IEEE P802.11  
Wireless LANs

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| Use Cases Requiring Fast Initialization | | | | |
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Abstract

There are multiple applications/uses for 802.11 devices that require extremely low latency when establishing a new link. The uses cases described herein will be the basis for defining specific system requirements to be used in creating the TGai draft amendment to 802.11.

**Note, this is a work in progress and not complete. It is provided now in order to show the direction in which it is going.**

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Structure of this document

The first section identifies the applications that may (or may not) use 11ai, followed by a section that provides a short description of this application and how it may impact the system requirements. For the purposes of this document, a use case consists of a description of an application, how it operates with respect to the 802.11 technology being used, and the resulting impact on system requirements (as they impact 802.11 devices). The second section presents and discusses the system requirements and how they are derived from the use cases. Applications which may need it will also have an expanded description/discussion in a separate Annex for each.

# Applications that would use Fast Initial Link Set-up (FI)

As a general rule, what distinguishes uses required FI are those involving devices that are operating while mobile (e.g a device mounted in a car) as opposed to devices that may be mobile but operate while stationary (e.g. the typical laptop computer). A non-exhaustive list of applications that would benefit from FI are given below, with summaries following, with more detailed description provided in the annexes when appropriate (one annex for each application).

### **Vehicular:**

Some of these applications do not truly require the low latency proposed for 11ai, but would be “bundled” with the more demanding applications in same device. If they may benefit from the added performance achievable with 11ai they are included here.

|  |  |
| --- | --- |
| Probe data collection | Rollover warning |
| Traffic information | Low bridge warning |
| Toll collection | Mainline screening |
| Traveler information | Border clearance |
| In-vehicle signing   * Work zone warning * Highway/rail intersection warning * Road condition warning | Vehicle safety inspection and on-board safety data transfer |
| Intersection collision avoidance | Driver’s daily log |
| Vehicle to vehicle   * Vehicle stopped or slowing * Collision avoidance | Transit vehicle data transfer (on route, at gate, and refueling) |
| Road infrastructure support (e.g. Signal Timing Optimization, Corridor Management, Load Balancing, and Winter Maintenance) | Transit vehicle signal priority |
| Ramp metering | Emergency vehicle signal preemption |
| Gas and drive-through payment | Emergency vehicle video relay |
| Parking lot payment | First responder/emergency vehicle on-site networking |
| Navigation (various forms) | Vehicle data transfer (PCI, IDB, J1708, J1939, etc.) |
| Access control | ATIS data |
| Diagnostic data | Unique CVO fleet management |
| Vehicle computer program updates | Rental car processing |
| Map and music data updates | Locomotive data transfer (including fuel monitoring) |
| Repair-service record | Light and heavy rail internet access for passengers |

Occasionally there will be reference to Vehicle-Infrastructure Integration (VII) which can be summarized as the system that would implement 11ai for vehicular applications.

**Non Vehicular:**

Themajor difference with this type of application is the speed being limited to a person’s walking or running speed but with the significant increase in density. The density of people (who may have multiple devices on each of them) can be very high in some situations, especially if an omni-directional antenna is covering multiple floors of a building (consider the case of a large sports stadium while people are entering on multiple levels and are shoulder-to-shoulder).

* Pedestrian Internet access
* Pedestrian Information Access/Distribution
* [Managing Pedestrians During Evacuation of Metropolitan Areas](http://www.its.dot.gov/its_publicsafety/pedevac/index.htm)

# Use Case Summary Descriptions

### General

When a STA is mounted on a vehicle, the combined unit is referred to as an On-Board Unit (OBU) or On-Board Equipment (OBE). Many uses require multiple radios, or at least multiple antennas to enable directional and selectable coverage both forward and behind the vehicle. Most, but not all, roadside STAs are also APs and the combined unit is referred to as a Road-Side Unit (RSU) or Road-Side Equipment (RSE). Some RSUs are mounted on poles beside the roadway, others on gantries suspended over the road.

The majority of vehicular use cases differ from more conventional 802.11 implementations not only because of the speeds at which the vehicles are travelling while communicating, but also due to the size and shape of the communication zones. In most cases, a significant difference is the need to communicate with only those vehicles travelling in a particular direction on a given stretch of road instead of the omni-direction (indiscriminate) communication zones of most 802.11 hot spots. In some use cases, there is a need to communicate only with vehicles in a particular highway lane (e.g only the right side lane out of the two or more present) which also limits the length of the zone to less about 4 or 5 meters. Thus the requirement is for the vehicle OBU to detect the presence of a new communication zone, establish a link, and complete a full set of data transfers before it has travelled 4 or 5 meters at speeds of up to 200kph (55.5 meters per second). Thus the vehicle total time in the communication zone can be as little as 0.072 to 0.090 seconds. This is not the time allowed for link establishment, but the time for the entire suite of activities from detection, link establishment, and data exchange.

Many of these applications could be satisfied with the use of 11p, but 11p operates entirely outside of a BSS (it uses broadcast addresses) and in order to satisfy the most stringent time requirements, forgoes many of the other benefits that 802.11 has to offer. If 11ai were available, these other 802.11 benefits would be available with 11p use limited to the most extreme situations. Many applications that plan on using 11p would benefit by operating with a BSS, especially with the addition of mesh networking and hand-off from one AP to another. Not included here are those applications that are met by 11p and would not benefit from having 11ai available.

Additional information is available in:

 

MTC\_IntelliDrive\_White\_Paper-508

VII - Apps for Transit (Updated Nov 2007

DSay-1 Use Case # Day-1 Use Case

### Curve speed warning (includes Roll-over Warning)

**Summary Description**

This system makes a calculation based on vehicle dynamics and provides a warning, transmitted from the roadside unit to the vehicle, when the driver’s speed is calculated to be too fast for an upcoming curve. This is also potentially useful for transit agencies, though most transit vehicles operate at fairlylow speeds in urban environments. Commercial vehicles (trucks) would include their own knowledge of loaded weight and center of gravity to determine the potential of a roll-over event.

**Summary Requirements Impact**

### Electronic Brake Lights

**Summary Description**

Electronic brake lightsprovide warning of rapid deceleration by a forward vehicle so that drivers behind can brake in time to avoid a rear-end collision. This is useful for avoiding collisions after sudden stops or in traffic that changes unexpectedly from free-flowing to stop-and-go. (Readers are reminded of Appendix 1, which discusses VII transit benefits by application area.)

**Summary Requirements Impact**

### In Vehicle Signing

**Summary Description**

In-vehicle signageuses roadside-to-vehicle communication to provide more legible versions of roadside signs in the cockpit, such as directional or regulatory signage. This is a form of driver assistance that is useful in inclement weather. Advanced warning information **and** localized road and weather informationuse information gathered from probe vehicles (such as speed, headlight and windshield wiper usage, and traction control and antilock brake application) to generate alerts about roadway conditions and weather-related hazards and send them to other drivers who may be affected.

**Summary Requirements Impact**

### Probe Data Collection

**Summary Description**

Vehicles collect various types of data such as average speeds, weather information, and recent hard braking experiences and then transfer this data to a roadside data collection point for various traffic management purposes. Data must be transferred at highway speeds while within the range of a roadside device that then transfers this data to a central facility (the data may be pre-analyzed prior to forwarding).

This function can be performed using 11p, but with the additional capabilities of 11ai, there could be enhanced performance/reliability by effectively extending the communication zone of the RSU utilizing either handover between RSUs or utilizing a mesh network.

**Summary Requirements Impact**

In general the communication zone, while directional to cover only a given direction of travel on the road, can be as large as the site permits, thus ranging from 10s to 100s of meters and covering up to 6 lanes of travel. The caveat is that to reduce infrastructure costs, the RSU may be one used for other purposes such as toll collection and thus may have a limited range of less than 10 meters (but would then be limited as to number of lanes). Must assume vehicles are traveling at up to 200kph. Typical data transfers from OBU to RSU are less than 10kbytes. Since it is the average values from multiple vehicles that is of interest, occasional transaction failures can be tolerated.

Vehicle anonymity is essential. Must not be possible to identify and track an individual vehicle as it moves around.

Must not be possible for false data to be transferred (verify the vehicle as a trusted source).

### TRAFFIC INFORMATION

**Summary Description**

A roadside device broadcasts relevant traffic information to all passing cars. Operation is similar to, but typical much more involved than, existing variable message signs on highways. The roadside device will use a directional antenna to communicate only with cars traveling in a given direction on a particular section of road. In general this is simple broadcast messages, but by using 11ai, the communication zone of a site could be effectively extended (such as with geo-casting).

**Summary Requirements Impact**

### TOLL COLLECTION

**Summary Description**

Comparable to existing electronic toll collection systems with the additional need to support open road tolling. Open road tolling system do not use conventional toll booths but instead have the roadside units mounted on gantries over the roadway, collecting the tolls as the vehicles pass underneath while at normal highway speeds.

**Summary Requirements Impact**

**(all other applications are pending)**

# Requirements

## Performance Requirements

This section lists the System requirements. The requirements will be categorized as follows:

* Constraint requirements specify predefined behaviors or characteristics of the System and its services. (ed note: do we need this?)
* Functional requirements specify actionable behaviors of System services. (ed note: this may or may not be necessary)
* Performance requirements specify quantifiable characteristics of System service operations. (ed note: this is felt to be the primary type of requirements that we need to specify)
* External interface requirements define system interfaces to other systems. (ed note: in the TGai context, this may consider interfaces to non-802.11 systems or it may be to other 802.11 amendments/functions)

The basis for creating TGai is to facilitate the very rapid creation of new communications links. The question is defining exactly what this means and to establish specific values to be met. At present, it appears that there may be a range of values, from the longest time necessary to be acceptable to the shortest time (lowest latency) desired. The question at present is if we need to establish other performance specifications, such as those associated with handover or mesh networking. An example of what might be used is the following graphic in which there are two levels of low latency, the blue line representing the minimal goal for acceptance, and the red one that does not have to be exceeded by TGai (the actual values are not important for now, it is the concept that I am trying to get across.

In determining performance requirements for vehicular applications, there are three related variables: vehicle speed, vehicle density, and the size of the communication zone.

There is a correlation between the average vehicle speed and the maximum density that may occur, a plot of this relationship is roughly a bell curve. Without getting into the details, when vehicles are going fast, they are more spread out and thus less dense. When going slow, they are capable of (if sufficient numbers are present) of being as dense as their physical size permits (think of stop-and-go driving). The impact on communications requirements is that when travelling at high speed, the latency becomes more critical, and when travelling at slow speeds, the number of STAs within the communication zone may be critical. In either case, the maximum number of STAs entering the zone per second may not differ enough to impact requirements because of the trade-off between number entering



In summary, the critical parameter is latency. In some scenarios the total number of STAs may be an issue, but that is secondary to the TGai goal. Typically, it would be the number of new STAs entering a communication zone every second that is an issue rather than the total number present. I the table summarizing the key requirement of identified applications, there are many that require latencies of less than 100ms. These are considered outside the scope of 11ai which will be arbitrarily set at 100 ms or greater. Those requiring less than 100ms will be assumed to be satisfied by the capabilities of 11p.

## Security Requirements

This section of the document lists the system requirements. Some of these requirements are definitely at the system level, not within the PHY/MAC scope of 802.11. In such cases, the TGai specification must allow and not prevent such requirements from being satisfied.

Req. # VII Security Service Functional Requirements

SEC-01 The system shall allow an authorized System User to access System services and stored information.

SEC-02 The System shall prevent an unauthorized System User from accessing System services and stored information.

SEC-03 The System shall implement means to minimize the impact of transmission of messages from a false or otherwise unauthorized Network User, Administrative User, Roadside Infrastructure User, or Mobile User.

SEC-04 The System shall provide means to authenticate messages.

SEC-05 The System shall not provide any information that is identified with a specific Private Mobile User to any public or private entity, unless that Private Mobile User has explicitly agreed to share such information.

SEC-06 The System shall provide means for a specific Network or Administrative User to obtain information stored by the System about that Network or Administrative User.

SEC-07 The System shall monitor, detect, report, log, and respond to security incidents.

SEC-08 The System shall implement means to terminate access to the System for any System User, Infrastructure Service Provider Management System, or External Data Source.

SEC-09 The System shall implement means to reinstate access to any System User, Infrastructure Service Provider Management System, or External Data Source that has had its access terminated.

SEC-10 The System shall provide a means to authenticate messages originating from a Private Mobile User without disclosing the identity of the Private Mobile User.

SEC-11 The System shall verify the authenticity and integrity of software and hardware installed in the System.

SEC-12 The System shall be protected against physical intrusion.

SEC-13 The System shall provide access control for physically protected elements of the VII System.

SEC-14 The System shall implement management, operational, and technical security measures to protect assets and information within the System boundary.

SEC-15 The System shall provide a means for encrypting and decrypting data.

SEC-16 The System shall monitor, detect, mitigate, and report software vulnerabilities.

SEC-17 The System shall monitor, detect, mitigate, and report malicious software.

SEC-18 The System shall provide mechanisms for creating, updating, and revoking security credentials.

# Annex A. TRAVELER INFORMATION

**4.1. Application Description**

The objective of the Public Sector Traveler Information application is to provide location and situation-relevant information to travelers while in their vehicles using the VII network and WAVE communications standards. Traveler information would be delivered to vehicles based on a standardized “language” consisting of message sets, data frames, and date elements. The public sector traveler information application is to be differentiated from private sector traveler and navigation assistance applications in that the information (messages) are delivered un-encrypted via the open-standard WAVE short message format as currently outlined in SAE J2735. In contrast, private sector traveler information applications would be encrypted and likely delivered via a propriety language. Additionally, unlike the private sector application, it is not envisioned that the public sector traveler information application would provide for maintaining a communications session as the vehicle moves from RSE to RSE (i.e., the application would not utilize “session management” network services with individual vehicles). Rather, all messages from a particular RSE would be broadcast to all vehicles within range of that RSE.

Within the scope of traveler information application, public entities (both state and local) collect information derived from vehicle probe data as well as from traditional traffic monitoring systems, and provide geographically-relevant information to vehicles. While not directly in the scope of the traveler information application, this same information content might be reformatted and delivered to traditional traveler advisory systems such as web sites, dynamic messages signs (DMS), 511 systems, and highway advisory radio (HAR).

The public sector traveler information application is at this point scoped to include the following message categories:

* Traffic Information
* Incident Information
* Local Signage.

Each of these message categories is discussed in more detail in the following sections.

***Traffic Information.*** The application would include provisions for broadcasting basic traffic information on defined roadway links within proximity to the RSE. Examples of traffic information would include average travel speeds, travel time, and other measures of traffic density (e.g., “percent utilization”). The roadway link descriptive information would be generated both through analyses of probe data as well as through more traditional sources of traffic conditions (e.g., CCTV, loop detectors, etc.). The OBE in the vehicle would then store and “assemble” the roadway link data to convey the “local” roadway traffic conditions to the driver.

While OEMs will employ different strategies to this end, it is envisioned that the roadway link information might be overlaid on a GIS map database and displayed to the driver. Alternative methods of conveying traveler information to the driver could be envisioned that are based on predefined threshold events or incidents, combined with voice annunciation (i.e., exceptionbased reporting).

There are, however, several significant design issues that must be addressed:

* How will roadway “links” be defined (e.g., beginning and ending latitude/longitude together with “link name”)? Will digital map notations available from commercial GIS databases be used for the “link name”? Conventions and standards remain to be finalized.
* How is “proximity” to be defined (i.e., what is the geographic coverage for a particular RSE)? How will coverage requirements vary for different RSE location environments (e.g.,
* CBD, suburban, rural settings)?
* Some RSEs in adjacent jurisdictions will likely have overlapping coverage. How will messages from different jurisdictions be coordinated so that vehicles do not receive conflicting data?
* What is the appropriate resolution for a link (i.e., what should be the length of a travel link as reported in a single WAVE traveler information message)? Can this vary with each reported roadway, and by jurisdiction, or is standardization needed?
* What is an appropriate cycle time for repeating traffic information messages? What are the implications for the number of roadway links (i.e., individual J2735 traveler information messages) for which traffic information can be reported from a particular RSE?

***Incident Information***. The public sector traveler information application would also provide for incident reporting, and would include event-driven messages relevant to a particular point location or roadway segment. Examples include location of an accident, blocked lane, and other types of localized traffic disruptions. Incident information may also include more widespread broadcasts related to emergency events.

***Local Signage.*** It should be noted that in previous documentation describing VII applications, local signage was often treated as a separate application. If local signage however is defined as the in-vehicle equivalent of roadside signage that is generally implemented and controlled by local and state governments, then the source of the local signage is in fact the public sector—and this application is arguably a subset of the public sector traveler information application. Local signage messages are intended to convey information that is temporary or periodic (i.e., may vary with time of day, day of week, etc.). Examples would include school zone warning and associated speed limits, work zone warnings/speed limits, cautionary warnings in place due to special events or conditions such as reduced speed due to surface conditions or fog. Detour information and road closures are also examples of local signage.

**Annex B. SIGNAL TIMING OPTIMIZATION**

**5.1. Application Description**

***Overview.*** At Day-1, VII will provide the ability to gather traffic related information necessary to monitor and refine the operation of traffic signals. When combined with other existing traffic data sets, more effective timing plans could be produced for both isolated and coordinated signal systems. VII data will provide detailed vehicle snapshots, including timestamp, position and speed, as well as the vehicle’s trajectory through the intersection. These data will be archived and analyzed to identify when a range of negative conditions occurs that currently cannot be efficiently measured using conventional traffic detection technologies. Automatic identification of these negative conditions will provide support for developing signal timings and daily schedules for coordinated signal systems.

In the future (beyond “Day-1”), as higher penetrations of VII equipped vehicles enter the market, traffic responsive (TRSP) and fully adaptive traffic signal control based on vehicle probe data could also be enabled. However, signaling systems that are capable of responding to real time traffic flow measurements do not have a high deployment rate in the U.S. Therefore VIIaugmented TRSP applications would likely not see high deployment rates. Additionally the TRSP application would require significant penetration rates of VII vehicles, along with a familiarization and confidence in VII data by practitioners. In addition, fully Adaptive traffic signal control is a very new concept that is not governed by any standard practices or technologies. Utilizing VII data to implement adaptive signal control may require partial or total revision of basic signal control concepts and architecture. Adaptive signal control that is enabled by VII technology is therefore not a Day-1 application and is not covered in this Application Development Plan.

For a more detailed discussion of traditional traffic signal control systems, see Appendix B.

***Background: Signal Timing Optimization Goals***

There is no general consensus on what constitutes good traffic signal operation. Some optimization tools are based on reducing stops and delay in various combinations, others on maximizing capacity. Still others are based on some surrogate performance measure such as progression. In practice, most agencies desire to please their motorists in order to minimize citizen complaints. Because the motoring public in a given region has been conditioned by the operation of that region, basing success on citizen complaints allows wide regional divergence. For example, some regions routinely use cycle lengths in the range of two to four minutes, while other agencies with equally congested networks would never implement a cycle over two minutes. Motorist opinion in congested areas is usually strongly held and vigorously expressed, and drivers accustomed to one system might find the operation of another system intolerable.

Despite these regional effects, motorists generally complain when they are forced to stop unexpectedly or for a longer period than they believe is “fair.” They often complain when forced to wait through more than one green period. Finally, they complain when queue lengths block access to intermediate intersections and driveways, or force turning lanes to spill out into through lanes. Thus, most skilled practitioners seek signal timings that minimize the following: queuing, unexpected and unexpectedly long stops, cycle failures, and queue spillover

***Implementation and Operation of Traffic Signal Systems***

Traditionally, traffic signal timings are developed on the basis of the volume of vehicles making each movement at each intersection. These counts are usually collected manually; although, during peak periods, some can be collected using a system of vehicle detectors if they are favorably configured. However, most agencies do not configure detectors for counting vehicles because such configurations are not necessarily the most effective arrangement for normal “calling” and “extending” functions that are part of actuated signal control. (see Appendix B for explanation of signal phasing, calling, and extending functions).

Data collected for signal timing plans also usually includes 24-hour vehicle counts made with temporarily located automatic traffic counters. These provide traffic volume data to support the initial development of signal timing (or phasing) plans for various periods throughout the day (i.e. daily schedules).

These data are programmed into signal timing optimization software that use volume-based delay and saturation equations, or volume-based macroscopic simulation, to optimize operation according to the objective function associated with the particular tool.

The signal timings as calculated by the optimization software are then scrutinized by the practitioners, refined as needed, and then installed into the local signal controllers. Daily schedules (i.e., the distinct periods throughout the day for which signal timing plans are changed) are typically implemented based on a visual review of 24-hour count data.

Thus, the operation of most traffic signal systems is based on a limited sample of data collected days, weeks, or months before timing implementation, and they remain in operation potentially for years thereafter.

Once installed, the signal timings are observed in the field for effective operation. Signal timing professionals will determine whether traffic is behaving as expected and therefore achieving the desired optimal operation. Inevitably, adjustments are made to fine-tune both the timing plans and the daily schedule, based on observation over a period of one or more days. The objective of those adjustments is to achieve operation that is visually effective from the perspective of the agency practitioner. That effectiveness is usually based on achieving *smooth flow* and *minimizing queue formation* and congestion. Both are visual manifestations of reduced delay and stops. Those objectives are generally not measurable using traditional traffic detectors (which only measure vehicle presence in a predetermined detection zone).

***Opportunities for Leveraging VII Probe data***

As noted, a critical activity is fine-tuning the signal timings when they are implemented, calibrating the daily schedule, and then evaluating the signal timing patterns over time. Currently, most agencies depend on direct field observations for all these activities which presents a resource challenge to many agencies.

VII probe data can be used to evaluate signal system operation in support of fine-tuning and evaluating signal timing patterns, and in support of calibrating the daily schedule to achieve the desired operation.

In particular, agencies fine-tune their signal timings to:

* Minimize unexpected stops and starts of the traffic stream
* Minimize intersection delay (and thus travel time)
* Minimize cycle failures
* Minimize queue spillover.

Depending on the manner in which probe data is coded, generated, and collected, it could, theoretically, support measuring time-in-queue by movement, deceleration, start of queue position, and unserved queues. These measurements could then be used to support control strategies that would fine-tune the signaling system. VII probe data can also be used to support the ability to supplement detector data in response to detector faults, even if providing an improvement on normal fail-on detector failure modes. Essentially, the probe data would offer a much more efficient means of measuring the effectiveness of the existing signal timing plans compared to manual counts and labor intensive observation by signal timing professionals.

It is possible that offline optimization algorithms can be crafted to use probe-based measures of effectiveness directly, rather than manually collected turning-movement counts. This would require extensive experimentation to develop optimization approaches that would be competitive with traditional methods. In practice, making the probe data available might attract support from the research and software community who have developed these optimization approaches.

Probe data can also evaluate whether progression is working properly by identifying approaches where large platoons arrive while the light is red. This can be used both to evaluate offset values and also to select a pattern that uses offsets more suited to progression in the direction of the problem.

***Supporting Traffic Responsive Signal Plans (TRSP).*** Most practitioners will try to optimize operations using conventional signal timing and daily schedule dimensions before developing traffic-responsive capability. Those agencies that have the resources and face the situations that allow for traffic-responsive operation will use appropriately designed systems to collect a range of volume and occupancy data from the designated system detectors. This historical data will be used to develop thresholds and/or traffic pattern profiles (depending on the system software), to which real-time detection data will be compared for pattern selection during normal operation. These thresholds (for changing signal timing patterns) will be fine-tuned in the same way that daily schedules are fine-tuned—so as to achieve pattern transitions at appropriate times to track the changes in demand patterns throughout the day.

Another opportunity for VII is to provide an alternative to the use of volumes and detector occupancies for traffic-responsive pattern selection. For example, queue spillover is usually a sign of a capacity issue, which is often addressed by engaging a pattern with a longer cycle (up to a point) to increase the capacity. Queue spillover may be detected as increases in occupancy on system detectors, but only if the system detector is ideally placed. The spatial perspective of VII likely makes evaluating the size of the queue far easier.

Clearance intervals provide another opportunity for VII. Timing professionals calculate clearance intervals on the basis of the approach speed and grade. Wet roads are assumed, and this assumption may be unnecessarily conservative during dry conditions and not conservative enough during wet conditions. Existing literature includes research on the necessary clearance intervals under various conditions, but measuring those conditions requires expensive environmental sensing at a wide variety of locations. Such data are not currently available to operating agencies. However, probe data from VII vehicles could be used to pinpoint when deceleration rates declined at certain intersections (in conditions of poor traction) and increase when conditions improve. VII vehicles could also yield useful data such as anti-lock brake actuation, the use of windshield wipers, and/or temperature data which might be used to support changing clearance intervals to track current environmental conditions.

***Supporting Adaptive Signal Systems***. Adaptive signal algorithms based on the ability to detect queue formation have been developed in the past, but were never implemented because queue data have been unavailable. VII probe data can be incorporated directly into adaptive algorithms to address this issue, but it requires designing the adaptive algorithm in light of the available data. Measuring queue lengths consistently and reliably enough to support adaptive control may require a higher penetration of VII-equipped vehicles than is anticipated for Day-1 implementation or demonstration. Moreover, at Day-1, traffic volume estimates using probe data will not be practical due to the limited, as well as fluctuating, number of VII vehicles within the total vehicle population. It is not envisioned that VII data would replace the traditional processes for developing signal timings initially. Traffic volume requires a predictable penetration, which assumes high penetration rates to minimize error.**References:**