Research Plan for a Transportation Industry Paradigm Shift
(The Impact of New Measures Produced by the VII Program)

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BACKGROUND

The Vehicle Infrastructure Integration (VII) program offers the potential of generating a significantly expanded set of measures for monitoring the status and operation of the surface transportation system. These measures include:

- Measures of effectiveness (MOEs) for the evaluation of the quality of the system operation. Representative MOEs include travel time, stops, delay and travel reliability
- Condition measures that provide information on the state of the roadway and environment. Representative condition measures include pavement traction, pavement roughness, precipitation, visibility and air quality. Note that air quality might also be considered an MOE.
- Demand measures that provide information on the vehicles, passengers and freight making use of the surface transportation system. These measures are typically counts of numbers of vehicles, numbers of passengers, tons of freight, tons of hazardous material, etc. Ideally, these measures should describe both the demand for the use of a specific segment of a facility (roadway link or transit route) as well as the origins and destinations of the transportation system users.

The term "measures will be used in this research plan, to represent the three categories described above.

The availability of these measures offers the possibility for greatly enhanced management of the transportation system, as well as superior evaluation of system operational effectiveness. The challenge is to identify the areas in which existing techniques can be improved, and new techniques developed that can take advantage of this improved capability. This challenge will only be met if researchers, system developers, and system managers are able to devise new approaches without being constrained by the technology of the past, much of which has been developed to avoid the limitations of existing traffic surveillance equipment. In other words, it is important that all members of the transportation community "think outside the box" when considering the applications that these new information sources make available.

Measures Potentially Available from the VII

The VII program is an extensive and ambitious effort to provide motorists with an expanded set of on-board services that can be made available through the use of dedicated short-range communications (DSRC). The system is based on the installation of devices on vehicles that communicate with roadside receivers (designated roadside units – RSUs). The public sector can take advantage of a subset of the VII program capabilities through the acquisition of information transmitted from the vehicle that provides an indication of traffic, roadway and environmental conditions. The VII measures are derived from this information. Table 1 has been prepared to provide an initial indication of the relationship between the transportation measures and the information provided from the vehicle.

Table 1. VII Measures

Measure	Information Source(s)	Current measurement
Traffic Demand*	• Vehicle location	Volume rather than demand
Space mean speed*	• Vehicle location	Spot mean speed only
Spot mean speed	• Vehicle speed	Measured
Travel Time*	• Vehicle location	Measured by fewer than 5 systems nationally
Origin-Destination (O-D)*	• Vehicle location • Vehicle ID	Not measured
Vehicle Location	• Vehicle location	Not measured (but needed for some safety applications)
Potential Lane blockage*	• Hazard signals • Air bag	Not measured
Incident indicators*	• Hazard signals • Air bag • Engine running	Reports from observers
Weather: Rainfall Temperature	• Wiper system state, rain sensor, wiper speed • Exterior temperature	Measured by roadway-weather information systems (RWIS)
Light level and potential sun interference*	• Sun sensor	Not measured
Pavement condition*	• Traction control state • Road condition • Instantaneous rough road detected	Measured by special surveys
Icing	• Traction control state	Pavement sensors
Accident reconstruction*	• Event data recorder	Manually performed

* New measure, not currently available in automated form

From this table, it is clear that many new measures are available from the VII system.

Several areas of clarification are required for the information in this table:

- Traffic Demand is identified as a new measure. Traffic volume measured by conventional detectors is frequently confused with demand. Volume is a measure of the traffic passing a point on the roadway, while demand is a measure of the traffic that desires to use the roadway. The two are different under congested conditions. For example, the demand at a signalized intersection is the volume plus the queue length, rather than volume alone.

- Space mean speed. Space mean speed is the average speed of a vehicle when it traverses a roadway segment. Traffic detectors measure spot mean speed, which is the speed of vehicles passing a point on the roadway. Obviously, the values of the two are often different, particularly during congested conditions, when traffic is not free flowing. Spaced mean speed is a preferred measure, since it provides a better estimator for travel time.

- Origin-destination (O-D). This will prove to be one of the most valuable measures both for active traffic management as well as transportation planning applications. Traffic management cannot be effective unless managers know the desired destinations of the vehicles they are managing. With this information, managers can provide accurate advisory information to motorists and manage alternate routes using measures such as lane control and revised traffic signal control. This is similar to the objectives of telecommunications managers, who control the routing of communications traffic with knowledge of the capacity and destinations of the traffic being routed. However, the public sector's use of origin-destination (O-D) information leads to questions of privacy, which may ultimately rule out its use as a source of information for the traffic manager.

With these considerations in mind, the VII system offers the potential for significant expansion of the types of information available for traffic management purposes.

Equally significant is the potential coverage possible with the VII system. An indication of the potential coverage is provided by the strawman VII architecture currently under development. The architecture currently defined, has been developed with the objective of providing the following levels of coverage:

- Installation of RSUs at the majority of freeway interchanges and signalized intersections

- Vehicle unit maintains history of sensor outputs when traveling between RSUs

- RSUs transmit data to a central data cache as it is received from vehicles. (Ten data caches currently assumed, nationally).

- Users of VII information, access the information from the central data caches.

Based on these assumptions, the data collection characteristics of the VII system will be as shown in Table 2. It is important to recognize that these characteristics are preliminary and could easily change as the definition of the architecture evolves.

Table 2. Data Collection Characteristics

Characteristic	Value
Data sampling at RSU	Data (see table 1) will be provided describing the conditions at all signalized intersections and freeway interchanges.
Data sampling between RSUs	Spatial sampling rate = 0.1 * RSU spacing
Delay	Maximum delay in receiving data = (travel time between RSUs) + 1 min.
Latency	Time data retained by the data cache = 1 min.
Special requirements	When delays are unacceptable, direct connection between RSU and field equipment (signal controller or special intersection equipment) will be possible

Current Data Collection Capabilities

The full potential of the VII system cannot be appreciated without an understanding of the data collection capabilities of existing traffic management systems. Table 1 has identified the types of data collected with these systems, which include:

- Traffic volume, speed and occupancy as measured by traditional traffic detectors
- Weather – Temperature, rainfall, air quality, visibility and wind speed.
- Pavement icing
- Closed circuit television (CCTV)

Note that air quality and wind speed would not be measured by the VII system. These measures are important, but can be collected at selected locations. Extensive coverage of a high percentage of the highway network is unnecessary. Thus, the VII system does not completely eliminate the need for supplementary data collection.

CCTV surveillance is also particularly important for traffic management purposes. Here again, the VII system will not replace this capability. As a result, there will be a continuing need for a roadside infrastructure that includes cameras, poles and communications.

In addition to the expanded suite of measures, the VII System will provide greatly improved coverage over that which currently exists with conventional sensors. Current automated measurement, which is very sparse, is performed by:

- Traditional vehicle detectors – currently less than 30% of urban miles of freeway and 6% of urban arterials are instrumented. An insignificant percentage of rural roads are instrumented. Various sources have reported that, on the average, as many as 30% of traditional vehicle detectors are inoperable.
- Roadway weather information systems (RWIS) – While accurate data regarding deployment of RWIS could not be located, it is likely that the extent of the RWIS

unit and pavement condition sensor installations is less than that of traditional vehicle detectors.

As a result, the availability of data from automated sensors is sparse at best. The absence of widespread, reliable data has inhibited the development of automated traffic management techniques. Failure to increase the installation of traditional vehicle detectors results from their lack of reliability and limited functionality. Traffic management personnel do not feel that the measures provided by traditional detectors are adequate for the identification and management of incidents. They also feel that the cost, lack of reliability and limited capabilities of detectors installed on arterials, limit their use for adaptive traffic signal control.

Application of VII Measures

Through their expanded capabilities and coverage, VII measures offer the potential to overcome the shortcomings of traditional detectors. Table 3, provides a summary of the various traffic management applications, along with an indication of the benefits that can be provided by these measures. This list is not intended to be comprehensive, but rather as a starting point for exploring ways in which VII measures can be used.

Table 3. Relationship Between Applications and Measures

Application	Measures	Comments
Freeway management	Space mean speed Travel time Volume Demand O-D Lane blockage Incidents Weather Icing Pavement conditions Light levels	Improved ability to detect incidents, lane blockage and reroute traffic with knowledge of demand and origin-destination. Reliable automated incident detection may be possible. Reliable recommendations of alternate routes to motorists may be possible. Improved reliability of VMS messages through the availability of comprehensive, reliable speed data
Arterial management	Same as freeway management	Same as freeway-management, as well as potential for improved signal control with capability to predict the impact of traffic diversions in presence of an incident
Traveler Information	Space mean speed Travel time Incidents Weather Icing	Travel time and weather highly desirable to travelers.
Safety applications	Space mean speed Time mean speed Demand Lane blockage	Variables needed for intersection collision avoidance, as well as lane departure

Application	Measures	Comments
	Incidents Weather Icing Pavement conditions Light levels Vehicle location	
Performance evaluation	Space mean speed Demand Volume Incidents Weather Icing Light levels	Evaluation of impacts of incident management on system performance.
Special events	Space mean speed Travel time Volume Demand O-D Lane blockage Incidents Weather	Information required for special controls during special events. This includes special event planning, integration of field personnel with automated management, and response to unusual conditions during incidents.
Toll systems	Same as freeway management Demand by lane at toll booths	Knowledge of travel time has been shown to provide improved staff management at tollbooths through improved data on lane demand and lane travel time.
Transit management	Same as freeway management	Better management of the transit fleet through improved knowledge of traffic conditions.
Fleet management	Space mean speed Travel time Lane blockage Incidents Weather Icing Pavement condition Vehicle location	Management of snowplows, service patrol vehicles, and incident responders improved through the availability of information that reduces travel time and improves routing. Snowplows and highway maintenance crews can take advantage of icing and pavement condition information.
Planning and engineering	Space mean speed Travel time Demand O-D Pavement condition	Data identified is typically collected manually for planning and engineering applications.

This table cannot begin to provide the level of detail required to fully define the new applications implied in the comments column. However, even from these overview descriptions, it is clear that the improved data provides the ability for significantly improved traffic management. The following research program is intended to develop these new applications.

RESEARCH PROGRAM

This program is organized into six research activities and their component tasks. As described in the Contracting Plan of the following section, it is envisioned that each of these research activities is intended to include a logical grouping of research to be performed as a single research contract. Major research activities have been defined in this manner to simplify program management and coordination.

A statement of objectives is provided for each activity, followed by a detailed discussion of the tasks it contains. The task information also includes a description of the related applications and anticipated outputs.

Two areas not explicitly covered in this plan are safety and traveler information. Safety is not explicitly included here as a research activity because of the work already performed in this area by the Intelligent Vehicle Initiative (IVI) program. Traveler information is not explicitly described since its functions are inherently contained in the traffic management research (freeway, surface streets and system-wide). It is not anticipated that separate traveler information research will be required.

Research Activity 1.0 – Characteristics of VII Measures (Enabling Research)

Objective: This research is conducted to develop an understanding of the new and expanded measures available from the VII system. There are numerous examples of the relationships to be developed during this research. One example would be to determine whether knowledge of origins and destinations of motorists would assist in predicting traffic demand on parallel facilities when an incident occurs.

Research Subjects: It should be the responsibility of the offeror to identify the full range of relationships to be explored. In general, the following subject should be covered during this research for each of the measures produced by the VII system:

- Value of the measure for evaluating system performance
- Value as measure of congestion
- Reliability of data produced by the VII to be used for the desired measure (for example, does windshield wiper speed provide a reliable indication of rainfall intensity?)
- Value of combining multiple data sources (for example can flashers, vehicle position and air bag activation be used as a reliable indicator of a lane blockage)
- Statistical characteristics of data – accuracy of measurement as a function of sample size

- Potential applications due to availability of detailed weather and pavement condition data – Potential uses of improved weather information to predict the presence of incidents, estimate capacity impacts, and enhance fleet management
- Comparison with traditional measures – are the VII measures more beneficial as indicators of system performance than traditional techniques?
- Development of a new simulation program and other tools, or the modification of existing software to produce these measures under simulated traffic conditions.

Outputs: The outputs of this research include a series of reports that will provide the basis for the remaining five research activities. To avoid the need to delay the initiation of these other activities until Research Activity 1.0 is initiated, it is recommended that a series of reports be conducted as the study of each of the measures is completed. The measures should be prioritized based on their importance to the support of these other activities.

Research Activity 2.0 – Impact of VII Measures on Planning, Engineering and Evaluation

Objective: The objective of this research is the identification of VII measures that can be used to support the transportation planning, engineering and evaluation process. This objective encompasses the adaptation of existing applications (simulation, analysis tools, presentation tools, etc.) to the use of the VII data, as well as the identification of new applications that will enhance the planning, engineering and evaluation process.

Research Subjects:

- Impacts of O-D data and vehicle demand on the planning process including the possibility of developing new improved planning models that are sensitive to operational changes.
- Using travel time as a measure of total trip time and travel reliability
- Derivation of secondary measures (operating costs, air quality, fuel consumption, etc.) from the primary VII measures listed in Table 1.
- Impact of the VII system on national architecture
- Use of travel time for performance-based pricing

Outputs: The output of this research will include reports evaluating the design of new and modified applications including design details and an assessment of the new applications' potential capabilities.

The outputs will include prototypes of simulation and/or analysis software that is tested and demonstrated in a planning environment.

Research Activity 3.0 – The Use of VII Measures for Freeway Management

Objective: This should be a comprehensive, yet detailed study of the impact of the VII system on the entire field of freeway management, including the management of both recurring and non-recurring congestion. The objective of this research is the enhancement of existing freeway management applications and the development of new applications with the objective of improving all aspects of the management process. Improvement is defined as improved service to motorists, more effective use of facilities, and increased staff productivity.

Research Subjects: Research subjects are listed generically, but each subject should include an evaluation of the impact of the VII measures on existing algorithms and the development of new algorithms. Each subject should be evaluated analytically, and where applicable should be tested using simulation and if possible, field applications. All new developments will be subjected to a review by practicing freeway traffic management staff to ensure that practitioners will accept it once it is ready for field implementation. The tasks covered by this research activity include:

Task 3.1 Ramp metering
Description: The availability of a continuous measure of vehicle travel times and speeds along an entire freeway section, offers the potential for improved ramp metering operation. Dynamic ramp metering, which automatically adjusts metering rates at individual ramps may be more effective because of the improved data quality. In addition, coordinated operation of ramp meters will now be feasible because the availability of high quality data will permit the overall optimization of the freeway operation. Since much work has already been performed in this area, it is not anticipated that significant effort should be expended on the development of ramp metering optimization algorithms. However, the impact of using travel time data in place of traffic volume data must be examined during this research.

Outputs: This task includes the development of algorithms for optimized operation of a coordinated system of ramp meters, using travel time and speed data. The effectiveness of the algorithms should be evaluated by comparing the performance of the algorithms developed under this task, with the performance of conventional ramp metering using conventional time-of-day control techniques. Performance should be evaluated using a microscopic simulation. The simulation studies should be conducted for a range of roadway and traffic conditions that include both normal recurring traffic patterns, as well as traffic patterns representing incident conditions.

Task 3.2 Advanced Ramp metering
Although the availability of aggregate origin-destination (O-D) data is currently uncertain, the potential benefits of this data for ramp metering applications should also be studied. It is possible that certain ramp metering rates will cause the diversion of traffic to parallel facilities, thus providing system mangers with the ability to balance traffic among the facilities within a corridor. The optimization of coordinated ramp metering should also include an evaluation of its potential when aggregated O-D information

becomes available, and parallel facilities can be used. Evaluation of the alternative approach should be performed in the same manner as described for Task 3.1.

Task 3.3 Variable Message Signs/Highway Advisory Radio (VMS/HAR)
Description: Because of their ability to communicate timely information to all vehicles in the traffic stream, Variable Message Signs (VMS) and Highway Advisory Radio (HAR) offer the potential to have a significant impact on motorist behavior. If accurately displayed VMS/HAR messages may offer the traffic manager the ability to truly manage traffic on freeway and arterial facilities. Unfortunately, the effectiveness of these devices is significantly reduced when inaccurate information is displayed. Although quantitative data related to output accuracy and motorists' response is not available, it is likely that message accuracy approaching 99% should be an objective of these systems. Instead, it is likely that current accuracies of 70% to 80% are more common.

Although desirable, a human factors-based evaluation of motorist behavior as a function of information reliability is beyond the scope of this research, it is possible to parametrically evaluate the impact of motorist behavior at various response levels on overall system performance. For example, it is possible to evaluate the impact of sign messages on the performance of a roadway corridor if, for example, 2%, 5%, 10%, and 15% of the vehicles divert when the appropriate message is displayed. In this way, it is possible to evaluate the impact of improved data quality on VMS/HAR effectiveness.

In addition, the availability of improved traffic flow data (travel time and speed) will permit traffic managers to display a richer set of information than is currently possible. This information includes:

- Comparison of travel times on alternative routes
- Comparison of travel times between highway and mass transit alternatives

Here again, the evaluation of the impact of these features will have to be performed parametrically.

This task should take advantage of research performed in connection with the dynamic traffic assignment, since it will be necessary to develop algorithms that predict congestion on alternative routes and alternative modes as a result of increased levels of traffic diversion.

Outputs: The results of this research include new or modified traffic management algorithms, along with an assessment of their impacts for a range of diversion assumptions. Algorithms produced during this research include optimization of corridor flow and prediction of traffic conditions on alternate routes.

Task 3.4 Incident Detection and Assessment
Description: To date, the performance of traditional incident detection algorithms, which rely exclusively on the volume, occupancy and speed outputs of traditional detectors, has been disappointing. This performance, expressed in terms of detection

probabilities and false alarm rates is generally not of adequate quality for use in an operational environment. As a result, traffic operations personnel continue to rely on police reports, cellular telephone calls and closed circuit television for identification of incidents.

There is a significant difference between the point data provide by traditional detectors and the spatially oriented travel time data. Traditionally, one of the shortcomings of point data, when detecting the presence of an incident has been the discontinuities in traffic flow, which require the use of filtering and other techniques to compensate for the effect of these discontinuities (shock waves). It is possible that the travel time data will provide a more usable indicator of incidents because it is measuring traffic flow over an extended roadway section. But other potential benefits exist due to the fact that this data is more complete than that which would be possible with point detectors. In other words, continuous measures of traffic flow are available, which might permit the development of incident detection algorithms with the capability of accurately locating the position of an incident through the identification of the location of changes in flow characteristics. The VII data also permits the use of supplemental information for incident detection such as the existence of higher than normal exit ramp volumes.

From this brief discussion, it is clear that the research should include the development of new automated incident detection algorithms. This development must be accompanied by an extensive data collection effort, as well as simulation studies to define the characteristics of the travel time data on which the incident detection development is to be based.

Outputs: The output of this research task will be a suite of new incident detection algorithms designed to operate under congested and uncongested conditions. The output will also include an evaluation of the algorithms' potential effectiveness, expressed in term of detection and false alarm probabilities.

Task 3.5 Traffic Management Decision Support

Description: Additional capabilities are needed to enhance traffic management effectiveness as well as traffic management center and field staff effectiveness. These capabilities include:

- Automated incident forecasting, detection, assessment, traveler information and incident logging. This capability would be used to influence service patrols, 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.
- Automated displays VMS/HAR messages alerting motorists of the presence and clearance of an incident. This function has been considered in the past, but the absence of adequately reliable data has prevented its acceptance.

- Provide the data needed to automatically modify ramp metering rates and traffic signal timing in the presence of an incident
- Other techniques likely to increase incident response time, incident management effectiveness, and traffic management staff productivity.

The software and other techniques implemented during this task will be evaluated using real-world data from a representative sampling of roadways and traffic conditions.

Outputs: This task includes the development of algorithms for optimized traffic management. The effectiveness of the algorithms should be evaluated by comparing the performance of the algorithms developed under this task, with the performance of the system without the availability of these algorithms. Performance should be evaluated using a microscopic simulation. The simulation studies should be conducted for a range of roadway and traffic conditions that include a range of traffic patterns occurring during incident conditions.

Task 3.6 Ancillary Forms of Control

Description: A number of forms of control can benefit from the availability of VII data, in addition to the mainstream functions of ramp metering, incident management, and VMS/HAR displays. These ancillary forms of control, which will be developed during this research task include:

- Monitoring and controlling special use lanes – Special use lanes including high occupancy vehicle (HOV) lanes, high occupancy toll (HOT) lanes, truck only lanes, and reversible lanes require special monitoring and control. The VII data accuracy will permit the monitoring of the operation of these special use lanes to determine the times for safe change in lane operation (such as the change in direction of reversible lanes), lane closures, assessment of lane effectiveness when compared with conventional lanes.
- Variable speed control – Variable speed control systems automatically adjust roadway speed limits in response to measured traffic speed. Studies have shown that roadway safety is improved when reasonable speed limits are displayed, due to reductions in the speed variance of vehicles using the roadway. The VII system, with its ability to provide accurate and comprehensive measurement of travel times and speeds can potentially ensure the economical implementation of this capability.
- Traffic management near construction zones – Management of traffic in the vicinity of construction zones is a challenge to operations personnel. Comprehensive traffic flow data is required to:
    - Facilitate scheduling of construction activities possibly in real-time, based on measurements of traffic delays due to the presence of construction.
    - Monitoring traffic speeds to determine when additional enforcement may be required as a result of excessive speeds

- Possibly even automating or enhancing the flagger process, by monitoring queues in the vicinity of alternating single lane flow, and providing recommendations (or signal indications) based on minimization of traffic delay.

Although the development of new algorithms to support these functions is possible, the majority of functions described here are within the current state-of-the-art. For this reason, the emphasis of this research is on the analysis of implementation alternatives, and an evaluation of the impact of VII data on their cost-effectiveness, reliability and likelihood of operational acceptance.

Outputs: The output of this research includes reports evaluating the design of new and modified applications including design details and an assessment of their potential capabilities expressed in terms of cost-effectiveness, traffic flow and safety impacts. Task documentation should also include a recommendation for their full-scale implementation based on potential system reliability and efficiency.

Research Activity 4.0 – The use of VII Measures for Arterial Management

Objective: This should be a comprehensive, yet detailed study of the impact of the VII system on the field of arterial management, including the management of both recurring and non-recurring congestion with emphasis on traffic signal system operations. The objective of this research is the enhancement of existing algorithms and the development of new algorithms with the objective of improving all aspects of the management process. Improvement is defined as improved service to motorists, more effective use of facilities, and increased staff productivity. For example, automated data collection is likely to reduce the staffing required for traffic signal retiming.

Research Subjects: As with the Freeway Management research, research subjects are listed generically, but each subject should include an evaluation of the impact of the VII measures on existing algorithms and the development of new algorithms. Each subject should be evaluated analytically, and where applicable should be tested using simulation and if possible, field applications. All new developments should be subjected to a review by practicing arterial traffic management staff to ensure that will be accepted by practitioners once it is ready for field implementation.

Task 4.1 Traffic Signal Control

Description: The effectiveness of traffic signal control systems is directly related to the quality of the available real-time traffic flow data. Most public agencies have traditionally avoided the implementation of various forms of responsive and adaptive control because of the cost (both capital costs and recurring maintenance cost) associated with the acquisition of extensive real-time surveillance data, and for this reason, the majority of systems in use today rely on time-of-day (time clock) operation that has been in use for the past forty years. In addition, the capabilities of advanced forms of "adaptive" control are constrained by the limitations of traditional traffic detectors, which are capable of measuring point flow data, and are limited to installations in the vicinity of the controlled intersections. This has prevented the measurement of mid-block traffic flows and turning movements, which has limited the ability of these algorithms to anticipate vehicle demand in the form of arriving platoons.

Depending on the accuracy, coverage and latency (time delays) associated with the VII data, it is likely that the installation of traffic adaptive systems will increase significantly. It is also likely that the expanded coverage of the VII data that includes turning movements, mid-block speeds, travel times and mid-block sources and sinks (primarily parking garages) will enable the development of new algorithms that were not previously possible. The promise of these new algorithms could prove to be one of the most significant traffic management benefits of the VII data.

The research conducted during this task will explore both possibilities:

- The impact on cost and cost-effectiveness when the VII data is used to support existing traffic signal control algorithms. This work will included an assessment of the impacts on both traffic responsive, first generation signal control in which stored plans are selected based on existing traffic conditions), and traffic adaptive control in which signal timing is calculated on-line using measured traffic flows.
- The development of new traffic adaptive control algorithms that take advantage of the VII data to optimize signal timing using the travel times, speeds, turning movements and mid-block data. Because of the many opportunities offered by this newly available data, this work should include the development of at least three different algorithms that can be subjected to comparison, initially using simulation techniques and finally using full-scale field evaluation.

Outputs: The results of this research include both a comparison of the cost-effectiveness of traditional implementations of existing forms of signal control with the cost-effectiveness of the same functionality, based on the use of VII data. This analysis will also include an assessment of the number of additional installations likely to result from the lower costs of their implementation.

The second result of this research will include three alternative adaptive traffic signal control algorithms that make use of the VII data. The three forms of control will be accompanied by evaluation results obtained under both simulation and real-world field conditions.

Task 4.2 Traffic Signal Priority and Preemption
Description: Normal timing operations can be interrupted by transit vehicles requesting preferential treatment at intersections (priority), and emergency vehicles requiring the signal system to override the current timing and provide a green indication in the shortest possible time (preemption). The VII data offers the capability for lower cost implementation of these features, in the event that transit vehicles and emergency vehicles are equipped in a manner that permits the unique identification of their presence and location to the system. In addition, the ability to track to the locations and travel

times of these vehicles permits the development of new algorithms that anticipate vehicle arrival times more accurately than is currently possible. The differences between preemption and priority are summarized in Table 4.

Table 4. Comparison of Preemption and Priority

Characteristic	Preemption	Priority
Objective	Schedule adherence Reduced route time	Reduced travel time
Usage	Continuous use	Intermittent and infrequent use
Travel	Predictable routes Unpredictable delays at stops	Unpredictable routes No stops
Action	Balance transit requirements with traffic conditions	Unconditional green in shortest possible time

From this table, it is clear that both preemption and priority require the identification of a vehicle needing servicing, and both involve the interruption of the normal signal timing in response to the request. However, the preemption strategy involves the continuous tracking of the transit vehicle to assess the impact of stops, as well as measurement of traffic conditions in order to provide a balance between traffic and transit requirements, while the priority strategy requires tracking emergency vehicle position and either travel times or speeds.

New preemption and priority algorithms utilizing improved knowledge of vehicle location and travel time to calculate needed signal timing for the entire route of the vehicle receiving preferential treatment. The modified signal timing should then be adjusted in real-time to compensate for unanticipated changes in travel time and/or route. The effectiveness of the new algorithms should then be evaluated using simulation techniques

Outputs: The output of this research will be an assessment in the change in cost effectiveness of signal preemption and priority when implemented using VII data. In addition, this task will produce new algorithms that take advantage of the VII data, for improved operational effectiveness. An assessment of their effectiveness, will also be provided.

Research Activity 5.0 – The Use of VII Measures for System-Wide Management

Objective: The objective of this research is the evaluation of the applicability of VII Measures for system-wide and regional transportation management. This activity is the cornerstone of the VII research program in that it permits the proactive control of corridors and other large areas, making use of the rich combination of traffic flow data, origin-destination information, weather and pavement conditions. It also makes coordinated use of the tools available to the traffic manager including signal control, ramp metering, variable message signs and highway advisory radio (which may now be used to provide alternative routing), ramp and roadway closures. Regional transportation management includes balancing of travel demand among roadway facilities and available transportation modes. In the future, these tools are likely to be expanded to include variable speed control, lane controls and road pricing. The combination of reliable data and the availability of an effective suite of controls provides the opportunity for proactive control of regional transportation systems, in much the same way as telecommunications managers are able to reroute communications traffic to optimize the use of their transmission facilities. Regional transportation management activities conducted during this activity are intended for both recurring and non-recurring congestion including response to major incidents.

Task 5.1 Areawide Transportation Management

Description: The coordinated application of traffic management tools for the areawide control of transportation systems offers significant potential for proactive management of these systems, as opposed to relying on traveler advisories to ensure efficient operation. The key to the success of this approach is the application of all available control systems and devices in a manner that ensures achieving a consistent objective, based on the availability of reliable and comprehensive (VII) information. The techniques considered during this task include:

- Enhanced traffic management, by directing traffic to passable routes and avoiding the diversion of traffic to undesirable routes whose capacity and safety have been impeded by incidents, construction, poor visibility, high winds, and degraded surface conditions. Provision of this information requires the development of technology capable of accepting a broad range of mixed data inputs, considering motorist behavior, and determining a set of control measures required for optimum system performance. This technology must be adaptive, to provide continuous adjustments to changes in conditions.

- An areawide transportation management system must be capable of diverting long-distance travelers prior to their arrival at congested facilities. This is capability, which offers significant potential for relief of non-recurring congestion requires knowledge of travel demand at significant distances from congested areas, and the ability to communicate with travelers prior to their arrival.

- During major incidents, it may be desirable to reroute transit resources, to facilitate their travel, to reduce their impact on the congestion, and to respond to changing requirements for transportation capacity. Dynamic rerouting of transit vehicles is currently being performed manually in a number of locations. Its coordination with an areawide transportation management system will enhance the effectiveness of this capability.

- True transportation management involves the diversion of vehicles and travelers with changes in facility loading. The response of travelers to diversion messages is unpredictable since it depends on many different factors such as time of day, trip purposes, mix of commercial and private vehicles, etc. Adaptive systems capable of measuring the impacts of various control actions (diversion messages, traffic signal timing changes, speed limit variations, modifications in ramp metering rates, etc.) and modifying system operation will compensate for performance that is difficult to model and predict.

Outputs: A number of different types of outputs will result from this task. These outputs will include decision support tools, optimization algorithms, database management systems, and prediction algorithms. In addition, graphical user interfaces must be developed for both local and long-distance travelers that provide displays of best routes and travel modes based on travel time and other transportation system conditions. The output of this task also includes assessments of the overall potential of areawide transportation management as a tool for relieving congestion during both recurring and incident conditions.

Task 5.2 Response to Major Incidents
Description: Major incidents, with system-wide impacts are differentiated from minor incidents, by their duration and scope. Major incidents typically require the initiation of traffic diversion plans, and could also require temporary changes to signal timing and ramp metering rates. They could also necessitate the posting of VMS and HAR messages describing the incident by agencies in nearby jurisdictions that do not have direct responsibility for the roadways on which the incident has occurred.

Traditionally, major incidents are serviced using response plans that have been developed off-line, which define all of the actions that must be taken to service the incident. These plans are comprehensive and carefully executed. They attempt to anticipate all combinations of incident circumstances for which the plans may be required. The advantage of this approach is that it permits careful consideration of the many aspects of traffic diversion that must be taken into consideration (truck height restrictions, turning radius', capacity of local streets, etc.), and provide a common reference database that can be used by all responsible personnel (transportation, police, fire, etc.). The disadvantage is that these plans cannot possibly anticipate all combinations of circumstances (for example secondary accidents), and may not include consideration of signal retiming or other measures that may be difficult to implement without a comprehensive knowledge of traffic demand on all facilities.

Reliance on pre-planned diversion plans during major incidents also reflects system operator's inability to evaluate the impact of alternative measures. Thus, diversion plans are only used during major incidents, and are introduced without consideration of other alternative measures that might be used, such as secondary diversion of traffic that normally uses the route selected for diversion, onto another more distant route.

On the basis of this consideration, the following functionality should be developed during this research task:

- The development of decision support software that permits the rapid evaluation of alternative incident diversions based on current and projected traffic conditions.
- The development of software that will evaluate the impact of incidents on transit operations, and evaluate the desirability of transit rerouting and

scheduling both to provide additional passenger capacity to service travelers impacted by the incident, and to minimize delays to transit operations.

- The development of software that automates the posting of variable message signs and highway advisory radio messages based on a comparison of desired and measured levels of traffic diversion, and automatically adjusts these messages to achieve the desired effect.

Multiple strategies should be developed to provide each of these functions. The effectiveness of these strategies should then be evaluated using simulation. Strategies whose effectiveness is demonstrated by the simulation evaluation will be integrated into a single traffic management support tool that permits the operator to review alternative solutions recommended by the system, and to automatically select and implement the preferred plan.

Outputs: The results of this work will include the algorithms, their software implementation, and an integrated traffic management package for use in the management of regional incidents. Documentation of these results will include an evaluation of the conditions under which the algorithms are applicable, and an assessment of their potential effectiveness.

Task 5.3 Major Evacuations

Description: Major evacuations of urban areas may result from a number of causes including weather emergencies, terrorist attacks, major spills or leaks of hazardous material from factories or transportation incidents. In many respects major evacuations present the same traffic management challenges as major incidents. However, there are also some significant differences that dictate the need for a separately defined research task. The research conducted during this task is intended to focus on these differences, which include:

- Traffic flow tends to be radial; away from an impacted area, rather than linear diverting traffic around an incident
- Traffic flowing toward the incident (emergency response vehicles, transit vehicles, etc.) must be accommodated
- Urgency for major evacuations may be higher than that of a highway incident. The panic associated with this urgency might reduce the willingness of motorists to heed advisory information and to obey traffic control devices
- Due to the difficulty of predicting the location and extent of most major evacuations (except for some weather emergencies such as hurricanes), pre-planning may be extremely difficult

These considerations define the need for an effective tool for tracking and displaying traffic conditions at a level of detail that will permit the rapid assessment of the situation and the dispatch of appropriate resources to problem locations. A GIS-based tool known as EMMA is currently under development by Towson State University for the Maryland Department of Transportation that offers the potential to serve as such a tool. EMMA combines available databases of infrastructure and other resources such as the locations of schools, factories, property owners, weather stations and roadways. It can also support models such as plume forecasts and overlay them on the GIS presentations of other resources. During this task, an EMMA-like capability must be developed and enhanced to include the display of traffic conditions provided with the VII data. Algorithms must be developed that project the utilization of infrastructure elements pertinent to the measured traffic flow, such as the identification of schools that must be adapted to serve as emergency shelters. The display capability should have full GIS features including layers, zooming, incorporation of photographic data and other functions anticipated for emergency evacuations.

Outputs: The output of this task should be a fully documented GIS-based emergency evacuation software package. The package documentation will also include descriptions of scenarios for its use.

Research Activity 6.0 – The Use of VII Measures for Transit and Fleet Management

Objective: Public agencies operate a number of different fleets including buses, police cars, maintenance vehicles, slow plows, emergency service patrols, and emergency response vehicles (fire trucks and ambulances). The effective management of these fleets can reduce emergency response time, increase public visibility and reduce operating costs. The fundamental requirement for management of these fleets is vehicle location information, and congestion data. With this information,

- Vehicle routes and patrol patterns can be optimized
- Dispatching of vehicles to incidents can be based on an informed decision regarding relative travel times
- Information about vehicle arrivals (both transit and emergency vehicles) can be more accurately provided to the public.

Research: Fleet management is a relatively mature discipline. Numerous algorithms are available for optimizing vehicle routing and to support vehicle-dispatching functions. This research is performed to quantify the improvements in dispatching, fleet route planning and information dissemination that will occur with the availability of VII data. It may be necessary to combine existing route optimization, fleet optimization, and traffic flow forecasting algorithms to provide the integration of functions that will become feasible with the VII data. In addition, this research should include an assessment of the change in cost-benefits that will occur with the use of VII data to provide integrated fleet management functions.

Output: The output of this activity will be transit and fleet management software packages that integrate the routing, dispatch and arrival time calculations in a manner that makes use of VII data in the execution of their functions. The documentation accompanying this software should include comparisons of the improved effectiveness of these functions with the availability of the VII data.

CONTRACTING PLAN

The success of this research plan will, to a large degree, be determined by the contracting methodology used for its execution. It is critical that the organizations conducting the research have both a thorough understanding of the existing state-of-the-art, while at the same time, the ability to think creatively. These characteristics are essential, if research products are to be developed that are capable of leading the transportation management industry in new directions that take full advantage of the VII system outputs.

The six research activities defined by this plan can be placed in two contracting categories: The first contracting category is a conventional research approach, in which a well-defined problem must be investigated and specific answers produced. The second contracting category (designated "Application Development") requires a more creative form of research, since there is no single correct solution to the problems being addressed, and the quality of the research depends solely on the background and capabilities of the research team. The second category of research is critical, since it must produce products that are both innovative and practical. It must also be defined in a manner that ensures its widespread and rapid acceptance by the public agencies that will be the ultimate beneficiaries. The relationship between the six research activities and the two contracting categories is shown in Table 5.

Table 5. Relationship Between Research Activities and Contracting Categories

Research Activity	Contracting Category
1.0 Characteristics of VII Measures	Type 1 – Conventional
2.0 Impact of VII Measures on Planning, Engineering and Evaluation	Type 2 – Application Development
3.0 The Use of VII Measures for Freeway Management	Type 2 – Application Development
4.0 The Use of VII Measures for Arterial Management	Type 2 – Application Development
5.0 The Use of VII Measures for System Wide Management	Type 2 – Application Development
6.0 The Use of VII Measures for Transit & Fleet Management	Type 2 – Application Development

Note that although there is commonality among the contracting categories being used for the various research activities, it would be a mistake to combine research activities into a single contract because of the size and complexity of these activities. Many of the research activities requiring Type 2 contracting, involve the development of significant new control strategies and software packages, which individually can be the subject of major research and development activities. This is a very large program.

In addition, Research Activities 1.0 and 6.0 should remain separate because of the differences between the sets of skills and types of organizations required to perform the work. Here again, these are each research activities that could be difficult to manage in combined form because of their complexity.

Type 1 – Conventional Contracting
The form of contracting recommended for the Type 1 Research Activities is the use of the Indefinite Delivery, Indefinite Quantity (IDIQ) contract. This form of contracting is recommended because of the uncertain nature of the research being conducted, which could uncover additional issues not included in the current research plan. The IDIQ contract will provide the Government with the flexibility of expanding and redirecting the work as the ongoing research proceeds.

Given the Government's preference for multiple awards of IDIQ contracts (FAR 16.504(c)(1)(i), and the scope of Research Activities 1.0 and 2.0, it is recommended that two contract awards be made for each research activity. As previously indicated, the two research activities should not be combined because of their complexity and the differences between the skills required by each.

Type 2 – Contracting for Application Development
The type 2 contracting is a particularly critical aspect of this research plan, and one that has the following set of specialized requirements:

- The research must be conducted in a manner that recognizes a high degree of creativity leading to the competitive evaluation of multiple alternative solutions
- The research must involve an adequate number of industry participants to ensure that the results are recognized and disseminated throughout the user community
- Cost sharing must be encouraged during the contracting process both to leverage the Government's investment in the research and to ensure the development of practical results that are attractive to the public sector (customers) of the research organization
- The research must be conducted in a manner that permits the government to evaluate alternative solutions and prioritize its funding to those that appear to offer the most promising possibility of success
- The research must be conducted in a phased manner that permits the success evaluation and comparison of research results through the stages of concept development, initial testing, simulation testing and field-testing.
- The Government must have the contractual flexibility to increase funding for promising applications and reduce or terminate funding for applications that do not appear to offer the promise of success.

As previously indicated, the research activities for which this form of contracting will be used are large and complex projects with uncertain outputs. However, the success of the VII project as a facilitator of transportation management, depends on the success of these research projects, and for this reason the contracting plan must provide the government's contracting team with the high degree of flexibility needed for them to lead the research in the most promising directions.

Based on these considerations, it is recommended that the Type 2 categories of research be conducted as a design competition. FAR paragraph 36.602-1(b) indicates that “Design competition may be used when –

(1) Unique situations exist involving prestige projects
(2) Sufficient time is available for the production and evaluation of conceptual designs; and
(3) The design competition, with its costs, will substantially benefit the project.

There is little doubt that the VII Research Activities designated for this type of contracting meet all three of these criteria. The FAR also requires that at least three firms be involved in the design competition.

A three-stage effort is proposed for the Type 2 contracting. During the first stage concepts development will occur. Between three and five firms will be involved at this stage. The number of firms will be reduced to approximately three firms for the second phase development of prototype and testing. Depending on their success, multiple firms (three has been assumed below) will be involved in the implementation of applications.

EVOLUTION FROM RESEARCH TO PRACTICE

The research activities have been defined as encompassing the time period from concept development through field-testing. Following the success of the field-testing activities, it will be necessary to provide seed money that will encourage the operational implementation of these applications. It is recommended that funding be provided to support the following implementation activities (typically designated field operational tests):

- Documenting implementation experience - This may be one of the more valuable activities, in that it will provide information for future implementation activities, and identify shortcomings in the applications that must be corrected.
- Evaluation - Evaluate the operational effectiveness of the strategy, so that its use will be encouraged by other agencies
- Supplement the development activity – either through provision of outside expertise, or by funding a predetermined percentage of the development activity, offset the extra cost that is invariably experienced by early adopters of new applications.

Field operational tests should be funded in at least two locations for each of the applications developed as part of this research.

In addition, application implementation should be supported by a preplanned outreach activity that includes publications, papers, and conferences that publicize the results of the research. The purpose of the outreach activity is to ensure that the new applications are accepted by the public agencies for which they were developed.

SCHEDULE AND BUDGET

Figure 1 provides a five-year schedule for this research plan. It is anticipated that the research will extend well beyond the five-year period due to continuous refinement and new development of applications as increased knowledge is acquired from the VII measures. This five-year schedule includes six-month periods for each research contract.

Figure 1. Research Project Schedule

Table 6 provides a cost estimate for each of the research activities. Needless to say, this is a very rough estimate of a range of costs. A range has been used because of the difficulty of developing accurate cost estimates at the very general level of research activity definition that currently exist:

Application costs:

- Concept development: \$100,000 to \$200,000 per application for each firm (\$500,000 to \$1.0 million per application for 5 firms)
- Prototype development: \$200,000 to 500,000 per application for each firm (\$600,000 to \$1.5 million for 3 firms)
- Final field implementation: \$500,000 to 1.0 million per application for each firm. (\$1.5 million to \$3.0 million for three firms) Includes field evaluation:
- Total cost per application = \$2.6 to \$5.5 million

Costs of other research activities – estimated at between \$100,000 and \$250,000 for each of the items listed in the Research Activity.

In all cases, it has been assumed that cost sharing will cover any additional costs that may be experienced.

Cost estimates have not been developed for the cost of field operational tests.

Table 6. Five Year Research Program Cost Estimate

Research Activity	No. of Applications	Cost	
		Low Range	High Range
1.0 Characteristics of VII Measures	N/A	$1.2 million	$3.0 million
2.0 Impact of VII Measures on Planning, Engineering and Evaluation	5	$13.0 million	$27.5 million
3.0 The Use of VII Measures for Freeway Management	8	$20.8 million	$44.0 million
4.0 The Use of VII Measures for Arterial Management	4	$10.4 million	$22.0 million
5.0 The Use of VII Measures for System Wide Management	7	$18.2 million	$38.5 million
6.0 The Use of VII Measures for Transit & Fleet Management	2	$5.2 million	$11.0 Million
Total	26	$68.8 million	$146.0 million