WHITE PAPER

VII Data Characteristics Task: Data Needs Assessment

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ABSTRACT

This paper describes Day 1 and Future Vehicle-Infrastructure Integration (VII) traffic management and traveler information applications and the data required by each application. Unlike the analytical elements of the VII Data Characteristics Task performed by Mitretek Systems, which will focus primarily on Day 1 applications, this paper also considers future applications when identifying data needs. This allows a qualitative view and assessment of future uses of VII data and provides some speculation about possible improvements to current methodologies if VII data is available.

The information presented in this paper is significant in that it provides an initial definition of the range of variables required to support traffic management and traveler information applications that offer the potential for greatly improving traffic operations using VII. In general the requirements of the Day 1 applications appear to be modest. However, some challenges exist, especially with respect to estimating demand (volume) when the percent of VII-equipped vehicles is relatively low. Since demand is fundamental to the majority of applications, its measurement (or derivation using surrogate variables) is essential. Future applications represent a different challenge. If the past represents a valid model for the future, it is likely that the future applications will be developed in a manner that takes advantage of the characteristics of the VII data elements without requiring excessive translation. Thus the requirement for emulating the conventional traffic detector is minimized or eliminated. However, due to the unknown nature of these future applications, it is difficult to anticipate their full range of data needs and required accuracies. The tables developed for this report represent "best guesses" regarding the manner in which these applications will be developed. This work concludes that the needs of the Day 1 applications are significantly different and less flexible than those of the future applications.

KEYWORDS: Vehicle-Infrastructure Integration (VII), Data Characteristics, Traffic Management, Traveler Information, Arterial Management, Freeway Management, Corridor Management, VII Day 1 Use Cases

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1. INTRODUCTION

This paper presents the results of Activity 1 of the Mitretek Systems Vehicle Infrastructure Integration (VII) Data Characteristics delivery order. We briefly describe Day 1, possible Day 1 and future applications related to traffic management and traveler information.

- *Official Day 1 applications* are those applications defined by Use Case documentation as VII applications that will be used shortly after VII deployment. Data described in the Use Case is provided in Table 2 in Section 6.
- *Other Day 1 applications* include a few for which algorithms currently exist and VII data may be available in the beginning of VII deployment which could be used in existing systems. These potential applications have not been included in the official Day 1 Use Cases but have been included here after discussion with teams of Federal subject matter experts as described in Section 1.2 below.
- *Future applications* may utilize newly available VII data and/or require algorithms that do not yet exist.

1.1 Purpose of the paper

This paper attempts to comprehensively describe possible Day 1 and Future VII traffic management and traveler information applications and the data required by each application. Unlike the analytical elements of the VII Data Characteristics Task performed by Mitretek Systems, which will focus primarily on Day 1 applications, this paper also considers future applications when identifying data needs. This allows a qualitative view and assessment of future uses of VII data and provides some speculation about possible improvements to current methodologies if VII data is available.

This paper is the first of four activities designed to investigate VII data characteristics related to traffic management and traveler information. The next task will map the data required here with the VII data expected to be available with the current probe message process. Real data and simulated data will be converted to vehicle trajectories representing probe data in the third and fourth activities of the project. These activities will provide estimates of the accuracy of needed data elements in terms of VII market penetration and other parameters like Roadside System Equipment (RSE) spacing, snapshot buffer size, and snapshot trigger thresholds.

1.2 Process used for identification of data needs

The first step of this activity was the identification of appropriate applications, data, and data descriptions. First and second drafts of Tables 2 and 3 presented in Sections 6 and 7 were considered and discussed by two groups of federal subject matter experts as shown in Table 1, first at an April 13, 2006 meeting at Turner Fairbank Highway Research Center (TFHRC) and then at an April 19 meeting held at Mitretek Systems, ITS site office. In addition, a number of references were used during the preparation of this document that described earlier work performed in connection with the VII project (1-4). These references provided a starting point for identification of potential strategies to be considered during this task. A draft of this paper was then reviewed by Mitretek personnel the week of April 24. This final report produced in June 2006 has incorporated the comments of federal reviewers.

Table 1 Federal Subject Matter Expert Review Teams

April 13, 2006 Turner Fairbank Highway Research Center
Toni Wilbur (HRDO-1)
Bob Ferlis (HRDO-2)
Raj Ghaman (HRDO-3)
Eddie Curtis (HRC-ATL)
Brian Cronin (HOIT-1)
April 19, 2006 Meeting held at Mitretek Systems ITS Site Office
Bob Rupert (HOTM-1)
Brandy Meehan (HOTM-1)
Brian Cronin (HOIT-1)
Bob Ferlis (HRDO-2)
James Pol (HOIT-1)

1.3 Report Organization

Traffic Signal Applications including official Day 1 applications, other possible Day 1 applications and future applications are described in the second section of this paper. In the third section, several Day 1 and future applications related to ramp metering and freeway traffic management are described. The fourth and fifth sections describe corridor management applications and traveler information applications. After the brief application descriptions, in Section 6 in Table 2 we enumerate the data listed in the VII Day 1 Use Cases and essential and enhanced data needed for each of the applications. Essential data is required by the current algorithms for that application. Essential data includes performance measure variables such as travel time, delay, and stops. Enhanced data may be available eventually from VII to improve algorithm performance. Each data item is described further in Table 3 provided in Section 7. Conclusions and next steps are presented in Sections 8 and 9.

2. TRAFFIC SIGNAL CONTROL APPLICATIONS

VII has great potential benefit if it can reduce the cost to collect the data required for updating signal timing plans. The Day 1 applications described below use VII data or data elements derived from VII data in existing algorithms. Applications that require modifications to existing algorithms or new algorithms to incorporate newly available VII data are categorized as future applications.

2.1 Day 1 Traffic Signal Control Applications, Off-Line Signal Timing (Application #1)

Time-of-day and traffic responsive forms of control are both based on the use of a stored library of timing plans that are generated off-line using either manual graphical techniques such as time-space diagrams, or using an optimization program such as Synchro, Passer II, or Transyt 7F. Time-of-day and traffic responsive forms of control differ in the manner in which the timing plans are selected from the library for control of the signals. The time-of-day form of plan selection is a “time clock” process in which the plans in the library are pre-scheduled for use by day-of-week and time-of-day. Most time-of-day systems have additional features that allow the use of plans for non-standard weekdays, which permit the scheduling of plans for holidays and special events.

The off-line timing plan development is intended to receive VII data for use as direct input to existing optimization programs (Synchro, etc.) bypassing the need for manual field collection of this data. Although the optimization processes used by the various available programs differ, they are all, in essence, based on models of the roadway/signal system. For this reason, they all require the same basic inputs including: roadway geometrics, traffic signal phasing, traffic signal type, and traffic characteristics. The latter includes volumes for all lanes and all turning movements, speeds, and saturation flow rates. The outputs of these software packages include stops, delays and in some cases emissions and fuel consumption.

The ubiquitous availability of this data from an automated system such as VII will significantly reduce the resources required for off-line signal timing, and hopefully encourage agencies to update their signal operations at more frequent intervals. This application corresponds with the official Day 1 Use Case: Traffic Management: Traffic Signal Optimization (Day 1).

2.2 Day 1 Traffic Signal Control Applications, Traffic Responsive Control (Application #2)

The traffic responsive form of control differs from time-of-day control in that the system uses traffic conditions from detectors that are used to provide representative samples of traffic conditions, and selects the plan that is best suited for current traffic conditions. This mode of operation requires a stored library of plans developed using the off-line techniques described in section 2.1. A variety of techniques are used, but their common objective is the selection of the plan that will provide the most effective control for existing traffic flow. The traffic responsive form of control has been demonstrated to provide improved operation under conditions when flow is unpredictable such as roadways impacted by incidents or the unpredictable demands of traffic generators such as major universities, shopping centers, or entertainment centers.

The algorithms used for traffic responsive operation differ among the various systems currently available. However they all have the following attributes in common:

- Traffic responsive algorithms attempt to match traffic patterns as defined by traffic volumes, and either speeds or occupancies as measured by system detectors. (Detectors associated with actuated controllers are rarely (if ever) used.)
- The number of detectors associated with traffic responsive operation is typically far less than the number of intersections in the system (less than 50%, and some studies have concluded that 10% provides adequate representation of traffic flow). The significance of this consideration depends on the manner in which VII is deployed. If traffic responsive applications are to be implemented, it is important that, through the combination of VII architecture and processing as well as roadside equipment (RSE) locations, the system offers the ability to estimate vehicle demands and speeds at intersection approaches that are representative of the overall flow.

The VII system's ability to provide measurement of single lane traffic volumes and either speed or occupancy that are representative of prevailing traffic conditions would be a valuable alternative to conventional detection. Here again stops and delays are a measure of the system effectiveness. This application is described in the official Day 1 Use Case: Traffic Management: Traffic Signal Optimization (Day 1).

2.3 Other Possible Day 1 Traffic Signal Control Applications, Transit Priority (Application #3)

Transit priority operates by modifying the signal timing either through provision of additional green time, or more quickly beginning the green display, in response to notification of an approaching bus. The objective of this application is to either reduce the delays experienced by buses, or to ensure that bus travel time is more reliable to provide improved schedule adherence.

The level of sophistication of bus priority strategies varies. In some cases, the signal controller attempts to display a green indication for the approach on which a bus is detected, and extend the duration of the green until a maximum value is reached or the bus clears the intersection, whichever occurs first. Other, more sophisticated strategies attempt to balance estimates of bus passenger occupancy against vehicle occupancy and adjust the signal timing to minimize the overall "person delay" at the intersection. Still other strategies have been tested that attempt to predict the overall bus trajectory along an arterial and adjust the signal timing to minimize the bus delay without requiring excessive numbers of last minute green extensions. For roadway networks with close intersection spacing, such as those found in central business districts of urban areas, it has been shown that bus priority systems will only operate effectively if all intersections along a given bus route have priority features.

All existing bus priority algorithms require knowledge of bus location and speed to operate effectively. The more sophisticated algorithms require knowledge of bus schedules, stop location, and vehicle demand at the intersections where priority is granted. Ideally, bus passenger occupancy would also be useful.

2.4 Other Possible Day 1 Traffic Signal Control Applications, ACS (Adaptive Control System) Lite (Application #4)

ACS (Adaptive Control System) Lite adjusts signal timing in real time to accommodate changing traffic patterns on arterial facilities. The system operates by measuring inbound and outbound flows, and adjusting signal splits and offsets based on these measurements. This system is particularly useful for arterials with a minimum of midblock sources and sinks. It is also attractive in that it requires minimum detection for measuring demands and speeds along the arterial. ACS Lite is considered a potential Day 1 application, because it is currently available, field proven, and represents a first step toward adaptive control. This application is currently receiving a high level of emphasis by FHWA for field implementation using conventional detectors.

VII data can be a useful alternative for the conventional detection required by ACS Lite. Vehicle demand data is only required at a sample of intersections along the arterial roadway. However, the opportunity exists to further improve the effectiveness of ACS Lite, when the more extensive data of VII is used.

2.5 Future Traffic Signal Control Applications, Adaptive Control (Application #5)

Adaptive control differs from time-of-day and traffic responsive control, in that areawide timing plans are calculated by the computer using on-line versions of optimization algorithms that may be similar to those employed by the off-line programs (Synchro, Passer II, etc.) Thus adaptive control strategies are designed to implement plans that are perfectly suited to existing flow conditions, and for this reason their theoretical performance should be better than any of the stored timing plan alternatives. The effectiveness of adaptive control strategies is limited by the fact that conventional detectors cannot measure all of the traffic flow data required for effective signal timing including; turning movements, queues, and mid-block entrances and exits. As a result, adaptive control provides the greatest benefits during unpredictable traffic conditions (similar to those that exist for traffic responsive), inclement weather, or when stored plans are updated infrequently. Several adaptive control systems are commercially available including SCOOT, SCATS, RT-TRACS, and RHODES.

Adaptive applications require the same ubiquitous data as that which is required for off-line signal timing, except that these applications require the data in real time as opposed to the 15 minute averages typically used for off-line timing plans. The performance measures used to evaluate their operation is also the same as that for off-line applications. The potential of VII to provide additional data including link travel times and speed profiles offers the opportunity for the development of a new class of “smarter” adaptive control applications with the capability of anticipated vehicle arrivals throughout the areawide system. These new applications might also offer the capability for analyzing unusual traffic flows and determining whether they are due to inclement weather conditions, incidents, or other unanticipated conditions, and adjusting the strategies appropriately. Perhaps most important, the potential availability of queue information will permit the development of strategies with the ability to respond to congested conditions, by adjusting signal timing to avoid queue spillback into upstream intersections and other forms of blockage that affect the operation of signal operation, but which currently cannot be measured by conventional forms of detection.

2.6 Enhanced Actuated Control (Application #6)

Individual intersections are currently controlled using either pretimed control or actuated control. Pretimed controllers allocate green time to intersection approaches without consideration of traffic conditions at the intersections they serve. The timing of pretimed controllers is defined by the areawide timing plans contained in the library (off-line control), or by the timing developed by adaptive control applications. Actuated controllers operate by measuring traffic demand on intersection approaches and allocate green time for each phase[1] based on vehicle presence measurements for each phase. An actuated controller at an isolated intersection that is not part of an areawide system will display the green for a given phase as long as vehicle presence is being detected by the detectors associated with that phase. When time separation of vehicle presence measurements exceeds a predefined threshold, or when the maximum allowable green time is reached, the controller terminates the phase for the movements being served, and displays the next phase in the sequence. This is known as full-actuated control.

Actuated control at intersections that are included in an areawide control system operate in the same manner as full-actuated control, except that the duration of one of the signal phases (usually the main street) displays a duration determined by the areawide traffic signal timing plan and available time left over from the actuated phases. This is known as semi-actuated control. Any intersection that “actuates” a signal phase for traffic on the side (non-main) streets and otherwise provides main street green phases is semi-actuated. Semi-actuated control is required for coordinated signal systems in order to maintain a constant signal cycle length, which is required to ensure progression along the main street. Semi-actuated controllers are, in effect, adjusting the areawide timing based on vehicle demand on the intersection approaches that are not on the main street.

One of the drawbacks (but not the only one) of semi-actuated control is the fact that available green time is allocated based on a historical measurement of main street demand, while all of the other signal phases are based on current measurements. In addition, higher than normal demand on the actuated phases results in a decrease in the green time being given to the main street, even though this street might also be experiencing a higher than normal demand. Tests of alternative forms of individual intersection control intended to overcome this

[1] A phase is a sequence of displays (typically green and yellow) that control a set of vehicle movements. For example, a phase might include northbound and southbound through movements along an arterial.

problem using conventional detection have been unsuccessful, due to the absence of adequate measurement of vehicle demand (volumes and queue lengths). The more comprehensive data available from VII which includes measurement of queue length offers the potential to overcome these problems, and to develop a form of actuated control at an intersection that takes vehicle demand into account. This will permit the individual intersection to balance the demand on all approaches, and calculate signal timing in a manner that will permit near term adjustments to areawide signal timing plans. Thus, if the VII system can provide short term estimates of demand for all phases, there is the potential for significant improvements over conventional actuated control.

2.7 Future Traffic Signal Control Applications, Work Zone Signal Control (Application #7)

Work zones on surface streets are often accompanied by traffic signal control, which may be installed on a temporary basis, or may include the use of an existing permanently installed controller operating in a degraded manner. This degradation is due to the fact that the work zone conditions prevent communications with a central site, and conventional vehicle detection cannot be used. The availability of VII data could overcome these difficulties. If adequate data were available, signals located in work zones could provide a modified version of the individual intersection operation described in section 2.6, by providing green times adjusted to reflect competing demands on the intersection approaches. Further enhancement may be possible to reflect the change in traffic flow characteristics that frequently exist in work zones as a result of distractions, obstacles, unfamiliar geometrics, and poor pavement conditions. The signal control application for work zones could measure and adjust to differing saturation flow rates on selected approaches reflecting the changing capacities and flows that exist in the work zone.

3. FREEWAY MANAGEMENT APPLICATIONS INCLUDING RAMP METERING

There are several freeway management applications that may utilize VII data either now or in the future. Here we have restricted Day 1 applications to applications where variables derived from VII data may be used in existing algorithms. VII data may also provide new types of data or inputs for new algorithms—these have been categorized as future applications.

3.1 Day 1 Freeway Management Applications, Offline Computation of Ramp Metering Rates (Application #8)

Freeway ramp meters are generally set such that the flow on the mainline remains optimal (as many vehicles as possible drive at an optimal speed for maximum throughput), while at the same time ensuring that ramp storage capacities and maximum waiting times are not exceeded. Adding more vehicles to the optimal flow results in a breakdown of conditions and slower speeds and fewer vehicles being able to use a section of roadway over an hour. Similar to offline computation of traffic signal algorithms, this application involves the derivation of mainline volumes (likely fused from VII data and existing sources) and determining offline the best time-of-day ramp metering plan from a suite of ramp metering plans using archived data.. VII data may ensure that timing plan choice is checked regularly and less manual data collection is required to maintain optimized-by-time-of-day plans. Similar to the traffic signal applications, travel time and delay will be used as performance measures. As an enhancement, VII-collected stop locations can be used to obtain ramp queue lengths by time of day to further refine the choice of ramp meter rates. Ramp queue lengths can be estimated using VII data by determining the stop locations of vehicles entering the ramp. This application corresponds with the official Day 1 Use Case: Traffic Management: Ramp Metering (Day 1).

3.2 Future Freeway Management Applications, Ramp Metering Implementation in Locations without Loops or Other Sensors (Application #9)

A potential application of VII will be to take advantage of the ubiquitous travel time and speed data produced by the VII system. Even with relatively low market penetration, this data may be used to select an appropriate ramp meter rate (in lieu of traffic volumes). However, new algorithms would need to be designed that determine ramp meter rates based on travel times and speeds. In general, faster speeds on the mainline would allow a greater number of vehicles to leave the ramp (a higher rate of ramp metering); lower speeds would lead to reducing the rate to allow fewer vehicles per time period to join the mainline. Current algorithms rely heavily on ramp and mainline volumes. Performance measures include travel time and delay. The optional operator-input opt-in Origin/Destination data may also contribute to ramp meter rate selection.

3.3 Future Freeway Management Applications, Metering of a Series of Ramps (Application #10)

Applying algorithms similar to the one described for Application #9 to a series of ramps, it may be possible to control the combination of vehicles entering the freeway from these ramps in a manner that optimizes overall freeway flow. This would require new algorithms that use different data than current corridor inputs but the resulting benefits may be large. Being able to meter a series of ramps would be a precursor to real-time corridor load balancing that is described in application 20 below.

3.4 Future Freeway Management Applications, Single Ramp Adaptive Control (Application #11)

Similar to adaptive control of signals on arterials, adaptive control of freeway ramp meters has large potential benefit. VII may enable real-time data collection of current inputs: volumes, turning movements (ramp to mainline and mainline to ramp), but also queue length on both ramps and mainline as well as travel times and speed profiles that may be used in five minute or fifteen minute increments to update the ramp meter rates and optimize flow on the freeway.

Adaptive algorithms can react to unusual flow due to weather or crashes or anything unexpected and put a metering scheme in place that accommodates current flows and, using VII opt-in O/D data, possibly anticipated flows.

3.5 Future Freeway Management Applications, Adaptive Variable Message Sign Control (Application #12)

Variable message signs or dynamic message signs or changeable message signs are currently in use on a number of freeways. Often the messages are generic: "congestion ahead" or "caution during wet conditions." VII may allow traveler information including travel times to be displayed on the signs (as described in Section 5 below). Additionally, incident information may be provided. Alternate routes prescribed by a lane balancing plan as described in Section 4 may be provided. With this strategy messages would be altered in real time in order to achieve desired levels of diversion.

3.6 Future Freeway Management Applications, Variable Speed Limits (Application #13)

Similar to setting ramp meter rates to optimize maximum flow and speed, another way to manage traffic for maximum throughput is to prescribe an optimal speed for the volume of vehicles on the roadway. By setting a speed limit for all vehicles to follow, engineers try to ensure that all vehicles can traverse smoothly without braking and causing shockwaves that may disrupt traffic. VII-provided speed profiles and stop data may depict where queues are forming on the roadway which may lead to determining and prescribing better speeds that will allow vehicles to flow continuously.

3.7 Future Freeway Management Applications, Lane Control (Mainline Metering and Speed Controls of Individual Lanes) (Application #14)

A few freeway management systems allow metering and speed control of individual lanes. These are often set up at a bottleneck such as the approach to a bridge or tunnel to ensure smooth flow through the bottleneck. If a lane is blocked due to an incident or construction, the lane management system can be used to efficiently move vehicles past the obstruction. Lane speed profiles provided by VII can be used to set speeds for the individual lanes.

3.8 Future Freeway Management Applications, Automatic Incident Detection (Application #15)

Much attention has been paid over the past thirty years to develop automatic incident detection algorithms. These algorithms generally use 30-second or one-minute aggregated volumes and occupancies (and sometimes point speed) from freeway inductive loop detectors. Often the automatic algorithms are abandoned because there are too many false alarms. Setting algorithm thresholds high enough to prevent false alarms may result in missing crashes or delaying the time to detect the incident. Currently automatic incident detection algorithms are rendered irrelevant because many motorists have cell phones and can close-to-instantaneously report crashes or significant problems on the roadway. However, cell phone detection has many problems because control centers are inundated with calls and few callers can precisely provide their location. For these reasons, calls are often routed to dispatchers who can not make traffic management changes.

The effectiveness of automated incident detection algorithms will be significantly increased with the availability of VII measures. Some research has shown that lane changes and increased travel times may be the best indicators of an incident (Parkany and Bernstein, 1995) (5). VII has the potential of showing that a large number of vehicles sharply braked on the roadway. VII can show where queues form.

3.9 Future Freeway Management Applications, Decision Support Tools for Freeways (Application #16)

Tools are needed to enhance the effectiveness and productivity of traffic operations center (TOC) personnel. During major incidents, TOC personnel make decisions based on their knowledge of the impacted roadways, past experience, and the advice of field commanders. The decision process could be significantly enhanced through the availability of software tools that permit these personnel to examine the impacts of alternative actions, and to provide them with information regarding past successes and failures with previous incidents that are similar in nature. The suite of software tools that provide these capabilities are considered to be decision support tools. The capabilities of these tools can include (but not be limited to):

- Automated incident forecasting, detection, assessment, traveler information and incident logging. This capability would be used to influence service patrol operations, and the installation of automated surveillance equipment.
- Decision support tools that can provide the capability of rapidly evaluating the impact of alternative incident response measures including diversion routes. This tool is likely to include a suite of faster-that-real-time simulation techniques that will permit the modeling of the impact of the incident response alternatives.
- Provide the data needed to automatically modify ramp metering rates and traffic signal timing in the presence of an incident
- Software that records TOC operator's actions during incidents for subsequent evaluation and use in response to similar incidents.

VII measures can be used to significantly enhance the capabilities of decision support tools. For example, the ability to provide ubiquitous surveillance of freeways and the surrounding roadway system will provide valuable information regarding the relationship between various types of incident conditions and the resulting traffic flows. This information can be used for evaluation of the most effective responses to be used when incidents occur depending on prevailing roadway and demand conditions. It can also be used for predictions of incident probabilities which in turn will serve as the basis for routing and pre-positioning of response vehicles. This information can also serve as the basis for planning the locations of closed circuit television and detection equipment to maximize the likelihood that they will be available for use in the presence of incidents. Thus VII data will be useful for both the management of ongoing incidents and the evaluation of incident response effectiveness, as well as the planning and engineering required to ensure that incident response is performed in an efficient and effective manner.

3.10 Future Freeway Management Applications, Dynamic Control in Work Zones (Application #17)

Similar to how VII can be used on arterials to set signals in work zones, VII may have the potential to alleviate construction traffic in freeway work zones. VII speed profiles and queue locations may be used to meter ramps or adjust mainline control such that traffic flows more smoothly through the area. VII data may be used to help balance traffic and route traffic similar to the applications described in Section 4.

4. CORRIDOR MANAGEMENT APPLICATIONS

By combining arterial and freeway applications described in Sections 2 and 3, there is the potential to reduce delays in a corridor system that includes at least one freeway and one adjacent arterial. The Day 1 use cases include load balancing among parallel routes during incident or unexpected conditions that use pre-determined corridor management strategies and planning applications that consider vehicle origins and destinations and chosen routes. With VII, it is expected that corridor management and load balancing will exist in real-time.

The VII Use Cases emphasize the balancing of vehicle flow rather than passenger flow. This philosophy has been maintained within the corridor management applications, although the emphasis might be changed as the definitions of these concepts evolve.

4.1 Day 1 Corridor Management Applications, Load Balancing Among Parallel Routes Using Pre-Determined Corridor Management Timing Plans (Application #18)

Corridor management is similar to the Day 1 traffic responsive case where real time measurement of volumes, speeds, and travel times result in selecting a signal timing plan from a suite of pre-determined plans. Similarly, during weather or incident conditions, pre-determined corridor management plans can be selected that include a number of freeway ramps and a number of traffic signals over at least two roadways. The goal of these plans is to encourage vehicles to use the roadways' capacity and not exceed capacity leading to excess delays. Thus, if a crash occurs on the freeway, some vehicles may be encouraged through in-vehicle messages or variable message signs to use adjacent arterials if extra capacity generally exists on the arterials. This application corresponds with the official Day 1 Use Case: Traffic Management: Corridor Management Load Balancing (Day 1).

4.2 Day 1 Corridor Management Applications, Planning Applications (Application #19)

This Day 1 application intends to archive VII data to improve the inputs to regional planning and forecasting models to determine better use of limited resources to improve roadways or plan new roadways and transportation facilities. Currently, regional models use traffic counts/volumes by vehicle type as inputs. Travel times may prove to be valuable supplements to these inputs, in that they reflect the combination of capacity, demand, and operational effectiveness for existing roadways. The availability of this data will permit a more holistic approach to long term planning in which the benefits of improved operations can be traded off against various construction options. This use case includes the optional "opt-in O/D" variable where operators of VII-enabled vehicles may volunteer their origin and destination to use for planning purposes and possibly real-time traffic forecasting. The "opt-in" O/D variable will likely be used as an "enhancement" of many Day 1 and future applications as shown in Table 2 in Section 6. The opt-in O/D variable can be used in current models that estimate O/Ds from traffic counts to improve the regional planning and long-term forecasting process. This application corresponds with the official Day 1 Use Case: Traffic Management: Corridor Management Planning Assistance (Day 1).

4.3 Future Corridor Management Applications, Real-Time Corridor Load Balancing (Application #20)

Real-time corridor load balancing would determine if roadways have excess capacity in real-time and try to encourage vehicles to leave one roadway and use another if that would make all traffic move more efficiently. Travel times, speed profiles, queue lengths, capacity measures, and volume by vehicle class would likely all be used to manage the corridor traffic in real-time. In the event that vehicle class becomes available from the VII data, more sophisticated load balancing (for example, including consideration of passenger throughput) will become possible.

Many of the current discussions related to corridors is based on the management of the corridor to maximize traveler throughput taking arterial and freeway roadways into account, as well as available capacity on both transit and non-transit facilities. This is accomplished by facilitating the appropriate use of alternative facilities and modes by encouraging appropriate diversion. It also includes increases in efficiency by enhancing transit operations through provision of transit priority, unimpeded busways, and expanded parking facilities to facilitate intermodal interfaces. Including transit routes and facilities in the overall corridor management process will be a future application.

5. TRAVELER INFORMATION APPLICATIONS

Traveler information applications will be important public sector as well as private sector VII applications. In this paper, we concentrate on public sector provided traveler information. The official Day 1 application follows the current guidelines for 511 services, although it is recognized that the information may also be delivered back to suitably equipped vehicles.

Future enhancements include utilizing VII-specifically-obtained data such as roadway conditions. Advanced applications such as providing tailored routes based on individually-specified origin-destination information will likely be provided only by the private sector. However, safety message aspects of traveler information such as intensive icing or a major incident may lead to public-sector-provided route-specific information.

5.1 Day 1 Traveler Information (Application #21)

VII data, most specifically travel times, will be used to provide arterial and freeway information to a variety of dissemination sources. Following the "Implementation and Operational Guidelines for 511 Services" (6), each route and segment will include information about construction/maintenance, road closures and major delays, major special events and weather and road surface conditions, as well as real-time traffic information such as segment travel times. Each information item in a 511 system may include location, direction of travel, general description and impact, days/hours/duration, travel time or delay, detours/restrictions/routing advice, forecasted weather and road surface conditions, and current observed weather and road surface conditions. Potential vehicle elements collected by VII that can be used for weather applications are presented in the Appendix. Day 1 weather applications include Traveler Notification (traveler information). The list in the Appendix was provided by the National Center for Atmospheric Research (NCAR), a contractor to the Road Weather Management program of the Federal Highway Administration (ITS Joint Program Office Weather Applications Technical Manager, James Pol).

Such traveler information systems include non-VII collected data such as road closures, special events, and work zones. VII-collected data includes travel times, speed profiles, stop locations and delays as well as weather-related data including wiper system state, exterior air temperature and whether vehicles have deployed anti-lock brakes or traction control. Eventually, the VII data can be fused with other data or processed to provide volumes and incident locations. The operator-provided Opt-in O/D data will be available for Day 1 but will not likely provide enough useful data in Day 1. In Day 1, only a small percentage of vehicles will provide snapshots and data. Only a portion of these will provide optional O/D data.

This application corresponds with the official Day 1 Use Case: Traveler Information (Day 1). The weather-related Use Cases: Weather Information: Traveler Notification with *Clarus* (Day 1) and Weather Information: Traveler Notification without *Clarus* (Day 1) have also been consulted in determining data needs identified in Tables 2 and 3 in Sections 6 and 7.

5.2 Future Traveler Information (Application #22)

Future VII traveler information includes roadway conditions. This will use data unique to VII such as pavement surface condition, precipitation intensity, visibility, and sun glare. Another future application will be the ability to convey National Weather Service Warnings and Advisories.

Opt-in OD may have enough participation and market penetration to be useful for future traveler information. If real-time O/D matrices are generated, then more is known and can be forecasted about how many vehicles will be on specific roadway links in future time periods. Travel times and traveler information will be a combination of current travel times and forecasted travel times using expected volume/demand additions or subtractions.

6. DATA NEEDS OF EACH APPLICATION

Table 2 includes the data/measures needed by each application sorted by application area: traffic signal (pages 21-24), ramp/freeway management (pgs 25-28), corridor management (pg. 29) and traveler information (pg. 30-31).

Essential Measures Needed include the measures expected by traffic controllers and other algorithms in use today. Essential measures also include Day 1 application performance measures (generally travel time and delay, stops on arterials).

Enhancement Measures include future measures. Most of these can be obtained with VII snapshots or derived from VII snapshots.

Table 3 in Section 7 describes the data elements mentioned in Table 2.

TABLE 2 APPLICATION DATA NEEDS

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
1	Traffic signal timing plan computation	Traffic Signal	Day 1	• At Day 1 will gather the information necessary to develop signal timing plans without sending personnel or setting up new equipment at intersections • Speed • Trajectory through intersection • Aggregated flow profiles of vehicles between intersections on per-lane basis • Percentage of turning vehicles	• Volume • Space mean speed • Percentage of turning vehicles • Saturation flow rates • Arterial queue lengths • Stops • Delay • Travel Time	• Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
2	Traffic responsive operation	Traffic Signal	Day 1	• Ultimately, weather and traction data	• Volume • Occupancy • Stops • Delay • Travel Time • Percentage of turning vehicles • Arterial queue lengths	• Space mean speed • Pavement surface condition • Stop location
3	Transit priority	Traffic Signal	Future		• Signal status • Transit vehicle location • Volume • Stops • Delay • Travel Time	• Speed • Saturation flow rates • Arterial queue lengths • Stop location • Number of transit riders • Transit schedule

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
4	ACS "Lite"	Traffic Signal	Future		• Volume • Saturation flow rates • Turning movements • Stops • Delay • Travel Time	• Space mean speed • Arterial queue lengths • Pavement surface condition • Opt-in O/D • Stop location
5	Adaptive signal control	Traffic Signal	Future	• Capturing individual vehicle movements through and between intersections	• Volume • Space mean speed • Arterial queue lengths • Speed profiles • Percentage of turning vehicles • Saturation flow rate • Stops • Delay • Travel Time	• Pavement surface condition • Sun angle/glare • Transit vehicle presence • Incidents • Special event schedules • Opt-in O/D • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
6	Enhanced actuated control	Traffic Signal	Future	• Stop location	• Volume • Space mean speed • Arterial queue lengths • Saturation flow rates • Stops • Delay • Percentage of turning vehicles	• Opt-in O/D
7	Work zone signal control	Traffic Signal	Future		• Volume • Space mean speed • Arterial queue lengths • Saturation flow rates • Stops • Delay	• Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
8	Off-line computation of ramp metering rates	Ramp Metering	Day 1	• Speed • Braking and acceleration • Vehicle trajectory through ramp and merge areas • Aggregated flow profiles (speeds) of vehicles between ramps by lane • Travel time • Mainline speed • Mainline delay • Ramp queue delay • Average ramp queue length (non-real time)	• Volume (mainline) • Space mean speed (mainline) • Travel time • Delay	• Saturation flow rates • Ramp queue lengths • Stop location
9	Ramp metering implementation in locations without current sensors	Ramp Metering	Future		• Volume (mainline and ramp) • Space mean speed (mainline and ramp) • Travel time • Stops	• Saturation flow rates • Ramp queue lengths • Opt-in O/D • Speed profile • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
10	Metering of a series of ramps	Ramp Metering	Future		• Volume (mainline and ramp) • Space mean speed (mainline and ramp) • Travel time • Stops • Ramp queue lengths • Travel time reliability	• Saturation flow rates • Opt-in O/D • Speed profile • Stop location
11	Single ramp adaptive control	Freeway Management	Future	• Average ramp queue (real time)	• Volume (mainline and ramp) • Space mean speed (mainline and ramp) • Travel time • Stops • Ramp queue lengths • Travel time reliability	• Saturation flow rates • Opt-in O/D • Volumes on parallel routes • Speed profile • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
12	Adaptive variable message sign control	Freeway Management	Future		Mainline: • Space mean speed • Travel time • Travel time reliability	• Volume • Mainline queue lengths • Stop location
13	Variable speed limits	Freeway Management	Future		• Space mean speed • Travel time • Speed profile • Travel time reliability	• Stop location • Pavement condition • Volume
14	Lane control (mainline metering)	Freeway Management	Future		• Space mean speed • Travel time • Speed profile • Travel time reliability	• Volume • Mainline queue lengths • Opt-in O/D • Stop location
15	Automatic incident detection	Freeway Management	Future		• Speed profiles • Travel time • Speed profile • Travel time reliability	• Sharp braking location • Change lane location • Mainline queue lengths • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
16	Decision support tools for freeways	Freeway Management	Future		• Travel time reliability • Space mean speed • Travel time • Speed profile	• Opt-in O/D • Volumes on parallel routes • Stop location
17	Dynamic traffic control in work zones	Freeway Management	Future		• Speed profiles • Travel time • Speed profile	• Volume • Mainline queue lengths • Opt-in O/D • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
18	Corridor management: load balancing using pre-determined plans	Corridor management	Day 1	• Speed • Real-time map of transportation network conditions and loading including layers of speeds, travel time, potentially hazardous conditions • Travel times • Speed profiles • Data available for both freeways and roadway network arterials	For freeways and arterials: • Space mean speed • Queue lengths • Travel times • Speed profiles	• Volume by vehicle type • Opt-in O/D • Stop location
19	Corridor management: planning applications	Corridor management	Day 1	• Travel times • From travel time data, an estimation of volume/capacity • Opt-in O/D	• Travel times • Volume • Capacity • Space mean speed profiles	• Volume by vehicle type • Opt-in O/D • Stop location
20	Corridor: real-time load balancing	Corridor management	Future		• Travel times • Volume • Capacity • Space eman speed	• Volume by vehicle type • Opt-in O/D • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
21	Information (including arterial and freeway travel time) inputs to DMS, HAR, 511, websites including both recurring and non-recurring conditions	Traveler information	Day 1	• Travel times provided on a regular recurring basis referenced either landmark to landmark or between geo-located road positions • Road closures • Special events • Non-recurring congestion • Work zones • Incidents • Civil emergency notifications	• Travel times (1,2) • Speed profiles • Incident locations • Number of lanes closed • Road closures • Special events • Work zones	• Opt-in O/D (limited value) • Stop location

Application Number	Name	Category	Day 1 or Future	Measures		
				Identified in Use Case (Updated 4/17)	Essential Needs	Enhancements
22	Enhancement of day 1 information to include roadway conditions	Traveler information	Future		• Travel times (1,2) • Speed profiles • Travel time reliability • Pavement surface condition • Precipitation • Sun glare • Air temperature	• Opt-in O/D • Stop location • Incident locations • National Weather Service Warnings, Watches and Advisories

7. DEFINITION OF DATA ELEMENTS INCLUDED IN THE APPLICATION DATA NEEDS

TABLE 3 DATA ELEMENT DEFINITIONS (ESSENTIAL AND ENHANCEMENT COLUMNS OF TABLE 2)

***** For Day 1, all derived measures use a sample of vehicles.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Volume for Application (1) (Off-line traffic signal optimization)	The number of vehicles per unit time crossing a predefined point on the roadway	Derived from speed-flow relationships	Derived*	Unknown	Spatial – measured at stop line for each lane Temporal – 15 min. resolution	Might be difficult to determine for Day 1 applications. Might be better to modify the applications to use alternative data elements. For enhanced functionality, volume by vehicle type is needed.
Volume for Application (2) (Traffic responsive operation)	Same as volume for Application (1)				Spatial – measured at stop line for a sample of significant links (number of links < 50% of the number of intersections) Temporal – 5 min. resolution	Same as volume for application (1)

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Volume for Application (3) (Transit priority)	Same as volume for Application (1)				Spatial – measured at stop line of all signalized intersections along the transit route Temporal – 5 min. resolution	Same as volume for application (1)
Volume for Applications (4), (5), (6) and (7)	Same as volume for Application (1)				Spatial – measured at stop line of all signalized intersections Temporal – 1 signal cycle resolution	Same as volume for application (1)
Mainline freeway volume (Applications 8-20)	The number of vehicles per unit time crossing a predefined point on the roadway	Derived from speed-flow relationships	Derived*	Unknown	Spatial – measured at interchanges (before ramp merge, after ramp merge) for each lane Temporal – 15 min. resolution; eventually 5 min resolution	Might be difficult to determine for day 1 applications. Might be better to modify the applications to use alternative data elements. For enhanced functionality, volume by vehicle type is needed.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Ramp volume (Applications 9-11)	The number of vehicles per unit time entering a freeway	Derived from speed-flow relationships	Derived*	Unknown	Spatial – measured at freeway entrance Temporal – 15 min. or 5 min. resolution	Might be difficult to determine for day 1 applications. Might be better to modify the applications to use alternative data elements. For enhanced functionality, volume by vehicle type is needed.
Space Mean Speed	The average speed of all moving vehicles traveling within the spatial and temporal limits of the measurement period	Vehicle snapshots	Measured directly	Unknown	Spatial – measured between signalized intersections or on specific freeway links. Ideally, by lane Temporal – same time periods as shown for volumes	May be difficult to estimate accurately if more snapshots are obtained from slower vehicles and snapshots are unassociated.
Percentage of Turning Vehicles	% vehicles traveling through, or turning left and right during the measurement period	Possibly derived from vehicle snapshots	TBD	Unknown	Spatial – measured at the intersection Temporal – same time periods as shown for volumes	Measurement approach to be determined by communications protocols. For enhanced functionality, needed by vehicle type.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Stops	% of vehicles stopped at an intersection during the measurement time period	Directly derived from stop snapshots	Measured directly	Unknown	Spatial – measured at the end of the queue Temporal – Same time periods as shown for volumes	Derived from vehicle speeds less than a predetermined threshold. Accuracy determined by need for sensitivity in evaluating effectiveness of alternative applications.
Delay	Time spent by stopped vehicles	Derived from stops data	Derived*	Unknown	Spatial – measured by evaluating queue lengths at intersection approaches Temporal – same time periods as shown for volumes	Derived by accumulating total stopped time of all vehicles Accuracy determined in same manner as stops.
Travel Time (1)	Time required for vehicles to travel between RSEs.	Derived from periodic snapshots Possibly from time of last probe message	Derived* Measured directly, maybe	10-20% [2](for ATIS)	Spatial – between RSEs Temporal – 5 min.	Approach/feasibility determined by system architecture.

[2] Toppen, A., and Wunderlich K., *Understanding Key Tradeoffs for Cost-Effective Deployment of Surveillance to Support Advanced Traveler Information Systems*, May 2004. USDOT Electronic Data Library (EDL), http://www.its.dot.gov/library.htm, Document #13991.

Data Element Name	**Preferred Description**	**Source**	**Directly Measured or Derived***	**Required Accuracy if Known**	**Required Frequency if Known (both temporal and spatial values)**	**Comments**
Travel Time (2)	Time required for vehicles to travel point to point (potentially smaller than RSE to RSE)	Derived from periodic snapshots	Derived*	10-20% [3](for ATIS)	Spatial—between landmarks or mile markers. Ideally, by lane Temporal—5 min.	Possible concerns about accuracy, especially at low market penetration or between distant RSE locations.
Saturation Flow Rate	Maximum number of vehicles per second flowing from intersection during queue discharge.	Derived from number of vehicles released from intersection at start of green	Derived by monitoring vehicle release rates over extended time periods.*	Unknown	Spatial – Downstream from all signalized intersections Temporal – One measurement required for each period of the day (AM peak, off peak and PM peak) and day-type (weekdays, weekends, holidays)	Used as a basic input to signal timing calculations. Requires coordination with signal timing

[3] Toppen, A., and Wunderlich K., *Understanding Key Tradeoffs for Cost-Effective Deployment of Surveillance to Support Advanced Traveler Information Systems*, May 2004. USDOT Electronic Data Library (EDL), http://www.its.dot.gov/library.htm, Document #13991.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Stop Location	Roadway location at which a vehicle is stopped	Vehicle stop snapshots	Measured directly (but with a delay, currently 5 seconds)	Unknown	Spatial – All approaches to all signalized intersections; all freeway locations Temporal – one signal cycle resolution	Stopped location furthest from an intersection is used to define queue length.
Arterial Queue Length for applications (1) and (2)	Maximum number of vehicles in standing queue at beginning of green (end of red)	Derived from stop location	Derived*	Unknown	Spatial – All approaches to all signalized intersections. Temporal – Averaged over either 15 minute or 5 minute time periods for applications (1) and (2) respectively	Important measure for estimating approach demand
Arterial Queue Length for applications (3) through (7)	Maximum number of vehicles in standing queue at beginning of green (end of red)	Derived from stop location	Derived*	Unknown	Spatial – All approaches to all signalized intersections. Temporal – measured at the beginning of each phase	Important measure for estimating approach demand

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Occupancy	The percent time that a vehicle is present at a predetermined location of the roadway.	Derived from speed and volume. (Occupancy is proportional to Volume/Speed)	Derived*	Unknown	Spatial – measured at stop line for a sample of significant links (number of links < 50% of the number of intersections Temporal – 5 min. resolution	This measure has only been included because it is a fundamental variable for existing traffic responsive control. Will not be required if speed can be demonstrated as a viable alternative
Pavement surface Condition	A measurement that will serve as a surrogate for traction. Two levels of traction should be identified: high and low.	Obtained from vehicle snapshots	Direct	N/A	Spatial – All roadways Temporal – 5 minute time period	Used to identify the presence of hazardous driving conditions leading to the need for implementation of special weather timing plans
Opt-in O/D	Percentage of vehicles that have traveled from a selected roadway location on the roadway to a specific roadway destination	Vehicle trajectories provided from opt-in vehicles.	Direct	N/A	Directly obtained for all opt-in vehicles traveling within the boundaries of a given control area (as defined by the traffic management system)	Assumes the existence of an opt-in O/D capability. Can be used to derive demand on specific links. This data might also be supplemented by derivation of O/Ds from vehicle turning movements and short-term vehicle paths available from snapshots.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Ramp Queue Length	Number of vehicles standing on ramp waiting to enter the mainline freeway.	Derived from stop location.	Derived*	Unknown	Spatial—All metered ramps (applications 1, 3,4); all on-ramps for application (2) Temporal—Averaged over 15 minutes for applications (1-3); 5 minutes for application (4)	In some locations, ramp meters are turned off or a new timing plan is chosen so that the ramp does not "back up" onto arterial roadways.
Mainline Queue Length	Number of vehicles in stop/start conditions on mainline freeway lanes.	Derived from stop/start locations.	Derived*	Unknown	Spatial—Desired for all freeway links Temporal—Averaged over 15 or 5 minutes.	Queue length is likely to vary greatly over 15 minutes and with different market penetrations; 5 minutes is more ideal.
Volumes on Parallel Routes	The number of vehicles per unit time crossing a predefined point on the roadway (on adjacent, likely arterial routes).	Derived from speed-flow relationships	Derived*	Unknown	Spatial—Desired for adjacent arterial links Temporal—Averaged over 15 or 5 minutes.	Desired in adaptive ramp metering, freeway management decision support, and corridor applications.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Sun Angle/Glare (Sun Sensor Vehicle Status Element)	Sunlight angle affecting drivers' visibility. Two levels of glare should be identified: not affecting performance and affecting performance (likely sun sensor status 6-7)	Obtained from vehicle snapshots (sun sensor vehicle status element)	Direct	N/A	Spatial – All approaches to all signalized intersections Temporal – 5 minute time period	Measure of ambient conditions likely to affect driver's performance.
Arterial Speed Profiles	Time history of vehicle speeds along a link between two RSEs	Derived from vehicle speed snapshots.	Direct	Unknown	Spatial – All approaches to all signalized intersections. Ideally by lane Temporal – one signal cycle resolution or time to travel between RSEs	Speed profiles may be a better data measure than travel time. Learning bottleneck locations may lead to better forecasts of travel times and conditions. Possible precursor measure for point-to-point travel times.
Freeway Speed Profiles	Time history of vehicle speeds along a link between two RSEs	Derived from vehicle speed snapshots.	Direct	Unknown	Spatial—All freeway links between RSEs. Ideally by lane Temporal—time to travel between RSEs, 5 mins, or 15 mins	Speed profiles may be a better data measure than travel time. Learning bottleneck locations may lead to better forecasts of travel times and conditions. Possible precursor measure for point-to-point travel times (RSE to RSE links and smaller links).

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Transit Vehicle Presence and Location	Locations of transit vehicles on intersection approaches	Received from transit vehicle OBUs	Direct	Unknown	Spatial – All approaches to all signalized intersections Temporal – one signal cycle resolution	Must be accurate to ensure transit vehicles receive consideration for priority when needed. Included for adaptive control to account for applications incorporating transit priority features.
Signal Status	The number of seconds until green or the number of seconds remaining of green for the signal in the direction that the transit vehicle is heading.	Requires communication with the signal controller.	Direct	Unknown	Spatial—Predefined distance from intersection Temporal—Predefined "time" away from intersection	Used to determine whether the signal will be changed to accommodate the transit vehicle.
Number of Transit Riders	Number of riders on transit vehicle	This may be determined with a presence detector as passengers enter and exit or may be input by transit operator.	Direct	Unknown	Spatial—Predefined distance from intersection Temporal—Predefined "time" away from intersection	Will be used to help determine whether signal will accommodate the transit vehicle.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Transit Schedule	Type of transit vehicle, route/trip identifier, number of minutes that transit vehicle is ahead or behind schedule.	Transit vehicle location in combination with exogenous sources	Direct and Reported	Unknown	Spatial—Predefined distance from intersection Temporal—Predefined "time" away from intersection	If the vehicle is ahead of schedule, transit priority is not needed. The need for transit priority increases with the number of minutes the vehicle is behind schedule.
Incidents	Existence (and location) of incidents within a predefined radius of the controlled intersection	Received from exogenous sources	Reported	N/A	Spatial – Predefined distance from intersection or exit ramp Temporal – 3 minutes	Valuable input to permit adaptive control applications to anticipate need for special controls
Special Event Schedules/Road Closures/Work Zones	Existence of special events/road closures/work zones within a predefined radius of the controlled intersection (RSE)	Received from exogenous sources	Reported	N/A	Spatial – Predefined distance from intersection/RSE Temporal – in advance of special event/road closure/work zone	Valuable input to permit adaptive control applications to anticipate need for special controls. May also include holidays. Also needed for traveler information.

Data Element Name	**Preferred Description**	**Source**	**Directly Measured or Derived***	**Required Accuracy if Known**	**Required Frequency if Known (both temporal and spatial values)**	**Comments**
Travel Time Reliability	Travel time reliability is a measure of the variability in travel time between two points. It is expressed in terms of additional time that must be added to the estimate of travel time by travelers, to ensure that they will arrive at their destination on-time 95% of the time.	Derived from variability of travel time from one time period to the next.	Derived	Unknown	Spatial—for travel time (1) "RSE" to "RSE". For travel time (2), an arterial or freeway link Temporal—5 min.	Needed for future freeway management and traveler information applications.
Sharp Braking Location	Identifies location where sharp braking has occurred.	Using longitudinal acceleration vehicle status element in snapshot	Measured directly	N/A	Spatial—N/A Temporal—N/A	For incident detection, but sharp braking in itself is not an event. So currently only captured if the braking occurs at the same time as a snapshot.

Data Element Name	**Preferred Description**	**Source**	**Directly Measured or Derived***	**Required Accuracy if Known**	**Required Frequency if Known (both temporal and spatial values)**	**Comments**
Change Lanes Location	Many vehicles changing lanes mid-link (freeway or arterial) is an indication of an incident.	Using "heading change from last snapshot" which has been proposed in snapshots	Measured directly	N/A	Spatial—N/A Temporal—N/A	For incident detection, but change lanes in itself is not an event. So currently only captured if the heading change occurs at the same time as a snapshot. Heading change can be used to identify turning movements, but may not work well to identify lane changes.
Capacity	The number of vehicles per hour that can be accommodated by a freeway or arterial link in saturated flow conditions.	Generally derived from volume and Highway Capacity Manual calculations. Use case suggests it can be estimated from travel time data.	Derived.	Unknown	Spatial—Desired for each link Temporal—Usually in 15 minute increments	Described in use case for corridor management: planning applications. Difficult to estimate using travel times.
Precipitation Gauge	A combination of rain sensor and wiper status.	Using the rain sensor vehicle status element. Using wiper vehicle status element.	Measured directly	N/A	Spatial—Desired for each link Temporal—5 minute time period	Along with sun sensor data and air temperature, weather information expected to be passed as traveler information.

Data Element Name	Preferred Description	Source	Directly Measured or Derived*	Required Accuracy if Known	Required Frequency if Known (both temporal and spatial values)	Comments
Air Temperature	Air temperature.	Using air temperature vehicle status element.	Measured directly	N/A	Spatial—Desired for each link Temporal—5 minute time period	Along with sun sensor data and precipitation, weather information expected to be passed as traveler information.
NWS Warnings	Sub-County or County Wide Warnings of imminent severe weather	NOAA / NWS	Both observed and derived	N/A	Issued only when severe weather is imminent. Typical duration of 30-60 minutes. Could extend to 6 hours or longer	Typically issued by local forecast offices. Different actions are required for different warnings (e.g., tornado, flood or hurricane)
NWS Watches	County Wide Watches of possible severe weather	NOAA / NWS	Derived (forecasts)	N/A	Issued on the forecast or potential for severe weather conditions. Typical duration of 6 to 36 hours.	Typically issued by NWS national centers (e.g., National Hurricane Center or Storm Prediction Center)
NWS Advisories	County Wide Advisories of significant or disruptive weather	NOAA / NWS	Both observed and derived	N/A	Issued on the occurrence or short term forecast of disruptive weather (e.g., dense fog, high winds)	Issued by local forecast offices. Many advisories can have significant impact on transportation.

8. CONCLUSIONS

The information presented in this paper is significant in that it provides an initial definition of the range of variables required to support VII-based traffic management and traveler information applications. These applications offer the potential for greatly improving traffic operations within the United States. In general the requirements of the Day 1 applications appear to be modest. However, some challenges exist, the most significant of which is the estimation of demand (volume) when the percent of VII-equipped vehicles is relatively low. Since demand is fundamental to the majority of applications, its measurement (or derivation using surrogate variables) is essential. When reviewing the data requirements of the Day 1 applications, it is also important to recognize that variables may have the same name and definition, but are measured at different locations. For example, vehicle volume on arterials, in some cases must be measured at the stop line and other cases at midblock. In the interest of minimizing the number of changes required to legacy systems and algorithms, this study focused on the manner in which VII data elements can be interpreted in a manner that permits their use by these legacy systems.

Future applications represent a different challenge. If the past represents a valid model for the future, it is likely that the future applications will be developed in a manner that takes advantage of the characteristics of the VII data elements without requiring excessive translation. Thus the requirement for emulating the conventional traffic detector is minimized or eliminated. However, due to the unknown nature of these future applications, it is difficult to anticipate their full range of data needs and required accuracies. The tables developed for this report represent "best guesses" regarding the manner in which these applications will be developed. They assume that the future applications will require adequate flow information for a comprehensive understanding of prevailing traffic conditions, as well as information related to environmental factors such as pavement conditions, visibility, and other factors that are likely to influence driver behavior. Although it is recognized that VII cannot provide all of the data that would ideally be required for effective traffic management, exogenous factors such as day type (special event schedules, construction, etc.) were identified as being useful for these strategies. No attempt was made to define what could or couldn't be provided by the system. As a result, the list of data required for future applications became quite long. However, in this case, it can be concluded that not all of the identified data elements are equally critical, in spite of the fact that each of the elements listed are likely to contribute to the effectiveness of its associated future application.

Therefore, this work concludes that the needs of the Day 1 applications are significantly different and less flexible than those of the future applications. The challenge of the next project step is to define "what is possible".

9. SUMMARY OF NEXT STEPS

With respect to the data characteristics project, the next step is a report mapping the application data needs with the data that can be produced by the current probe message process. A draft of this was delivered 9 June 2006.

With the data needs and data processing white papers, project team members are studying related VII documents including the draft DSRC standard (SAE J2735), probe message process documents generated by PB Farradyne, privacy-related documents generated by Raytheon, and the Requirements document by Booz Allen Hamilton. These other documents are reviewed to ensure consistency with the project documents and to identify differences. Where possible, comments are provided to authors to promote understanding and consistency.

Simultaneous with the data needs vs. VII Day 1 data report activity, alternate probe message strategies will be identified. Both the current probe message scheme and a few alternatives will be tested with real and simulated data. Multiple message strategies will be tested in order to generate better inputs to the applications described above in this white paper.

By the late June project briefing, we expect that the results of the first two activities will be used by the project management team and other subject matter experts to generate a priority list of which data elements should be investigated by the remaining project tasks. The guidance may be, for example, to study obtaining travel time, stops, delay, etc. from the probe messages and snapshots obtained from collected microscopic data sets. A trajectory processor will be developed and used to obtain snapshots and probe messages from real data sets such as the NGSIM freeway and arterial data sets collected in California.

Additional deliverables include a Data Characteristics White Paper delivered 1 September 2006 and the Day 1 Draft Final Report due 1 January 2007.

REFERENCES

1. Tarnoff, P., "Research Plan for a Transportation Industry Paradigm Shift", prepared for Mitretek Systems Inc., July 26, 2004.

2. Tarnoff, P., "Evaluation of the Potential Traffic Management Benefits Resulting from the Availability of VII Information, Prepared for Mitretek systems Inc., October, 2004.

3. Row, Shelley, "VII Workshop – Arterial Management, Summary of Results", Prepared for FHWA, February 2005.

4. Row, Shelley, "VII Workshop – Freeway Management, Summary of Results", Prepared for FHWA, February 2005.

5. Parkany, Emily and David Bernstein, "Design of Incident Detection Algorithms Using Vehicle-to-Roadside Communication Sensors," in *Transportation Research Record No. 1494*, 1995, pages 67-74.

6. 511 Deployment Coalition, "Implementation and Operational Guidelines for 511 Services" Version 3.0, September 2005. Found at: http://www.deploy511.org/implementationguide.htm (Accessed April 24, 2006).

7. Toppen, A., and Wunderlich K., *Understanding Key Tradeoffs for Cost-Effective Deployment of Surveillance to Support Advanced Traveler Information Systems*, May 2004. USDOT Electronic Data Library (EDL), http://www.its.dot.gov/library.htm, Document #13991.

APPENDIX POTENTIAL VEHICLE DATA ELEMENTS FOR WEATHER APPLICATIONS

(From National Center for Atmospheric Research (NCAR) and James Pol, April 2006)

DATA ELEMENTS	ANTICIPATED	SAMPLE RATE	REPORT RATE	RETENTION TIME	DATA TYPE	RANGE	ACCURACY	PRECISION	SENSOR PLACEMENT	COMMENTS
Potential VII weather application data elements	Data element could be made available for weather application development	The frequency at which the data element is measured (e.g. once per second)	How often the data element is recorded	Length of time data element is stored on the vehicle	Integer, Float, Character, Array, etc.	Lower and upper limits of measurement Only elements denoted by *	The extent to which the data element value approaches truth (e.g. temperature accuracy ± 2^{o}C) Only elements denoted by *	The degree of refinement at which a data element is measured (e.g. barometric pressure precision 0.01 in Hg) Only elements denoted by *	Location of reporting sensor Only elements denoted by *	Note any other technical challenges associated with utilizing data element for weather applications
GPS Location (latitude, longitude)	YES						*	*		
Speed	TBD					*	*	*		Could be restricted
Direction	NO					*	*	*		With multiple GPS locations, this variable could be computed
Time	YES						*	*		
Date	YES									

DATA ELEMENTS	ANTICIPATED	SAMPLE RATE	REPORT RATE	RETENTION TIME	DATA TYPE	RANGE	ACCURACY	PRECISION	SENSOR PLACEMENT	COMMENTS
Elevation	YES					*	*	*		
Windshield Wipers (front) **On/off**	YES									This should not be based on switch position. It may be more beneficial to examine wiper motor speed
Windshield Wipers Speed (front) **Low/High/ Intermittent**	YES									This should not be based on switch position. Examine wiper motor speed
Windshield Wipers (rear) **On/Off**	YES									May not be useful. In some cases, could actually be misleading
Windshield Wipers Speed (rear) **Low/High/ Intermittent**	YES									May not be useful. In some cases, could actually be misleading
Headlights (Auto/on/off/ high/low)	YES									On, off, not equipped, high, low

DATA ELEMENTS	ANTICIPATED	SAMPLE RATE	REPORT RATE	RETENTION TIME	DATA TYPE	RANGE	ACCURACY	PRECISION	SENSOR PLACEMENT	COMMENTS
Daytime Running Lights	YES									May not be valuable
Fog lights	YES									May not be relevant
Exterior Temperature	YES					*	*	*	*	multiple sensors, need to ID proper one, air intake is likely to be available
Interior Temperature	YES					*	*	*	*	too many zones, may not be practical
Windows Defroster	YES									Some linked to mirror defroster
Mirror Defroster	YES									
Rain sensor	TBD					*	*	*	*	Used to turn on wipers, technology is too variable. It would be beneficial to work directly with sensor manufacturer to understand this technology
Sun sensor	TBD					*	*	*	*	Technology is variable now, direction dependent, watts/m2. Not day-1. Tied to A/C unit – black box. Inside dash
Traction control	YES									System only works up to 12 mph. On/Off/engaged

DATA ELEMENTS	ANTICIPATED	SAMPLE RATE	REPORT RATE	RETENTION TIME	DATA TYPE	RANGE	ACCURACY	PRECISION	SENSOR PLACEMENT	COMMENTS
Stability control	YES									On/Off/Engaged, event driven, OEMs not sure what data means as it's a 3rd party system. Can indicate friction, but it would be derived.
Antilock Braking System	YES									On/Off
3-axis accelerometer data	TBD					*	*	*	*	Black box, data not always on data bus. Multiple sensors. Dynamic range variable. Not recommended. Sensor data highly location specific. Suspension impacts values.
ACC: Millimeter-wave radar	NO									Not broadly available now. Ten years, maybe 3% uptake. Data part of black box. Need to work with supplier.
Ambient Noise Level	TBD					*	*	*	*	To diagnose hail or rain. Used to blank out white noise on entertainment system. Long shot to make it useful. Some cars have "impact sound" sensors, but research based. Siemens testing this technology.

DATA ELEMENTS	ANTICIPATED	SAMPLE RATE	REPORT RATE	RETENTION TIME	DATA TYPE	RANGE	ACCURACY	PRECISION	SENSOR PLACEMENT	COMMENTS
HVAC status (Cooling, Heating, On/Off, High/Mid/Low, Temp. Setting)	YES									Not likely useful due to variable sensor placement. In addition other sensors, like sun sensor impacts output. Heat On/Off, A/C On/Off, Defroster On/Off
Barometric Pressure	YES					*	*	*	*	
Intake Air Temperature	YES					*	*	*	*	
Air Density	?					*	*	*	*	Not sure if it is on bus, could derive from pressure and temperature
Vehicle type	YES									Motorcycle, passenger car, x-axle unit, special use, etc Question whether a portion of the VIN could be used (riddled with privacy issues)
Hours of Operation	TBD					*	*	*		Time since ignition, data available. Could be useful to determine warm-up period, but coolant temperature may be more useful.
Coolant Temperature	YES									