements, and 3) emerging cellular technologies should be tested and evaluated for vehicle probes.

5. PRIVACY ISSUES OF WIRELESS SERVICES

The wireless Communication and Public Safety Act of 1999 states that: 1) 911 be the universal emergency assistance number, 2) emergency call-related immunity be offered to mobile phone companies comparable to that enjoyed by other phone companies, 3) subscriber information be provided by phone companies when necessary to provide emergency services and 4) instructions by the FCC be given to encourage and support state development of comprehensive deployment plans that feature broad participation by affected parties (Doyle, 1999). The proposed Wireless Privacy Protection Act (H.R. 260) would require written informed consent ("opt-in") for use or disclosure of wireless location and for carriers to adopt procedures to ensure compliance by third parties. Exceptions would include: emergency dispatch, family notification, and other data services to assist in an emergency (Hurewitz 2001). H.R. 260 was never passed.

In July 2002, the FCC denied the Cellular Telecommunications and Internet Association's (CTIA) request that the Commission adopt wireless location privacy rules to implement the Wireless Communications and Public Safety Act of 1999 (the enabling legislation for E911) which was filed in November 2000. The CTIA had requested that the E911 Act direct carriers to obtain a customer's prior express authorization before using or disclosing wireless location information. An important aspect of the privacy act is that laws vary considerably by state. Several states already require consent for vehicle monitoring; this may impact vehicle probe activities.

Wireless privacy issues related to E911are yet to be defined. Hurewitz (2001) pointed out several factors that are ahead in wireless privacy: "increased public concern and awareness, proliferation of wireless business models, emergence of best privacy practices, continued FCC activity, selective enforcement, inconsistent international standards, privacy litigation, possible limits on anonymity, targeted legislation intervention."

Recent studies indicate that consumers are consistently concerned with privacy related to new technologies. A Business Week survey in 2001 indicated that 59% wanted more federal privacy legislation and an AT&T survey of 1999 showed that 87% of the survey participants were concerned with on-line privacy invasion. Public concerns about and awareness of privacy issues may become a major impediment to the development and deployment of cellular probe technologies.

6. RECOMMENDATIONS FOR FUTHER RESEARCH

As shown in Table 3, four cellular position technologies are currently or partially deployed. Assisted GPS and E-OTD (enhanced observed time differential) are handset solutions and Grayson Wireless and TruePosition are network solutions. These location technologies have the potential to provide acceptable travel time data through vehicle probes.

1) <u>Examine the deployed cellular technologies for probe applicability</u>
It is necessary to further examine and evaluate these carrier location technologies. Field tests of these technologies should be oriented to the acceptable level of travel time accuracy for traffic surveillance. Major carriers have established programs to support the development of commercialization and applied technology innovation of their location systems. It is possible to

thoroughly evaluate the extensive field trial results of FCC certified technologies conducted to show compliance with the E911 mandate.

2) Select promising technologies and develop them further for probe application.

The deployed cellular geolocation technologies are limited to meeting the E911 mandate. Criteria for travel time data collection are different than those of E911. E911's cellular location requirements allow 50 meter (164 feet) and 300 meter ranges. This is sufficient for link-based travel times and speed measurements. For using probe information to generate lane by lane traffic information, greater accuracy is needed. Road lane width is typically 12 feet and the one-directional four-lane freeway is about 60 feet. Therefore, E911 technologies would require further refinement to meet certain traffic data collection needs.

3) Conduct field tests of those areas needing traffic information from vehicle probes

Obtaining travel time information from cellular probes is possible for the areas where no infrastructure is provided. Most city or county streets do not have instrumentation. Real-time traffic data at the local level permits better traffic management on city streets.

4) Investigate privacy issues in using the cellular technologies for vehicle probes

The transportation community has raised the issue of privacy in the use of cellular probes. Federal privacy protection policies specifically address the need to protect the privacy of cellular customers. However, cellular policies are in need of interpretation. In addition, privacy laws vary significantly by state. Wireless privacy issues related to E911 are yet to be identified. Public concerns with and awareness of wireless privacy are the potential issues facing cellular probe projects.

5) Identify institutional issues and challenges associated with using cellular probes

The use of cellular probe data among local agencies presents institutional issues and challenges to those who have never had such data availability. Vehicle probe projects for local areas would require inter-jurisdictional arrangements and mutual understanding of traffic data collection and process. The issues include how to examine and analyze the costs and benefits of cellular probing and the institutional barriers and the opportunities to implement such technologies. In addition, inter-jurisdictional agreements will be necessary for emergency response services and evacuation planning under the threat of terrorism. In some cases, cities prohibit the use of cellular phones within the city boundary while driving, for safety reasons, i.e., the City of Berkeley, California. If such restrictive policies are implemented in many cities or urban regions, cellular probes might be institutionally infeasible even if they are technically feasible. Additional institutional issues include to what extent cellular carriers would participate in the vehicle probes, who should own the probe data, and whether the public participants should be able to sell the data?

6) Establish public-private partnerships to elicit cellular carriers' participation

Unlike the toll tag probes, cellular probes need the carrier's cooperation. As previous studies have shown, cellular probes require very little capacity, therefore, cellular carriers do not need to be concerned with developing additional services for vehicle probes. However, they do need a cost recovery and revenue producing business model. Without a clear avenue to generating a return on their investment of time, resources and effort, the carriers will be reluctant to provide locations for generating traffic information.

7. SUMMARY AND CONCLUSIONS

Vehicle probes using cellular phones have been considered a promising technology for generating reliable travel time information. As wireless carriers develop cellular geolocation technologies, vehicle probes become attractive to the transportation community. This paper investigated the current status of the cellular probe technologies by reviewing studies and field tests within the past three years. Several geolocation technologies are certified by the FCC and deployed; they include Assisted GPS and E-OTD (enhanced observed time differential) for handset solutions and Grayson Wireless and TruePosition for network solutions. These location technologies have the potential to provide acceptable travel time information through vehicle probes. However, E911 cellular geolocation technologies are limited in the level of precision required for travel time information. The deployed technologies should be sufficient for generating travel times. For traffic information beyond travel time and link-based speeds, such as lane differentiation, greater accuracy would be required.

Cellular probe technology is one of the potentially promising technologies for data collection of accurate travel time. Despite years of research on cellular probe potentials, cellular probes are not yet deployed for many reasons. Cellular carriers have concentrated on the development of geolocation technologies to meet the E911 requirements. Until recently, very few carriers were interested in collecting and processing travel time data for commercial use. To successfully deploy cellular probe projects, carriers' cooperation is mandatory. Public-private partnership is necessary to successfully implement cellular probe projects. From the public perspective, cellular probes are highly beneficial because they will cover areas without instrumentation and augment data in areas with instrumentation. From the private perspective, the carriers should be able to get substantial benefits from selling probe data. The probe work should not interfere with the daily operations of cellular phone services. One of the concerns carriers have had was how much capacity they had to give up for vehicle probes. The field tests of cellular probes have shown that probes take very little capacity. The other concern is what will be the return on the investment.

Further study is recommended in several areas: improvement of cellular geolocation technology for vehicle probes, establishment of public-private partnerships between transportation agencies and cellular carriers and investigation of institutional issues and challenges in the deployment of cellular probes.

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