NCHRP Project 70-01
Private-Sector Provision of Congestion Data

Probe-based Traffic Monitoring State-of-the-Practice Report

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University of Virginia Center for Transportation Studies
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EXECUTIVE SUMMARY

While the use of a "network" of point sensors to monitor traffic conditions has been, and continues to be, the most widely used approach in the public sector, a concept that is gaining increasing attention is to purchase traffic data from a private sector provider. Given that the private sector generally does not have access to the right-of-way to install point sensors, they have largely turned to probe-based approaches for traffic monitoring. By tracking a series of positions of a sample of traveling vehicles, it is theoretically possible to generate speed and/or travel time estimates for roadway links. However, before the public sector enters into significant agreements to purchase data, it is important that agencies understand the capabilities and limitations of such services.

The key challenge to implementing a probe-based system lies in collecting a representative sample of vehicle positions in both time and space. Two primary approaches have been considered. The first approach is the use of wireless location technology (WLT) to automatically and anonymously track wireless devices as they traverse the system. The second approach is to "recruit" floating vehicles equipped with GPS devices to voluntarily report their location as they travel. Given the challenge of recruiting floating vehicles (i.e. the floating vehicle must take action in order to serve as a probe), this approach has seen considerably less attention than WLT-based approaches (in which probe vehicles must do nothing besides "carry" a cellular phone). Therefore, the focus of this state-of-the-practice report will be on WLT-based monitoring. For the sake of completeness, Appendix C is included in this report with a review of major private-sector floating car deployments.

There have been a number of deployments of WLT-based monitoring systems both in the United States and abroad. These deployments have occurred under a broad range of roadway conditions, technology platforms, and legal/institutional situations. This document reviews over 16 planned or completed deployments of WLT-based traffic monitoring systems. The review of these deployments was limited to what could be found in the open literature. No independent interviews or surveys of involved parties were conducted for this report (these will take place as part of the future work for the NCHRP project). In some cases, results have been self-reported and have not been independently verified. The researchers reviewed results of the evaluations to determine the benefits and opportunities provided by these systems, as well as the barriers and knowledge gaps that may act as an impediment to their use.

Appendix A of this document provides a detailed summary of each of the 16 WLT deployments that were examined. A standard format was used to summarize each deployment. In some cases, publicly available descriptions of the systems were limited or incomplete which resulted in gaps in some of the summaries. The following categories were used to summarize each deployment:

- **System Coverage:** A description of the size and type of network monitored by the system. Depending on the data available, the system coverage may be expressed in terms of geographical boundaries or lane-miles of roadway. An indication of the spatial dispersion of roads and whether the monitored region was an urban or rural area is also provided.

- **Participants:** A listing of the public and private sector organizations involved in the project.
- **Relationship with Cellular Service Providers:** This describes the number of wireless providers involved in the project, as well as the nature of their involvement.
- **Technology:** A brief description of the technology used in the deployment.
- **DOT Requirements:** A summary of the performance requirements specified by the transportation agency, if any.
- **General Results:** A summary of the evaluation results of the deployment, if any. This may include discussions of speed estimation accuracy, location accuracy, system availability, and any operational or institutional issues that were encountered.
- **Independent Evaluator:** This category notes whether there was an independent evaluator for the project.

In addition to the review of deployments in Appendix A, the research team also reviewed simulation studies of WLT-based systems. While these do not prove (or disprove) the potential of this approach, they provide an additional source of information. This review is presented in Appendix B.

Several trends become apparent when WLT-based traffic monitoring is reviewed. For the sake of consistency, these trends are summarized below using the same categories as were used to discuss the deployments in Appendix A.

System Coverage:

The majority of field tests have "covered" freeways in urban areas. This is primarily due to the facts that (a) there is a significant need for freeway data, and (b) freeways tend to have more robust cellular coverage, higher traffic volume, simpler path estimation, and higher frequencies of motorists crossing cell boundaries.

Several of the deployments noted that data became scarce in off-peak hours, particularly the middle of the night. As a result, in some cases data availability and accuracy suffered during periods of low traffic volume since the number of probes was limited.

There are several apparent gaps in the deployments that have occurred to date. Relatively few deployments have attempted to monitor arterial roadways. Arterials introduce additional complexity as more paths are potentially feasible and systems must be able to correctly distinguish between wireless devices that are not located within vehicles and those inside a vehicle.

Participants

Public private partnerships have been the most common arrangement for WLT field tests. The national, state, and local public transportation entities benefit from systems requiring lower initial investments, and they have access to traffic data, and more control over local system deployments. Private entities benefit from obtaining funding, the support of the public entities, and the opportunity to test and improve their technology. Questions of data ownership sometimes arise from public private partnerships and should be resolved within the initial contract negotiations.

There is very little experience with completely private WLT-based traffic data services. Thus, there is no information on fee structures for data services.

Relationship with Cellular Service Providers

In nearly every case, WLT-based traffic monitoring system vendors have entered into contractual relationships with wireless providers to gain access to the data that allows for the tracking of cellular phones. Developing relationships with multiple service providers supplies additional data to drive travel time estimates, which increases the coverage and accuracy of estimates.

While most deployments appear to be cognizant of the potential privacy issues related to WLT-based monitoring, there has not been a detailed description of how these privacy concerns have been dealt with. Most deployments simply have reported that the wireless provider strips identifying information before sending it to the traffic-monitoring vendor, and sensitive data is kept behind the wireless provider’s firewall.

Technology

The trend in WLT-based traffic monitoring is toward network-based systems that mine existing data from the cellular service providers. While early generation deployments used a variety of trilateration and signal analysis techniques to “pinpoint” individual vehicle locations, the majority of recent deployments use cell handoffs to define vehicle paths and speeds. The handoff information is already collected by the wireless provider, and provides a ready set of data that can be processed to generate travel time estimates.

DOT Requirements

DOT’s have set very few requirements for the data provided by probe-based systems. As a result, there are usually no benchmarks that must be met in terms of system accuracy, availability, or initial delivery. The lack of well-defined requirements and clear contracting language may have limited the amount of useful information that could be generated by these systems. Requirements should be defined based on the anticipated uses of the data.   In other words, the system should be able to support the accuracy and availability requirements dictated by whatever performance measurement, traveler information, or traffic management application that the DOT intends to use the data to support.

General Results

Many of the deployments that have occurred to date have lacked a strong, quantitative analysis of the performance of the system. Few deployments measured system accuracy, data availability, location accuracy, and system limitations. The accuracy and availability of traffic condition estimates generated in early generation (i.e. prior to 2000) systems was not sufficient to produce data useful for traffic management or performance measurement purposes. In particular, those deployments exhibited difficulty in matching vehicles to roads, generating long vehicle tracks, and properly filtering the data.

Deployments have had trouble with small sample sizes and speed and location data with high variances. Small sample sizes result in little or no data for segments of roadway and disruptions in travel time estimates. Larger sample sizes of accurate travel time estimates will lower the variance of aggregated data and provide for more reliable travel time information. Larger samples sizes are necessary for, but not sufficient means to increase accuracy. Data with a high variance results in low confidence levels in inadequate estimates of travel time.

More recent deployments have shown stronger accuracy results, but the data sets are often relatively limited. A few recent deployments have reported a significant correlation between cellular probe data, loop detector data, and floating car data. However, recent deployments indicate that call volume is not well correlated to traffic volume. More data from field tests will be necessary to determine whether the technical hurdles documented from the early generation tests have truly been resolved.

Independent Evaluator

In most cases, no formal independent evaluation was performed on the deployments. In some cases, only qualitative data was reported, or the vendor self-reported performance. It is essential that future deployments of this technology include an independent evaluation to document the performance of the system. The identification and validation of system accuracy, data availability, location accuracy, and system limitations should be completed by an objective third party after each deployment to measure the success and failures of each system.

Summary

Based on the activity to date, the following general conclusions can be made:

- Initial deployments did not produce data of sufficient quality or quantity to provide reliable traffic condition estimates. More recent deployments appear to produce better data, but there is not enough information to completely characterize the quality of the data.
- While performance of these systems has been demonstrated to a limited degree on freeways, there is very little experience on monitoring arterials.
- In general, the simulation studies have shown that WLT-based systems can conceptually produce good performance for simple networks. Performance appears to worsen for more complex networks, illustrating the need to use well-developed map matching and data screening methods.
- Most recent WLT deployments rely on cell handoff data, as opposed to "direct" vehicle location determination. Despite this, no published simulation studies have explicitly examined a handoff based WLT system.
- In a number of cases, inadequate sample sizes were generated to produce accurate speed estimates. This problem appears to be most pronounced in the off peak hours, such as the middle of the night.
- Transportation agencies have historically not defined detailed performance requirements for these systems. Prior to using this technology, a DOT should ensure that requirements are in place to support the transportation applications for which the data will be used.
- Many deployments have lacked a well-developed, independent evaluation that quantitatively assessed the system performance. Future deployments should include an independent evaluator that will examine the availability and accuracy of the data.
- Many of the institutional and legal issues are not clearly defined in past deployments. Likewise, financial and contractual information is also not often available in the literature. More information on these areas is needed to help assist agencies that are entering into contracts with providers of this technology.

Given these findings, it is essential that further investigations be made into ongoing deployments to better define the technological, economic, and legal frameworks of these systems. Future phases of the NCHRP project will help further develop these frameworks, and provide guidance to transportation agencies about how WLT-based systems should be deployed and evaluated.

Appendix A

Wireless Location Technology-Based Traffic Monitoring Deployments

This appendix provides a summary of completed, ongoing, and planned deployments of wireless location technology- (WLT-) based traffic monitoring systems. The contents of this appendix were developed based on publicly available information (a list of references is provided at the end of the appendix). In some cases, this information incompletely describes the system or its performance. In other cases, performance claims have not been validated by an independent source.

Northern Virginia Field Test

Deployment Location:
The CAPITAL (Cellular Applied to ITS tracking And Location) project gathered traffic condition data in the Virginia suburbs of Washington, D.C.

System Coverage:
This system provided coverage for I-66, I-495, and various state routes in Virginia.

Project Period:
The operational period started in 1994 and ran for 27 months.

Participants:
Participants in the deployment included the Federal Highway Administration, Virginia Department of Transportation, Maryland State Highway Administration, Raytheon E-Systems, Farradyne Systems Inc., Bell Atlantic NYNEX Mobile, and the University of Maryland (UMD, 1997). The Federal Highway Administration, Virginia Department of Transportation, and Maryland State Highway Administration were the public sponsors for the project. Raytheon E-Systems provided the equipment to locate and track cellular phones. Farradyne Systems provided the traffic management information system to convert cellular location data to traffic data. Bell Atlantic provided the communications network infrastructure. Finally, the University of Maryland conducted the independent evaluation of the project.

Relationship with Cellular Service Providers:
The CAPITAL project used Bell Atlantic NYNEX Mobile's cellular network. Call detection and location equipment were located on 8 cellular towers in the area.

Project Goals:
The CAPITAL project planned to deploy a WLT based system for traffic monitoring on a wide geographic range of roadways. The goal was to generate traffic condition estimates, such as speed and travel time.

Technology:

Cellular call detection and location equipment was installed to gather location data at 8 Bell Atlantic tower sites. Cellular calls were detected when they were initiated in the test area. The location of the phone was then calculated using the signal's line of bearing and time of arrival as seen by multiple eight-element antennae. If a cellular phone was estimated to be on a roadway of interest, multiple measurements were performed to calculate the vehicle's speed.

DOT Requirements:
None Specified

General Results:
CAPITAL was the first major deployment of wireless location technology (WLT) in the US. The system was able to locate static cellular phones within an average of 107 meters of their actual position during the final static accuracy evaluation. Speed information could not be calculated because at least four positions are needed to calculate speed. Less then four position estimates were collected 80% of the time (UMD, 1997).

The system was not able to accurately estimate the speed for segments of roadway and detect incidents. The field study demonstrated that improved sampling techniques and map matching methods were needed to accurately monitor traffic.

Independent Evaluator:
Performed by the University of Maryland

Billings, Montana Field Test

Deployment Location:
Billings, Montana

System Coverage:
The system was deployed on rural arterial roads in Montana.

Project Period:
The project period started in 1998 and ended in 1999, this included an operational period of 5 months (Kauffman, 2001).

Participants:
The cooperative development effort involved U.S. Wireless, the State of Montana, the local Billings 9-1-1 center, and six telecommunications organizations (Directions Magazine, 1999).

Western Wireless Corporation provided the cellular network that U.S. Wireless' RadioCamera used to gather location information from cellular phones. US

West, Inc. provided the network connection between 911 callers and the emergency center. XYPOINT Corporation provided network services and location database processing for the RadioCamera. Nortel Networks(TM) supplied enhanced public safety workstations for processing and displaying 911 caller information and provided advanced mapping software that was developed by Combix Corporation. William Communications Solutions supplied the telecommunications system for the emergency center

Relationship with Cellular Service Providers:
Western Wireless operated the cellular network that RadioCamera used to gather location information from cellular phones.

Project Goals:
To demonstrate the ability of WLT technology to located cellular phones, especially those dialing 911, and generate traffic conditions estimates in a rural setting.

Technology:
This deployment consisted of a field test of U.S. Wireless Corporation's RadioCamera technology. The technology estimates a cellular devices location using location pattern matching technology. "Location Pattern Matching recognizes the distinct patterns, or "signatures", of incoming radio frequency (RF) signals, and associates them with the specific locations from which they originated. Radio frequency characteristics that define the signature include relative power, direction of arrival, number of dominant reflections, and multipath phase and amplitude. The RadioCamera system learns the signature patterns and logs them into a reference database, thereby identifying calls coming from the same location by their similar signatures." (Kaufman, 2001)

The system was able to locate cell phones that had dialed 911. This was done by matching the cell phone signal characteristic to a database of locations and then matching that location to a map. The RadioCamera system could monitor traffic by deriving travel time information. Traffic data was derived by gaining multiple positions from the same cellular phone and matching the locations to a map. Travel times could then be calculated by taking the difference of the times at each location and dividing that by the distance traveled.

DOT Requirements:
None stated.

General Results:
U.S. Wireless reported that the system was able to distinguish between an in-vehicle and out-of-vehicle cell signals. A roadway grid was set up, and probe cars traveled the roads to create a virtual map that would later be used to "map" cell phone data points. When a data point did not fall on the roadway grid it was thrown out. If a data point was stationary, it was thrown out. Engineers were

unable to develop algorithms to reduce location errors enough to provide usable traffic data.

Independent Evaluator:
None

Oakland, California Deployment

Deployment Location:
A small area in the San Francisco Bay region.

System Coverage:
US Wireless provided researchers at University of California - Berkeley with data on I-580 east bound, I-580 west bound, and Broadway, a major arterial in Oakland.

Project Period:
In 2000, researchers at the University of California - Berkeley were provided with 44 hours of data collected by U.S. Wireless in Oakland.

Participants:
California Partners for Advance Transit and Highways (PATH) at the University of California - Berkeley, and the US Wireless Corporation.

Relationship with Cellular Service Providers:
Not specified

Project Goals:
To measure the accuracy and reliability of vehicle speed or travel time on the Bay Area freeway network using wireless location tracking and GPS probe data.

Technology:
The University of California developed the Travel Information Probe System (TIPS) software that estimated probe location and travel times based on wireless location data. TIPS mapped the estimated location of probes to a Geographic Information System (GIS) to determine the path of the probe. The travel time for each road segment traversed was then calculated. The research team claimed that a technology with 20-meter accuracy could produce data for 99.2% of road segments and 98.9% of the freeway segments in the two counties studied (Youngbin and Cayford, 2001).

DOT Requirements:
None Specified

General Results:
Researchers were often able to determine the location of the cellular phone on the roadway network. For those that were matched, the location estimates of cellular phone were regularly accurate within 60 meters, however 66 percent of cellular devices tracked had at least one outlier with an error of more then 200 meters (Smith, et al, 2003).

U.S. Wireless located cellular devices making phone calls, but the average call was only tracked for 30 seconds, not allowing for prolonged tracking of a vehicle. The low call length was due to the sampling methods of US Wireless. Researchers were unable to match vehicles' locations to a roadway 60% of the time and make travel time estimates (Smith, et al, 2004).

Independent Evaluator:
California Partners for Advance Transit and Highways (PATH) at University of California

Washington D.C. Demonstration Project

Deployment Location:
Washington D.C. Region.

System Coverage:
The field test covered the Capital Beltway and many major arterials. The Beltway is an eight-lane freeway that experiences significant congestion. The system was designed to generate 4,800 data points every minute by tracking 160 phone calls every 2 seconds (Fontaine and Smith, 2004).

Project Period:
2000 - 2001

Participants:
U.S. Wireless, Virginia Department of Transportation, Maryland State Highway Administration, the University of Virginia, and the University of Maryland.

Relationship with Cellular Service Providers:
None required (WLT infrastructure separate from cellular infrastructure)

Project Goals:
Test the feasibility of the RadioCamera system to measure vehicles speeds on congested roadways.

Technology:
The RadioCamera analyzed the signal characteristics from cellular phones and attempted to locate the devices by comparing the signal characteristics to

established patterns, which were stored in a central database (see description for the Billings, Montana Field Test).

DOT Requirements:
None reported

General Results:
An issue of ITS America News in March 2004 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.

Results of the independent evaluation revealed that the deployment produced small sample sizes for the 10-minute measurement intervals, especially on less traveled roads and during night and early morning hours. In roughly 5% of measurement intervals, no speed estimate was produced because the sample size was zero (Smith, et al, 2004). The wireless location technology based system speed estimates were significantly different from the population's mean speed for segments of I-495 at night. A maximum absolute mean error of 23.9 mph was observed (Smith, et al, 2004). Data was too unreliable to be used by traffic information system because "errors varied by statistically significant margins, with errors up to 25 mph (Fontaine and Smith, 2004)."

U.S. Wireless filed Chapter 11 bankruptcy in August 2001 causing the field test to be terminated.

Independent Evaluator:
University of Virginia's Center for Transportation Studies served as the traffic monitoring evaluator. The University of Maryland evaluated the location estimation of individual vehicles.

Calgary, Alberta Field Test

Deployment Location:
Calgary, Alberta.

System Coverage:
Not Specified

Project Period:
Cell-Loc gathered data from predetermined cell phones during the morning, noon and evening rush periods of March 2, 5, and 6, 2001. Anonymous location data was collected from random phones during daylight hours on April 27, 28, and 30 and May 1 and 2, 2001 (Cell-Loc, 2002).

Participants:
Cell-Loc Inc. and Transport Canada

Relationship with Cellular Service Providers:
None Known

Project Goals:
"The objective of this research was to study the technical feasibility of using cellular phone-equipped vehicles as traffic probes for monitoring flow using a wireless location system developed and operated by Cell-Loc Inc (Cell-Loc, 2002)."

Technology:
The system calculated cellular phone locations using network-based time difference of arrival (TDOA). This is done by monitoring the time of arrival of cellular signals at more then 3 cellular base stations/receivers.

DOT Requirements:
None reported.

General Results:
Cell-Loc reported the system estimated wireless probe locations within 100 meters 67 percent of the time, and within 300 meters 95 percent of the time (Cell-Loc, 2002).

The system was constrained by the limited number of samples collected. Vehicle velocities could not be accurately calculated because of the low sample sizes and the system could not track vehicles rapidly changing speeds.

Independent Evaluator:
None

STRIP Field Test

Deployment Location:
The field test took place in the Rhone Corridor of Lyons, France.

System Coverage:
Two roadways were used for the field test. They include an urban freeway between Chanas and Tain, south of Lyon (a 32 km freeway that was subdivided into eight segments - four northbound and four southbound) and an urban freeway west of Lyon (a 4km freeway that was divided into two segments – one Northbound and one Southbound) (Yim, 2003).

Project Period:

September 15 - October 15, 2001.

Participants:
Abis/A Probing technology and SFR.

Relationship with Cellular Service Providers:
A partnership was created with SFR, one of the three French cellular carriers.

Project Goals:
The STRIP project was part of the Southern European Road Telematic Implementations (SERTI) that monitors traffic in Germany, Switzerland, France, Spain, and Italy during holidays when traffic is heavy.

Technology:
Abis/ A Probing system is a network-based solution that gathers data from the cellular service providers. The system then uses Abis and A interface, which includes algorithms and databases of information to identify the location of a cellular phone (Ygnace, et al, 2001).

DOT Requirements:
None Known

General Results:
Yim reported that the freeway segment between Chanas-Tain showed little variation between the cellular phone data and the loop detector data (Yim, 2003). The freeway west of Lyon showed a large variation between the probe and the loop data. In the northbound link the loop data showed the vehicle speed was 24% greater than the speed indicated by probe vehicles. In the southbound link the loop data was 32% greater than the speed obtained from the probe vehicles (Yim, 2003). The variation in the observation of mean speeds obtained from probes was much greater then that obtained from loop detectors. One factor contributing to this is that the freeway west of Lyon has many commercial stops.

Independent Evaluator:
None

Tel-Aviv, Israel Deployment

Deployment Location:
The Ayalon freeway in Tel-Aviv, Israel.

System Coverage:
The main section of the Ayalon freeway has 4 to 5 lanes in each direction and is heavily used. It is 14 km long and has 10 interchanges. The roadway is equipped with a set of dual inductance loop detectors for all lanes approximately every 500 meters.

Project Period:
A field test was completed from January through March of 2005 along the Ayalon freeway.

Participants:
ITIS Inc., Estimotion Ltd, Ayalon Highway Company

Relationship with Cellular Service Providers:
None Reported

Project Goals:
Determine the relative performance of the WLT-based system traffic condition estimates versus those produced by loop detectors.

Technology:
The Estimotion technology of ITIS, Inc. uses a statistical approach to infer traffic speeds as cell phones move from cell tower to cell tower. Software filters weed out non-vehicles. The technology may be classified as a handoff-based approach.

DOT Requirements:
None Known

General Results:
The initial focus of the evaluation was to compare loop detector and cellular data captured in five-minute intervals for an entire day on the Ayalon freeway in Israel. The researchers reported, “Our main finding is that there is a good match between the time-space speed patterns as depicted by the cellular phones system and those depicted by the loop detectors (Bar-Gera, 2005).” The cellular phone data contained more variation than the loop detectors data, which may have resulted from small sample sizes (Bar-Gera, 2005). During the night hours the amount of data greatly decreased.

The second focus of the evaluation was on estimating travel times for the entire length of the roadway. The researchers reported that “there was a good match between travel times computed from the loop detectors data and travel times computed from the cellular phones data, as well as with travel times measured by a floating car (Bar-Gera, 2005).” There was “good” agreement between the loop and cellular data for the uncongested intervals. The congested intervals show a travel time difference of 1-2 minutes between the WLT and loop data, but this was probably due to the long reporting interval lengths of nearly 20 and 40 minutes (Bar-Gera, 2005). When comparing loop and cellular data to the floating car data from 25 vehicles it was reported that the overall the correlation was very good, with only four outliers in which the floating car measurements were substantially longer than the loop and cellular data. Bar Gera reported, “The average difference between the loop detectors computed travel time and the floating car measurement is 0.9 min, and the average absolute difference is 0.93 min. The equivalent values for computed travel times based on the cellular phones data are average difference of 0.49 min and average absolute difference of 1.07 minutes (Bar-Gera, 2005)."

Independent Evaluator:
Evaluation performed by Ben-Gurion University of Negev, Israel. Note that the authors claimed that their work was funded in part by ITIS, Inc. and Estimotion, Ltd.

Noord-Brabant Deployment

Deployment Location:
Province of Noord-Brabant in the Netherlands.

System Coverage:
The system was tested on A16, A58, A59 and N261 roadways. These roadways represent highways, urban arterials, and rural roadways.

Project Period:
The operational test took place in mid 2003.

Participants:
RoDIN24, a product of Applied Generics, was tested in the province of Noord-Brabant in the Netherlands in partnership with LogicaCMG and Vondafone of the Netherlands. LogicaCMG provided the program to convert RoDIN24 location information into usable traffic information. Vondafone Netherlands has a partnership with LogicaCMG and agreed to host Applied Generics software on their network, giving the RoDIN24 program a wireless network from which to collect location data.

Relationship with Cellular Service Providers:
Vondafone was a project participant.

Project Goals:
Validate the use of RoDIN24 technology to derive traffic data on various types of roadways.

Technology:
The location data is captured using enhanced observed time difference of arrival calculation in which cell phone locations are triangulated from more then three cell towers. The location data is then used to compute travel speeds with the Applied Generics software NERO24.

DOT Requirements:
None Known

General Results:
RoDIN24's speed results were compared to GPS tracking in professionally driven vehicles and loop detector data. Goudappel Coffeng found RoDIN24 to be comparable to these systems of traffic monitoring and, in some cases RoDIN24 data was better than the data of the other systems. Coffeng reported that RoDIN24 is reliable at speeds less than 20km/h (loops tend to fail at these low speeds, standstills provide no information at all with loops) and compute journey times accurately across junctions.

Higher variation does exist in the data due to individual motorist behavior on very lightly loaded routes. The variation lowers as more vehicles are sampled (MTS quality assessment results).

RoDIN24 technology is still being used in Noord-Brabant.

Independent Evaluator:
The independent consulting firm Goudappel Coffeng Traffic Research Consultancy of The Netherlands tested the accuracy of the traffic speed information collected by the RoDIN24 program.

Southern Germany Deployment

Deployment Location:
A9 section of the German autobahn, North of Munich, in Southern Germany.

System Coverage:
Major multilane freeway in a rural area.

Project Period:
Vodafone collected GSM cellular data in July and September of 2003. Loop data and probe vehicle data was collected simultaneously to validate the WLT-based monitoring estimates.

Participants:
Vodafone gathered cellular GSM (Global System for Mobile Communications) data and derives location data from time and direction data. Location data is derived by mining the data from cellular phone handoffs when vehicles cross cell boundaries.

Relationship with Cellular Service Providers:
Vodafone participated in the project.

Project Goals:
To determine the viability of GSM data for traffic monitoring and whether call volume is related to traffic volume.

Technology:
Vodafone determines the location of cell phones based on when a handoff occurs between adjacent cells. By tracking a series of handoffs, a vehicle track can be generated.

DOT Requirements:
None Known

General Results:
The cellular phone GSM data was compared to publicly owned stationary sensors (loop detectors) and probe vehicle data from taxis to validate the GSM data. It was found that call volume is not well correlated to traffic volume. There are low call volumes in the morning and a slightly higher amount in the evening, possibly due to cellular plans. Also when vehicles slow they do not go though cell boundaries as frequently and many calls are ended before crossing boundaries.

The GSM data had a larger variance than the probe vehicle data. This could have been due to the fact that probe vehicle data was from taxis and the GSM data came from a variety of vehicles.

Challenges also exist when determining the location of a cellular device when multiple roadways exist within a region. In this study only one major roadway exist within the cells.

Independent Evaluator:
Evaluation done by researchers at the Institute of Transport Research in the German Aerospace Centre. The difference between the three technologies was never quantified.

University of Akron and University of Wisconsin

Deployment Location:
China.

System Coverage:
The test area covers an expressway section that is approximately 2.5 miles long and a surface street section that is about 2 miles long.

Project Period:
Data was collected for several days in April 2005.

Participants:

Not Known

Relationship with Cellular Service Providers:
None Known

Project Goals:
The deployment aims to test the feasibly of WLT for use in developing countries.

Technology:
Not Known

DOT Requirements:
None Known

General Results:
Data was collect during peak and non-peak hours. Data was logged when a cell phone in use was communicating with a tower. Information was gathered from locations other then roadways 90% of the time. From the data collected, the mean absolute speed estimation error was between 5.8 and 8.8 mph. Researchers from the University of Akron and University of Wisconsin reported that a Chi-square test was conducted separately on the two roads each day, and the results showed that in most cases the errors passed the test at a 90% confidence level.

Independent Evaluator:
University of Akron and University of Wisconsin

Tampa, Florida

Deployment Location:
The traffic monitoring system covers the western coast of Florida from Dunnelon in the North, eastwards to Winter Haven, and southward to Naples. This includes the metropolitan areas of Tampa, St. Petersburg and Sarasota.

System Coverage:
Tampa's traffic monitoring system stretches over approximately 2200 square miles of which 555 are directional miles of freeway and 7644 are directional miles of major surface streets (Cayford and Yim, 2005).

Project Period:
The traffic monitoring system became operational in June of 2005.

Participants:
IntelliOne Technologies and a tier 1 US telecommunications carrier

Relationship with Cellular Service Providers:

An unspecified Tier 1 US telecommunications carrier.

Project Goals:
To create a traffic monitoring system using wireless location technology in Florida.

Technology:
Cellular phones are tracked using network measurement report (NMR) records, which provide cell phones signal power for all cellular towers with reach. NMR records are already created by cellular providers and are produced when a call is made and cell phones transfer between towers.

DOT Requirements:
None Known

General Results:
The results presented for this system dealt with the feasibility of the system to effectively monitor traffic. However, no actual validation of traffic data was reported.

Travel time measurements were calculated for a 24-hour period and aggregated into 5-minute intervals. The percentage of roads monitored in each 5-minute interval was calculated. The numbers of measurements in each time period were compared to desired sample sizes for different degrees of accuracy and confidence. Over 24 hours, the traffic monitoring system produced measurements for 98.7% of all freeways and major surface streets in the study area. Between 10:00 am and 10:00 pm, the system produced data for an average of 76% of all the freeway miles in every 5-minute interval (Cayford and Yim, 2005).

The field trial involves only phones from only a single carrier representing less than 15% of the available phones in the area. With phones from a single carrier, the number of measurements was sufficient to generate average speeds accurate within 5 mph with 95% confidence for 38.1% of the freeways and within 10 mph with 95% confidence for 71.5% of the freeways in every 5-minute interval between 10:00 am and 10:00 pm (Cayford and Yim, 2005).

Independent Evaluator:
None

Hampton Roads, Virginia Field Test

Deployment Location:
Hampton Roads, Virginia.

System Coverage:
Freeways and arterials in the Hampton Roads region of Virginia.

Project Period:
2003 - Present

Participants:
Virginia Department of Transportation, Federal Highway Administration, AirSage, and the University of Virginia.

Relationship with Cellular Service Providers:
AirSage has partnered with Sprint on this field demonstration.

Project Goals:
The project aims to provide travel data, including travel time and speed information on all roadways.

Technology:
AirSage is using their technology patented in January of 2005 to estimate vehicle location, speed, travel time, and other performance measures on roadways in Hampton Roads. The technology works by mining data that is already collected by cellular service providers. A cell phone's location is estimated when it leaves and enters a cell within the cellular network using characteristics of the signal.

The data is transferred through a firewall from the cellular provider's system to an AirSage computer after all personal information is stripped and a unique identification number is assigned to each cell phone. The information is then transferred to the main AirSage computer system where information is aggregated and converted to travel time and speed estimates.

DOT Requirements:
None

General Results:
The project is currently in the development phase. There are no results yet to report. The project is currently 2 years behind schedule. Field evaluation is scheduled for December 2005.

Independent Evaluator:
Due to setbacks the data from the system has not been made public and the system has not received a comprehensive evaluation. The University of Virginia has been contracted by VDOT to perform an independent evaluation.

Baltimore, Maryland Field Test

Deployment Location:
Baltimore, Maryland and the suburbs of Washington, DC.

System Coverage:
Freeways and arterials.

Project Period:
A two-year agreement starting in October 2004

Participants:
Public-private partnership between Delcan-NET, ITIS Holdings, the I-95 Corridor Coalition, and the Maryland State Highway Administration.

Relationship with Cellular Service Providers:
ITIS Holdings has a contract with Cingular.

Project Goals:
Aims to provide traffic information though CHART on freeways and major arterials in Baltimore.

Technology:
The system works by mining data from cellular providers that estimate a cell phones location, for cell phones that are turned on, as they transfer between cells in a network. Once the location of a cell phone has been estimated several times, then an estimate is made about the travel time of road segments that the driver has traveled on. This data is fused with existing RTMS detectors and incident information to determine a final estimate of travel times and speeds. Data is aggregated for the road segments and travel times and speeds are calculated.

DOT Requirements:
The Maryland Department of Transportation contract states "The Department may only integrate Fine Data into CHART if it is demonstrated to the satisfaction of the Contractor that the Fine Data will not as a result be made publicly available," but does not cover issues of accuracy and coverage of the system.

General Results:
Not yet available

Independent Evaluator:
University of Maryland

Atlanta, Georgia Field Test

Deployment Location:
Interstate 75 between Atlanta and Macon, Georgia.

System Coverage:
The system will cover Interstate 75, known to be one of the busiest corridors in the region. The pilot project will cover 65 miles of I-75.

Project Period:
2005 - present

Participants:
The Georgia Department of Transportation (GDOT) contracted AirSage.

Relationship with Cellular Service Providers:
Not reported

Project Goals:
Provide traffic data for a multilane interstate without the expense of loop detectors.

Technology:
AirSage's patented technology. The same technology described in the Hampton Roads, VA deployment.

DOT Requirements:
None Known

General Results:
None reported

Independent Evaluator:
None Known

Missouri Field Test

Deployment Location:
Statewide deployment in Missouri

System Coverage:
First, a prototype test will be conducted on no less then five freeway miles and five arterial miles. Then, full deployment will provide traffic data for 5500 miles of roadway in Missouri.

Project Period:
Request for proposals released in 2005, currently negotiating a final contract.

Participants:

Not finalized

Relationship with Cellular Service Providers:
Not known at this time

Project Goals:
Obtain and disseminate traffic data for 5500 miles roadway maintained by the Missouri Department of Transportation.

Technology:
Not known at this time

DOT Requirements:
Plan and carry out a development test, full deployment, and traveler information services that make the data available to the public.

General Results:
To be determined

Independent Evaluator:
Not known at this time

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Oakland, California Deployment

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Calgary, Alberta Field Test

Traffic Monitoring Application of Cellular Positioning Technology: Proof of Concept. http://www.tc.gc.ca/tdc/summary/13900/13936e.htm. Cell-Loc Inc., 2002.

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Tel-Aviv, Israel Deployment

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Ottawa and Gatineau, Canada Field Test

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Cayford, Randall and Yim, Youngbin. A Field Operation Test Using Anonymous Cell Phone Tracking for Generating Traffic Information. 2005.

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Baltimore, Maryland Field Test

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Atlanta, Georgia Field Test

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Missouri Field Test

Request for Proposal: Traffic Data and Traveler Information Services. Missouri Highways and Transportation Commission. June 2005.

Appendix B

Simulation Studies of Wireless Location Technology-Based Traffic Monitoring

This appendix provides an annotated bibliography of simulation studies of wireless location technology-based traffic monitoring systems. While these studies do not represent “real world” deployments, they do offer some additional insight into the potential operational and performance characteristics of this technology. The simulation studies range from simulations of the technical operation of a WLT-based system to an assessment of sampling characteristics required to support traffic monitoring applications. It should be noted, however, that the simulation studies described in the literature have not addressed systems that utilize call handoffs to generate speed estimates. Alternatively, as seen in Appendix A, the handoff-based approach appears to be the technology that is gaining widespread application in WLT.

1. Ygnace, J-L., J-G. Remy, J-L Bosseboeuf, and V. Da Fonseca. *Travel Time Estimates on Rhone Corridor Network Using Cellular Phones as Probes: Phase 1 Technology Assessment and Preliminary Results.* French Department of Transportation, 2000.

A study conducted by the French transportation research organization, INRETS, focused on developing a discrete event simulation of traffic flow in order to determine the sample size requirements and accuracy of a hypothetical WLT system. The researchers examined three relatively simple traffic networks:

A. an isolated 15-km freeway consisting of ten 1.5 km links
B. the same freeway as (A) paralleled by a frontage road 200 m away for 3 km
C. the same freeway as (A) with a frontage road 200 m away for its entire length and an underpass under the midpoint of the freeway.

The simulation examined the impact of varying levels of probe vehicle penetration on the accuracy of travel time estimates, assuming a location error of 150 meters. The simulation results showed that freeway link travel times could be estimated to within 10 percent of their actual value if there is at least 5 percent penetration of wireless devices in the traffic stream.

The simulation evaluated relatively simple geometric conditions on small networks, which may have had an impact on the promising results. The researchers do not describe how they matched vehicles to the network, although the report implies that it was a simple form of geometric map matching where positions were simply matched to the nearest link. This map matching method probably performed better in this study than it would on more complex networks that would be seen in the real world. The simple, unambiguous nature of the network simplified map matching and may not be able to be replicated in the real world. The study also did not explicitly consider issues like the time between location readings or non-vehicle based probes.

2. **Lovell, D. "Accuracy of Speed Measurements from Cellular Phone Vehicle Location Systems."** ***ITS Journal.*** **Vol. 6, No. 4. 2001.**

The University of Maryland used simulation to examine wireless location technology based on a network-based WLT approach. The purpose of this study was to generally characterize the impact of a variety of parameters on the accuracy and sensitivity of network-based WLT systems, rather than to reach definite conclusions about the utility of WLT-based traffic monitoring. The researchers used a simple network consisting of an 8000 meter one-lane roadway to test two positioning algorithms: an angle-angle location algorithm and an angle-hyperbola location algorithm. Sampling time, vehicle position relative to simulated receivers, and speed variance were examined to determine how they impacted the accuracy of speed estimates. The simulation results indicated that WLT-based systems could provide a general characterization of flow on a freeway, but accurate speed estimates were beyond the capabilities of the simulated system.

3. **Roos, T. P. Myllymaki, and H. Tirri. A Statistical Modeling Approach to Location Estimation.** ***IEEE Transactions on Mobile Computing.*** **Vol. 1, No. 1, January-March 2002, pp. 59-69.**

Researchers from the Helsinki Institute for Information Technology developed a simulation of a network-based WLT. They created a hypothetical road network and overlaid simulated wireless towers on the network. Their model used signal strength, combined with a wireless signal propagation model, to try to estimate vehicle locations. As a comparison, the researchers compared their model results to a very simple process whereby locations were assigned to the wireless tower that received the largest signal strength (Cell ID method). The results of this comparison are shown in Table B-1 below:

Table B-1. Results from Helsinki Simulation.

Measure	Statistical Modeling Approach	Cell ID Method
Mean error	279 m	1092 m
67th percentile error	320 m	1202 m
95th percentile error	620 m	3108 m

The researchers found that their algorithms produced more accurate location estimates than simply assigning positions to the nearest cellular tower. Errors in positioning were still significant in the researchers' model, however. It should be noted that the researchers were only concerned with determining position estimates, and not developing speed or travel time estimates from the location information.

4. Cayford, R., and T. Johnson. Operational Parameters Affecting the Use of Anonymous Cell Phone Tracking for Generating Traffic Information. On *Transportation Research Board 82nd Annual Meeting CD-ROM.* Transportation Research Board, Washington, D.C., 2003.

The Berkeley Institute for Transportation Studies examined factors that could affect the use of WLT. The researchers examined three variables in their simulation: location accuracy, frequency of locations of a single wireless device, and the total number of locations that could be determined per square mile per second. The variation in the number of roads that could be traversed by at least one vehicle within a five-minute period was used as the measure of effectiveness to compare different system design alternatives. The major findings of this research effort were:

- Assuming a network-based system with an accuracy of 100 meters, at least one measurement can be generated on 85 percent of the roads every 5 minutes. This assumes that positions are updated every 30 seconds, and a maximum of 40 locations are determined every second per square mile.

- Assuming a handset-based system with an accuracy of 50 meters, a measurement can be generated on 90 percent of the roads every 5 minutes. This assumes that positions are updated every 30 seconds, and a maximum of 40 locations are determined every second per square mile.

The researchers did not address whether the observed sample sizes were sufficient to produce accurate estimates of speeds or travel times for the entire traffic stream, nor did they produce any estimates of speeds. Furthermore, they do not explicitly describe how they matched vehicles to roads, or describe their test network or simulation method in a detailed manner.

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

6. Fontaine, M.D. and B.L. Smith. Probe-based Traffic Monitoring Systems Using Wireless Location Technology: Investigation of the Relationship Between System Design and Effectiveness. To be published in the *Transportation Research Record*, 2005.

This research investigated the relative importance of system design and roadway network characteristics on the overall performance of WLT-based monitoring systems. A test bed was created that combined a WLT-based monitoring system emulation with the microscopic traffic simulation model VISSIM. WLT-based monitoring was simulated as a handset based system that could provide locations anywhere on the network. This test bed was used to examine a variety of system design, traffic, and geometric characteristics through a combination of tests on simple geometric networks and case studies of simulated complex, real world traffic conditions. Some of the major findings of this work included:

- Map-matching plays a critical role in the effectiveness of WLT-based systems, especially for complex urban networks. WLT-based systems should use robust map matching methods to ensure that vehicle tracks are correct. If map-matching methods are strong enough, the system should be able to distinguish between traffic located on roadways and that located off of the roadway network.

- Using a relatively infrequent mean time between samples generally improves speed estimation over frequent sampling intervals. Using longer sampling intervals allows the system to gather information over longer distances, reducing the chance of capturing a non-representative speed.

- Large errors in vehicle positions usually translate into larger errors in speed estimation. Location errors should be minimized to improve system accuracy. Speed estimation errors are largest when the mean time between location estimates is short and position errors are large. If the system has large errors in positioning that cannot be reduced, it should be designed to use long sampling intervals to mitigate this problem.

- Satisfaction of central limit theorem based sampling requirements does not ensure the desired level of accuracy can be achieved. Map matching errors are the main reason for this. It appears that sample sizes two to three times those specified by the central limit theorem may be required.

The research also showed the need for WLT-based systems to be able to change system parameters, especially the number of vehicles tracked, based on the characteristics of different parts of the network. More vehicles will be required for complex parts of the network than for simple portions to ensure that adequate probe vehicle penetration is achieved. The research indicates that the design of a WLT-based monitoring system is not a “one size fits all” problem and that systems will have to be scalable to accommodate location-specific characteristics. Likewise, the research showcased the need to develop stronger data screening techniques to remove problems associated with map matching.

Appendix C

Floating Car
Traffic Monitoring Deployments

There are a number of deployments of private sector, probe-vehicle (floating car) based traffic monitoring systems. Unfortunately, detailed data is not available for many deployments. Summaries of three of these systems are summarized below.

<u>FVD System</u>

Deployment Location:
United Kingdom Department for Transport

System Coverage:
Unknown

Project Period:
Three year project, started February 2004

Participants:
ITIS Holdings, UK Department for Transport

Project Goals:
To measure congestion across the road network – enabling DfT to producte detailed reports on the pattern and location of congestion.

Technology:
FVD – floating vehicle data network. Probes automatically collect and re-transmit location (via GPS), and average vehicle speed. ITIS signs data supply contracts with large telematic companies that track vehicles for logistics and fleet management purposes.

General Results:

Accuracy results are not reported. However, FVD is gaining a number of users, including government, automotive, content aggregators, etc. This would imply that the data accuracy is of sufficient quality for use.

<u>VERDI Field Test</u>

Deployment Location:
The VERDI (VEhicle Relayed Dynamic Information) field test gathered data in Germany

System Coverage:
Approximately 850 probe vehicles were used to gather travel information

Project Period:
Unknown

Participants:
Mannesmann-Autocom, Telematic service providers, the regional ministry of transportation and the motoring club, ADAC.

Project Goals:
To develop and test procedures for Mannesmann-Autocom's floating car data that uses GPS and GSM technology.

Technology:
GPS sensors were chosen to determine the location of the probed vehicle. The information is transmitted to the servers managing the data by a GSM network.

The roadway system is broken into segments. Probed vehicles transmit location data periodically. The location data is matched to a digital map. The travel time is the difference from when a probe leaves and enters a segment of roadway.

General Results:

Floating car data over a six week period was able to detect 45% percent of the traffic disturbances, which were confirmed by the Northrhine-Westphalia police. The VERDI system was able to recognize about 25% of the disturbances an hour earlier than they were broadcasted on the radio (Fastenrath).

Fastenrath analyzed congestion on a highway near Cologne. The location, duration, and structure of the congestion is practically the same for the incident measured by 20000 measurements of inductive loops and only 200 floating car data points.

OPTIS Field Test

Deployment Location:
The OPTIS (Optimized Traffic In Sweden) field test took place in the city of Gothenburg, Sweden.

System Coverage:
223 vehicle equipped with probes took part in the field test. The criteria for participating in the field test included vehicles frequently traveling many miles per day on the arterial and secondary road network in the city of Gothenburg (IVsource.net et al, 2003).

Project Period:
The six month field test took place from April to September in 2002.

Participants:
The OPTIS project is a joint venture between the government and car manufacturers. The government entity is the Swedish National Road Administration. The car manufactures include SAAB Automobiles, Scania Commercial Vehicles, Volvo Cars, and Volvo Truck Corporation.

Project Goals:
To develop a successful and cost effective method of collecting data on traffic that will provide motorists traveling information.

Technology:
The roadway system is broken into segments. The travel time is the difference from when a probe leaves and enters a segment of roadway. GPS sensors were chosen to determine the location of the probed vehicle. The information is transmitted to the servers managing the data by GSM or SMS networks. OPTIS designed their probes after the Volvo OnCall product by Volvo that included the location and transmission hardware in one unit.

General Results:
Marika Jensta reported the OPTIS concept has also been evaluated in terms of traffic- and environmental effects using the scenario method. It shows that travel time information of good quality can be produced with the OPTIS concept. In case of major incidents alternative routes can reduce travel time as much as 25 minutes for the areas affected. Rough calculations concerning emissions indicate that they also can be reduced. A positive business case requires that future vehicles are equipped with the OPTIS algorithm in a telematic platform from the start in order to avoid expensive retrofit installations. There is also a need for a large number of cars to be equipped. The cost of communicating data is a major part of the total cost in a FCD operation

Niclas Karlsson reported that computer simulations show that penetration of probes needs to be around 3-5% in a mid sized city (1 million inhabitants) to give good quality travel times with updates each minute. The OPTIS field trial has a probe penetration of around 0.5%.

RESOURCES

FVD System

Numerous sources of information at:
www.itisholdings.com

VERDI Field Test

IVsource.net and Richard Bishop Consulting (RBC). "Floating Car Data" Methods are Gaining Momentum Worldwide. http://ivsource.net/archivep/2003/nov/031112_FCD.html. 12 November 2003.

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