Arizona I-19 Wi-Fi Corridor: Assessment of Opportunities for Probe Data Operations

Report TRQS-02

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Executive Summary

A WiFi (wireless broadband) corridor has been implemented with Homeland Security funding on a 30-mile section of Interstate 19 in southern Arizona, near the Mexican border. The corridor presents an interesting opportunity for the Arizona Department of Transportation (ADOT) to utilize probe data collection techniques for monitoring traffic and road condition parameters.

Part of the CANAMEX trade corridor, the Arizona I-19 WiFi Corridor offers a very promising testbed to explore probe vehicle data techniques. The intent of this brief report is to examine features of the WiFi corridor to identify low cost, near term means of experimenting with probe data techniques for these purposes.

A variety of probe data approaches have been and continue to be assessed in the U.S, Japan, and Europe, some of which are operating commercially. This work provides a foundation for assessing the I-19 corridor for probe data collection. Using a WiFi roadway corridor in this way would be a first and would be strongly aligned with the national Vehicle Infrastructure Integration initiative.

This study conceptualized six methods for using the roadside WiFi infrastructure and Mobile Access Devices (MAD) on-board the vehicles to generate probe data. A key factor is to determine time-tagged vehicle location at points along the corridor in order to calculate travel time. This report identifies the candidate methods and assesses advantages and disadvantages. The methods are:

- Method One: Vehicles traveling the corridor which are not MAD-equipped using registered laptops.
- Method Two: Assess location of MAD-equipped vehicles based on received signal strength.
- Method Three: Obtain location of vehicles via GPS-equipped laptops on-board.
- Method Four: Track the antenna handoff times as a MAD-equipped vehicle passes a roadside radio tower.
- Method Five: Track received signal strength and antenna handoff times as a MAD-equipped vehicle passes a roadside radio tower.
- Method Six: Equip on-board MAD devices with GPS positioning.

A subset of these methods, incorporating both vehicle-based and non-vehicle-based techniques, are recommended for further evaluation in proof-of-concept testing. As next steps, tasks to complete this proof-of-concept work are provided, as are issues and approaches regarding field operational testing.

The report also explores the advantages of connecting to the vehicle data bus, which can provide expanded data collection in the areas of weather and road condition. Partnering with a vehicle manufacturer is the most straightforward way of accessing this type of data.

This document was reviewed by technical representatives of several car manufacturers, who provided some very useful input. Two manufacturers have indicated that they are interested in discussing partnership possibilities with ADOT regarding probe data efforts on this WiFi corridor.

By moving forward with this work, ADOT has the opportunity to directly explore the potential of probe vehicle data to enhance operations, building on the successes of many others around the world. Further, ADOT could potentially position itself as a national testbed for probe data applications in support of the federal Vehicle Infrastructure Integration initiative.

I. Introduction

A WiFi (wireless broadband) corridor has been implemented with Homeland Security funding on a 30-mile section of Interstate 19 in Arizona near the Mexican border. Part of the Canamex corridor, this corridor presents an interesting opportunity for Arizona DOT to utilize probe data collection techniques for monitoring traffic and road condition parameters. A map showing the WiFi corridor location, between Rio Rico and Green Valley in southern Arizona, is shown in Figure 1.

The CANAMEX Corridor is a joint project of Arizona, Nevada, Idaho, Utah and Montana, with the primary objective of stimulating investment and economic growth in the region and enhancing safety and efficiency within the corridor. Accomplishing this objective will maximize the economic potential for the United States, Canada, and Mexico. CANAMEX includes transportation, commerce and communications components.

The intent of this brief report is to examine features of the I-19 WiFi corridor to identify low cost, near-term means of experimenting with probe data techniques for these purposes. The report begins with an overview of probe data techniques and R&D and deployment relating to probe systems worldwide. The specifics of the WiFi corridor are then described, and several methods for probe data collection using the corridor WiFi equipment are explored. An approach to proof-of-concept testing is provided, and a Field Operational Testing approach for the most promising implementation is offered. This is intended to provide a foundation for ADOT to pursue further work in this area.

Figure 1: Corridor Map

II. Overview of Vehicle Probe Data Techniques[1]

Given the sensing and computing power on today's vehicles, each vehicle on the road is a storehouse of valuable information about current travel conditions. Vehicle Probe Data Systems are based on the premise of harvesting this information from hundreds or thousands of vehicles across a wide region and putting it to good use.

More specifically, probe vehicle systems collect information from vehicles as they go about their normal business through the road network. Data is collected which is relevant to traffic, weather, and safety, with each message also including time and location. A central entity, such as a Traffic Operations Center, then assimilates and processes that data and distributes results to travelers and road authorities to support traveler information, road management, and safety. In essence, the "information horizon" for travelers is greatly extended.

For instance, by collecting speed and location data from vehicles, the presence of traffic congestion can be easily determined. One or two vehicles that report sudden slowing could be doing so for any number of reasons. But when dozens of them report the same speed profiles at the same location, a high certainty is gained as to the traffic picture. Thus, by "averaging" data from many vehicles, the overall situation is well characterized. Further, experiments conducted to date show that data reporting from only a small percentage of vehicles is adequate to get a good overall picture.

Similarly, geographically-precise weather data can be generated from probe vehicles simply based on the vehicle's location when windshield wipers are activated, combined with temperature sensors. Traction control systems, common on today's vehicles, can generate data as to slippery areas of the road, which when aggregated provides road managers an excellent resource for the deployment of snow plow and salt trucks, for instance. The same type of data, when distributed to drivers, helps them be more cautious in those slippery areas, and vehicle systems can even adjust automatically (i.e. an Adaptive Cruise Control system increasing inter-vehicle gap due to low pavement friction).

Of course, such data is collected now by roadside traffic counter systems and weather stations – but these are spot measurements and usually only exist on major roads. The beauty of probe vehicle systems it that they provide for ubiquitous coverage of the entire road network – wherever cars are traveling.

A key idea for probe vehicle systems is in collecting data that already exist on-board vehicles. The system concept does not demand that any special equipment be fitted on vehicles just to serve the probe vehicle function. Even the communications package must be multi-functional, serving a variety of applications such as electronic payment, automatic crash notification, WiFi services, etc.

Two fundamental approaches to probe vehicle systems are being pursued. For information on motorways rural and suburban areas, data collection via private vehicles or heavy trucks is most appropriate. For information on dense urban environments, taxis are particularly useful, as they are numerous and already have on-board communications gear for dispatching, which can be used to send probe data to a processing center.

II.A. Probe Vehicle Applications

As noted above, probe vehicle techniques can be very useful is gaining a picture of traffic, weather, and road conditions for the entire road network. In addition, given the need for digital

[1] Bishop, Richard: *Intelligent Vehicle Technology and Trends*, Chapter 11, published in 2005 by Artech House, ISBN 1-58053-911-4

maps to be as accurate and up-to-date as possible, vehicles reporting exceptions to their map database can serve an important role in contributing data which supports creation of real-time map updates.

Table 1 provides some examples of existing vehicle sensors and their applications within a probe vehicle approach. In many cases, of course, these parameters would be combined to create meaningful information.

Table 1: Probe Car Data Application Examples

On-Board Sensor	Traffic Application	Weather Application	Road Management Application	Safety Application	Map Database Application
Position (latitude/ longitude)	core data	core data	core data	core data	map corrections
Vehicle heading	core data		core data	core data	core data
Speed	traffic flow status			advance notice of stopped traffic	
Ambient Temperature		icing conditions	application of de-icing	indicator of road friction	
Windshield Wiper Status	traffic slowing due to intense precipitation	precipitation	spot flooding	indicator of road friction	
Longitudinal Acceleration/ Deceleration	detect sudden slowdown indicating a traffic incident		earlier dispatch of incident response teams	advance notice of traffic incident	
Lateral Acceleration			detect hazardous ramp and road curvatures	input to Curve Speed Warning system	
Anti-Lock Brake System Activation			detection of slippery road for dispatching maintenance crews	detection of slippery road	
Traction Control System Activation			detection of slippery road for dispatching maintenance crews	detection of slippery road	
Suspension			presence of rough road or pothole		
Obstacle Detection	first indication of condition to cause a traffic jam		removal of obstacle	input to crash avoidance system	

The trend in probe vehicle system deployment is for traffic and weather data to be reported in first generation systems, with safety relevant data being introduced in subsequent generations.

II.B. Policy Issues Relating to Probe Vehicle Techniques

Some interesting policy issues arise with probe vehicle techniques, of which only a few are reviewed here.

Foremost among these are privacy issues which arise as everyday road travelers are asked to share information regarding their movements and speeds. The case can of course be made that those who share also get the benefit of a rich information flow of data coming back to them. Further, the fundamental concept for probe vehicle systems calls for no identifying information to be sent with the basic data. This can be easily implemented from a technical perspective; the larger issue is the public's *perception* of whether their privacy is protected or not. In essence, this question is not markedly different from other aspects of modern life, where we are assured that our cell phones and emails are not monitored by authorities or accessible by others, yet we cannot really know that this is true in an absolute sense. Rollout of probe vehicle systems, then, must proceed carefully to gain the public's trust.

Secondly, there are issues of data ownership. Probe vehicle systems will result in massive databases of useful travel data. Do the contributors each own a share of it? Does the aggregating entity own it outright? Or, if the data can only be transmitted by equipment installed by the vehicle manufacturer, do they lay some claim to ownership? These are thorny issues which must be worked out gradually and over time, as various implementations are experimented with.

Privacy, data ownership, and other policy issues are being actively addressed by systems developers in the U.S. and Europe, particularly within the Vehicle Infrastructure Integration activity in the U.S. (described below). Privacy principles and operating techniques used by established commercial wireless service providers are expected to form a good foundation for defining this domain for probe data services.

There are also divergent opinions as to the roles of government and industry in implementing probe vehicle systems. This will, to some extent, vary regionally based on the role government plays in society overall. For instance, in Sweden, recommendations have been made that the government should finance implementation of the probe vehicle concept during a transitional period until there are enough equipped production vehicles on the market to provide wide benefits to all users. Alternatively, some car companies have asserted that development of probe vehicle approaches is mainly the responsibility of the auto manufacturers.

II.C. Technical Issues

At the technical level, communications loading dominates, which translates to operating cost and the overall business case.

Depending on the communications media used, and the probe vehicle approach, the cost of communicating this data can quickly skyrocket as packets of data are sent every few minutes by thousands of vehicles. However, current R&D is focused on minimizing the communications loading to reduce costs. Techniques are expected to be deployed soon which will reduce the needed airtime by a factor or 2 or more.

The communications riddle has two facets: reporting data from vehicles, and transmitting processed data back to the drivers/vehicles as the ultimate user. In both cases, synergies must exist with other services to support the cost of the communications equipment in the eyes of the customer.

II.D. Data Reporting

Data reporting from vehicles occurs in the form of short messages which are time-relevant but not time critical. Transmission delays of several minutes or even more are acceptable for traffic and weather information, whereas safety information requires less latency. It is typically the frequency of the messages, rather than their length, which affects airtime costs.

Exception-based reporting will be key to communications efficiency. By referencing an on-board database (which is updated as needed via broadcast), vehicles would only send messages when their own situation is different than information in the database. For instance, the database could contain time-of-day speed profiles for individual links in the road network.

Further, in a mature system in which the majority of vehicles are equipped to provide probe vehicle reports, only a portion of them need to provide information for the overall situation on the road to become clear in the data. Therefore, a communications management loop may be required to instruct on-board systems to temporarily cease reporting.

Data reporting can be accomplished through a wide variety of communication media, including cellular, cellular data, General Packet Radio Service (GPRS), Dedicated Short Range Communications (DSRC), Wireless Access Vehicular Environment (WAVE), and 802.11 wireless hotspot technology. Where DSRC beacons are already common, such as in Japan for their ITS information system, DSRC is a good option and commercial airtime costs are not an issue since the system is operated by the government. In the commercial wireless arena, new cellular data services are under development which are expected to offer lower rate structures for probe vehicle and similar data – telecommunications companies know they have a major business opportunity with vehicle-sourced data and want a piece of the action. Generally, use of hotspots will require agreements with service operators; hotspots are beginning to proliferate along the road network to serve truckers at truckstops, for instance. The Arizona I-19 WiFi network is another example, in this case implemented for purposes of homeland security.

II.E. Overall Probe Data Processing Picture

Figure 2 captures most facets of the discussion above by showing the overall data flows which may occur in a probe car data processing operation. The left-most box labeled “vehicle” shows vehicle sensors feeding an on-board data collection system, which is generating probe messages based on comparing current data with the on-board database. Probe messages are sent to an on-board communications device to be sent outwards to the probe processing center. The Land-side Processing function receives data from many vehicles, processes the data, and fuses it with other data sources to deliver processed probe data to application providers and eventually to end users. Data flowing back to vehicles from the Land-side Processing center updates their on-board databases and manages message flow. Processed probe data also flows back to the vehicles, which is then used by on-board applications to deliver information to the driver and/or support vehicle systems.

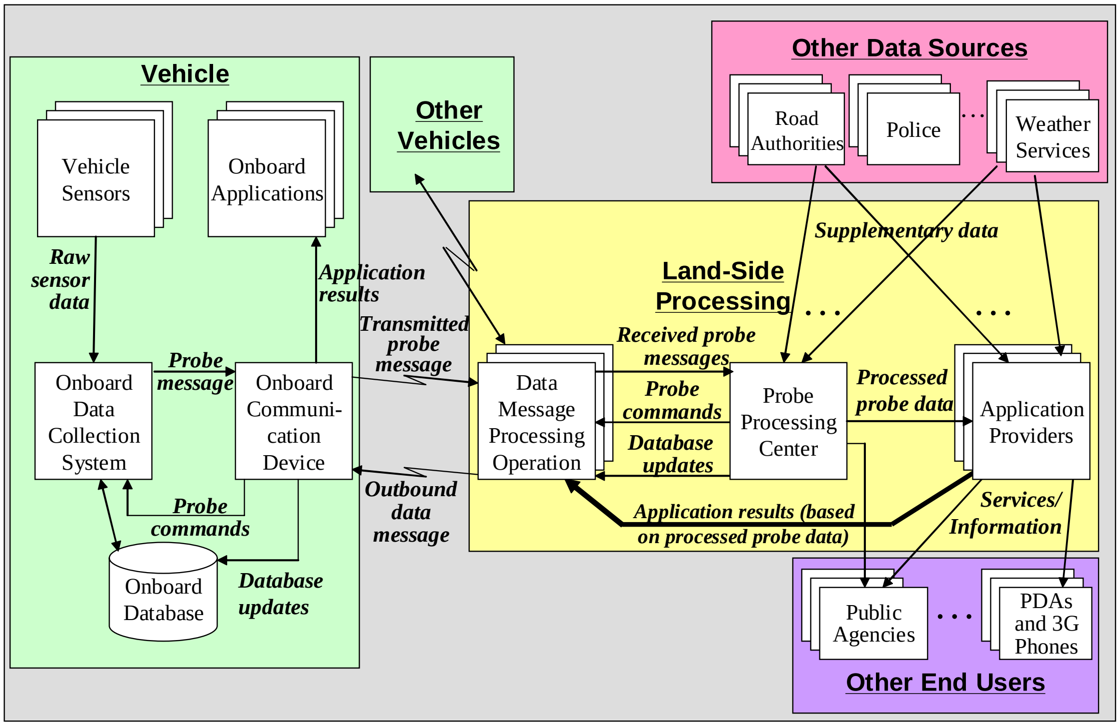

Figure 2: Typical Probe Data Processing Data Flows (source: R. Weiland, Ygomi LLC)

III. Vehicle Probe Data Testing and Deployment -- Europe

Europe is a hotbed of probe vehicle activity for both passenger car and taxi based systems. Probe vehicle systems have also been a part of early telematics offerings -- this work in passenger car probe data is driven strongly by the auto manufacturers, as they see these services as one aspect of enhancing the customer relationship. At the same time, governments are facilitating probe data projects because of the benefits to road management and society overall. The European term for probe data is Floating Car Data systems, or FCD. Current activity can be framed in terms of a) current commercial FCD offerings and b) Research and Development towards next-generation FCD systems.

III.A. Commercial Probe Data Services

A sampling of commercial probe data services is provided here to provide a sense for the degree to which these techniques are currently in use.

ITIS Holdings

ITIS entered the telematics and traffic business in the United Kingdom (U.K.) in 1997, initially to serve trucking companies and now serving travelers in general. They ventured quite early into the probe vehicle field by designing an in-vehicle device which logs, stores, and transmits vehicle position, speed, and direction information. The information collected enables traffic flow rates to be known in real-time, and flows can also be predicted based on historical and other data. Their customers serve as both the data providers and data consumers. Their probe vehicle coverage extends across motorways in several British cities, and plans call for coverage over the entire trunk road network of England, Scotland and Wales. ITIS is also experimenting with measuring real time traffic flow based on anonymously sampling the positions of mobile phones in moving vehicles. This approach is being tested via test deployments in Antwerp, Belgium and Baltimore, Maryland. Results are expected in 2005.

Trafficmaster

Trafficmaster was established in 1988 in the U.K. as a private company collecting and processing traffic data to offer traffic information services. The major part of their data comes from stationary sensors which are supplemented with probe vehicle data. Their probe vehicle approach requires subscribers to mount units in their cars to transmit and receive the traffic information. Trafficmaster is now active across Europe, particularly in Germany and Italy.

Mediamobile

Mediamobile provides data primarily from the French road administration in the Paris area, which is supplemented with probe data from 4,000 taxis. Over 40,000 customers use the Mediamobile service.

DDG

The German firm DDG initially provided traffic information services based upon deployment of thousands of road-based traffic sensors. Via separate agreements with BMW and VW, they are now collecting probe vehicle data as well. Approximately 40,000 probe vehicles (close to 1% of total passenger cars in Germany) are reporting data. DDG is currently processing 30M records daily from reporting vehicles. As a first generation system, the DDG approach is hampered by high communications costs, as vehicles are reporting at regular intervals whether data is needed or not. As will be discussed in the following section, BMW is addressing this issue in their current R&D.

Taxi-FCD System

The Institute of Transport within the German Aerospace Center has implemented the Taxi-FCD System in 2300 taxis operating in several European cities. Because they are capitalizing on fleet management information, there are no on-board expenses for data collection nor are there additional communication expenses. The data structure is simple, with Vehicle ID, timestamp, position, and taxi status being transmitted at intervals between 15 and 120 seconds. This approach yields excellent information on traffic.

III.B. Research and Development Towards Next-Generation Probe Vehicle Services

The following projects provide a sampling of research activity funded by the public sector and the automotive industry. They are presented in a rough chronological order.

Road Traffic Advisor

The Road Traffic Advisor project in the U.K. was an early foray into vehicle-roadside communications for evaluation purposes. Sponsored by the UK Highways Agency, 350 km of the motorway M4 from the London airports to Swansea was instrumented with 80 5.8 GHz beacons. The goal was to develop the necessary in-vehicle electronics and an open architecture to support a variety of applications. Among the applications investigated, probe vehicle data was shown to be technically viable.

Sweden OPTIS Probe Vehicle Data Pilot

OPTIS (Optimized Traffic In Sweden) was a project with the purpose of developing cost effective methods of collecting traffic data in order to provide high quality traveler information. Major partners in OPTIS were SAAB Automobiles, Scania Commercial Vehicles, Volvo Cars, Volvo Truck Corporation, and the Swedish National Road Administration.

At a high level, the OPTIS goal was to show the feasibility of obtaining a quality picture of the traffic status in a metropolis with wide geographical coverage, given a reasonable number of FCD vehicles. The project also sought to establish that FCD is a cost effective alternative to stationary sensors, that FCD provides a cost-efficient means of collecting data in more situations and locations than with other methods, and that FCD can be implemented in such as way that it is commercially attractive to telematics service providers.

The specific objectives of OPTIS were to build a server solution for FCD, verify it through simulations, perform a realistic field trial to verify the simulations, and establish an action program for deployment.

Field trials with 250 vehicles took place in Gothenburg during a six month period in 2002. The data concept was based on travel time. The cars in the study were equipped with Volvo Oncall units modified with OPTIS algorithms. Position data was transmitted to the OPTIS center where the data was processed into travel times. Map matching was performed at the center, so that the cars did not need an on-board digital map. Travel times were calculated at the road link level for each probe by determining a position in the road network and identifying when a vehicle passes the beginning and end of a link. The difference in the two times constituted the measured travel time for the link.

OPTIS evaluations indicated that high quality travel information could indeed be produced with this system approach. The data allowed drivers to choose alternative routes at major incidents, saving as much as 25 minutes on their trip. This was in turn related to emissions reductions if such a system were deployed widely. Overall, the probe vehicle data was shown to offer a better overall picture of the traffic situation as compared to road-based sensors. Further, the installation cost of the probe vehicle solution was estimated to be half that of a fixed detector system.

Communications costs were assessed at a high level. Simplicity at the vehicle level resulted in higher communication loads between the probe and server, compared to an implementation in which the probe vehicle calculates link travel time. Short Message Service (SMS) over the GSM cellular network was used in the pilot, but this is not seen as feasible for deployment due to cost. The General Packet Radio Service (GPRS), a commercial radio service becoming available in

Europe, is seen as an attractive alternative. Generating probe data via GPRS is expected to be 1/10 the price of SMS.

The OPTIS final report called for OPTIS to be followed by a large-scale demonstration project in Gothenburg and Stockholm. The recommendation called for a total of 3% of all vehicles in Gothenburg and Stockholm to be equipped with probe vehicle equipment. The cost was estimated at approximately $5M. Deployment activity along these lines is underway.

Smart FCD: Floating Car Data Collection via Satellite
The European Space Agency has completed a feasibility test with small number of vehicles in the Rotterdam area using satellite communication to collect FCD data from vehicles. The advantage of the satellite approach, of course, is that the entire road network is covered by the satellite footprint. Researchers concluded that this approach to the collection of traffic information is technically feasible. Even though shadowing by large buildings was a concern, the data gathered shows that the coverage of the satellite system is adequate, even in densely urbanized areas. Further, analysis showed that traffic jams were detected effectively with the algorithms used. The project team noted that, compared to conventional detection methods, this concept offers better coverage and better data at competitive costs.

BMW Extended Floating Car Data R&D
Some 40,000 probe BMW vehicles are currently operating on German roads, reporting data through the DDG service described above. Their approach to second-generation probe data systems, called Extended Floating Car Data (XFCD), is based on reporting by exception, data management, advanced event detection algorithms, and data cleansing.

The key to exception reporting is the presence of an on-board database which is frequently refreshed by new data. Although this data refreshment requires communications airtime, it can be transmitted in a broadcast mode which is much less costly. XFCD applications implemented by BMW include traffic, weather (precipitation, visibility), and road conditions. Data elements collected include speed, acceleration, windshield wiper status, ABS signals, headlight status, and navigation data.

BMW researchers have performed extensive analyses to understand the tradeoffs between the quality of traffic information and the necessary penetration rates of equipped XFCD vehicles. They assumed a period of 10 minutes for detection of a traffic incident, which is seen as satisfactory precision for reporting on traffic conditions. One factor affecting needed penetration rates is traffic volume. For example, mean passenger car volumes of 1000 cars/hour require penetration rates of 3.8% in order to reliably detect an incident (reports from at least three XFCD vehicles) within 10 minutes. The necessary penetration rates are halved if a 20-minute detection period is allowed.

The researchers applied their methodology to the Munich road network as a case study. Results showed that, at a penetration rate of 9%, traffic conditions on 50% of the secondary network are detected. If only the primary network is analyzed, a penetration rate of only 5% is sufficient to cover two-thirds of that network. Overall, the analysis showed that an XFCD-capable fleet of 7.3% of the total number of passenger cars is sufficient to detect traffic conditions for over 80% of the main road network. For the overall German federal motorway network, analyses showed that penetration rates of at least 2% are required for good incident detection at peak traffic times, and that satisfactory traffic information can be generated on 80% of the motorway network at penetration rates of around 4%.

DaimlerChrysler CityFCD
Daimler is similarly focused on reducing message frequency through on-board measurement of link travel time and exception reporting based on an on-board link time database.

Researchers have concluded that only two to four probe vehicle messages are necessary to detect the congestion fronts, and their analysis of necessary equipped-vehicle penetration rates yielded results similar to those of BMW: a 1.5% probe vehicle penetration rate gives sufficient service quality in urban traffic. This relies also on the traffic center employing a predictive interpolation algorithm to process the data in the most efficient way and broadcast the predicted link information to the all other probe vehicles to update their databases.

Each CityFCD vehicle measures its travel time on a network section and makes a decision as to whether to transmit this data to the probe service centre or not, based on the previous information received via broadcast.

In terms of communications factors, this optimized message generation process was shown to reduce the amount of messages by factor of 40. Candidate communication channels for data outbound from the vehicle are GSM point-to-point, SMS, Digital Audio Broadcast, and GPRS. Data inbound to the vehicle would be transmitted via broadcast.

IV. Vehicle Probe Data Testing and Deployment – United States

IV.A. USDOT Vehicle Infrastructure Initiative (VII)

In the United States, USDOT is working with car manufacturers and state DOTs (Departments of Transportation) to explore VII. Key VII applications focus on localized services, such as intersection collision avoidance, and network-oriented services that focus on overall regional conditions. Probe vehicle data is seen as key to the latter.

While safety applications are seen as the eventual goal, it is also a longer-term goal and the VII program recognizes that various stepping stones must be in place to get there. Probe vehicle techniques are seen as part of the early VII rollout, as it is less complex technically than advanced safety applications. Further, probe data lends itself to retrofitted equipment more than many other cooperative vehicle-highway applications, and this in turn facilitates accelerated market penetration. This offers the potential to demonstrate clear system benefits in the near term, which is essential to build public and Congressional support for further deployment.

State DOTs participating in VII discussions see the potential for probe vehicle data to save them money in the long term: to the degree probe data deployments are successful, they can reduce their investments in fixed roadside and in-road traffic and weather sensors.

At the current early stages of VII, no probe vehicle work is underway at the Federal level; operational test projects are being planned. However, DaimlerChrysler, a key participant in VII, is demonstrating probe vehicle capabilities at the November 2005 ITS World Congress.

IV.B. Ford Probe Vehicle Experiments

In recent years, Ford has become a very active player in experimenting with probe vehicle techniques. A partnership with the Minnesota DOT (MnDOT) is currently underway, as well as fleet testing in the Detroit, Michigan area.

Minnesota

The Minnesota project calls for 50 state police cars, ambulances and state-owned cars and trucks to be outfitted with sensing devices to collect traffic and weather-related data. Data elements include vehicle speed, location, heading, windshield wiper operation, headlight status, outside temperature, and traction control system status. The information will be transmitted to the Condition Acquisition Reporting System for state roads. Based on data analysis, key information will be derived and distributed to highway message signs, 511 telephone services, and related websites. Vehicles began reporting in late 2004 throughout the Minneapolis/St. Paul metropolitan area.

The Minnesota DOT sees significant public sector benefits from the data collected, such as:

- Decreased time needed for emergency response
- Traffic management
- Road maintenance
- Improved identification and location of incidents
- Decreased cost to collect data, relative to existing techniques using roadside infrastructure
- Expanded data collection coverage to all roads traveled by vehicles equipped with the system
- Enhanced data quantity and quality due to fusion of data from multiple sources (inductive loops, Road/Weather Information Systems, vehicles, cameras, etc.)
- Improved ability to specifically target the warnings and advisory messages to drivers (in vehicles equipped with the system) as they approach the conditions identified

For incident detection and traffic management, MnDOT engineers see the following FCD data elements as useful:

- Travel times between major junctions (for reporting travel times)
- Abnormally slow travel on freeways (indicating stop and go conditions)
- Alternating acceleration and deceleration on freeways (indicating stop and go conditions)
- Numerous indications of significant acceleration and deceleration on freeways in a general vicinity (indicating congestion shock wave condition)
- Abnormally slow travel on non-freeways (indicating congested conditions)
- Abnormally long stopped condition in one vicinity on non-freeways (indicating congestion at a traffic signal, signal malfunction, or incident)

Road maintenance managers within MnDOT expect to benefit from data relevant to icing (ABS or traction control activation, windshield wiper status, ambient air temperature, humidity) which can be fused with other data to direct winter maintenance crews more effectively to needed areas. Also, pavement conditions can be indicated by frequency, amplitude and rate data from vehicle suspension components.

Detroit

Ford is also equipping a fleet of vehicles in the Detroit area near its headquarters with data reporting capability. This includes more than 20 employee shuttle buses that operate in the area, as well as 15 area police cars.

IV.C. Indiana Real Time Transportation Infrastructure Information System

ZOOM Information Systems, under a grant from the State of Indiana, is developing a Real Time Transportation Infrastructure Information System (RTTIIS) based on probe data techniques. Other partners in the effort include Ford, Boeing and Purdue University, with Indiana DOT and the Federal Highway Administration (FHWA) providing requirements inputs for the project.

RTTIIS objectives are to collect road condition, traffic, hazard, and vehicle data in real-time, non-intrusively, and in a cost-effective manner, from road users as they go about their daily business. Processed information will then be provided to public agencies, fleet managers, and back to the drivers themselves.

Plans call for RTTIIS to be based on an open architecture. Demonstration applications will cover a diverse range including: driver information; traffic management; roadway condition and repair; operations, public safety and crash prevention; fleet management; law enforcement; homeland security; and defense.

Initial configurations will contain satellites, both broadcast and two-way, as key elements, although many communication channels will be supported for specific applications.

The work will focus on four research sub-projects addressing the following questions:

- How can current and new vehicle sensors and systems be used to identify road, traffic, vehicle data and other characteristics on-board?
- How can this information be transmitted reliably and bi-directionally to millions of vehicles?
- What is the best architecture and mechanism for storing, aggregating and accessing the data in an open way that is in line with INTI/VII principles?
- How can this multi-vehicle information be analyzed to determine road, traffic and vehicle information and report or display it in a way that is actionable?

The RTTIIS project began in May 2004 with architecture definition. The 21 month project will culminate with an end-to-end, limited functionality system demonstration, which is intended to lead to more extensive deployment.

IV.D. Baltimore Cell-Phone Based Probes

Delcan Consulting is working with ITIS Holdings (see above) to demonstrate the effectiveness of collecting vehicle movement data using cell phone network data. Individual phones are not monitored. As individual phones are passed from cell to cell in the network switching system, this movement can be overlaid on the road network and travel times can be assessed. The system is partially deployed and currently generating data covering Baltimore and the surrounding region. Data quality is reported to be at least as good as the traditional traffic surveillance system.

V. Overview of the I-19 WiFi System

As can be seen above, there are many approaches to collecting probe data. If some means of data communications exists with vehicles in a particular area, then the opportunity exists for probe vehicle data collection.

The I-19 WiFi system presents just such an opportunity, as will be explored in following sections. This section provides an overview of the system.

The WiFi Security Project for First Responders is one of several national information technology demonstration grants awarded by the Information Technology and Evaluation Program (ITEP) of the Department of Homeland Security (DHS) in 2004. It is a "proof of concept" to initiate Phase I of securing Wireless Broadband (WiFi) along a 30 mile corridor between Rio Rico and Green Valley, Arizona. It utilizes existing and new 802.11x access points, strategically placed for rural users, including law enforcement, first responders, or civilians, to obtain broadband connectivity along the corridor. Corridor users will have access while mobile. The long-term plan calls for expanding the end-user categories to include private individuals, businesses and organizations along the corridor, who do not have broadband connectivity today.

The Arizona Telecommunications and Information Council (ATIC) is leading the implementation effort for the Award Grantee, the Arizona Division of Emergency Management (ADEM).

A 30-mile stretch of the CANAMEX trade corridor near Mexico has been equipped as a First Responder WiFi "hot spot" with sufficient access points to enable in-vehicle "WiFi ready" devices moving into and through the area to have mobile access to the Internet or Internet based Virtual Private Networks (VPNs), and with various applications associated with those resources, at broadband (1 Mbps +) speeds. System development and installation was performed by WI-VOD Corporation.

The wireless corridor is one mile wide and is designed to be seamless along its length when working in conjunction with equipped vehicles. The service implemented offers 4 Mbps bandwidth to users for internet access.

In the system, vehicles are used as mobile access points. They are equipped with high-gain antennas which enable robust and seamless communications, as well as wireless routers to create a wireless WiFi environment in and around the vehicle, much as a home router can provide wireless access throughout a house. Wireless devices (such as laptops) within the vehicle connect to the roadside-based network via this equipment. Wireless devices within adjacent vehicles which are registered with the network administrator and which are within range of this "traveling hotspot" can also access the network. At this time, approximately 150 vehicles are equipped with such Mobile Access Devices (MAD) to access the WiFi network.

Each vehicle's MAD has a range of approximately 300 feet, i.e. registered wireless devices inside other vehicles within this range could access the network.

The roadside equipment consists of radio hardware, antennas, and a connection to a landline broadband network. Average spacing of the WiFi beacons is 1.8 miles along the corridor, and the typical north-south range is approximately 3 miles. The precise spacing and range for each beacon is different due to the road geometry and topography.

Each radio tower is equipped with four directional antennas, as shown in Figure 3. Highly directional, narrow beamwidth antennas (Antennas 1 and 3) cover the north-south direction along the roadway, and a wide beamwidth antenna (Antenna 2) covers the area just in front of the tower. Antenna 4 provides coverage of the local area adjacent to the roadway. WI-VOD uses antennas with beamwidths of 20, 60, and 120 degrees, with varying gain, to implement this type of coverage and accommodate the topography at any particular site. (Note: Figure 3 is intended to be illustrative and is not a precise drawing with regard to antenna coverage.)

As a MAD-equipped vehicle travels along I-19, the radio equipment on the tower automatically switches the connection between antennas. For instance, a southbound vehicle would initially be covered by Antenna 1, then be switched to Antenna 2 near the tower, then be switched to Antenna 3 as it travels beyond the tower.

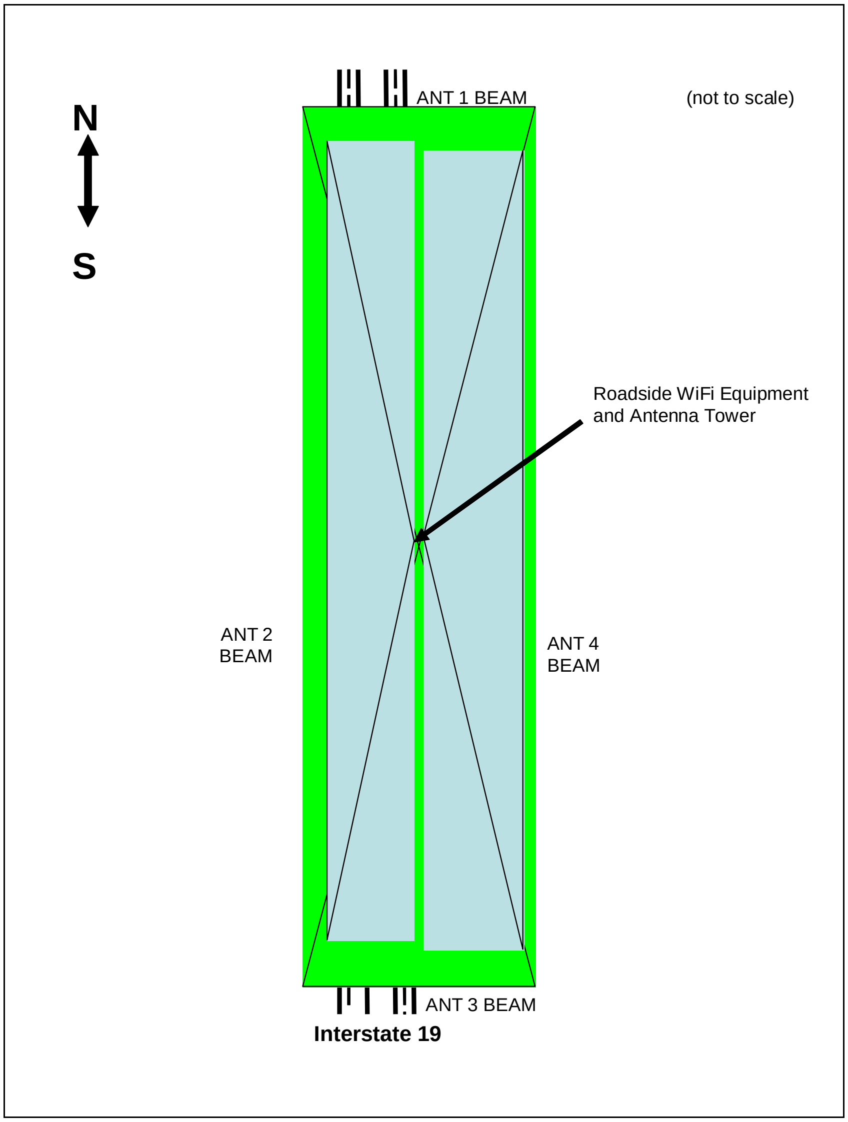

Figure 3: Antenna Beam Coverage for WiFi Tower (conceptual drawing)

VI. How Might the WiFi Corridor Support Probe Data Collection?

There are several methods which could be employed to extract link travel time from vehicles traveling the corridor. These are elaborated here.

Method One: Vehicles traveling the corridor which are not MAD-equipped using registered laptops.

Because a device within such a vehicle will not have the advantage of the MAD equipment amplifying the WiFi signal, gaps in coverage will exist along the corridor. The gaps would be at consistent locations along the roadway and a “gap map” could be created. A software routine running on the on-board laptop could note the time of signal loss and signal re-acquisition and correlate this to the gap map to estimate link travel times.

Advantages: Data could be collected from any vehicle with registered laptops, thereby increasing the pool of vehicle reporting data.

Disadvantages: The actual location of the gaps would depend on the type of vehicle, the location of the laptop within the vehicle, and the radio characteristics of the wireless modem within the laptop. A change to any of these features would change to gap locations. Therefore, a unique gap map would have to be created for each vehicle, and the laptop used and its location would have to be unchanged while collecting and reporting data.

Action Needed to Assess Further: A single vehicle could drive multiple traversals of the corridor with a GPS-equipped laptop collecting data to capture the gap locations. From this data, the consistency of the gap locations could be assessed. As a second phase, the sensitivity of the gap locations to differing vehicles, laptops, and laptop placement within the vehicle could be assessed by conducting additional traversals and varying these parameters.

Method Two: Assess location of MAD-equipped vehicles based on received signal strength.

This technique would rely on the initial creation of a lookup table of the received signal strength based on location. Then, as vehicles travel the corridor, the on-board laptop could continuously log signal strength and correlate that to location; comparison of successive log entries would provide an estimate of the vehicle speed for that section of the corridor.

Advantages: If the correlation between signal strength and location is good, then this technique would provide an excellent means of continuous speed information based on the travel time.

Disadvantages: Since the signal strength can vary with atmospheric conditions, the consistency of the data may be poor at times.

Action Needed to Assess Further: A single vehicle could drive multiple traversals of the corridor with a GPS-equipped laptop collecting data to capture the signal strength versus location information. This should be done on several different days and at several different times of day/night to assess variations in signal strength with location. From this process, data consistency across varying conditions can be assessed.

Method Three: Obtain location of vehicles via GPS-equipped on-board laptops.

Laptops on board vehicles that are equipped with GPS could create time/location logs and send this data to the traffic management center via the WiFi network. Link travel times could then be calculated. This data transmission would be seamless with MAD-equipped vehicles, and intermittent for normal vehicles. Most likely, though, information would only need to be transmitted on a periodic basis, say every 5 minutes, such that the WiFi connectivity would be adequate for either type of vehicle.

Advantages: The combination of GPS and a communications network form the key elements of a full function probe data system. Superb data could be collected through this means.

Disadvantages: A process would have to be initiated to equip the laptops with GPS. Since the owners of the laptops come from a variety of government agencies, this could be difficult institutionally.

Action Needed to Assess Further: This method is quite straightforward technically and no testing is needed to confirm its basic validity. Institutionally, the receptivity of the various users of the network to adding GPS units to their laptops can be assessed. Or, a survey can be done to discover if any existing users already have GPS-enabled laptops.

Method Four: Track the antenna handoff times as a MAD-equipped vehicle passes a roadside radio tower.

As noted in the previous section, each roadside tower has four antennas, each with a dedicated radio. The WI-VOD system switches the connection between these antenna/radio pairs as the vehicle approaches, passes, and departs the immediate location of the tower. WI-VOD system designers note that this handoff zone is on the order of 100 meters. Therefore, data could be gleaned from the switching system at the roadside tower showing an in-vehicle laptop (uniquely identified by its registration number) passing by the tower. For a southbound vehicle, the laptop would initially be communicating through the narrowbeam north-pointing antenna, then be switched to the broadbeam antenna near the radio tower, then be switched to the south-pointing antenna shortly thereafter. The process would repeat itself as the vehicle neared the next radio tower, approximately 3 miles further south. Therefore, the time of the vehicle passing each radio tower along the corridor would be precisely known.

Advantages: This method does not require data collection within the vehicle; instead data can be extracted from the roadside equipment and sent via landline broadband to the traffic management center. With the vehicle transitioning through a 100 meter zone in the radio switching process, the precision of the link boundaries would be adequate for generating good link travel times. Also, because this approach requires no processing on-board the vehicle, a wireless device of any type can be tracked, i.e. a PDA or similar device.

Disadvantages: Potentially, the switching location would be less predictable and thus occur over a zone larger than 100 meters.

Action Needed to Assess Further: The system approach detailed for this method would have to be prototyped to prove the concept. The complexity of the technique to extract the handoff data could be assessed, as well as the length and consistency of the handoff zone for a particular tower. Further, the nature of the handoff zone for each tower can be measured and assessed; the zone will be different for each tower as the antenna patterns on each tower are optimized for the topology within its coverage area.

Method Five: Track received signal strength and antenna handoff times as a MAD-equipped vehicle passes a roadside radio tower.

The received signal strength of the mobile device as well as the handoff times could be tracked at the Road Side Unit while the device is traveling the corridor.

Advantages: Adding received signal strength to the handoff times may provide a better indication of vehicle location than handoff times alone.

Disadvantages: The mobile device must be in a communication session for this method to be effective. A device in stand-by does not send data to the network; therefore the Roadside Unit would not be able to track signal strength or handoff times when the device is in stand-by.

Action Needed to Assess Further: The ability of the Roadside unit to read/track received signal strength from a mobile device must be assessed. The methodology described in Method Two should be used for determining roadside received signal strength vs. mobile device location and the methodology described in Method Four should be used for determining handoff times.

Method Six: Equip on-board MAD devices with GPS positioning.

Here, the MAD equipment would be upgraded with a GPS receiver so that each MAD-equipped vehicle would know its position at all times. The communications management data stream within the WI-VOD system could be modified to include a location/time log, which could then be transmitted to the Traffic Management Center to generate link travel times, as in Method Three.

Advantages: Because this technique relies on changes only to the WI-VOD system, it would not encounter the institutional challenges of Method Three. The data generated would be superb for calculating link travel times.

Disadvantages: This method is constrained to MAD-equipped vehicles only, thereby reducing the pool of reporting vehicles. Also, these capabilities do not now exist in the current system. To implement this method, a hardware upgrade to add GPS would needed for every MAD-equipped vehicle and new communications management software would have to be written to gather and forward the location/time log. These are not seen as challenging technically and are primarily a matter of time and funding. WI-VOD is planning on including GPS in the MADs in a future generation system.

Action Needed to Assess Further: This method is quite straightforward technically and no testing is needed to confirm its basic validity.

<u>Integration with Vehicle Data Bus</u>

Each of these methods can be enhanced by a connection to the vehicle data bus. Per Table 1, data such as windshield wiper status, air temperature, traction control activation, and anti-lock braking activation would enable a quite precise mapping of weather and road conditions. To add data from the vehicle data bus to the probe data stream, connections would have to be implemented between either the on-board laptop or the MAD, depending on the method used. This could create some institutional complexities. For the case of Method 4, which does not rely on in-vehicle data logging, vehicle parameters could nevertheless be reported via the WiFi network. In this case, the parameters would apply to the link and not specific locations along the link as could be done with some of the other methods.

Issues that arise in connecting to the vehicle data bus are discussed in Section VIII.

VII. Proof-of-Concept Testing Approach

In this section, the methods described in Section VI are examined for practicality and payoff. A high-level methodology for on-road proof-of-concept assessment of the most promising methods is provided.

Overall Assessment of the Methods

The most promising method is Method Four (tracking antenna handoffs at the radio towers) because it offers the opportunity to harvest communications management data already existing within the WI-VOD system. Further, there is no need to work directly with the vehicles or in-vehicle laptops at all, reducing complexity.

Method Three and Method Six, which rely on GPS capability to be added either to on-board laptops or the MADs, would provide very good data. If GPS already exists on the laptops of some users, this data should be utilized if possible. Or, if providing GPS to a subset of the users is feasible, then this type of data can be collected.

Methods One and Two rely upon measurements of received signal strength. While these could potentially work, they require extensive characterization of the radio signal and, in the case of Method One, constraints on the location of the in-vehicle device. However, if the radio signal strength *does* correlate well with location in a consistent manner, this could provide a useful source of data at precise points along the roadway, thus providing an advantage over Method Four which is "blind" between radio towers.

Proof of Concept Testing

A proposed proof-of-concept approach would assess a combination of these methods to understand their strengths, weaknesses, and potential synergies. Based on the above discussion, further investigation into Methods Two, Three, Four, and Five is warranted. This is proposed in two phases.

Technical Phase

a. (Method Two) Characterize the correlation of signal strength to location per the discussion in Section VI
b. (Method Three) Equip at least one vehicle with a GPS-enabled laptop and software to create time/location logs and send these to the Traffic Management Center
c. (Method Four) Characterize the technical performance of this method using a single test vehicle equipped with GPS data logging. Traverse the corridor and collect data using Method Four and compare the link travel times to data collected via GPS. Assess the consistency of the handoff point and the length of the handoff zone.
d. (Method Five) Assess the ability of the roadside unit to read/track received signal strength from a mobile device. Combine this data with results from task c. to determine if the fused data improves overall performance.

All of these steps could be performed with a single vehicle equipped with MAD and a GPS-enabled laptop and related software to create data logs. Once the basic technical capability is established, data collection using these techniques should be performed over several days or weeks to assess the consistency of the data and identify the source of any anomalies.

A rough cost estimate for these activities is provided as follows:

- Equip vehicle with MAD, GPS laptop, and data logging software $20K
- Task a. above $10K
- Task b. above $10K

• Task c. above	$20K
• Task d. above	$10K
• Additional testing to assess consistency of results	$15K
TOTAL	$85K

Probe Data Phase

Assessment of the probe data concept can begin once the technical foundation is in place. Fundamentally, probe data techniques rely on many vehicles reporting across a common area, and this is appropriate for field operational testing. Nevertheless, use of only a few vehicles for proof-of-concept can enable traffic engineers to assess the quality of the data for traffic and road management purposes. Vehicles implementing Method Three provide "ground truth" data for comparison purposes to validate the other methods.

Additionally, during this phase some or all data collection vehicles could be upgraded with connections to the vehicle data bus, to provide a richer set of data for evaluation.

Software should be developed during this phase to aggregate data reports from multiple vehicles, and sort, filter, and process this data as needed to generate useful information from a traffic management perspective.

A rough cost estimate for these activities is provided as follows:

• Equip 10 vehicles for probe testing @ $3000 each	$30K
• Interface vehicles to vehicle data bus (hardware/software)	$20K
• Data aggregation software development	$15K
• Evaluation of Data	$20K
• Proof of Concept Testing Final Report	$10K
TOTAL	$95K

An approximate Proof of Concept program total cost would be $180,000.

VIII. Connection to the Vehicle Data Bus

If a probe data operation is able to connect to the vehicle data bus, a richer data set overall can be provided. Key parameters would include speed, air temperature, wiper status, ABS activation, traction control activation, and instances of severe braking.

This data is extant on today's passenger vehicles on the "CAN bus." For access to the vehicle data bus, standard passenger vehicles are equipped with wiring under the dashboard or a connector located in the engine compartment. However, even though the CAN communication protocol is standardized across the industry, the software and codes to access the specific data content are closely held by vehicle manufacturers to avoid tampering with on-board software. Further, the data available on the bus typically varies by model year and even across models in the same model year. Conversion tables would be required for every make, model, and year of vehicle in the fleet to make sense of the data is as it comes off the bus.

For ADOT to access vehicle data bus information would require cooperation with a car manufacturer. This could take the form of a non-disclosure agreement, which would include a stipulation that data would be used under a restricted purpose.

Commercial off-the-shelf equipment is available to obtain vehicle data. In particular, The Dearborn Group specializes in building hardware and software that connects to the On-Board Diagnostic port of a vehicle to read and log bus data. The basic cost of these devices is in the range of $2K. If this type of device is used, it is possible that The Dearborn Group can include Wi-Fi and GPS in their module, at added cost, which would have the advantage of eliminating the need for a laptop in the vehicle just for probe data.

Heavy trucks are also equipped with a similar connector. In this case, by contrast, the data is readily available via the SAE J1708 and J1939 data buses, which conform to an open standard. Therefore, information useful for probe data collection is readily available from heavy trucks.

IX. Field Operational Testing

A proposed structure for a Field Operational Test (FOT) of the most promising probe approach is provided here.

The Methods that are successfully evaluated in the proof-of-concept testing should be included in the FOT. As they are somewhat dissimilar, the FOT may be structured as up to three parallel activities. At the Traffic Management Center (TMC) side, however, this data can be integrated to create a real-time picture of road and traffic conditions.

<u>Number of Participating Vehicles</u>

How many vehicles should participate? The simple answer is to work with as many vehicles as is practical. Probe data scales – the more the better, although there is a point of diminishing returns when the number of reporting vehicles is on the order of 20% or more of the traffic stream.

The time to detect an incident or new condition is a metric that relates directly to the number of reporting vehicles. As an example, the BMW Group's work described in Section III focused on percentages of reporting vehicles to enable detection of an incident within ten minutes.

Based on information from the WiFi Corridor operators, approximately 150 vehicles are equipped to access the WiFi services at this time. Their assumption is that approximately 50% (or 75 vehicles) will be online simultaneously at any one time. Thus, if data is being gathered from all of these vehicles – most likely with Method Four – then one can expect to have a 7.5% probe vehicle penetration if there are 1000 total vehicles on the corridor – an excellent penetration level for probe purposes. This penetration would be halved for every additional thousand vehicles on the corridor. (It would be very helpful to monitor traffic volumes on the corridor during the FOT so that the percent of vehicles reporting can be determined.)

<u>Baseline Data Sources</u>

It is important for the FOT to have a "ground truth" baseline for evaluation purposes. If GPS-equipped vehicles are operating as part of the FOT (Method Three), such ground truth is provided. Any traffic surveillance equipment operating on the corridor can also contribute to the evaluation process.

<u>User Pool</u>

As to the user pool, existing users of the WiFi network would be the group initially targeted. The operational mode of these users should be assessed to determine what types of laptop computers or other wireless devices are used, and how often. An "always on" mode is most useful for probe data collection. For Method Four, any wireless device on-board the vehicle (which is using the WiFi connection and not the cellular connection) can be tracked between links, whereas Methods Two and Three requiring computing power and would therefore require laptops.

Potentially, additional users could be recruited by identifying frequent users of the corridor. Additionally, at 40% of total volume on this corridor, heavy truck traffic is a major portion of the roadway users. Since the SAE standards allow ready access to vehicle data parameters, equipping trucks that make regular runs through the corridor would greatly enhance the data set.

<u>FOT Timing</u>

Depending on the seasonal variations in this area, it may be prudent to run the FOT over one or more seasonal transitions, if vehicle-based data is part of the data set. This would allow for detection of road icing, for instance. The length of the FOT is somewhat arbitrary, but a minimum of three months of active data collection is recommended.

FOT Metrics

Metrics for FOT should be defined, which may include:

- Intervals between link reports, i.e. data availability
- Comparison with ground truth
- Data loading on WiFi network (extrapolated to all vehicles)
- Overall quality of traffic data
- Overall quality of road condition data

Access to Vehicle Data

It would be highly valuable to include a vehicle manufacturer in the FOT which is willing to provide access to the vehicle data bus. However, this is complicated by the fact that they would provide access only to vehicles produced by their company. An examination of the key public safety users may reveal that one particular vehicle make is predominant, and the manufacturer of these vehicles could be approached for cooperation. Further, as noted above, access to data on heavy trucks is quite straightforward.

FOT Participants

In summary, potential participants in the FOT could include:

- Public safety and other government users of the WiFi network
- Heavy trucks with fleets that frequently travel the corridor
- Private citizens regularly using the corridor
- One or more vehicle manufacturers
- Information technology companies familiar with aggregating probe data

X. Conclusion

The Arizona I-19 WiFi Corridor offers a very promising testbed to explore probe vehicle data techniques.

Several methods have been examined in this report. A subset of these methods, incorporating both vehicle-based and non-vehicle-based techniques, are recommended for further evaluation in proof-of-concept testing. As next steps, tasks to complete this proof-of-concept work are provided, as are issues and approaches regarding field operational testing.

This document was reviewed by technical representatives of several car manufacturers, who provided some very useful input. Two manufacturers have indicated that they are interested in discussing partnership possibilities with ADOT regarding probe data efforts on this WiFi corridor.

It is recommended that this proposed plan of work be carried out to confirm these concepts in the near future, while the I-19 WiFi Corridor infrastructure are fully operational and the key participants remain fully active. By moving forward with this work, ADOT has the opportunity to directly explore the potential of probe vehicle data to enhance operations, building on the successes of many others around the world. Further, ADOT could potentially position itself as a national testbed for probe data applications in support of the federal Vehicle Infrastructure Integration initiative.

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List of Acronyms

ABS	Anti-Lock Braking System
ADEM	Arizona Division of Emergency Management
ADOT	Arizona Department of Transportation
ATIC	Arizona Telecommunications and Information Council
CAN	Controller Area Network
DHS	Department of Homeland Security
DSRC	Dedicated Short Range Communications
FCD	Floating Car Data
FHWA	Federal Highway Administration
FOT	Field Operational Test
GPRS	General Packet Radio Service
INTI	Integrated Network of Transportation Information
ITEP	Information Technology and Evaluation Program
MAD	Mobile Access Devices
MnDOT	Minnesota Department of Transportation
OPTIS	Optimized Traffic In Sweden
PDA	Personal Digital Assistant
RTTIIS	Real Time Transportation Infrastructure Information System
SAE	Society of Automotive Engineers
SMS	Short Message Service
TMC	Traffic Management Center
VII	Vehicle Infrastructure Initiative
VPNs	Virtual Private Networks
WAVE	Wireless Access Vehicular Environment
WiFi	Wireless Broadband
XFCD	Extended Floating Car Data