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. The Use Case definitions are felt to be complete as of v4, with remaining work to be done on extracting requirements. Additional Use Cases are known to exist, there are just none identified that would have any further impact on requirements or determining the scope and nature of the work to be done in TGai.**

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Structure of this document

The first section identifies the range of applications that may (or may not) use 11ai, followed by Section 2 that provides a short description of Use Cases based on these applications and how they may impact system requirements. The third section presents and discusses the system requirements and how they are derived from the use cases. Some applications require an expanded description/discussion, this description is provide in a separate Annex for each (not all applications have an Annex as some are more self-evident or else are of relatively minor importance).

# Applications that might 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 more detailed descriptions provided in the Use Cases and in annexes when appropriate.

**Non Vehicular:**

Themajor distinction of this type of application versus the vehicular applications is the speed being limited to a person’s walking or running speed but occasionally with the significant increase in density or the need for very short link or transaction latency requirements. 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 (including both public and private sector uses)
* Transition to 802.11 from other communications technologies (e.g. cellular)
* [Managing Pedestrians During Evacuation of Metropolitan Areas](http://www.its.dot.gov/its_publicsafety/pedevac/index.htm)

### ****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. Some of these are adequately supported by 11p but are included here to assist in establishing the bounds of TGai (e.g. establishing low limits as well as high limits on latency for 11ai).

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| 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 (primarily or only 11p) | Driver’s daily log |
| Vehicle to vehicle (primarily or only 11p)   * 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 |

Because the information provided here originated from multiple sources, and there has been an evolution of these concepts over time, there are instances of different terms/names for what is essentially the same thing. For the purposes of TGai it is not considered critical to find and fix all such instances as they do not impact the outcome of this analysis.

# Use Case Descriptions

### General

When a STA is mounted in/on a vehicle, the combined unit is referred to as an On-Board Unit (OBU) or On-Board Equipment (OBE). The distinction between these terms is not important for 11ai purposes. 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 or on highway overpasses.

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 5 meters (actual values vary). 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 5 meters at speeds of up to 200kph (55.5 meters per second). Thus the 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. While TGai is only addressing link establishment times, the requirements for such times is often dictated by the total transaction time required and an understanding of the total time limitations aids in establishing 11ai requirements.

Many of these applications could be satisfied with the use of 11p, but 11p operates entirely outside of a BSS 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 the 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.

In all of the following descriptions, only a summary is provided. There are so many variations and scenarios possible that it would be unrealistic to account for any but the most obvious that impact the requirements analysis. Thus do not consider the following use cases as complete, it is merely meant to be representative but sufficiently complete for establishing requirements.

Additional information is available in:

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|  |  |
| VII - Apps for Transit (Updated Nov 2007 | MTC\_IntelliDrive\_White\_Paper-508 |

### Electronic Payment Use Case

There are multiple subclasses of this use case, including vehicle toll collection, parking payment, food payment, fuel payment, rental car processing, and other e-payment.

### Actor(s)

There will be a mobile STA, either mounted in a vehicle or carried by a pedestrian that will be referred to as the payer. The payer will link to, and interact with, a fixed STA that will almost always be an AP and be referred to as the payee. The physical relationship (speed of motion, size of the communication zone, number of other STAs within range, etc,) will differ considerably between the various use case subclasses and scenarios. These differences will be highlighted in the scenario descriptions below. Since the payer must divulge sensitive financial access information, data security is paramount. Also, it is very important (with the understanding that there are no guarantees possible) that once initiated, that the link be maintained until that transaction has been completed and acknowledged.

### Device sets

Mobile pedestrian STAs will typically be imbedded in either a smart phone or a laptop/pad style computer. In the future, it will become ever more common that a single pedestrian will have multiple STAs in their possession, and it will be important to identify which of multiple STAs will be the one conducting the transaction. Mobile vehicular STAs will be mounted in vehicles (cars, trucks, busses, rail, etc.). There may be multiple STAs per vehicle with the same need as for multiple pedestrian STAs to determine which of multiple STAs will be used for the transaction. There will also be frequent instances of a pedestrian STA also present in the vehicle, with the same need to determine which STA is to be responsible for the payment. In-vehicle STAs typically have directional antennas pointing forward and in some cases backwards.

For pedestrian use, the fixed STA (the payee) will typically be located in a kiosk or at a retail store counter. For vehicular use, the fixed STA may be mounted over the roadway on a gantry, or at the roadside, typically on a pole or a kiosk such as is used for drive-through restaurants. For either case, the fixed STA will require interaction with some “backroom” server which will typically, but not always, occur over an Internet connection. In most cases, both types of fixed STAs will require a controlled antenna pattern in order to limit coverage to only those mobile STAs that are subject to payment. For instance, in a store, the fixed site might want to link only to those devices that are at the checkout counter rather than every mobile STA within the store (or those of pedestrians walking by just outside the store).For payments with vehicles, the fixed STA will usually want to limit coverage to a limited area such as the entry or exit of a parking lot (exclude those vehicles that are driving by and to differentiate between those cars entering the lot versus those exiting). On highways, there are many situations that require (such as for purposes of managing system performance and for enforcement purposes) that the fixed STA’s coverage be limited to only a single lane when multiple lanes exist. This also limits the length of this communication zone to typically less than 10 meters, in some cases to only 5 meters.

Operating range for vehicular use will vary from just a few meters (such as for parking lots and drive-through retail) to a hundred meters or more for a few applications.

### Goal

The payer desires to identify that this is a valid charge and authorize payment. In many cases, the mobile STA will also be used to present information to the user/payer such as a duplicate of the cash register receipt.

### Scenario(s)

* 1. Pedestrian at retail checkout – After bringing purchases to the checkout counter, or at the pickup window of a drive-through store, the customer elects to pay electronically using their Wi-Fi capable smart phone or hand-held computer. In addition to being recognized as a frequent customer for various benefits, electronic coupons are used and they see the statement/bill on the screen (preferably duplicating the cash register display as the items are scanned), add tip if appropriate, and pay using their digital signature and/or password. The payment is charged to their pre-established account (typically a credit card).   
       
     The time-critical aspect of the transaction is that the mobile STA may not be within range of the fixed AP until moments (only a second or more) before the transaction is to be completed. Should expect association to be completed in the time it takes a person to make one step forward (can assume one meter at a normal walking pace). In high traffic scenarios, conventional association delays can cause unacceptable delays with long lines forming at the counter. In all cases under this scenario, the worst case rate of entry should be just a few (less than 5) devices entering the zone at a time.
  2. Vehicle parking payment – When entering the parking lot, the fixed STA at the entrance identifies the car and associates it with the mobile STA present in that car. Various techniques are used for this, including license plate readers. If multiple mobile STAs are present in the car someone in the car may have to elect at this time which one will be responsible. For cars having WAVE/DSRC OBUs, they will be built into the vehicle and it will be assumed that this will be the STA used for payment.(to avoid the issue of every person in the car having their own mobile STA and having to select between them). Many parking lots are already introducing systems that can notify the driver of where open spaces are located, and the mobile STA would then be used for this purpose. When exiting the lot, the charges are calculated by the parking controller and presented to the mobile STA when it reaches the exit turnstile. If preapproval for charges has been made, the turnstile is raised as the car approaches, negating the need to stop on the way out.   
       
     Much as with the pedestrian at retail checkout, the mobile STA may not be within range of the fixed AP until moments (only a second or more) before the transaction is to be completed. Should expect association to be completed in the time it takes the vehicle to travel one car length (assume speeds of less than 10kph). Conventional association delays can cause unacceptable delays with long lines forming at the entrance or exit. In all cases under this scenario, the worst case rate of entry should be just a few (less than 5) devices entering the zone at a time
  3. Toll road payment – There are two primary systems for electronically collecting road tolls, the conventional toll-booth wherein the fixed STA antenna is mounted over each booth lane, and open-road tolling wherein there are no toll lanes and other than signs, the only indication of toll collection is an overhead gantry containing the various electronics and communications systems needed not only for charging the tolls, but also for enforcement (such as when a car that does not have a toll tag tries to use the road).In either case, the driver simply drives through and the toll is collected without the need to stop or for any action on the part of the driver. Hand-held mobile STAs would probably not be used for this scenario because of the need for human interaction to approve the transaction (e.g. prevent a passenger’s smart phone from being charged instead of the driver’s). Open road tolling has proven to be the preferred approach for multiple reasons, so over time it should be expected that this will represent the majority of toll systems.  
       
     The worst case scenario for establishing latency is the situation where the communication zone is restricted to a very small area (details of why this is done are outside the scope of this document), with a total travel length on the order of 10 meters and cars traveling at up to 200 kph. The number of vehicles per second traveling through this zone depends greatly on the speeds of operation (faster speeds have more spacing between vehicles) and the mix of cars and trucks/buses. Normal spacing at higher speeds can be assumed to be approximately 15 to 30 meters (for this purpose, one should forget what drivers are told to do and instead think about what actually happens on the road). Spacing at low speeds can approach 0 to 2 meters.
  4. Pedestrian payment for subway, train, and bus – This is somewhat of a combination of retail sale payment and toll road payment. It is like retail sales in that it is for pedestrians and the person will have to authorize payment at the place of payment, but is like toll roads in that it is best if there is no need for the person to stop walking while the transaction is taking place. Ideally, the fixed device would be able to cover a relatively wide area when compared to retail sales, the entire entryway for a train/subway platform for instance. There are too many implementation details for the scope of this document, it is hoped that this summary is sufficient..   
       
     Association latency and rate of entry is highly dependant upon the manner in which it is implemented, be it a kiosk-like payment station or like open road tolling wherein people do not stop but merely walk down a hallway or through a doorway. Expect the worst case situation to be an open area space that people walk through, in which case, people are walking at a normal to high rate of speed and the width of the walkway may be several to many meters wide. Payment should occur within the time span it takes to walk one or two paces.
  5. Fuel payment – This is like the conventional gas station pump credit card payment except that the charge is being made electronically via a Wi-Fi connection. It has the advantage, especially when the car is equipped with a WAVE/DSRC OBU, of the driver not having to have a credit card out and the transaction can be pre-approved before the car even comes to a stop at the pump.   
       
     The only need for low latency in this scenario is the potential delays that would be objectionable to the driver before pumping can begin (especially true in foul weather).
  6. Rental car processing – As a rental car drives through the gate upon returning, all relevant data is automatically transmitted to the office and the car “checked in”. The car’s diagnostic connector supplies key information such as the vehicle ID, mileage, fuel level, and any diagnostic codes that appeared. All electronic fees paid for by the on-board systems, such as tolls, parking, fuel, or retail sales that were charged are added to the rental bill. This not only improves the check-in procedure, but also allows rental cars to use electronic toll collection and parking, which they cannot easily do today.   
       
     The latency requirement is to allow all charges to be calculated and a final bill available before the car is parked. The rate of entry can be assumed to be a single line of cars entering at a relatively low rate of speed (less than 15kph).
  7. Food payment – This is either a special case of retail sales payment or, for drive-through restaurants, it is a mix of the retail sales and fuel payment scenarios.   
       
     Latency and rate of entry are comparable to previous scenarios, no new requirements.

### Traveller Information Use Case

Traveller Information may be either hand-held pedestrian services or in-vehicle mobile services. Each of these may then be either region specific (e.g. omni-directional coverage over an area or highly location and directional specific (e.g. covering only those on a specific sidewalk/roadway travelling in a specific direction).

* + 1. **Actor(s)**

There will be a mobile STA, either mounted in a vehicle or carried by a pedestrian that will be the recipient of the information. The recipient device will link to, and interact with, a fixed STA that will almost always be an AP that is the information provider. The physical relationship (speed of motion, size of the communication zone, number of other STAs within range, etc,) will differ considerably between the various use case subclasses. These differences will be highlighted in the scenario descriptions below. In general, data security is not of paramount concern, but the identity of the mobile device may considered critical be to avoid unauthorized tracking of people’s location and movements.

* + 1. **Device sets**

For pedestrian use, the fixed STA will typically be located in a kiosk, outside of or in a retail store, or for public sector services, it may be mounted on utility poles, traffic lights, or any other convenient location for the services to be provided. For vehicular use, the fixed STA may be mounted over the roadway on a gantry, or at the roadside, typically on a pole. For either case, the fixed STA will usually require interaction with some “backroom” server which will typically occur over an Internet connection. In most cases, both types of fixed STAs may require a controlled antenna pattern in order to limit coverage to only those mobile STAs for which the information to be provided is relevant.

Operating range for vehicular use will vary from just a few meters (such as within parking lots or at drive-through retail) to a hundred meters or so for a few applications.

Mobile pedestrian STAs will typically be imbedded in either a smart phone or a laptop/pad style computer. Mobile vehicular STAs will be mounted in vehicles (cars, trucks, busses, rail, etc.). For these use cases it is rare that multiple STAS on a person or in a vehicle present any issues or need to distinguish which one is being used.

* + 1. **Goal**

The goal of these applications is to provide useful information to individuals wherever they may be. The information must be accurate and relevant to the user.

* + 1. **Scenario(s)**
  1. Walking pedestrian – A pedestrian walking down the street, opting to see tourist information about current location. Ability to get map, navigation directions, local attractions, restaurants, etc. Unlike things like the iPhone app “AroundMe”, the information provided would be even more site specific and could be interactive.   
       
     Latency should be no longer than it takes for one or two steps while walking. The rate of entry cannot be explicitly be given without knowing exactly what the coverage area is. For practical purposes, assume an extra walkway 30 meters wide (could be more but this is believed to be a reasonable basis for estimating the rate).
  2. Museum attendee – This is similar to the pedestrian scenario except that it is in a confined, controlled, environment. The person obtains information about an object on display as they walk up to the object. Instead of the current recorded voice guides currently in use, this service would be automatically activated by the current location, within a meter or two if necessary, of the user and could even take into account the direction the person is looking in. The information could be multimedia and be interactive.   
       
     In this case, people are generally walking slower than when going down a sidewalk, but for analysis purposes, the same speeds can be assumed and association should again be completed within one or two steps. Because the communication zone is limited to cover a specific exhibit or piece of art, there will be few people entering at once, assume the equivalent of a 2 meter wide sidewalk.
  3. Car driver – The driver (or passenger) obtains information about upcoming road conditions and travel times from a roadside AP. This would be similar in concept to, but much more advanced than the variable message signs in current use. If major delays exist, it could be expanded into automatically diverting traffic to alternative routes and providing turn-by-turn directions while on these detours. Current traffic management systems hesitate to initiate detours when the problem is a simple backup due to congestion or accidents because of the negative impact on the side streets used. With this approach only selected vehicles could be diverted, or multiple detours used. Each vehicle would be assigned to a specific route and thus may be getting unique directions.  
       
     The latency should be on the order of the time it takes to travel one or two car lengths at highway speeds. The communication zone for this scenario will usually be all of the travel lanes going in one direction (an example to consider is a Los Angeles freeway having 6 lanes in each direction).
  4. Navigation – This could be provided on-demand, with special maps and directions being downloaded as needed. Such downloads could occur spread out over multiple APs to distribute the download time. For commercial trucks, this could include downloading special routing and delivery instructions from their dispatcher and automatically updating the dispatcher with their status and location.   
       
     The requirements for this scenario should be based on the same conditions as previous scenario.

### General Purpose Internet Access

1. **Actor(s)**

There are the fixed sites advertising (and perhaps charging for) Internet access services. These fixed sites are detected and accessed by STAs used by pedestrians or by people riding in vehicles. As with the general subject of Internet Access (which includes social networking, general web browsing, and searching), the subject covers an extreme range of applications/uses. One must not automatically assume that this is limited to Web browsing and the streaming of audio/video files. This can include highly specialized applications such as specialized traveler information, transit information for passengers, and private applications not available to the general public (such as might be used by police or fire departments). It can be hard to discriminate between this and the other Use Cases herein, such as Traveler Information.This Use Case is provided to cover all forms of Internet access so as to avoid the creation of what could be an almost limitless list of uses.

1. **Device sets**

The fixed STAs, which in this case are always serving as APs, are mounted wherever the Internet access service is to be provided, such as along the roadway, sidewalks, parks, or in stores. Coverage would generally be as widespread as practical, but there may be instances wherein coverage is intentionally limited to provide the service to a select group of users (located within this space). The mobile STAs are any combination of handheld devices or vehicular OBUs.

1. **Goal**

The objective is to provide Internet access to people who are mobile.

1. **Scenario(s)**
   1. Pedestrian – Ignoring the already covered scenario such as a coffee shop wherein the service user is stationary (sitting), this scenario is concerned with a pedestrian, a person walking around either indoors or out. They will be using their mobile device, be it a smart phone or tablet computer, to obtain Internet access while walking. There is the possibility of the person running, not just walking, such as when a jogger is asking for streaming music.   
        
      Latency should be no longer than it takes for one or two steps while walking. The rate of entry cannot be explicitly be given without knowing exactly what the coverage area is. For practical purposes, assume an extra walkway 30 meters wide (could be more but this is believed to be a reasonable basis for estimating the rate).
   2. Vehicular – A person in a car may be requesting Internet access at any time under any driving circumstances in which there is available coverage. This may be within a parking garage to obtain information about stores in the area or it could be along the roadside for Web access or to download files or streaming audio/video. In these cases, there will likely be a need for very fast handover from one AP to the next.   
        
      The latency should be on the order of the time it takes to travel one or two car lengths at highway speeds. The communication zone for this scenario will usually be all of the travel lanes going in one direction (an example to consider is a Los Angeles freeway having 6 lanes in each direction).

### Emergency Services

### Actor(s)

There will be a mobile STA, either mounted in a vehicle or carried by a pedestrian that may be either the source or recipient of information pertaining to emergency services. The mobile device will link to, and interact with, either one or more other mobile devices or with a fixed STA that will almost always be an AP. The physical relationship (speed of motion, size of the communication zone, number of other STAs within range, etc,) will differ considerably between the various use case subclasses. These differences will be highlighted in the scenario descriptions below. In general, data security is of paramount concern to prevent either denial of service or spoofing, but device identity is of lesser concern.

### Device sets

The fixed STAs, which in this case are always serving as APs, are mounted wherever the service is to be provided, such as along the roadway, sidewalks, parks. Expect most urban traffic lights to be modified to serve as an AP. Coverage would generally be as widespread as practical. It may be that public APs intended for other uses are temporarily taken over for Emergency Services during critical emergencies. The mobile STAs are any combination of handheld devices or vehicular OBUs.

### Goal

There is a need for improved multi-media communications capabilities within all aspects of emergency service operations. In many cases, such communications will be strictly between the emergency service operators (police, fire, ambulance, etc.), but there may also be the need to improve communication between these emergency service operators and the public, either acting as pedestrians or as vehicle operators/riders.

### Scenario(s)

1. Traffic Signal preemption – Currently, many emergency vehicles are capable of causing a red traffic light to turn green via strobe light communication with the traffic signal controller. Using 11ai, this capability can be greatly expanded, not only in terms of the operating range, but also to take into account the navigation plan of the vehicle so that other lights in the area can be controlled to clear traffic in advance of the emergency vehicle’s arrival at the intersection, but to account for planned turns. This avoids the frequently encountered problem wherein cars in front of the emergency vehicle are totally blocking the roadway. This capability can then be expanded to download data to the emergency vehicle to augment any information previously given to them. This can include video of the scene they are going to and updated navigation directions to account for previously unknown problems. This scenario obviously needs considerable security protection to prevent hackers from posing as emergency vehicles in order to control traffic signals in their favor. An extension of this application is the ability for the emergency vehicle to directly communicate with private sector vehicles ahead of it (and those approaching on cross streets) that they are approaching, from which direction they are approaching, and especially important in congested urban areas, if they desire the private vehicle to move to the right or the left depending on the needs for clearing the intended path.   
     
   The latency is similar to other vehicular scenarios in that association should occur within one or two car lengths while traveling at high speeds. The rate of entry will be low, with no more than one or a very few such vehicles traveling together. Security must be extremely good not only to prevent denial of service, but also to prevent unauthorized users from controlling the signals.
2. Ambulance interaction with hospital – Most likely coupled with the previously described traffic signal preemption, an ambulance can upload vital patient information to the hospital they are going to (or to any other specialists that need to be consulted) while en-route.  
   Such data may include video as well as instrument readings. If the AP is available, such data can be uploaded prior to leaving the scene, perhaps as a means of better defining the best course of action.   
     
   The latency is similar to other vehicular scenarios in that association should occur within one or two car lengths while traveling at high speeds. This is a situation where a very rapid handover from one AP to the next will be very important. The rate of entry will be low, with no more than one or a very few such vehicles traveling together.

1. On-site emergency services coordination – There are many initiatives to enhance the management of emergency situations, both between the various public sector/first responders and the interaction with the public. For first responder interactions (such as at a major accident, fire, or natural disaster) there are currently communication difficulties between the many parties and jurisdictions that may be involved. One scenario being considered is to establish a temporary IP network on-site to go beyond what can be done with simple voice-based systems. In addition to voice, text, and graphics (e.g. building plans), video from a variety of sources can be shared by all on-site responders and shared with fixed site control centers.   
     
   Latency is not as critical as with some of the other scenarios, but still needs to be better than typical 802.11 associations, especially when a new arrival needs to be associated and obtaining data as soon as it arrives. Therefore the typical vehicular association occurring within one or two vehicle lengths of travel should be the requirement. The rate of entry will be from one or two to no more than 10 vehicles arriving within a few seconds of each other.
2. Public Interaction – During an emergency situation, there is a need for improved communication between the emergency services agencies and the public, whether this is to on notice about a situation, to assist in looking for someone (e.g Amber alert) or to conduct an evacuation of an area. The public can be advised about actions that they should take that is specific to their location (don’t send out a city-wide evacuation when only a small specific area is involved) and manage the routing of cars and people to avoid grid-lock for either an evacuation or simply when temporarily rerouting traffic.   
     
   This is comparable to general Internet Access for both pedestrian and vehicular users.

### Commercial Vehicle Operations

### Actor(s)

There will be a mobile STA, usually mounted in a vehicle but possibly handheld by a driver of that vehicle. The mobile device will link to, and interact with, a fixed STA that will almost always be an AP. If a handheld device is used, it will generally be interacting with the vehicle OBU. The physical relationship (speed of motion, size of the communication zone, number of other STAs within range, etc,) will differ considerably between the various use case subclasses. These differences will be highlighted in the scenario descriptions below. In general, data security is of paramount concern to prevent denial of service or spoofing, but also to prevent data theft.

### Device sets

The fixed STAs, which in this case are always serving as APs, are mounted wherever the service is to be provided, such as along the roadway, or at freight terminals. Roadside STAs may be in joint use with applications in other Use Cases. Coverage would generally be as widespread as practical.

### Goal

Freight companies are always looking for any advantage they can find to reduce costs (mostly by improving efficiency) and increasing customer satisfaction. With relatively widespread Wi-Fi communications between the fleet headquarters/dispatcher and the trucks, there are new opportunities for achieving both goals. Currently, most trucking fleets use a combination of cellular phone and satellite communications to interact with their trucks. These forms of communications are relatively expensive when compared to Wi-Fi. Publically accessible hot spots are becoming ever more common, but with the deployment of roadside APs for other vehicular applications, there will be a fairly widespread accessibility on highways and city streets.

### Scenario(s)

1. Vehicle safety – There are requirements for operators to not simply keep their vehicles in a safe condition, but to keep records and undergo occasional safety inspection. Using the capabilities of 11ai, the on-board records can be downloaded to a certified inspection station without the vehicle having to stop and physically hand over these records (electronic scrrening). Some of the data that is available via on-board data networks can also be downloaded to the inspection station at this time. Then, if everything is judged to be OK, the inspection station can upload the fact where and when this vehicle was checked. This would expand on the currently implemented weight-in-motion systems, with the weigh-in-motion function being included in the same system.  
     
   There are two potential implementations, one with a roadside AP acquiring data as the vehicle passes by, the other where vehicle to be inspected is stopped and data is downloaded while stationary. There is the possibility of vehicle to vehicle communications wherein the inspector interrogates the vehicle to be inspected as they are travelling down the road together (the inspected vehicle would be pulled over if there was questionable visual or data issues). The moving vehicle case should allow association before the vehicle has traveled no more than one vehicle length at highway speeds. The difference between this and other vehicular scenarios is that these vehicles are generally longer and moving at slower speeds than private cars, consider the length to be 10 meters or more and speeds to be no more than 120 kph. Rate of entry should consider this difference in speeds and sizes but would otherwise be comparable to open road vehicular scenarios.

1. Hazardous Goods (HazMat) – This would enable the automated monitoring and tracking of shipments of hazardous goods (also known as Hazardous Materials or HazMat). Such shipments have prior approval, not only of the goods themselves, but the route to be taken, with considerable paperwork for the various aspects of the shipment. With the capabilities of 11ai and the existence of various roadside APs, the shipment can be tracked in real time, including monitoring the status of the goods and any on-board security systems.   
     
   Latency and rates of entry are comparable to the previous scenario, including the possibility of both stationary and moving interrogations and tracking.
2. Border Crossing – All of the necessary paperwork, including driver information (which can include biometrics) can be transferred to the boarder inspection station as the vehicle is approaching the station. Thus not only is the inspector ready with all of the necessary information prior to the vehicle arriving, but any missing or questionable data can be identified in advance. Many border crossings have periods of congestion that result in long backups which not only cause a waste in time, but also can cause traffic management problems. With the capabilities of 11ai, the truck can announce itself at a roadside AP hours before reaching the border and can be given an appointment for when to arrive at the same time it is transmitting all of its electronic paperwork.. Thus if there are major delays, the truck can stop at a service or rest area before arriving at the border and wait until the appointed time. Then when the truck actually arrives, there is little waiting time and the inspector can merely verify that the information previously sent is correct and still valid, speeding up the crossing process considerably.  
     
   Latency and rates of entry are comparable to the previous scenario, including the possibility of both stationary and moving interrogations and tracking.
3. Vehicle tracking – All fleets attempt to keep track of all of their vehicles at all times. This capability has evolved over time, from the driver making calls from pay phones at truck stops to cellular phones, to today’s use of satellite tracking systems. The relatively frequent updating possible from satellite systems has proven to have great benefit but at a high cost. Widespread Wi-Fi hot spots along roadways and throughout urban areas can be used by trucking fleets to quickly link to their home office to not only indicate where they are located, but at the same time to download any necessary updates to the driver.   
     
   Latency and rates of entry are comparable to the previous scenario, including the possibility of both stationary and moving interrogations and tracking.
4. Dynamic Load Allocations and Routing and fleet management – Currently, especially with Less Than Truckload (LTL) fleets, there is a need to provide dynamic rerouting of a truck to pick up a previously unscheduled load. This is currently done via cellular phones and satellite systems, but would be much more efficient using Wi-Fi. In doing so, with the additional bandwidth available, navigation updates can be made towards the new destination which take into account all other stops that will be required during that day (a capability that is beyond conventional navigation systems).   
     
   Latency and rates of entry are comparable to the previous scenario, including the possibility of associations both while stationary and while moving.

### Safety

Most of the safety implementations are expected to use 11p and not 11ai. This use case is here in the event we identify any that would be applicable to 11ai. Two examples are left turn assist (right turn in England and Japan) and what is sometimes referred to as “moving stop sign” where low latency is required, but not to the extreme of 11p and where it would also be desirable to have direct addressing to a particular vehicle rather than broadcast to all within or near the intersection.

### Actor(s)

### Device sets

### Goal

### Scenario(s)

### Public Transportation

This includes subway, bus, light rail and heavy rail trains. All of these applications are very close in description to previously described scenarios, especially the electronic payment for fare collection, traveller information for schedules and platform information, and general purpose Internet access for passengers either while waiting for their train/bus or while riding as a passenger. Other applications, such as between buses/trains and a central dispatch center, or in a maintenance facility, can be considered variations of some of the Commercial Vehicle Operations scenarios. For this reason, no new Actors/Device Sets/Goals/Scenarios will described here as even though they may be identifiable as unique applications/scenarios, they should not have any impact on the system requirements.

Two aspects of public transportation that require special note are the issues of how passengers may attempt to access the Internet while under way and of trains entering and leaving stations. While underway, it is expected that there will be an on-board AP that the passengers will use and thus there is no issue with respect to passenger devices attempting to associate with roadside APs while underway. The train’s system will be associating with roadside systems but this becomes just another example of the vehicular Internet Access Use Case.

A special situation is when a train is entering or leaving a station and there may be hundreds of passengers getting on or off and thus attempting to associate with the new AP at essentially the same time. For people getting off of the train, there may be hundreds getting off but they can only exit through the doorways at a rate comparable to people walking through a corridor of the same width as the doorways. The problem that may occur is if they do not perform an association or hand-over as they are getting off, but maintain association with the on-board AP and the train leaves. The reverse is when passengers board a train and the train leaves the station. The result is a potentially very large number of devices attempting to associate or hand-over at essentially the same time due to the sudden loss of the previously associated AP. It is not clear at this time how this can be translated into a quantified and substantiated requirement.

# Requirements (this section is in development)

Requirements fall into three primary categories: Functional; Performance; and Security. Each of these will be defined in their own subsection below. All requirements will be derived from the previously defined Use Cases.

## Functional Requirements

The resulting specifications must allow the establishment of an 802.11 BSS with all of the functionality and capability of a “normally” created BSS. The addition of 11ai shall not alter nor impact the results of a STA joining a BSS.

## Performance Requirements

Performance requirements are in three catagories: 1) the time required to associate (association latency); 2) the number of devices attempting to associate at any one time (the rate of entry into a BSS); and 3) the total number of STAs that may be associated at any one time (this may or may not be important to TGai but will be considered until it is determined to not be a requirements parameter).

The total number of STAs that are already associated (as opposed to those in the process of associating) will be referred to as the BSS population (or simply “population”).

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### Association Latency

The purpose of TGai is to greatly shorten the time required for a STA to associate with a BSS . This is the association latency. The time requirements also apply to the hand-over from one AP to the next and for the purposes of defining requirements this will be considered the same as association latency. The primary performance requirements to be defined are those relating to completing this process. The previously defined Use Cases will be used to derive this requirement.

For pedestrian Use Cases, the majority of scenarios are of the pedestrians walking. Average walking speed (measured in Lower Manhattan) is 1.1 to 1.43 meters per second (3.6 to 4.7 feet per second). Interestingly, headphone listeners walk faster than normal, tourists and people over 65 are the slowest. For determining association latency requirements, we can assume that the mobile pedestrian STA takes 0.6993 seconds to travel a meter. If association is required and any application data is to be transferred before the person has travelled one meter (it is assumed that this is a reasonable requirement), then there is a need for a latency of 0.7 seconds or less. It is assumed that under these scenarios, this translates to an association requirement of less than 0.6 seconds. There was no Use Case scenario that indicated a need for association to occur in less time than it takes to walk one pace, thus this is considered the worst case, and thus bounding, latency requirement for Use Cases involving pedestrian.

For vehicles, the normal speeds are not critical to requirements, it is the maximum expected that are important. With the exception of the unlimited speed limits on sections of the German Autobahn, the normal maximum speed limits around the world are in the range of 100 to 130 kph. There will always be some fraction of vehicles that exceed the limit, so actual speeds will be higher. There is the need to ensure, especially with toll collection, that a vehicle cannot avoid paying the toll by simply driving faster than the system can respond. For this reason, and with some degree of purely subjective opinion, the maximum speed at which these systems must operate is 200 kph. The maximum speed of of 200 kph (55.5 meters per second) must be combined with the minimum communication zone of 10 meters for a total time available from when the mobile device first detects a beacon until multiple data packets have been exchanged. This is approximately 0.180 seconds. It is assumed that under these scenarios, this translates to an association requirement of less than 0.07 seconds *(merely guessing at this point at this value)*. This represents the bounding requirement for latency of all Use Cases involving vehicles.From this, it can be seen that the critical association latency requirement of 0.07 seconds from the vehicular applications is the bounding requirement.

### Rate of Entry

Under some circumstances, the critical performance parameter is the number of STAs attempting to associate with the BSS per second. This will be referred to as the “Rate of Entry”.

For both pedestrians and vehicles, the above speeds are in uncongested conditions. For both people and vehicles, when congestion occurs, they slow down. There are formulas that can be used to define what is essentially a bell shaped curve of average speed versus traffic density, but that is felt to be going into too much detail for the needs of 11ai. For worst case scenarios with the pedestrians, we could assume that there is no slowing down with congestion and that all of the people are able to continue walking at their normal pace of 1.1 to 1.43 meters per second. For vehicles, there is a more dramatic effect and we can assume that the speeds will drop from the maximum of 200 kph to a range of 30 to 60 kph depending on the level of congestion.

For pedestrians, a standing density of 2 people per square meter can be assumed, with a worst case scenario of each person carrying 2 mobile devices. However, at this density, very little motion will occur. Allowing for a crowd that is in motion, a density of 1.5 people/meter2 is a reasonable estimate. At this density, with a walking rate of 1.1 meters/second it becomes a matter of determining the size of the sidewalk/corridor in which the people are walking. A possible worst case scenario is a large subway entrance/exit or a large sports stadium. For our purposes, we will assume a corridor that is 10 meters wide. A 1 meter long section of this corridor would then contain 150 people, which if walking at 1.1 meters/second is 16.5 people per second, and with 2 devices each, is 33 associations per second. This number is of course highly sensitive to the size/shape of the communication zone. One can scale this accordingly for different scenarios, but this seems to be a reasonable set of assumptions.

For vehicular applications, the first case to consider is on an open road with relatively high density of vehicles operating at high speeds. On a large limited access motorway, as many as six lanes of traffic could be within an AP’s range. Considering the average vehicle length (not including trucks) to be 5 meters, and they are maintaining a spacing of 5 car lengths while travelling at 100 kph. The vehicle speed is 27.78 meters/sec and they are entering the zone at one vehicle every 30 meters travelled for an entry rate of one car every 0.926 seconds per lane. Considering each car containing 2 devices and coverage of 6 lanes, this is 12.47 associations per second.

For the same roadway that is heavily congested, the spacing between vehicles is reduced (will assume no spacing for worst case analysis), and the speed may be only 25 kph (6.95 meters/sec). The entry rate is then about 16 associations per second. For the nature of this analysis combined with the assumptions made, we can consider the rate of associations for vehicles to be the same in either high or low speed conditions. The number of lanes involved has a greater impact than the vehicle speed.

From these, the pedestrian entry rate of 33 associations per second exceeds the vehicular rate of 12 to 16 and is thus the bounding requirement.

## 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.