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Vehicle-Infrastructure Integration: Applications for Public Transit

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EXECUTIVE SUMMARY

Introduction

The purpose of this report is to discuss the ways in which Vehicle-Infrastructure Integration (VII) technology could be used to support public transit and paratransit services. More broadly, it seeks to engage the transit community in a discussion of transit's interests and priorities in the development of VII and VII-supported applications. This information can serve as the basis for providing informed input to VII participants about the nature of transit's potential role in the initiative. This work is being sponsored by the federal Intelligent Transportation Systems (ITS) Joint Program Office, in coordination with the Federal Transit Administration's Office of Research, Demonstration, and Innovation.

This report was prepared in 2006 using input from a panel of transit industry experts, and then updated in 2007 through a second round of contacts with the panel. The update round found that the conclusions reached in the 2006 report were still valid as representations of the panel's viewpoints and priorities.

The Volpe Center Study team prepared the first part of this report, which summarizes VII technology and deployment assumptions and presents two sets of potential VII applications: VII "Day One" applications and a list of transit-related applications that were deemed feasible using VII technology. The Volpe Center team generated the second list after consultation with transit experts.

For long-term planning purposes, a distinction was made between applications that could be ready for deployment in the early years of VII (initially planned for 2011 but subsequently pushed back by several years) and those that would require additional time and would see deployment when the VII network would be complete (initially planned for 2020 and also pushed back). Section II provides details on these applications and their potential benefits, with a summary table in Appendix 1.

This background section of the report (Sections I and II) was distributed to transit agency representatives who are leaders in the world of ITS and knowledgeable about the opportunities and challenges of applying ITS to transit. The following summarizes their collective review of VII options as they relate to transit.

Potential Applications of VII To Transit

Safety is the chief goal of the VII initiative and is every transit agency's top priority. Nonetheless, the conference call discussion indicated that transit agencies generally envision the greatest benefits from VII as coming from operational applications (which provide a mixture of efficiency gains, safety benefits, and customer service improvements) than in applications that are oriented solely toward crash avoidance *per se*. Part of this difference may be due to the fact that transit agencies have a per-mile transportation fatality rate that is only one-tenth of that for highway travel. Another relevant factor is that transit agencies face the constraints of the transit vehicle market – one that is marked by much lower production volumes and reliance on overseas suppliers – and thus may not be able to expect on-board safety applications to be implemented as quickly as in the private automobile market. As noted above, transit agencies are also currently more inclined to view VII as a way of expanding their existing operational capabilities.

As noted, transit industry participants tended to see VII for transit as having the greatest potential in operational efficiencies, cost savings, and improvements to the customer experience. Overall, their highest priority applications for 2011 were *traveler information, traffic signal control* (including adaptive control and transit signal priority) and *incident management*.

For 2020, *fleet management* led the list of priorities, followed by *electronic payment*. Fleet management includes the use of VII data to maintain headways on bus routes in which real-time operational data could be used at dispatch or by drivers to make service adjustments and improve schedule adherence and reliability. (See Appendix 1 for a listing of benefits by VII application in greater detail.)

To one degree or another, each application involves issues of institutional coordination and/or technical interoperability. These are discussed in the body of the report, and a summary of institutional and technical questions yet unanswered on VII is summarized in Appendix 2. Perhaps most importantly on the issue of coordination, a consistent theme from the transit agency discussion was that the transit community's approach to VII should be different for the Day One applications *already* being planned by the VII Working Group, versus other transit-specific applications not currently under development. There was a general consensus that transit interests should work toward getting a "seat at the table," wherever possible, as the technical specifications for the Working Group's Day One applications are developed. This will ensure that the system architecture developed by the Working Group does not preclude transit applications and that transit agencies and their customers will be able to reap the benefits of the VII applications that would otherwise be designed only for passenger cars.

The chart below summarizes the highest priorities of the transit agency representatives for VII-enabled applications.

Application	**Origin of Application Concept**	**Expected Deployment Year ****
Traffic signal timing (incl. adaptive control and/or TSP)	VII Working Group – Day One	2011
Traveler information	VII Working Group – Day One	2011
Incident management	Proposed by Transit Industry*	2011
Electronic payment	VII Working Group – Day One	2020 (earlier in some forms and locations)
Fleet management	Proposed by Transit Industry*	2020

*Developed by the Volpe Center team and confirmed with transit experts

**** Based on Original Assumption of VII Build-Out in 2011**

Next Steps

This report has discussed the potential ways that VII technology could be applied to improve the safety and efficiency of transit and paratransit services. It was written with the objective of identifying shared values and interests between the transit industry and the VII Working Group. It hopes to ensure that the Working Group includes applications of particular interest to transit in their future plans, and enables transit to actively participate in VII discussions. This document can serve as a point of departure for those discussions.

SECTION I: BACKGROUND

Introduction

The purpose of this report is to discuss the ways in which Vehicle-Infrastructure Integration (VII) technology could be used to support public transit and paratransit services. More broadly, it seeks to engage the transit community in a discussion of transit's interests and priorities in the development of VII and VII-supported applications.   This information can serve as the basis for providing informed input to VII participants about the nature of transit's potential role in the initiative. This work is being sponsored by the federal Intelligent Transportation Systems (ITS) Joint Program Office, in coordination with the Federal Transit Administration's Office of Research, Demonstration, and Innovation.

VII is an ITS initiative that envisions the ability of vehicles to exchange information with each other and with the roads they are traveling on, using dedicated short-range communications (DSRC) and a nationwide network of roadside transponders.   These communication links would be used to enable a range of safety- and mobility-related applications. As an example, a vehicle that is decelerating sharply would be able to send a message – wirelessly and nearly instantaneously – to the vehicles behind it in order to warn those drivers of a potential rear-end collision.

As with the development of the Interstate Highway System in the 1950s, VII represents both a large-scale federal investment and a new paradigm for travel in the United States. The primary goal of VII is to improve the safety of travel, so many of its envisioned uses are safety-related warnings and driver assistance programs. A secondary aim is to reduce delays and congestion, and the associated air pollution and wasted fuel, through applications such as improved traffic signal timing patterns and information for travelers.

For transportation agencies, including transit properties, an additional benefit of VII is that its roadside units would capture an enormous store of real-time data on traffic volumes, vehicle speeds, and roadway weather conditions, which could be used to improve traffic management, incident management, maintenance, and local transportation planning across the modes. This data can help transit agencies improve their ongoing operational efficiency and safety, which in the end, enhances customer satisfaction. It is also worth noting that VII is being pursued as a public-private partnership with the automobile manufacturers and would create opportunities for private sector transit applications, such as remote diagnostics and electronic payment.

Transit and paratransit agencies could reap substantial benefits from VII-enabled applications – including safety improvements, operational efficiencies, faster and more reliable service, and enhanced customer satisfaction and increased ridership. This document discusses those possibilities and the associated technical and institutional issues.

VII Technology and Deployment Assumptions

The VII initiative has analyzed a range of telecommunications technologies and concluded that VII will be based on DSRC operating at 5.9 GHz. Other technologies were judged to have insufficient availability, excessive latency, or other characteristics that made them unsuitable for the range of safety and mobility applications envisioned for VII. The 5.9 GHz band (strictly speaking, the range from 5.85 to 5.925 GHz) has also been allocated for this purpose by the Federal Communications Commission.

The VII concept requires vehicles to be equipped with certain forms of on-board equipment, consisting principally of a global positioning system (GPS) unit and a DSRC radio, along with some form of driver interface. At the time this report was prepared, the VII initiative had been working on the assumption that *new* light vehicles sold in the United States will be equipped with the requisite equipment over the course of a three-year phase-in period starting in 2011. [1] In other words, one-third of new vehicles sold in 2011 would have the equipment, as would two-thirds of vehicles sold in 2012, and all light vehicles sold thereafter. This timetable has been pushed back by several years, and may also involve a longer phase-in period. No deployment schedule has yet been proposed for heavy vehicles.

On the infrastructure side, VII also calls for the installation of thousands of pieces of roadside equipment (RSE) – essentially DSRC radios that can communicate with equipped vehicles and that are linked to the national telecommunications backbone so that data can be transmitted onward to transportation agencies. As with the on-board equipment, expected deployment dates for RSE have been pushed back by several years. The deployment of RSE had been assumed to take place in two phases, the first focusing on major urban areas and running from 2008 to 2011, and the second completing a nationwide system from 2012 to 2017. It is now unlikely that any RSE deployment would take place before 2011, and these dates may change further as the program evolves.

The VII program plan calls for the VII network to be "switched on" after the first phase of RSE deployment. At this point, the first group of roadside units would be installed and the first new vehicles would be leaving factories and dealerships with the on-board equipment. These equipped vehicles could begin to use the applications that are based on infrastructure-to-vehicle communication. Over the course of time, more and more vehicles would be equipped, and more applications would be powered by direct vehicle-to-vehicle communication. At this point, transit vehicles would need to be equipped for VII if they were to benefit from the various safety applications.

Day One Applications

"Day One" applications are those that, by their nature, can function and offer benefits even during the initial years of the program when a fairly small share of the on-road vehicle fleet would have the required equipment. This is in contrast to applications that would require a certain critical mass of vehicles to be equipped before they could function properly.

As of August 2005, the VII initiative had identified the following fifteen VII-enabled applications as likely candidates for Day One status. The list continues to evolve as of this November 2007 update but has not been formally updated:

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[1] Information in this section on deployment schedule assumptions is drawn primarily from William S. Jones, "A VII Deployment Scenario," prepared for VII Working Group, December 2005.

- **Signal violation warning**
- **Stop sign violation warning**
- **Curve speed warning**
- **Electronic brake lights**
- **Ramp metering**
- **Signal timing and adjustment**
- Winter maintenance
- **Advance warning information**
- **In-vehicle signage**
- **Corridor management**
- **Localized road/weather condition**
- **Traveler information**
- **Electronic payment**
- Probe-based mapping
- Private applications

While the written descriptions of these applications that have so far been produced by the VII initiative are largely highway-oriented and do not specifically refer to transit, many of them clearly have potential relevance to transit. These applications are in bold type in the list above and will be discussed as part of Section II of this report. Because VII is still in the formative stages and the list of applications is not set in stone, the discussion in Section II is <u>not</u> limited to this group of fifteen applications, but rather includes a wider range of potential applications that could become part of a multimodal VII initiative.

SECTION II: POTENTIAL APPLICATIONS OF VII TO TRANSIT

In its work to date, the VII initiative has focused its attention on developing applications for light-duty passenger vehicles and on developing a partnership with the automakers and selected states. This collaboration will lead to the installation of onboard equipment in all cars and light trucks sold in the U.S, and the installation of infrastructures systems by the states. The VII Working Group has not focused on the potential benefits of VII for public transportation or on the prospect of equipping transit vehicles. It is evident, however, that VII offers many potential opportunities for transit agencies to improve the safety, quality, and cost-effectiveness of their services – both in the applications that have been outlined to date and in other applications that could potentially be developed.

This section discusses these potential links between VII and transit. VII applications for transit are presented below in the following groups:

1. Currently planned Day One applications with the potential to provide value to transit
2. Other proposed applications for transit, in the areas of:
    - Crash Avoidance and Vehicle Control
    - Operations
    - Maintenance
3. Existing transit functions that could be enhanced by analysis of VII-supplied traffic and roadway data

1. Planned Day One applications with the potential for value to transit

The primary goal of the VII initiative is to improve the safety of roadway travel and thus to reduce the number of transportation-related injuries and fatalities, consistent with the Safety objective in the USDOT Strategic Plan[2]. Many of the safety-related applications involve providing assistance to drivers so that they can take corrective or evasive action to avoid a collision. Additional applications are also being planned to advance the Mobility objective – that is, to improve infrastructure, reduce congestion delays, improve reliability, and offer greater access to transportation services. Many of these involve using the real-time vehicle and roadway data generated by VII to adjust operations and improve traffic flow. The following discussion describes both safety and mobility applications in more detail.

Two of the safety-related applications being developed for VII are **signal violation warning** and **stop sign violation warning**, both of which use communication between roadside units and vehicles to warn drivers that they are at risk of violating a red light or stop sign. These warnings are based on calculations of vehicle location, speed, and acceleration vis-à-vis the intersection. In the signal violation case, the "state" of the signal (i.e., its timing plan and whether it will be green or red at the expected arrival time of the vehicle) is also part of the calculation. The warnings are intended to prevent intersection crashes caused by inattention or distraction by providing an alert to the driver. Future versions of these applications may also include vehicle-

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[2] United States Department of Transportation, *Strategic Plan 2003-2008: Safer, Simpler, Smarter Solutions*, September 2003.

to-vehicle warnings so that other drivers near the intersection can also take action to avoid a collision.

Curve speed warning is similar in concept – that is, it 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 fairly low speeds in urban environments. **Electronic brake lights** provide 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.)

In-vehicle signage uses 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 information** use 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.

Each of these safety applications has at least the potential to be applied not only to private passenger cars but also to transit vehicles. In each case, some adaptation of the warning algorithms and driver interfaces would be required to make the application suitable for transit vehicles. For example, the curve speed warning would require the development of specialized pitch and yaw sensors for buses, along with algorithms that account for the different dynamics of a transit vehicle. In the 2007 update round, it was re-emphasized that the dynamics of heavy vehicles with unsecured passengers (including, in many cases, standees) are quite different from light vehicles and require significant changes to the warning algorithms.

Transit agencies would benefit from a reduction in the number of crashes involving their vehicles, which would improve safety for their employees and passengers, and would bring safety benefits to other road users. In addition to being the recipients of these warnings and information, instrumented buses could also send information out to *other* vehicles and the roadside. This would be useful, for example, in the case of electronic brake lights, since buses make frequent stops that are not always anticipated by other drivers.

Among mobility-oriented Day One applications, **signal timing and adjustment** and **ramp metering** are designed to reduce congestion by using VII-provided traffic data to optimize signal timing plans and the timing of freeway on-ramp meters. These applications could be adapted to consider transit when adjusting signal timing at intersections and freeway entrances, though full-fledged transit signal priority is discussed separately below. Even in the absence of a specific transit component, these applications would tend to benefit transit agencies, since a reduction in the overall level of traffic congestion on transit routes would help with schedule adherence.

The **traveler information** and **electronic payment** applications envision using VII's telecommunications capabilities to provide travelers with the means of receiving in-vehicle information about travel conditions and of making payment for tolls, gasoline, or other services. These applications are currently described in mostly highway terms, but if made fully multimodal they could also provide substantial benefits to transit agencies and their customers. Transit customers could be provided with real-time status information at stops and stations, such as estimate waits and arrival and departure times. Once aboard, they could receive service updates and information about connections, making transfers more convenient. Travelers en route to park-and-ride stations could receive in-vehicle information about parking availability, transit schedules and expected vehicle arrival times, and traffic conditions on the way to the station. It is also possible that in-vehicle signage and announcements could be linked to location data so that passengers could receive information about the shops and services near each station, though this would raise issues about network access and the appropriate role for commercial messages.

VII data could also play a major role in supplying more accurate information to a regional or statewide multimodal 511 telephone and website information system, covering many more roads and transportation facilities than current systems, and at a lower cost. This would allow residents to use current and forecasted travel and weather conditions to make informed choices about their travel routes, times, and modes. Itinerary planning could include multimodal options and be refined to take account of current travel conditions. Multimodal information of this type is expected to be quite useful to transit agencies and their customers; qualitative research has shown that travelers place a high value on being able to know what to expect, both for its own sake and for the ability to avoid delays[3]. More informed travel could also translate into reduced congestion, for example by reducing the amount of "secondary" congestion associated with an incident as travelers find alternative routes. (Reduced traffic congestion, in turn, benefits transit agencies by reducing travel times and variability.)

Of course, supplying this information requires processing software that can translate raw VII data into meaningful information for customers. Many agencies already have software in place that calculates "next bus" arrival and departure information, but these systems would need to be adapted to the VII environment and data structures. As with all forms of traveler information, it is also important to ensure the accessibility of the information to customers with sensory impairments or other disabilities. VII might even be able to facilitate additional forms of communication for visually or hearing impaired customers, such as providing additional orientation and wayfinding information via communication from a roadside unit to a handheld device.

With regard to VII-enabled electronic payment, it is possible that transit fares, road and bridge tolls, and parking fees could be consolidated into a single, convenient payment mechanism with one-stop billing. (One approach would be to create a portable transit smart card that could also "plug in" to the vehicle and its VII equipment.) This could reduce revenue-collection and processing costs. At the margins, the more convenient fare payment mechanism could draw additional casual transit customers and encourage existing customers to make more trips. Because revenue collection is a delicate subject both for transit agencies and their customers, there are major institutional issues involved with any potential change to fare media and policies.

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[3] ITS Joint Program Office, ITS Benefits Database – Traveler Information

This is doubly true when discussing any plans that entail coordinating with other agencies on shared billing and payment – each agency will want to ensure that it is getting its "fair share" of the revenues, and transit agencies need to ensure that there is a full accounting of their ridership since this is a component of funding formulas. Because of these issues, it is likely that some agencies will be quicker than others to adopt VII-enabled electronic payment.

Corridor management involves the coordinated operation of a set of nearby transportation facilities in order to maximize mobility and reduce delays. A number of different strategies can be employed, including ramp metering, dynamic re-routing, and changes to lane usage. While the VII Working Group has not yet considered the role of transit in its descriptions of the corridor management application, transit can indeed play an important role, for example through the use of a parallel transit line to relieve pressure on a congested roadway. This can be particularly useful for dealing with congestion related to special planned events and during roadway construction projects. The federal Integrated Corridor Management initiative is pursuing a multimodal vision for corridor management that includes a potential role not only for transit but also for pedestrian, bicycle, and water transportation.

There are practical limits to the ability of transit agencies to contribute to this vision – most notably the fact that they simply do not have spare vehicles or staff available to provide extra service on a corridor in the event of a roadway incident. Many park-and-ride garages also fill up early in the morning and have little capacity to accommodate additional patrons. More broadly, the dispersed land-use and activity patterns of most American cities limit the ability of commuters to switch from driving to transit with little notice. Integrated corridor management does however also offer potential benefits to transit agencies, including improved access to multimodal data and stronger relationships with other transportation agencies.

2. Additional transit-oriented applications

Crash Avoidance and Vehicle Control

As noted above, a number of crash avoidance and other safety applications have been considered for "Day One" of VII deployment, with most of them designed to provide extra information and warnings to drivers in order to prevent dangerous situations and vehicle conflicts. Many of these applications could be adapted for use on transit vehicles. In addition, transit operators face a number of more specialized safety issues due to the size, maneuverability, and travel patterns of their vehicles. The transit community has therefore expressed interest in additional crash avoidance applications that would benefit transit operations. For example, **gap assistance for merging** would use vehicle-to-vehicle communication to provide information to bus drivers on when a safe gap was available to merge back into the traffic stream after making a stop, and/or give other drivers notice of the bus' intention to enter the lane. This is a major area of concern, particularly for buses operating on arterial streets with high traffic volumes and relatively high speed limits. It could also be linked to the freeway ramp metering application that is listed as a Day One application by altering ramp entrance timing patterns to account for transit vehicles.

Another concept that has been discussed is **grade crossing warnings**, which would use vehicle-to-vehicle and infrastructure-vehicle communication to provide drivers with in-vehicle alerts about the approach of a train (passenger or freight) or a light-rail transit vehicle. This could supplement the gates at protected crossings and would be particularly valuable at non-gated crossings. This application would bring safety benefits for motorists, transit passengers, and transit employees. While safety is clearly the primary consideration, transit agencies would also benefit from fewer operational disruptions caused by collisions and near misses at grade crossings.

Assisted lateral control uses infrastructure-vehicle communication (though alternative approaches are also feasible) to monitor the lateral position of the vehicle and provide feedback to drivers so that they can keep the vehicle centered within a narrow lane. This is useful in tight downtown areas. In certain circumstances it can be used to facilitate bus service along highway shoulder areas. This is an approach that has been taken on some highways in the Minneapolis-St. Paul area, though highway shoulders in other geographic areas may be less suitable for this. A related application, **precision docking**, provides assistance in properly aligning the transit vehicle at a stop or station or at the maintenance yard. This can help expand the possibility for transit service in space-constrained areas and allow increased speeds in narrow lanes. It is also a necessary part of some bus rapid transit (BRT) deployments. For example, if a BRT station includes a specific boarding location that can be accessed after paying the fare (as in Curitiba, Brazil), precision docking is critical so that the vehicle lines up exactly with the boarding opening in the station. Precision docking can also be used to assist drivers performing "bus to block" movements in maintenance yards.

Other forms of **collision avoidance** systems have also been discussed, including frontal collision warning, side collision warning, and rear impact collision warning[4]. These use vehicle-to-vehicle and/or vehicle-to-infrastructure communication to help maintain vehicle position and to warn (based on calculations of vehicle dynamics) of impending collisions to the front, side, or rear. Many of these collision avoidance systems are also being developed for heavy commercial vehicles, and the transit industry should take advantage of the innovation taking place in this much larger vehicle market.

One collision avoidance system that may be of particular interest to transit is cooperative adaptive cruise control (ACC), which is a variant of cruise control that allows vehicles to maintain not just a constant speed but also a fixed following distance from the vehicle ahead. Adding a "cooperative" element to ACC means that vehicles can also communicate with each other about changes in speed, so that, for example, the rear vehicle in a platoon can quickly decelerate as soon as the lead vehicle slows. This would be especially useful for express buses operating on highways in stop-and-go conditions. Since the underlying technologies used for collision avoidance help maintain lateral and longitudinal position, they could also play a part in the development of fully automated transit services on guideways.

All of these safety applications are considered feasible, but they represent technological challenges in designing the applications that would translate VII data into specific driver assistance messages. Developing the driver interfaces is also a challenge because of the issues with driver distraction and cognitive overload – it is important to ensure that the warning system

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[4] Federal Transit Administration, *Summary of Current Transit IVI Projects*, prepared for Transit IVI Committee Meeting, October 2002.

is not more of a danger than the event it references. False alarm rates are also important, because drivers learn to ignore systems that are unreliable. These human-factors issues are even more complicated for transit, where the driver faces the challenges of maneuvering a large vehicle in a complex urban environment, while also interacting with customers.

It is not yet clear whether these applications would be developed via public sector programs or research grants, or if it would require investment in product development by commercial software vendors. In either case, transit agencies would also need to provide the relevant training to their drivers so that the safety systems are used as intended.

Operations

Most large transit agencies already use various forms of ITS and telecommunications to improve the efficiency and safety of their operations, particularly for **fleet management**. One well-known example is computer-aided dispatch and automatic vehicle location (CAD/AVL), which allows dispatchers and supervisors to track the location of buses in operation, monitor route and schedule adherence, keep tabs on potential safety issues, and make service adjustments in response to changing conditions. Just over two-thirds (69%) of the fixed-route buses in the U.S. are equipped with AVL according to 2005 deployment statistics gathered by USDOT[5]. Most CAD/AVL deployments also include private radio networks that allow communication between operators and dispatchers.

AVL information can also be processed and relayed to customers to help them make informed decisions about travel times and routes. At a few agencies, it is also used to as part of a “connection protection” program for customers making transfers. Other technologies currently in place include automatic passenger counters (APC), automated stop announcements, covert driver alarms, and onboard video monitoring. Together, these ITS provide agencies with opportunities to improve the operational efficiency and cost-effectiveness of their routes and schedules, provide better service to customers with varying needs, and ensure the safety of their passengers and staff.

One potentially valuable role for VII in the transit arena could be to replace or supplement much of the existing telecommunications infrastructure used for these applications, allowing fleet management and operational applications to be conducted via the VII backbone. This raises a number of technical questions about compatibility. It also involves some institutional considerations, particularly around the question of whether transit agencies that have already invested millions of dollars in private networks for data communications would be willing to consider replacing them with the VII approach. The answer to this question will be different for each agency, but in general the switch over to VII, particularly for large agencies, may be delayed by the “path dependence” of earlier investments, concern about the technical performance of the VII approach, and the cost of systems integration. The picture is somewhat different for the mostly smaller and rural agencies that have not yet invested significantly in ITS for fleet management. These agencies may find that the deployment of the national VII backbone gives them an opportunity to develop these capabilities for less than what a custom

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[5] ITS Joint Program Office, Deployment Tracking Database, National Summary.

deployment would cost. To the extent that they are currently limited by telecommunications access, VII may also provide access to a communications backbone along their major corridors.

One idea along these lines that has been discussed is the use of VII as an emergency communications "bridge" between transit agencies, first responders, and roadway operators. Again, though, the utility of VII to these agencies depends crucially on the RSE coverage in their service area – which may be inadequate in rural areas – and on the availability and cost of the telecommunications bandwidth. It would also depend on the development of software and algorithms that would translate raw VII data into usable fleet management applications. To be cost-effective for these agencies, this software would need to be made available at little cost, either through a direct federal technology-transfer program or as an inexpensive commercial product. Experience has also shown that, for these agencies, training and peer-to-peer assistance are particularly important components of ITS deployments.

One aspect of fleet management that is worth discussing separately is the potential for **dynamic routing** of transit and paratransit vehicles. Using VII-provided data to get an "overlay" picture of both transit operations and general traffic conditions, dispatchers could make alterations to vehicle routes to the extent permitted by the overall route and stop network. In particular, vehicle runs with more latitude for deviation – such as suburban express buses, paratransit, or non-revenue deadhead and positioning trips – could be re-routed to avoid delays and incidents. This would tend to reduce travel delays, accommodate service requests more efficiently, and reduce the costs of the service. Again, there is an existing commercial market for routing software, and it would be worthwhile to develop strategies to encourage these vendors to include VII in their future products and plans.

Dynamic routing would also be one building block of a more ambitious effort to provide demand-responsive "community transit" systems of the kind used in some parts of Europe. Community transit has great potential for providing mobility to citizens of lower-density areas where conventional fixed-route transit is not viable. In some places, pursuing the community transit vision may require relaxing regulations that are designed to prohibit transit agencies from providing taxi-like ("as soon as possible") service.

Another operational application that is already in use is **transit signal priority** (TSP), which changes the timing of traffic signals to allow extra "green" time (and/or reduced red time) for transit vehicles. As of 2004, some form of signal priority for buses and/or light rail had been deployed by approximately 30 transit agencies across 21 metropolitan areas[6]. Signal priority helps to reduce running-time variability, thereby improving the reliability of transit service, improving customer satisfaction and ridership, and reducing operating costs. Existing TSP systems operate using commercial technologies for communication between the vehicle and the traffic signal. VII might permit TSP to be implemented without this dedicated hardware at each signal, by instead making use of the VII roadside units that would be in place at many urban intersections. By lowering the cost of implementation, VII may thus present an opportunity to expand the number of agencies using TSP and the number of intersections equipped. Integrating other data made available from VII could also help TSP operate in a more sophisticated way, for example by making priority contingent on upstream conditions, time of day, direction, and/or

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[6] USDOT, ITS Joint Program Office, ITS Deployment Statistics, 2004.

vehicle occupancy (e.g. by giving priority to crowded buses traveling in the peak direction rather than empty buses going the other way). VII also offers the promise of TSP that is coordinated with the optimization of traffic signals over a wider area (although to some extent this can also be accomplished now using a combination of technologies). Conceivably, all of these elements could be folded into the “traffic signal timing and adjustment” application that is currently listed as a Day One application.

As with AVL, signal priority is something that is already possible via other technologies, so the role for VII depends on agencies’ ability and willingness to migrate to a VII-based approach. (The influence of past investments is somewhat less of an issue in this case, given the relatively small number of agencies that have already deployed TSP). Signal priority also faces institutional hurdles in the form of disagreements on signal policy between transit agencies and the agencies that ordinarily own and operate the signals – state and local DOTs. Local DOTs are often concerned that signal priority may disrupt the “green waves” that they have built into their signal timing plans or create additional delay for intersecting streets. These differences of opinion can take time to resolve. Fortunately, VII offers the potential to help bridge these differences through dynamic signal control based on current traffic conditions, which can reduce signal delays for all vehicles.

Vehicle-to-vehicle communication has also been discussed as a means of providing an “electronic towbar” for removing vehicles. In the transit context, one related application would be **automated platooning** of buses (sometimes called a “virtual articulated bus”), whereby two buses could be linked to provide the seating capacity of an articulated bus, while preserving the flexibility to run the buses separately at off-peak times. This approach also allows agencies to avoid the cost and complexity of maintaining and servicing an additional vehicle model. While there may be agencies that are interested in this application, it also presents numerous practical challenges and appears to be of limited usefulness to most agencies.

Maintenance

It is widely assumed that one of the private applications that automakers will pursue for VII is **remote diagnostics**, which allows mechanical problems to be checked via telecommunications link. Remote diagnostics – particularly *live* diagnostics – is useful for transit agencies as well, helping to detect maintenance issues on their vehicles and thus to extend their service life. Remote diagnostics can also produce maintenance cost savings, allowing transit agencies to reduce the number of maintenance staff on “standby” for on-the-road repairs. The ability to diagnose problems remotely also translates into fewer service disruptions, especially in cases where benign issues can be identified as such without the need for the vehicle to go out of service and return to the garage. One variant of remote diagnostics that is also useful for transit is the ability to provide active monitoring of vehicles – for example, in situations where a supervisor must ensure that a bus is shut down to prevent engine damage.

VII also has many potential uses for transit **maintenance facilities**, including the tracking of buses and spare parts and the collection of mileage and other data for refueling and reporting. There is also the possibility that the VII network could augment (or, in some cases, replace) the short-range data communication networks used to download data from vehicles. Current practice is to download information (such as passenger counts, mileage, and vehicle status) in a batch at end of the day at the maintenance yard. With VII, the data could instead be sent in many smaller batches over the course of the day while the vehicle in still operating, providing managers and service personnel with more up-to-date information.

3. Transit applications for offline analysis of VII-provided data

When fully deployed, VII will include hundreds of thousands of roadside units in communication with millions of equipped vehicles, transferring and collecting data 24 hours a day and seven days a week. Vast stores of information about traffic volumes, speeds, and roadway weather conditions, across all times of day, will be available for much of the urban road network. Much of this information will also be available, albeit at a lower level of detail, even during the early years of deployment, because a fairly small number of equipped vehicles can serve as “traffic probes” and generate data on traffic conditions.

If – and this is an important *if* – the proper institutional arrangements are put in place to allow transit agencies to have access to these data, there are a number of opportunities to improve transit service through analysis and processing of these data. It is important to note that this can occur even if transit is *not* otherwise included in the VII deployment plans.

One of the main beneficiaries of the VII-supplied data would be **service planning**. Agencies periodically decide on route configurations and scheduling and then assign operators and vehicles to each work shift and service run. Data on local travel patterns (origin-destination counts) by time of day, either for the region’s traffic generally or for transit passengers via integration with APC, could help planners optimize the route network to offer service to their regions that matches both demand and existing traffic patterns. Analysis of traffic volumes and speeds can help to identify recurring bottlenecks, quantify delays, and produce better estimates of running times and variability. All of these factors can then be taken into consideration during the scheduling process, subject to the constraints of work rules and operator “picks.” For example, bus schedules and driver assignments on a particular line could be adjusted over time to account for location-specific delays during the afternoon hours, thus reducing service variability and the need for overtime labor. From a strict cost-benefit viewpoint, this may be one of the most profitable areas related to VII for transit agencies, since shaving even a percentage point or two off of their overall operations costs would produce substantial savings.

Analysis of data after a major transportation incident (planned or unplanned) could also be reviewed as part of **incident management** planning. This would enhance the ability of transit agency staff to assess how well their incident management protocols worked, and to identify “lessons learned.”

Another area that could potentially benefit from offline analysis of VII data is **marketing**. Marketing staff could, for example, conduct comparisons of actual peak-hour travel times (car vs. transit) in order to highlight particularly effective transit services in advertising or marketing materials. The region's patterns of congestion and changes in origin-destination patterns could also be tracked as means of identifying potential new transit customers. This has been identified as a particularly valuable application of the data because of its ability to help attract new transit customers. Of course, one of the most effective marketing strategies is to improve the quality of the underlying product, and VII has great potential to do so by improving service reliability and travel times.

Summary

Overall, VII's capabilities offer the possibility of improved safety, efficiency, customer service and cost-effectiveness for transit services as well as increased ridership. **Appendix 1** summarizes the potential applications described in the sections above and the range of benefits for transit agencies and their customers. As these sections have also noted, VII – like any emerging technology – also raises a number of technical and institutional questions. These range from issues about communications protocols and compatibility to broader concerns about VII's relationship to existing investments and business practices. These issues are listed in **Appendix 2**. This list is not meant to cast doubt on VII's potential, but merely to identify the issues where additional clarification would be useful.

SECTION III: REVIEW BY TRANSIT AGENCY EXPERTS AND 2007 UPDATE

An essential component of any attempt to characterize the relationship between VII and transit is input from the people who would ultimately be responsible for managing a transit VII deployment – namely, transit agency managers and technical staff. Ten transit agency representatives were recruited to serve as an advisory panel for this report and to share their agencies' priorities and perspectives regarding VII.

Members of this group reviewed an earlier draft of this report and shared their ideas during a telephone conference call held on July 27, 2006. Participants, both those who participated in the call, and those who were available only by email, were re-contacted in October 2007 to confirm that the views they expressed earlier were still valid. Members of the panel were chosen among transit agency representatives who are leaders in the world of ITS and knowledgeable about the opportunities and challenges of applying ITS to transit. They included the following people – names that are starred (*) were not contacted due to retirement or job change:

- Graham Carey and Stefano Viggiano of Lane Transit District
- *Ginger Gherardi, Ventura County
- *Ina Heffner, Houston Metro
- John Inglish, Utah Transit Authority
- Doug Jamison, Orlando Lynx
- Bibiana Kamler McHugh, Tri-Met (email only)
- Peter Meenehan, Washington Metro (WMATA)
- Mike Nevarez, City of Phoenix Transit
- Koorosh Olyai, Dallas Area Rapid Transit
- John Toone, King County Metro
- Gerry Tumbali, Chicago Regional Transportation Authority.

The ten conference call participants were asked for their perspectives on the applications that they believed would be most useful to their transit agencies and most worthy of further pursuit. For long-term planning purposes, a distinction was made between applications that could be ready for deployment in 2011, when the VII initiative had been scheduled to begin, and those that would require additional time and would see deployment when the VII network was complete. In this task, panel members were asked not to limit themselves solely to applications identified by the Volpe Center but rather to feel free to describe other capabilities. Participants were also asked to base their judgments of priority according to the following criteria:

- The feasibility of the application at different levels of deployment of roadside units and onboard equipment;
- The ability of the applications to "piggyback" on equipment installed for other VII applications;
- The potential contribution of the application to transit agency operational effectiveness, especially impact on safety and security;
- The potential for cost savings;
- The ability of the application to make transit a more attractive mobility choice; and
- Institutional issues.

Conference Call Outcomes

Conference call participants tended to see VII for transit as having the greatest potential in operational efficiencies, cost savings, and improvements to the customer experience. Overall, their highest priority applications for 2011 were traveler information, traffic signal control (including adaptive control and transit signal priority) and incident management. Several participants pointed out that the "incident management" applications of VII should not be limited simply to planning activities and review of past performance, but should also include real-time operational adjustments to improve safety and reduce delays during traffic and transit incidents.

For 2020, fleet management led the list of priorities, followed by electronic payment. Although fleet management and electronic payment are not new concepts, these applications were viewed as more suitable for the later time period because of the technological and institutional complexity associated with converting to a VII-based approach, as well as the time lags involved in decommissioning and replacing existing equipment.

The use of VII data to maintain headways on bus routes was discussed as another high-priority potential application, especially for high-volume corridors. For the purposes of this report, this functionality is considered part of the "fleet management" application group, in which real-time operational data could be used at dispatch or by drivers to make service adjustments and improve schedule adherence and reliability. It was noted in the 2007 update that fleet management could also encompass the use of VII communications to quickly notify dispatch centers with the location of transit vehicles that have broken down.

All of these high-priority applications – traveler information, traffic signal control, incident management, fleet management, and electronic payment – relate to functions that some transit agencies have already implemented to one degree or another using existing (non-VII) technologies. Therefore, it might be fair to say that, at least at this point, the transit industry views VII primarily as a way to expand and enhance their efforts in these existing areas.

Another consistent theme from the conference call discussion was that the transit community's approach to VII should be different for the Day One applications *already* being planned by the VII Working Group, versus other transit-specific applications that are not on the Working Group's list but that could potentially be developed. The latter applications include fleet management, a focus on transit signal priority, and the use of VII data for enhanced incident management.

More specifically, there was a general consensus that transit interests should organize themselves and work toward getting a "seat at the table," wherever possible, as the technical specifications for the Working Group's Day One applications are developed. This will ensure that the system architecture developed by the Working Group does not preclude transit applications, and that transit agencies and their customers will be able to reap the benefits of the VII applications that would otherwise be designed only for passenger cars. Dialogue between the transit industry and its vehicle manufacturers may also be necessary in order to modify Day One applications for use on buses and rail vehicles.

The requisite degree of coordination between transit agencies and VII leadership varies considerably across these applications. Fleet management, for example, might only require subscription access to VII's stream of real-time traffic data (which agencies could then use on their own to make operational adjustments). Electronic payment, on the other hand, would likely require extensive coordination regarding system architecture, protocols, and interoperability. In particular, for VII-based electronic payment to be workable for transit agencies, the payment device likely would need to be both personally portable and compatible with existing transit smart card applications – something that would not be true for, say, equipment that was vehicle-mounted and used only for roadway toll payment. The conference call discussion emphasized the fact the responsibility for inclusiveness ultimately rests with the VII Working Group and that transit has not been a priority in the early stages of the Working Group's discussions.

Safety is the chief goal of the VII initiative and is every transit agency's top priority. Nonetheless, the conference call discussion indicated that transit agencies generally envision the greatest benefits from VII as coming from operational applications (which provide a mixture of efficiency gains, safety benefits, and customer service improvements) than in applications that are oriented solely toward crash avoidance *per se*. Part of this difference may be due to the fact that transit agencies have a per-mile transportation fatality rate that is only one-tenth of that for highway travel. Another relevant factor is that transit agencies face the constraints of the transit vehicle market – one that is marked by much lower production volumes and reliance on overseas suppliers – and thus may not be able to expect on-board safety applications to be implemented as quickly as in the private automobile market. In the update cycle, one panel member also pointed out that transit operators' familiarity with their routes somewhat reduces the need for warnings of unwitting violations of stop signs or traffic signals. As noted above, transit agencies are also currently more inclined to view VII as a way of expanding their existing operational capabilities.

Next Steps

This report has discussed the potential ways that VII technology could be applied to improve the safety and efficiency of transit and paratransit services. It was written with the objective of identifying shared values and interests between the transit industry and the VII Working Group. It hopes to ensure that the Working Group includes applications of particular interest to transit in their future plans, and enables transit to actively participate in VII discussions. This document can serve as a point of departure for those discussions.

Appendix 1

Summary Chart of Potential VII Applications for Transit

Application	**Description**	**Part of Current VII Day 1 Plan?**	**Potential Benefits for Transit**
Signal / stop sign violation warning	In-vehicle warning of imminent violation of red traffic signal / stop sign	Yes	Safety of employees and customers; reduction in operational disruptions and vehicle damage related to collisions
Curve speed warning	In-vehicle warning to reduce speed for upcoming curve	Yes	Safety of employees and customers; reduction in operational disruptions and vehicle damage related to collisions
Electronic brake lights	Following vehicles receive warning of sharp braking by lead vehicle	Yes	Safety of employees and customers; reduction in operational disruptions and vehicle damage related to collisions
In-vehicle signage	Information from highway signage displayed in cockpit	Yes	Safety; navigational assistance
Advance warning info / localized road and weather info	Information on local conditions (e.g. road work), pavement conditions displayed in cockpit	Yes	Safety; ability to make operational adjustments based on conditions
Signal timing and adjustment	Use of VII data to refine signal timing patterns	Yes	Reduced traffic congestion, greater travel time reliability, reduced operating costs
Ramp metering	Use of VII data to refine ramp meter timing patterns	Yes	Reduced traffic congestion, greater travel time reliability, reduced operating costs
Traveler information	Use of VII data to enhance multimodal traveler info	Yes	Improved customer service
Electronic payment	Multimodal personal payment mechanism linked to VII	Yes	Reduce revenue collection costs, greater customer convenience, partnership opportunities
Corridor management	Use of VII data to coordinate usage of set of transportation facilities	Yes	Reduced traffic congestion, greater travel time reliability, reduced operating costs
Gap assistance for merging	Driver assistance for safely entering traffic stream	No	Safety of employees and customers; reduction in operational disruptions and vehicle damage related to collisions
Grade crossing warnings	In-vehicle warning of conflict with approaching train or light-rail vehicle	No	Safety of employees and customers; reduction in operational disruptions and vehicle damage related to collisions
Assisted lateral control	Driver assistance for maintaining lateral position of vehicle	No	Safety; ability to operate in space-constrained areas
Collision avoidance	In-vehicle warnings of imminent collisions and driver assistance in maintaining safe position	No	Safety of employees and customers; reduction in hard braking and associated injury claims; reduction in operational disruptions and vehicle damage related to collisions
Fleet management	Use of VII data (e.g. vehicle location) at dispatch to make adjustments to services; use of VII telecom for data exchange	No	Operational cost savings, improved service; additional telecom option for regions with less access

Application	**Description**	**Part of Current VII Day 1 Plan?**	**Potential Benefits for Transit**
Dynamic routing / community transit	Use of VII data to make pick-up requests efficiently and minimize travel delays	No	Operational cost savings, improved service
Transit signal priority	Extra green time to transit via communication between vehicle and traffic signal	No	Improved travel time reliability, operational cost savings, improved service
Automated platooning	Automated operation of second bus "in tow" to simulate articulated bus	No	Operational flexibility
Remote diagnostics	Use of VII telecom for remote diagnosis of vehicle repair issues	No	Reduced maintenance costs, improved vehicle life, fewer service disruptions
Maintenance applications	Use of VII telecom to track vehicle status, download vehicle data	No	Reduced maintenance costs, improved vehicle life, fewer service disruptions
Service planning	Use of VII data to improve service planning and staff assignments	No	Reduced operational costs, improved service reliability, potential for new ridership
Incident management	Use of VII data to improve incident / emergency response plans and assess performance	No	Safety and security, reduction in incident-related service disruptions
Marketing	Use of VII data (e.g. on regional travel patterns) to focus marketing efforts	No	Potential for new ridership

Appendix 2

Institutional and Technical Issues

All emerging technologies, particularly ones that involve significant changes to current business practices, involve technological and institutional questions. The following list is not meant to cast doubt on VII's enormous potential to contribute to transit's safety, efficiency, and customer service, but merely to identify the issues that will require additional clarification before the outlines of these contributions can be known with greater certainty. These are listed briefly below, phrased as questions to help focus the discussion:

- What is the role for transit in VII? Should it be a partner in developing its application requirements and capabilities, or just a consumer of the available data once VII is deployed?
- In using VII for operations, to what extent will agencies be able to integrate existing (i.e., non-DSRC based) and new systems? What will become of current ITS investments? More broadly, will transit ITS architectures be designed to integrate DSRC and VII equipment and data products?
- How will transit-oriented VII applications be developed? Public sector grant, research funds, public-private partnership, publicly funded vendor? What are the prospects for standardization of the interfaces and functionality of the VII supported applications? How will the USDOT protect the transit industry's ability to use these applications in an open, intellectual property-free environment while at the same time promoting commercialization and choice in the market place for these products? Are there opportunities to adapt technologies from the much larger commercial truck market?
- What is the migration plan for equipping transit vehicles with VII onboard equipment? Would transit vehicles be fitted with VII's on-board equipment only as old vehicles are replaced or overhauled? If so, what does this imply for the implementation timeframe, given that vehicles may stay in service for 10-15 years?
- How will the development, operations, and maintenance costs of VII be shared across federal, state, and local DOTs, transit agencies, and other users? Who will control network access and own the data?
- Will the network of roadside units provide sufficient coverage, in both urban and rural areas, to support the applications that transit agencies consider a priority? Will it provide status updates at the intervals that agencies are currently accustomed to?
- To what extent will transit agencies have access to communications bandwidth on the VII network? At what cost? Would commercial messages such as advertising be permitted?
- Could the VII network be used as a common platform for communication between transit agencies during an emergency or major service disruption?
- In establishing protocols for DSRC messages, how will the need for safety-related messages be balanced against the need for network security?
- What will be the impact of VII applications on transit drivers? Can interfaces be developed specifically for the transit environment so that they reduce, rather than increase, sensory and cognitive overload?
- Do VII's capabilities for vehicle tracking create concerns about Big Brother and other labor-relations issues, or have these already been sufficiently dealt with since the introduction of AVL?

- Can VII help or hinder the inter-agency coordination needed to implement applications such as traffic signal priority?
- What are the legal or regulatory barriers to achieving parts of the transit-VII vision? For example, do regulations related to taxi-like transit services need to be relaxed?