U.S. Department
of Transportation
Federal Highway
Administration

Final Summary Report
Information Elements to Support Traffic Management Services

April 2003

Notice

Final Summary Report Information Elements to Support Traffic Management Services

FHWA Contract: DTFH61-96-C-00047

INTRODUCTION

This document presents the summary of an effort undertaken to develop information requirements and cost estimates requirements to support various traffic management services. The intent is to document the effort by describing the tasks undertaken, assumptions and agreements, describe the processes used, and itemize the findings so that future users of the materials understand its context.

BACKGROUND

Public Agencies responsible for managing various operational aspects of the highway system require numerous types of information on the current conditions of the system to support delivery of effective services. This required information varies widely depending on the service being provided and also varies in terms of how often it needs to be collected and how accurate it needs to be (e.g., for traffic control purposes, simply knowing whether pavement is wet or not may suffice; for purposes of managing snow and ice control activities, more detailed information is required).[1] In essence, meeting public expectations for transportation delivery in the 21st century requires we not only build and maintain the transportation system, but also **operate** it to maximize the safety, security, mobility and reliability of travelers.

Information is crucial for successful operations of the transportation network. As noted by FHWA, "Operating the highway system to achieve security, safety, and reliability objectives requires an ability to know what is happening on the system. Real-time information on highway system performance and weather conditions / events is vital to assist highway professionals in managing the available capacity, responding to disruptions to capacity (including emergencies, evacuations, and security threats), and to system users in planning the timing, mode, and route for their trips". However, the level of surveillance information currently available is relatively limited. For example[2]:

- Less that 25% of the urban freeways in our largest cities are instrumented for traffic surveillance
- Arterial surveillance is virtually non-existent, mostly involving simple vehicle presence detection for signal control
- Only 25 transit agencies in our 78 largest cities have automatic vehicle location systems on their fixed route busesThere are virtually no systems in place designed to provide for security of our surface transportation system
- Fifteen percent of all fatal crashes occur during adverse weather conditions, yet road weather data collection stations exist at an average spacing of over 130 miles on the National Highway System.

[1] From Task Order Scope of Services prepared by FHWA.
[2] From FHWA slide presentation on "Infostructure", delivered at TRB, January 2002.

Accordingly, FHWA is developing a program concept of an ITS Information Infrastructure. This"Infostructure" program would support both national and State/local interests. The national program element would include:

- Statewide reporting of capacity reducing events on the National Highway System (e.g. crashes, work zones, road weather events) using a consistent reporting format, such as is already being done in Arizona and a few other States
- System performance and weather monitoring of freeways, key arterials (including evacuation routes), and transit systems in large metropolitan areas (those with populations exceeding 1 million). This could be accomplished through deployment of electronic monitoring infrastructure, acquisition of data from private sector sources, or a combination of these approaches.
- Monitoring of critical transportation infrastructure (e.g. bridges, tunnels, military routes) for security purposes

The State/local element of the program would be focused on producing information for locally determined security, safety and reliability purposes, in order to support traffic management, traveler information, transit management, CVISN, emergency management, E-911, and security activities and services.

Development of the Infostructure concept has involved several activities and individuals, including the work performed under this task order. The rest of the paper discusses the activities and recommendations from this task order, and how it influenced the Infostructure concept.

TASK ORDER ACTIVITIES

The initial goal of the task order (fall, 2000) was to "Prepare High-Level Requirements of the Type, Frequency, and Level of Information Necessary to Support Transportation Management Services" – that is, "What Minimum Information Should Be Expected From a 21st Century Highway?" The purpose of the effort was to help shape FHWA efforts to develop technical and policy guidance on information collection and analysis to support provision of transportation management services on the National Highway System (NHS).

The services proposed for examination included:

- Traffic control
- Incident management
- Work zone management
- Special event management
- Winter road management
- Demand management
- Freight management
- Performance measurement
- Emergency management
- Highway-based transit management

Information Requirements Matrices

The initial activity was to develop high-level requirements matrices of the type, frequency, and level of accuracy of information to support the various transportation management services. In order to develop these matrices, several tasks were undertaken. The first task was to divide the transportation management functions noted above into sub-functions. Moreover, to better understand the functions and sub-functions, and how the data might apply, it was important to define these sub-functions, including the development of scenarios. These definitions were submitted to FHWA for review and comment. As a result of this "definition" effort, some of the initial sub-functions were eliminated or combined with others. The functions, sub-functions, and their respective definitions are listed in Appendix A.

Potential data and information elements were then identified. When this task was completed, 33 information elements were identified (refer to Appendix B). I t is emphasized that these information elements represented data that can be collected by surveillance technologies installed in, above, or to the side of the roadway infrastructure.

Different types of highways have different operational characteristics. In examining highway classifications, it was determined that, with respect to ITS deployment, two classifications of highway could be assessed: freeway and arterial. The initial effort to identify the data elements that pertained to the desired functions were no different for arterial and collector, so it was decided that collectors could be included in the arterial category. Upon further examination of the freeway classification, it became apparent that bridges and tunnels were a unique category, and as such was assessed according. To that end, three classifications were assessed: freeway, arterial, and bridge / tunnel.

Within each highway classification, certain factors, or "differentiators", affect the information needed to support a function. For example , traffic flow in urban areas tends to be more congested than in rural area; and because of the potential impacts and number of drivers affected, more information is typically needed. "More" in this case doesn't necessarily mean different information, but could mean the same information (e.g., volumes and speeds), but collected more often (frequency) or at more closely spaced points (location).

The freeway and arterial classifications were examined separately for both urban and rural applications.[3] It is noted that these definitions of "urban" and "rural" were more qualitative than quantitative. For the purposes of the matrices, urban refers to stretches of roadway where traffic flows are near or above capacity during some or much of the peak period and/or a significant portion of the congestion is nonrecurring (i.e., incidents) – a condition typically found in urban SMSA's. Rural refers to stretches of roadway where traffic flows are usually free-flow. However, there may be roadways located in rural surroundings (little population) that could be categorized as "urban" because of heavy seasonal traffic flows

Additional differentiators were identified that impact the information needed as well as how the information might be gathered. These differentiators effect each classification by its environment and traffic characteristics. Specifically, these differentiators were:

- Freight Route – Highways used for the movement of cargo, characterized by a significant number of large trucks. Such routes typically serve intermodal terminals, and include roadside commercial vehicle check facilities.

[3] Tunnel / bridge classifications were considered demographic-neutral because of the relative impact to traffic and safety in the event of a traffic problem. These facilities have special / unique information requirements regardless of where they are located.

- Evacuation Route (for hurricanes and floods) – Highways that may be used for the ordered evacuation of impacted locations in advance of a natural disaster (e.g., hurricane, flood).
- Military Deployment Route – Highways that support the mobilization needs of the U. S. Armed Forces. This "Strategic Highway Corridor Network (STRAHNET) links military bases with railheads, seaports, and airports. Approximately 15,000 miles of the NHS are part of this network.
- Snow / Ice Route – Highways located in a "snowy region" – defined as greater than 13 cm average annual snowfall – and requiring some form of winter maintenance (e.g., snow removal by plowing, chemical / grit application, anti – icing strategies prior to plowing).

It is noted that these roadway use classifications are not mutually exclusive. A section of roadway may be used as a freight route, military deployment route, special event route, and snow / ice route inclusively, or any other combination of use categories, with the associated operational requirements combined.

Matrices identifying the "minimum information requirements" were prepared, with the horizontal axis listing the data / information elements , and the vertical axis listing the various transportation management functions and sub-functions. Additionally, the information elements were identified as "Required", "Desired", or not applicable for each sub-function, along with recommendations as to the frequency at which the collected information is provided to operators / managers, the location / spacing of information collection devices, and the overall accuracy of the information. A sample of a matrix is illustrated in Exhibit 1. Data in the cells were developed using the following scenario:

"If I want to provide the function / sub-function, I will need to collect the identified data"

In all, 25 different matrices were prepared – specifically, freeway and arterial matrices were prepared for each of the following "domains".

- Typical – Urban ("Typical" corresponds to a highway without any differentiators.)
- Typical – Rural
- Winter Weather Zone – Urban
- Winter Weather Zone – Rural
- Disaster Evacuation Route – Urban
- Disaster Evacuation Route – Rural
- Military Deployment Route – Urban
- Military Deployment Route – Rural
- Freight Route – Urban
- Freight Route – Rural

Bridge / Tunnel Matrices were also prepared for the following domains: Typical, Winter Weather Zone, Disaster Evacuation, Military Deployment, and Freight.

INFORMATION ELEMENT / FUNCTION AND SUBFUNCTION	Volume			
	X (required) / O (desired)	Frequency	Location	Accuracy
1. TRAFFIC CONTROL				
Signalized Intersection Operation				
Signal Coordination (Traffic Responsive)				
Signal Coordination (1.5 GC)				
Signal Coordination (Real-time adaptive)				
Critical Intersection Control (ELIMINATED)				
Ramp meter control (TOD)				
Ramp meter control (local area control)	X	1 minute	Vicinity of ramp	10 % error
Ramp meter control (areawide control)	X	1 minute	2 mile spacing	10% error
Expressway interchange control	X	1 minute	2 mile spacing	10% error
Reversible lane control	X	1 minute	1 mile spacing	10% error
Variable speed limits	O			
Speed enforcement				
DMS Operation	O			
Identify trapped vehicle in Hwy - Rail intersection				
Intersection collision warnings (ELIMINATED)				
Intersection red light violations				
Access management				
Cross Jurisdictional Coordination	X	5 minutes	2 mile spacing	10% error
2. INCIDENT MANAGEMENT				
Incident Detection (automated algorithms)	X	1 minute	1 mile spacing	10% error
Incident Detection (manual)				
Incident Verification				
Incident Diagnosis / Response / Clearance				
Track incident response vehicles				
Routing of incident response vehicles	X	1 minute	1 mile spacing	10% error
Traffic Diversions	X	1 minute	2 mile spacing	10% error
DMS Operation (fixed)	O			
DMS Operation (portable)	O			
Collision Notification				
Signal Preemption (N/A)				

Exhibit 1. Sample Section of Matrices (Note: This sample is a only a portion of the matrix for 'Typical Urban Freeway".)

Minimum Information Requirements

These initial matrices were very large – each one consisting of an Excel spreadsheet greater than 1 MB in size; and while they provided useful information as to how a 21st Century highway might be outfitted for surveillance, they did not readily indicate or quantify where the minimum information requirements might be deployed nor lend themselves to estimating deployment costs. Accordingly, the matrices and information therein were summarized and quantified, while the overall concept of "minimum information requirements" was also expanded, as discussed below.

Traffic Flow and the Volume – Capacity Ratio

Traffic flow information was identified as data – such as volume, occupancy, speed, travel times, etc. or some combination thereof – that are needed to manage and operate the highway via traffic control strategies (e.g., ramp metering, timing plan selection), traveler information, and performance measures. Instead of using the relatively qualitative designations of urban and rural, it was determined that peak period service level – as measured by the volume to capacity ratio (V/C) – gives a better, quantifiable index of a highway's need for traffic management applications and the supporting traffic flow information. Exhibit 2 (i.e., the "sideways bell curve" from traffic flow theory) shows the relationship between speed (vertical axis) and V/C ratio (horizontal axis). The curve depicts several important characteristics.

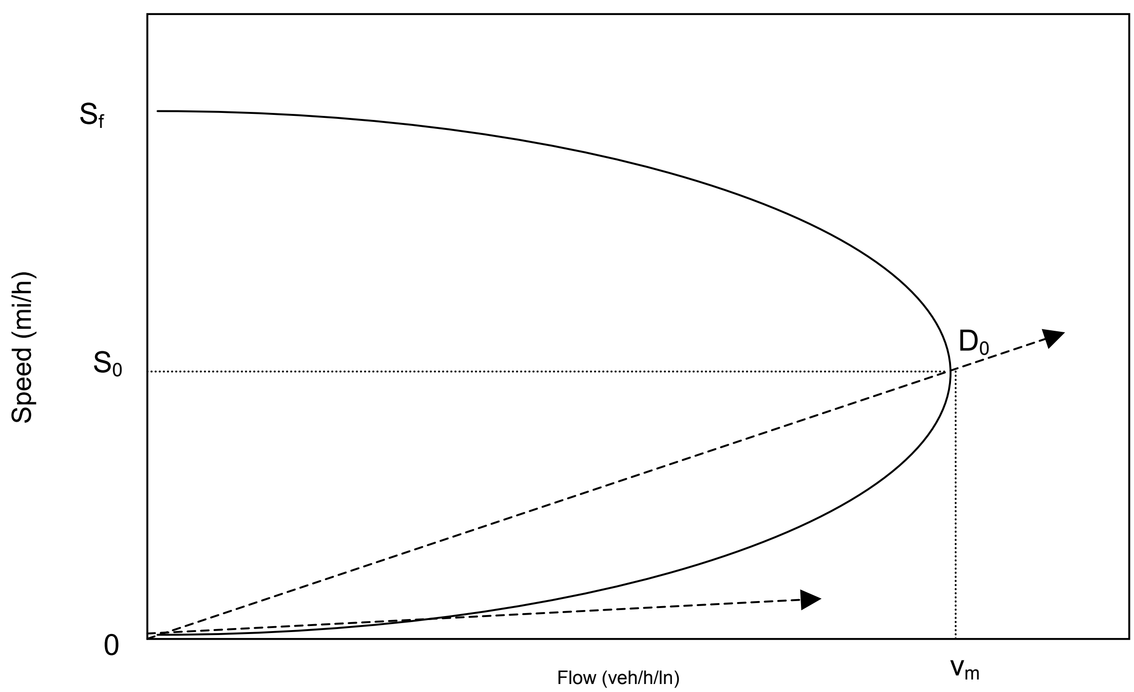

Exhibit 2. Speed, Flow Relationship (Source: Highway Capacity Manual HCM2000, TRB)

- The location on the curve depends on volume and roadway capacity (i.e., service flow). Significant changes in volume /traffic flow typically occur at interchanges (for freeways) and signalized intersections (for arterials), with the greatest changes in volume occurring at "major" freeway interchanges (e.g., freeway-to-freeway or to major arterial) and at "major" signalized intersections (e.g., crossing of two major arterials, or at freeway on-ramps).

- As the flow approaches capacity, speed drops off at a sharp rate. When the roadway is operating in the > 0.75 V/C area (i.e., Level of Service D and E per the 1994 AASHTO "Green" Book on Geometric Design of Highways and Streets, which in turn references the 1994 Highway Capacity Manual), it is approaching instability. Even the smallest increase in volume (or decrease in capacity due to an incident) can cause the traffic flow to breakdown and become "forced" (LOS F). Such roadways must be closely monitored – in both time and space -- such that any flow and / or capacity changes are identified almost immediately, thereby permitting operators and managers to quickly respond to (and even predict) these changes, implementing appropriate traffic management strategies to either prevent breakdown or otherwise minimize its duration and impact. Accordingly, roadways operating in this region of the curve – that is, highly congested – have the greatest level of real-time[4] information requirements in terms of the types of information, the information "coverage" (where along the roadway the information is required, such as between every intersection / interchange), and the accuracy and timeliness of the information.

- For the 0.5 – 0.75 V/C area (Level of Service C), operation is stable, but becoming more critical. A volume increase and / or capacity decrease will impact traffic flow; but the degradation and threat of breakdown will not be as great. Nevertheless, if the volume increase / capacity reduction is significant enough, breakdown can still occur unless appropriate traffic operations and management activities are initiated. Accordingly, real-time information on these roadways is still necessary; but at a less dense information coverage than the > 0.75 category of roadways (e.g., between every major intersection / interchange). The accuracy and timeliness requirements are also not as great.

- The < 0.5 V/C area (Level of Service A & B), represents free flow such that the speed is relatively insensitive to the flow rate. In general, only a catastrophic event (e.g., roadway infrastructure failure) can cause the traffic flow to breakdown. Given the small probability of such events and the significant amount of highway mileage operating in this area of the curve, these segments have minimal information requirements in terms of coverage and timeliness. The means by which the information is gathered may also be affected.

The above discussion on volume – capacity relationships focuses on "typical" conditions for monitoring traffic flow. Roadways that are used for emergency evacuations and special event traffic typically have additional requirements in terms of types of information and information coverage, regardless of their normal peak period V/C ratio. As a general rule, the minimum traffic flow information requirements for these roadways should be based on the V/C ratios that occur during these special circumstances.

Other special-use roadways include those used for military deployments (i.e., the aforementioned STRAHNET). These designated routes require some minimum level of surveillance regardless of their congestion levels. For the purpose of defining and costing the

[4] Real-time in this context means the information is provided to operators / managers within one minute or less.

Infostructure, it was assumed that data collection along these routes would occur between every major interchange as a minimum, and between every interchange wherever the peak period ratio was greater than 0.5.

Other Considerations

Other conditions and roadway uses and functions will affect the minimum information requirements as noted below.

- **Incidents and Video Surveillance** – Incidents reduce the capacity of the roadway and can cause the flow to suddenly breakdown. Moreover, there are other concerns associated with incidents beyond their impact on traffic control, including life safety (e.g., getting medical treatment to injured parties as soon as possible) and environmental (e.g., containing and cleaning up any spills of hazardous materials). Incident frequency is often highly correlated with congestion level – after all, congestion does cause incidents. The minimum information requirements do **not** include the infrastructure to detect incidents (e.g., closely-spaced detectors and automated incident detection algorithms). Detection of incidents is typically best accomplished via cellular phone call in, service patrols, "Mayday" features, etc. The minimum information requirements do include video coverage for incident verification and "diagnosis". However, from the perspective of defining and costing minimum requirements, this video is assumed to be low bandwidth (e.g., still frame, a few frames / second)
- **Inclement Weather –** Capacity and operating conditions may also be affected by inclement weather, requiring information on atmospheric and road surface conditions. This information is also often required to manage winter maintenance activities. The information gathered and location of weather monitoring stations doesn't depend on V/C ratios. It was determined that, as a minimum, there should be nationwide "grid" of measurement stations for the purpose of meso-forecasting. It is envisioned that the basic information would include atmospheric temperature, humidity, wind speed / direction, and precipitation. This forecast grid represents the minimum "baseline" information and spacing. Additional information and closer spacing of information collection points will often be required depending on a number of factors, including:
  - Average annual snowfall – the greater the snowfall, the need for more information (e.g., roadway surface information) at closer intervals. Similarly, areas / segments with significant rainfall and / or icing potential will also need roadway surface information.
  - Level of snow maintenance activities – an organization that regularly performs anti-icing strategies prior to plowing will typically need more weather information than an agency that just plows and spreads salt / grit.
  - Terrain – areas of higher elevation, with steep upgrades / downgrades, and/or plains subject to high winds and blowing snow, may need a greater coverage of weather information.
  - Spot problems – areas with very local influences (e.g., fog, high winds, frequent icing) necessitate a focused coverage of partial weather information as a minimum.

It is also important to consider the location and capabilities of "other" weather information gathering locations (e.g., NWS, airports, agriculture), using these in the grid as much as possible.

- **Transit –** An important element of the nation's highway network is the transit buses that utilize the roadways. Accordingly, in addition to monitoring the real-time operations of the roadways, surveillance of the buses themselves (e.g., location, schedule adherence) was also identified as a minimum information requirement.
- **Security –** The horrific events of September 11, 2001 resulted in a reappraisal of what should be considered as a minimum information requirement. The concept of an "evacuation route" was significantly expanded, with access by emergency responders also included. 9-11 also demonstrated the need for information that would help protect critical infrastructure elements surrounding those cities, including critical infrastructure along our roadways and on our transit systems. Damage or destruction of a major tunnel, bridge or transit facility could cause significant injuries and fatalities, as well as disrupt the transportation system for an extended period of time. It is imperative that systems be in place to monitor critical infrastructure, major transit facilities, military routes, and freight intermodal connectors and terminals to detect problems quickly and reliably and to facilitate rapid evacuation and emergency response if needed.
- **Information Integration –** In addition to collecting this information, it was determined that the minimum requirements should also include some form of statewide and regional integration and exchange of this information between multiple locations and transportation management centers. This included Statewide reporting of capacity reducing events on the National Highway System (e.g. crashes, work zones, road weather events) using a consistent reporting format, such as is already being done in Arizona and a few other States.

Coverage Area

The NHS is made up of approximately 160,000 centerline miles of roadway, most of which is classified as "rural". Moreover, each state has defined what constitutes part of the NHS in a slightly different manner. In order to be consistent and cost-effective in a subsequent deployment of the Infostructure, it was determined that the coverage area should include all expressways and principle arterials (regardless of their NHS designation) within CMSAs with a population greater than 1 million. Mileages for these roadways (by Interstate, Other Expressways, and Principle Arterials; by the three V/C categories previously discussed; and by annual snowfall) were obtained from FHWA. Appendix C lists these CMSAs and their respective mileages.

RECOMMENDED INFOSTRUCTURE & ESTIMATED COST

Based on the various considerations summarized above in Section 3.2, the Infostructure concept was divided into the following information categories:

- Traffic flow
- Video
- Weather
- Transit
- Security
- Integration

Exhibit 3 provides a summary of the recommended spacings and related assumptions for these categories

Exhibit 3 – Recommended Infostructure

Traffic Flow Collection Points

Volume, occupancy, speed, and/or travel time

- *V/C > 0.75*
Freeways: 1-mile
Arterials: 2-miles

- *0.5<V/C <0.75*:
Freeways: 3-miles
Arterials: 5-miles

- *V/C < 0.5*:
Freeways: 3-miles
Arterials: 5-miles

- *Tunnels / Bridges*
1-mile

Video Collection Points

Broadcast-quality / full-motion video not required

- *V/C > 0.75*
Freeways: Full coverage (assumed as 1-mile spacing)
Arterials: Full coverage (assumed as 2-mile spacing)

- *0.5<V/C <0.75*:
Freeways: High incident locations (assumed as 3-mile spacing)
Arterials: High incident locations (assumed as 5-mile spacing)

- *V/C < 0.5:*
Freeways: No video
Arterials: No video

- *Tunnels / Bridges*
Full coverage

Road Weather Information Sensors (RWIS)
RWIS information includes air temperature; road surface temperature, wet, ice, snow and chemical concentration; atmospheric visibility, humidity, and precipitation; and wind speed and direction. Partial capability does not include all of these elements (e.g., road surface snow / chemical concentration in areas with little or no snow).

- Annual Snowfall > 75 cm: Full capability RWIS at 15 mile spacings
- Annual Snowfall between 12.5 and 75 cm: Full capability RWIS at 30 mile spacings
- Annual Snowfall < 12.5 cm: Partial capability RWIS at 30 mile spacings

Transit
Installation of GPS logic units on buses and wireless communications between buses and central monitoring location. Required in 50 of the urban CMSA's, with an average of 1000 buses per CMSA.

Critical Infrastructure
The following was assumed in developing cost estimates for surveillance of critical infrastructure:

- Average roadway length of 2 miles
- Concentrated density of surveillance, including traffic flow monitoring (every ½ mile), full coverage of broadcast quality video (cameras on both sides of the road to minimize the need to pan, tilt, zoom), plus cameras to monitor off the travel way (e.g., underneath a bridge)
- Special software to automatically detect potential problems (e.g., stopped vehicles)
- 500 such critical locations throughout the United States

Information Integration
"Centers" – either real or virtual – for collecting information from multiple agencies and sources, combining and processing the information, and distributing to information users throughout the state or region.

- 50 statewide centers for rural areas (one per state)
- 50 regional centers for urban areas

END of Exhibit 3

Infostructure Costs

Using the criteria and assumptions noted above, a cost for deploying the Infostructure concept was developed as summarized in Exhibit 4. The unit costs used for this cost estimate are provided Appendix D. While the intent of this effort was to be "technology neutral", specific approaches for collecting the information were identified for the purpose of developing the Infostructure costs. For example, the costs of collecting traffic flow information were based on the assumption of point detection – with existing technology – installed along the roadway. In-vehicle probe technology that does not require roadway infrastructure (e.g., GPS, cell phones) could conceivably reduce these costs.

Exhibit 4 – Estimated Infostrucutre Costs

INFOSTRUCTURE Item	Interstate / Freeway	Principal Arterials	All / Other	Total
Traffic Flow	$ 291,065	$ 301,423	$ -	$ 592,488
Video (Low Bandwidth)	$ 401,522	$ 333,771	$ -	$ 735,293
Weather	$ 27,520	$ 51,417	$ -	$ 78,937
Transit	$ -	$ -	$ 700,000	$ 700,000
Security	$ -	$ -	1,150,000	$ 1,150,000
Data Integration	$ -	$ -	$ 66,250	$ 66,250
TOTAL CAPITAL COST	$ 720,107	$ 686,611	$ 1,916,250	**$ 3,322,968**
ANNUAL O & M COST				**498,445**

INFOSTRUCTURE ISSUES

There are a few issues that need to be resolved before the Infostructure concept can be finalized. These are summarized below:

- **Definition of Principal Arterials** – Every principal arterial in a CMSA of 1 million plus may not need to be part of the Infostructure[5]. After all, the geographic area of many CMSA's is quite large – encompassing areas and counties that are predominately rural – and including every principal arterial within these areas in the Infostructure may not be cost-effective. Some additional criteria and definitions for principal arterials may therefore be necessary, such as:
    - o Serves the major centers of activity of urbanized areas, the highest traffic volume corridors, and the longest trip desires.
    - o Must be a US or State designated route
    - o Must have a minimum of 4- thru lanes
    - o Parallels an expressway and can therefore be used as a diversion route for the expressway (e.g., some of the Avenues and major streets in NYC that are NOT a designated State or US route).
    - o Runs adjacent to critical facilities

  It must also be determined if there is there an "and" or an "or" between these and similar criteria

- **Coverage Area** – It may not be appropriate to consider CMSA's at all; but to address individual MSA's and PMSA's, including only those with a population greater than some value. (NOTE -- CMSA's (Consolidated Metropolitan Statistical Areas) are metropolitan areas with a population of greater than 1 million, and they may be divided into multiple PMSA's (Primary Metropolitan Statistical Area)). As noted above, CMSA's can include areas and counties where deployment of an Infostructure may not be cost-effective. Using this approach and a minimum population value of 300,000, the following PMSA's would be eliminated from the NY-NJ-CT-PA CMSA from the perspective of defining the Infostructure requirements:
    - o Danbury, CT PMSA (Northern Fairfield County and Litchfield County)
    - o Duchess County, NY PMSA (Poughkeepsie)
    - o Waterbury, CT PMSA

  Moreover, these and similar areas might be eliminated from the Infostructure concept in terms of instrumenting principle arterials, but not necessarily freeways; or different spacing criteria might be used for such areas. (Note – Unfortunately, this PMSA approach / criteria doesn't work very well for the Washington D.C area. There are only 3 PMSA's in the WDC CMSA – Baltimore, Hagerstown, and Washington D.C. Hagerstown doesn't meet the PMSA criteria of 300,000; but the Washington D.C. PMSA includes a very large geographic area, including the more rural counties of Virginia and West Virginia, all of

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[5] It is assumed that all expressways and tunnels / bridges, with their greater traffic flows and longer trips, should be included.

which are in the single MSA. Accordingly, some sort of "Urbanized Area" criterion might be necessary.

- **Critical Infrastructure** – The notion of surveillance of critical infrastructure for security purposes is relatively new (post 9-11). More research and field testing of this concept is required.

APPENDIX A – FUNCTION DEFINITIONS

Function / Sub function	Description
1. TRAFFIC CONTROL	
Signalized Intersection Operation	Description: Operating and maintaining intersection signals. Scenario: Signal timing and phase selection based on real-time data collected at the approaches to the intersection, and fed to local controller. Operators need data to maintain phases and timing plans.
Signal Coordination (Traffic Responsive)	Description: Automated selection of coordinated timing plans (i.e., cycle length, split, offset) based on current conditions. These are pre-developed plans that have been developed for a variety of conditions (e.g., average speeds, volume, occupancy, weather, environmental). Scenario: The system collects real-time information, compares this information to the "signature" information associated with each pre-stored timing plan, and selects / implements the timing plan that most closely matches the current conditions. Operators need data to maintain phases and timing plans.
Signal Coordination (1.5 GC)	Description: Same as Traffic Responsive, but now the system is capable of updating the pre-stored plans to reflect changes over time, and to display timing plan changes to operator for review and adjustment prior to being input to the system. Scenario: System collects and stores data, and uses this information to run signal timing programs (e.g., Transyt) to develop new plans for storage and implementation.
Signal Coordination (Real-time adaptive)	Description: Signal timing (cycle length, split, offset) is adjusted at each intersection on a cycle-by-cycle basis, based on real time information on traffic flow and other conditions. Scenario: With this subfunction, no timing plans exist, per se. Signal timings are continuously "adapted" so as to provide optimum coordination between signals.
Critical Intersection Control	ELIMINATED FROM LIST
Ramp meter control (TOD)	Description: Control of access onto freeways at on-ramps using traffic signals with metering rate plans (time interval between green indication / release of vehicle) based on time-of-day. Scenario: Signals change regardless of vehicular demand on the freeway. Only exception to this is queue length on the ramp, where the metering rate may be changed to dispense the queue.
Ramp meter control (local area control)	Description: Traffic flow levels along a segment of freeway within the immediate vicinity of an on-ramp are maintained by controlling (i.e., metering) the rate at which traffic enters the freeway from the ramp. Scenario: Real-time traffic flow parameters collected along the mainline freeway in the immediate vicinity of the on-ramp provide a measurement of service level. The ramp meter controller takes these service level measurements and adjusts the metering plans (release rate) at the ramp to maintain or reach a particular service level in the vicinity of the ramp. Like TOD operation, queue lengths on a ramp may result in changing the timing plan at the ramp regardless of mainline service levels.

Appendix A - Function Definitions (continued)

Ramp meter control (areawide control)	Description: Traffic flow levels along a wide – area portion of the freeway are maintained by controlling (i.e., metering) the rates at which traffic enters the freeway from ramps. Scenario: Real-time traffic flow parameters collected along most of or the entire mainline freeway provide a measurement of service level. The management system takes these service level measurements and adjusts the metering plans (release rate) at selected ramps (possibly all) to maintain or reach a particular service level. Like TOD operation, queue lengths on a ramp may result in changing the timing plan at the ramp regardless of mainline service levels.
Expressway interchange control	Description: Similar to “Ramp Meter Control”, but the metering and access control operations occur on a freeway- to-freeway ramp. Scenario: Real-time traffic flow parameters collected along the mainline freeway and freeway-to-freeway ramps provide a measurement of service level. The management system takes these service level measurements and adjusts the metering plans (release rate) at expressway interchanges to maintain or reach a particular service level. (Note – For a bridge or tunnel entrance, where the number of lanes approaching the bridge / tunnel entrance is significantly greater than the number of lanes on the bridge / tunnel, metering may be implemented on the approaches, and the metering plans adjusted to maintain or reach a particular level of service on the bridge / tunnel.
Reversible lane control	Description: Segments and/or selected lanes of highway (freeway or arterial) are operated in either direction, usually based upon TOD. Scenario: Entire cross-sections of a roadway (typically freeway operations) operate in one direction during part of the day and the other direction during other times of the day. Most often used in HOV operations, where control is maintained with physical gates and/or temporary delineators, and travelers are informed of conditions with either static or DMS. In arterial applications, it is most common to use individual lanes of a cross-section (typically the center lanes) in either direction during different parts of the day. Overhead lane control signs area common for this application, in addition to static signing. During changeover of directional flow, a transition period is required to clear the roadway of vehicles traveling in the soon-to-be “wrong direction”.
Variable speed limits	Description: Dynamic speed limits are used during particular conditions or on TOD. Scenario: Used along freeway to change either the entire cross-sections speed (during poor weather conditions or traffic congested periods), or to vary the speed of individual lanes along a portion of freeway resulting from congestion -- for example, an incident or other condition (e.g., work zone).May be used along arterials to display the average speed for which the signalized intersections have been coordinated. Cross-sectional changes in speed limit are typically conveyed via changeable speed limit signs on both sides of the roadway, where individual lane variations are conveyed via overhead lane control sign.
Speed enforcement	Description: Gathering real-time information on individual motorists along the roadway to either reduce their speed or to produce a speed limit violation summons Scenario: Real time speeds of individual vehicles are measured at a spot location. The actual speed (or an indication that the motorist is exceeding the posted speed limit) may be displayed on a DMS; or the speed information may be combined with a camera that takes a photo of the vehicle as it is speeding. The vehicle is identified by its license plate number either manually or used optical recognition systems.

Appendix A – Function Definitions (continued)

DMS / HAR Operation	Description: Use of Variable, changeable, or blank-out message signs, or Highway Advisory Radio to convey traveler, special event, or hazardous condition information to motorists. Scenario: Messages are placed on signs to inform motorists of traffic conditions downstream such as a lane closure or congestion, or to provide network information such as expected travel times (e.g., “10 minutes to I-10 Junction”). In non-peak times, they can convey non-real-time information such as future construction, for example.
Identify trapped vehicle in Hwy - Rail intersection	Description: System determines that a vehicle is trapped in on a rail crossing. Scenario: Real-time information is collected from the Hwy – Rail Intersection to determine the presence of a vehicle and whether it is moving or not. This information may be transmitted to emergency service providers, train dispatchers, or directly to any oncoming trains in the vicinity of the rail crossing.
Intersection Collision Warnings	(ELIMINATED FROM LIST – More a function of in-vehicle devices; not roadway infrastructure
Intersection red light violations	Description: Devices located along the roadway detect a red light violation and gather/store the information to process a violation summons. Scenario: A camera and strobe light, interfaced with intersection detectors and the local traffic signal controller, takes a photo of a vehicle as it runs a red light, showing it entering the intersection while the light is red . The vehicle is identified by its license plate number either manually or used optical recognition systems.
Access Management	Description: Access / entry to a facility is controlled Scenario: Typically used for metering access to a bridge or tunnel so the flow on the bridge does not exceed capacity or breakdown (e.g., Bay Bridge between SFO and Oakland)
Cross Jurisdictional Coordination	Description: Sharing of systems and/or system information between multiple jurisdictions to ensure efficient operation and signal coordination of the traffic network. Scenario: Coordination of an arterial traffic signal system that crosses multiple jurisdictions, where real-time traffic information is shared to ensure consistency in cycle length and offset between near-by intersections in adjacent jurisdictions. Real-time traffic conditions (e.g., incidents, congestion, etc.) are shared with other jurisdictions to enhance regional travel efficiency.
2. INCIDENT MANAGEMENT	
Incident Detection (automated algorithms)	Description: Automated processes (e.g., software programs) that utilize real-time data to identify traffic flow abnormities that are likely caused by an incident. Current technology includes the California Algorithms, speed-based algorithms, and probe-based travel time (expected arrival) algorithms. Scenario – One or more thresholds (e.g., minimum speed, expected vehicle arrival time, difference in flow rate between adjacent roadway locations) are met by current traffic flow conditions, indicating the possible occurrence of an incident.

Appendix A – Function Definitions (continued)

Incident Detection (manual)	Description: Detecting an incident via human analysis of information collected from motorists (e.g., cell phones) or roadway infrastructure (e.g., call boxes). Scenario: Operators in a control room monitor CCTV images and detect unusual traffic conditions. Operators in control room answer mobile phone calls from motorists reporting incidents or unusual traffic conditions.
Incident Verification	Description: Human analysis of information collected from roadway infrastructure to ascertain if a potential incident detected by other means (automated algorithms, call–in) is indeed an incident. Scenario: Operators in a control room receive notification of a possible incident, either dispatch a response vehicle to verify or if possible, check for evidence on CCTV monitors.
Incident Diagnosis / Response / Clearance	Description: Identifying the nature and attributes of an incident (e.g., number of vehicles and type, hazardous materials, injuries and their extent), determining the appropriate response, and on-scene management during incident clearance (e.g., clearing lanes or shoulders of disabled vehicles Scenario: Upon verification of incident, control room operators and/or emergency service providers assess the severity of the incident to determine what emergency services are necessary, whether hazmat is involved, what equipment will be needed to clear roadway (wreckers, absorbent, front-end loader, etc.), and what is the extend of the back-up for response.
Traffic Diversions	Description: Diverting and routing traffic away from a congested (or otherwise hazardous) roadway to another. Information requirements in this context include both the affected route as well as potential alternative routes. Scenario: While managing an incident, operators in a control room may want to divert traffic from an affected roadway to another roadway to reduce congestion and queue length. Similarly, operators may need to divert traffic from a roadway that is potentially hazardous (e.g., ice, low visibility) to another roadway where the potential for incidents is less. In order to do this, operators must know the conditions on the roadway in question and for the route(s) to which they are diverting traffic.
DMS / HAR Operation	Description: Displaying real-time information regarding incidents and traffic conditions to motorists via Dynamic Message Signs (DMS) or Highway Advisory Radio (HAR) installed along the roadway. These DMS / HAR installations may be “fixed” (e.g., permanent foundations and support structures) or “portable”, however, both can be communicated with in real-time. Scenario: In the context of the incident management function, DMS / HAR may be used to notify motorists of congestion or road closures resulting from a downstream incident. The may also be used to provide guidance as to possible diversion routes.
Collision Notification	Description: Automatic means of detecting a collision and notifying an appropriate authority that a collision has occurred and the location of the collision.

Appendix A – Function Definitions (continued)

3. WORK ZONE MANAGEMENT	
Lane control (closures / shifts) Combined with "Traffic Flow Monitoring"	Description: The closure of lanes or shifting of lanes in the vicinity of, and within, a work zone. Scenario: During construction or maintenance, lanes may be closed or shifted to route traffic past a work zone. Operators must know when and where these shifts occur in real time in order to communicate to motorists about conditions.
Variable speed limits	Description: Dynamic speed limits may be used during roadwork. The speed limits may be varied as the result of lane shifts or closures, rough pavement conditions, narrowing of lane widths, reduced visibility from dust, etc. Scenario: During construction or maintenance along the roadway, speeds may need to be reduced to protect workers and motorists. Can be accomplished across the entire cross-section or on a lane-by-lane basis. Speed selection is accomplished either though a standard posting of a work zone speed limit, or by means or monitoring conditions in real time, and reducing speed (across the road or lane-by-lane) as conditions require. Cross-sectional changes are typically conveyed via changeable speed limit signs on both sides of the roadway, where individual lane variations are conveyed via overhead lane control sign.
Traffic Diversions	Description: Diverting and routing traffic away from a congested (or otherwise hazardous) roadway (due to construction or maintenance) to another. Information requirements in this context include both the affected route as well as potential alternative routes. Scenario: While managing traffic in the vicinity of a work zone, operators in a control room may want to divert traffic from an affected roadway to another roadway to reduce congestion and queue length. In order to do this, operators must know how far traffic is queued in order to make recommendations to motorists via DMS, and they have to know the condition of the route(s) to which they may be diverting traffic.
DMS / HAR Operation	Description: Displaying real-time information regarding lane closures/ shifts/narrowing, traffic conditions within a work zone, and vehicle restrictions to motorists via Dynamic Message Signs (DMS) or Highway Advisory Radio (HAR) installed along the roadway. These DMS / HAR installations may be "fixed" (e.g., permanent foundations and support structures) or "portable", however, both can be communicated with in real-time.
Automated Speed enforcement	Description: Gathering real-time information on individual motorists within a work zone to either reduce their speed or to produce a speed limit violation summons Scenario: Real time speeds of individual vehicles are measured at a spot location within the work zone. The actual speed (or an indication that the motorist is exceeding the posted speed limit) may be displayed on a DMS; or the speed information may be combined with a camera that takes a photo of the vehicle as it is speeding. The vehicle is identified by its license plate number either manually or used optical recognition systems.
Collision warning (safety of workers)	Description: Workers are warned, via audible alarm, that a vehicle is entering their work area. Motorist may also be warned in-vehicle of a pending or likely collision. On-board devices may take control of vehicle to prevent collision. Scenario: A system of detectors identifies the presence and movement of a vehicle into the work area (e.g., erratic driving such that motorist veers off the travel way) Workers are alerted so that they may immediately seek a safe location.

Appendix A – Function Definitions (continued)

Traffic flow monitoring (Lane shifts, restrictions, closures)	Description: The real-time characteristics of traffic flow at a work zone where lane shifts, restrictions, and /or closures are in effect. Scenario: During construction or maintenance, lanes may be closed or shifted to route traffic past a work zone; or roads may be restricted to particular traffic with specific characteristics (e.g., height, HAZMAT, weight, length). Operators monitor congestions levels at a work zone or the vicinity of a work zone and respond with appropriate traffic management procedures.
Roadway restrictions / closures (COMBINED WITH TRAFFIC FLOW ONITORING)	Description: As a result of construction or maintenance, roads may be restricted to particular traffic with specific characteristics (e.g., height, weight, length). Scenario: During bridge maintenance, vertical clearance may be reduced and overheight vehicle restricted. Similarly, weight restrictions may be in place. When lane widths are reduced, oversized vehicles are restricted from the roadway or to specific lanes. Trucks may be restricted from shoulder lanes. Hazmat vehicles may be restricted from particular work zone roadways or not be able to use selected detour routes. It is noted that this subfunction may also require "diversion" and "DMS" – to alert vehicles that they exceed these restrictions in advance of the work zone, and to direct them to other roadway segments where these restrictions do not exist.
Special traffic signal control / coordination	Description: Operation of special / temporary traffic signals to control and regulate traffic flow within a work zone. Scenario: Single lane roadway widths during construction/maintenance that are controlled by a traffic signal at each end, allowing the opposing vehicle streams to pass through the single lane section in an alternating fashion. For arterials, multiple signals within the work zone may require special coordination and timing plans. .
4. SPECIAL EVENT MANAGEMENT	
Reversible lane control	Description: Segments of highway (freeway or arterial) – usually serving a special event venue -- are operated in either direction during special events. Scenario: During special events (e.g., sporting events or parades, etc.) entire cross-sections or individual lanes of a roadway operate in one direction. Motorists are typically informed of conditions with either static or DMS (portable signs are common). For recurring / repetitive special events, permanent features such as overhead lane controls signals or access gates for freeways are used. During changeover of directional flow, a transition period is required to clear the roadway of vehicles traveling in the soon-to-be "wrong direction".
Roadway restrictions / closures (COMBINED WITH TRAFFIC FLOW MONITORING)	Description: As a result of a special event, roads may be restricted to (particular) traffic, or perhaps closed. Scenario: During a special event, roadways are closed for the event such as for a parade, or portions of a freeway are closed for a road race.

Appendix A – Function Definitions (continued)

Traffic Diversions / Best Route Identification	Description: Diverting and routing traffic away from a roadway that is closed / restricted for a special event, or congested (or otherwise hazardous) due to the special event. This also includes assessing and identifying the best route available to those attending a special event or travelers wanting to avoid the effects of the event. Information requirements in this context include both the affected route as well as potential alternative routes. Scenario: While managing traffic in the vicinity of a special event, operators in a control room may want to divert traffic from an affected roadway to another roadway to reduce congestion and queue length; or in the case of a closed or restricted access roadway, to alert motorists and divert them to other routes. They may also want to identify the “best” routes by which travelers may get to the special event venue. In order to do this, operators must know how far traffic is queued in order to make recommendations to motorists via DMS, and they have to know the condition of the route to which they are diverting traffic.
Special traffic signal control / coordination	Description: Modification of normal traffic signal operations to accommodate traffic during special events. Scenario: Special traffic plans are implemented (e.g. favoring traffic flow into or out of an event venue; or traffic signals are placed on flash.
DMS / HAR Operation	Description: Displaying real-time information regarding roadway restrictions and closures, traffic conditions, and diversions / “best route” to motorists during special events via Dynamic Message Signs (DMS) or Highway Advisory Radio (HAR) installed along the roadway. These DMS / HAR installations may be “fixed” (e.g., permanent foundations and support structures) or “portable”, however, both can be communicated with in real-time.
Access / Ramp control	Description: Controlling access to / from ramps leading to a special event venue. Scenario: Many sporting venues have their own ramps that are open to traffic only during an event at the venue.
Traffic flow monitoring (restrictions / closures)	Description: The real-time characteristics of traffic flow during a special event , particularly when restrictions and closures are in place.. Scenario: Operators monitor congestions levels along routes affected by a special event and respond with appropriate traffic management procedures.
Dedicated Lanes (HOV, participants)	Description: Use of dedicated lanes for special event traffic only. Scenario: Monitoring operation and enforcement of lanes or entire roadways – typically leading to and away from a special event venue -- that are reserved for use by traffic meeting specific criteria (e.g., buses / HOV, event participants and officials, VIPs). The purpose is to assure that this traffic reaches the venue unencumbered.
"Best Route" identification (COMBINED WITH DIVERSION)	Description: Assessing and identifying the best route available to those attending a special event or travelers wanting to avoid the effects of the event. Scenario: Real-time traffic conditions are monitored, and travelers are advised of the bests approach routes and best diversion routes.

Appendix A – Function Definitions (continued)

5. WINTER MOBILITY	
Potential loss of vehicle traction/maneuverability/stability	Description: Monitoring of real-time roadway and atmospheric conditions to minimize potential for loss of vehicle traction / maneuverability / stability on roadway Scenario: Adverse weather conditions (e.g., rain, snow, ice, high winds) can increase the possibility of vehicles losing control and increase the likelihood of roadway incidents. Operators may use this information to reduce speed limits or possibly to close the roadway and divert traffic
Need for plowing (maintenance vehicle dispatch)	Description: Determining whether snow exists on the pavement, and whether it needs removal or other treatment Scenario: Identify the presence and location of snow-covered roadways, and dispatch vehicles to plow as appropriate.
Lane(s) obstructions / Impaired Plowing	Description: Winter (or other weather) conditions obstruct travel lanes. Examples may include flooding, piled-up snow, fallen trees (wind damage), and stalled vehicles (e.g., stuck in snow or high water) Scenario: These conditions must be identified as soon as possible, as they can severely restrict traffic flow, as well as impair / impede plowing and related activities.
Need for chemical application	Description: Monitoring road surface and atmospheric conditions to determine need for chemical (or other) application to roadway surface. Scenario: Identify the presence and location of ice or snow on roadways, and dispatch vehicles to treat the roadway as appropriate. In some instances, the possibility that ice may soon start to accumulate
Impaired Plowing (INCLUDED IN "OBSTRUCTIONS")	
Low / loss of visibility	Description: Weather conditions (e.g., heavy snowfall, fog, smoke) reduce visibility along roadway Scenario: Operators may use this information to reduce speed limits along the affected segment, or possibly to close the roadway and divert traffic.
Other impairments to vehicles / crews	Description: Other weather conditions – in addition to those identified above -- may prove hazardous to vehicles / crews while performing their winter mobility functions. For example, extreme cold and/or wind chill. Scenario: Dispatchers may limit the time each crew is on the roadway, or take other precautions.
Short - term weather forecast	Description: Monitoring of real-time information along the roadway that contributes to short – term weather forecast for the entire roadway. Scenario: Information gathered from the roadway is combined with other weather information to improve weather forecast. These forecasts may including identifying the possibility of ice forming on selected segments of roadway, high winds, snow, etc, such that appropriate preparations can be made in an efficient manner.

Appendix A – Function Definitions (continued)

Maintenance vehicle monitoring	Description: Tracking and monitoring location of winter maintenance vehicles. Scenario: Operators desire to know what resources are available to respond to a particular need. For instance, if it is determined that a segment of highway is freezing or ice is present, dispatchers want to know where the nearest chemical vehicle is. Agencies wish to track and record contract maintenance vehicles for payment (typical contracting terms are by lane-mile).
DMS Operation	Description: Displaying real-time information regarding road surface, visibility, and other weather related conditions / hazards to motorists via Dynamic Message Signs (DMS) or Highway Advisory Radio (HAR) installed along the roadway. These DMS / HAR installations may be "fixed" (e.g., permanent foundations and support structures) or "portable", however, both can be communicated with in real-time.
6. EMERGENCY MANAGEMENT	NOTE -This overall function applies to the use of roadway during emergencies that are not directly associated with the roadway proper (e.g., roadway incident), but for which the roadways are necessary to move vehicles to or away from the emergency site. Examples include evacuations for hurricanes, and military deployments where military vehicles must move from bases to points of embarkation.
Track emergency vehicles	Description: Tracking the real-time position of emergency response / military vehicles and resources. Scenario: Control room operators and emergency service providers/ military headquarters desire to know where dispatched vehicles are located, so as to minimize response time to emergencies / deploy military resources.
Monitor Emergency Routes	Description: The real-time characteristics of traffic flow on special emergency routes during an emergency. Scenario: Operators monitor congestions levels and other attributes along routes affected by an emergency / military deployment.
Reversible lane control	Description: Segments of highway (freeway or arterial) are operated in one direction during emergency events. Scenario: During emergency events (e.g., evacuations) entire cross-sections or individual lanes of a roadway operate in one direction – typically opposite from their normal operation. Operators must monitor this "unique" traffic flow scenario. Motorists are typically informed of conditions with either static or DMS (portable signs are common).
Signal Preemption	Description: Green phases are provided for approaching emergency vehicles—either at an individual intersection, or throughout an entire system route or segment of the route. Scenario: Emergency vehicles en-route to a scene can either automatically preempt the signal phase(s) to green though an on-board transponder, or manually by activating an on-board device, or a system will detect the emergency vehicle and centrally activate preemption at one or more signals.

Appendix A – Function Definitions (continued)

Traffic Diversions	Description: Diverting and routing traffic away from a roadway that is closed for an emergency event, or congested (or otherwise hazardous) due to the event. Information requirements in this context include both the affected route as well as potential alternative routes. Scenario: While managing traffic during a hurricane evacuation, operators in a control room may want to divert traffic from an affected roadway to another roadway to reduce congestion and queue length. In order to do this, operators must know how far traffic is queued in order to make recommendations to motorists via DMS, and they have to know the condition of the route to which they are diverting traffic.
DMS / HAR Operation	Description: Displaying real-time information regarding lane closures or shifts, reverse operation, and traffic conditions to motorists during emergency situations via Dynamic Message Signs (DMS) or Highway Advisory Radio (HAR) installed along the roadway. These DMS / HAR installations may be "fixed" (e.g., permanent foundations and support structures) or "portable", however, both can be communicated with in real-time.
7. DEMAND MANAGEMENT	
HOV compliance verification	Description: Capability to monitor and enforce compliance to HOV restrictions using information gathered by the roadside. Scenario: Planners or enforcement officials identify vehicles that are certified HOV vehicles (van pool programs), or use video and optical recognition to identify the number of persons in a vehicle.
HOT operation	Description: Monitoring in real-time, the operation of high occupancy toll lanes. Scenario: Operators monitor the use of lane as transit- or HOV-only lanes along an arterial for instance, or an entire roadway cross-section used for HOV-use during certain times of the day. Non –HOV vehicles may use these lanes provided they have paid a toll or fee of some sort.
Value pricing	Description: Vehicles are charged for using a segment of roadway. Scenario: Similar to a toll road; but the price varies depending on a number of potential conditions, such as time of day, current level of congestion / average speed, pollution levels, number of occupants in the vehicle, etc.
8. FREIGHT MANAGEMENT	
Automated clearance @ roadside facilities	Description: Vehicles and cargo are cleared and allowed to bypass weigh stations using electronic identification and inventory. Scenario: Long-haul truck is weighed and cleared for safety at initial weigh station. It is then allowed to bypass subsequent stations without the need for paperwork inspection.
Automated clearance @ border crossings	Description: Vehicles and cargo are cleared (i.e., customs) at border crossings using electronic identification and inventory. Scenario: Long-haul truck is weighed and cleared for safety and customs compliance , without the need for paperwork inspection.

Appendix A – Function Definitions (continued)

Ramp rollover warning	Description: Trucks are warned of potential to rollover on a ramp, based upon vehicle characteristics (weight, speed) and ramp geometrics. Scenario: Trucks are assessed from their characteristics and approach speed, and warned by means of a DMS, blank out, static sign (with flashing beacons), or in-vehicle device that they must alter their approach.
Downgrade warning	Description: Trucks are warned of potential to loose control on a downgrade, based upon vehicle characteristics (weight, speed) and grade characteristics (slope), and road conditions (presence of ice/snow/wet). Scenario: Trucks are assessed from their characteristics and approach speed, and warned by means of a DMS, blank out, static sign (with flashing beacons), or in-vehicle device that they must alter their approach.
Monitor HAZMAT vehicles	Description: Knowing status (e.g., location) of a vehicle carrying hazardous materials, or knowing that a vehicle is carrying hazardous material. Scenario: Vehicles carrying hazardous materials in advance of a tunnel or other facility that restricts HAZMAT vehicles are identified to the facility's operator for response, or to the carrier (via in-vehicle device or side of the road sign) to advise them to divert or stop.
Monitor / warn overheight vehicles	Description: Vehicle heights are monitored, and vehicles are warned if they are too tall to clear a downstream obstruction. Scenario: Overheight detectors are installed in advance of a tunnel portal, or lower-than-standard-height overpass by means of a DMS, blank out, static sign (with flashing beacons), or in-vehicle device that they must alter their approach.
9. PERFORMANCE MEASUREMENT	
General Planning Requirements /Benefits	Description: Calculate quantitative measures of effectiveness on ITS and travel management; and collect roadway data for modeling. . Scenario: Managers use time-to-clear measurement to assess their i.m. program, average speed or travel time to assess their traffic management, loaded cycles or queue length to assess their traffic signal program.
Diversion performance ELIMINATED – Really part of Diversion sub-function in other categories.	Description: Measurement of the level of diversion when diversion measures are in place. Scenario: Monitor the level of diversion resulting from DMS or other information to motorists, to determine if too much diversion is occurring (i.e., alternative routes becoming more congested than primary route)
Incident detection/verification/response time ELIMINATED – Not readily measurable with roadway infrastructure.	Description: Measurement of false alarms (for automated incident detection), time-to-respond and time-to-clear
10. HIGHWAY-BASED TRANSIT MANAGEMENT	

Appendix A – Function Definitions (continued)

Transit vehicle preemption	Description: Green phases are provided for approaching transit vehicles —either at an individual intersection, or throughout an entire system route or segment of the route. Scenario: Transit vehicles can either automatically preempt the signal phase(s) to green though an on-board transponder or manually by activating an on-board device, or a system will detect the emergency vehicle and centrally activate preemption at one or more signals.
Transit vehicle schedule adherence	Description: Measuring and maintaining transit vehicle schedule adherence. Scenario: Bus can be tracked and notified if stops must be skipped in order to make up time for late schedule, or the bus must dwell at a stop if it's ahead of schedule.
Transit vehicle routing	Description: Providing route information to transit vehicles to assist in the meeting schedule adherence. Scenario: Operators monitor network conditions and notify transit vehicle of best route, or of upcoming conditions on transit route. This can be done via voice communications or in-vehicle device. This is typically used for express bus operations where multiple routes exist between the origin and the destination.
Bus stop VMS operation	Description: Real-time traveler information on transit status. Scenario: DMS provides awaiting travelers of the identification of the next vehicle (bus or train) to arrive and approximate arrival time. It also conveys messages on any changes to schedule.

APPENDIX B – DATA / INFORMATION ELEMENTS

Volume
Occupancy (Density)
Speed (Aggregate)
Speed (Individual Vehicle)
Travel Time
Queue Length
Waiting Time
Vehicle Direction
Vehicle Length
Vehicle Height
Vehicle # Axles
Vehicle Weight
Vehicle Location
Vehicle Identification
Vehicle Contents
Air Temp.
Rd. Surface Temp.
Rd. Surface Chemical Conc.
Rd. Surface Ice
Rd. Surface Wet
Rd. Surface Snow
Total Precipital Water Vapor
Atmos. Visibility
Atmos. Temp.
Atmos. Humidity
Atmos. Precipitation
Wind Speed / Direction
Environment CO
Environment NO
Environment HC
Environment Ozone
Origin – Destination
Video Image

APPENDIX C – INFOSTRUCTURE CMSA'S AND MILEAGE

Rank	Area Name	URBANIZED AREA	< 0.50	0.50-0.75	> 0.75	Interstate	< 0.50	0.50-0.75	> 0.75	other	EXPRESSWAY		0.50-0.75	> 0.75	ARTERIAL	< 0.50	0.50-0.75	> 0.75	TOTAL	ANNUAL SNOW
												MILEAGE								
1	New York--Northern New Jersey--Long Island, NY--NJ--CT--PA CMSA	New York-Northeastern NJ	69	131	247	448	218	119	334	671	1,119	689	723	821	2,234	977	973	1,403	3,353	
1	New York--Northern New Jersey--Long Island, NY--NJ--CT--PA CMSA	New Haven-Meriden	18	16	9	44	10	15	8	33	76	44	21	35	101	72	52	53	177	
1	New York--Northern New Jersey--Long Island, NY--NJ--CT--PA CMSA	Bridgeport-Milford	-	5	14	19	18	4	20	41	60	11	21	26	57	28	29	60	117	> 75 cm
1	New York--Northern New Jersey--Long Island, NY--NJ--CT--PA CMSA	Trenton	17	20	1	39	5	8	4	17	56	41	37	37	114	63	65	42	170	
1	New York--Northern New Jersey--Long Island, NY--NJ--CT--PA CMSA	Stamford	-	4	9	13	-	-	10	10	23	21	13	15	49	21	17	34	72	
2	Los Angeles--Riverside--Orange County, CA CMSA	Los Angeles	5	59	312	376	48	40	188	276	652	1,052	646	817	2,514	1,105	745	1,317	3,167	
2	Los Angeles--Riverside--Orange County, CA CMSA	Riverside-San Bernardino	5	32	43	80	5	22	32	59	139	90	78	11	180	100	132	86	319	
2	Los Angeles--Riverside--Orange County, CA CMSA	Oxnard-Ventura	-	-	-	-	10	7	41	58	58	50	59	38	147	60	65	79	205	< 12.5 cm
2	Los Angeles--Riverside--Orange County, CA CMSA	Lancaster-Palmdale	-	-	-	-	8	4	1	13	13	38	21	13	71	45	25	14	84	
2	Los Angeles--Riverside--Orange County, CA CMSA	Hesperia-Apple Valley-Victorville	-	11	4	15	-	-	-	-	15	4	15	16	35	4	25	20	49	
3	Chicago--Gary--Kenosha, IL--IN--WI CMSA	Chicago-Northwestern IN	81	186	151	418	25	28	2	55	473	521	589	498	1,608	626	804	651	2,081	> 75 cm
4	Washington--Baltimore, DC--MD--VA--WV CMSA	Washington	5	27	134	166	35	38	63	136	302	209	96	270	576	249	161	467	878	12.5 < X < 75 cm
4	Washington--Baltimore, DC--MD--VA--WV CMSA	Baltimore	9	49	76	134	52	54	38	144	278	156	83	120	359	217	185	235	637	
5	San Francisco--Oakland--San Jose, CA CMSA	San Francisco-Oakland	6	21	173	200	-	12	117	129	330	212	207	167	586	218	240	457	916	
5	San Francisco--Oakland--San Jose, CA CMSA	San Jose	-	11	30	41	1	16	68	85	126	140	113	70	323	142	140	168	449	< 12.5 cm
5	San Francisco--Oakland--San Jose, CA CMSA	Santa Rosa	-	-	-	-	-	5	19	24	24	19	10	3	32	19	15	21	56	
6	Philadelphia--Wilmington--Atlantic City, PA--NJ--DE--MD CMSA	Philadelphia	12	85	101	198	39	82	29	150	348	230	385	316	931	280	552	446	1,278	12.5 < X < 75 cm
6	Philadelphia--Wilmington--Atlantic City, PA--NJ--DE--MD CMSA	Wilmington	15	23	9	47	3	4	2	8	56	79	48	11	137	96	75	22	192	
7	Boston--Worcester--Lawrence, MA--NH--ME--CT CMSA	Boston	15	41	91	147	18	28	18	64	211	304	166	293	763	338	235	402	974	
7	Boston--Worcester--Lawrence, MA--NH--ME--CT CMSA	Worcester	20	22	18	59	10	-	-	10	70	27	35	34	96	57	57	52	166	> 75 cm
7	Boston--Worcester--Lawrence, MA--NH--ME--CT CMSA	Lawrence-Haverhill	22	17	7	47	-	4	-	4	51	13	18	54	84	35	39	61	135	
7	Boston--Worcester--Lawrence, MA--NH--ME--CT CMSA	Lowell	-	14	1	15	2	7	6	15	30	24	8	18	50	26	29	25	80	

Rank	Area Name	URBANIZED AREA	< 0.50	0.50-0.75	> 0.75	Interstate	< 0.50	0.50-0.75	> 0.75	other	EXPRESSWAY		0.50-0.75	> 0.75	ARTERIAL	< 0.50	0.50-0.75	> 0.75	TOTAL	ANNUAL SNOW
												MILEAGE								
8	Detroit--Ann Arbor--Flint, MI CMSA	Detroit	18	57	128	203	21	40	20	81	283	229	485	304	1,018	268	581	452	1,301	> 75 cm
9	Dallas--Fort Worth, TX CMSA	Dallas-Fort Worth	29	80	182	291	43	39	220	302	594	493	201	300	994	565	320	702	1,587	< 12.5 cm
10	Houston--Galveston--Brazoria, TX CMSA	Houston	-	29	108	137	103	24	103	231	368	389	197	110	696	492	250	322	1,064	< 12.5 cm
11	Atlanta, GA MSA	Atlanta	21	179	46	246	19	26	15	60	306	323	204	111	638	363	409	173	945	< 12.5 cm
12	Miami--Fort Lauderdale, FL CMSA	Miami-Hialeah	-	9	18	27	23	28	42	93	119	48	84	74	207	71	121	135	326	< 12.5 cm
12	Miami--Fort Lauderdale, FL CMSA	Fort Lauderdale-Hollywood-Pompano Beach	4	14	35	53	18	32	4	54	107	37	66	68	171	58	112	107	278	
13	Seattle--Tacoma--Bremerton, WA CMSA	Seattle	14	91	7	112	44	49	36	129	241	121	127	169	417	179	267	212	659	12.5 < X < 75 cm
13	Seattle--Tacoma--Bremerton, WA CMSA	Tacoma	-	20	3	23	12	10	10	32	55	79	52	44	175	91	82	57	230	
14	Phoenix--Mesa, AZ MSA	Phoenix	2	23	27	53	53	24	34	111	163	301	234	85	620	357	281	146	784	< 12.5 cm
15	Minneapolis--St. Paul, MN--WI MSA	Minneapolis-St. Paul	1	48	148	197	3	37	80	120	316	51	49	87	186	54	133	315	503	> 75 cm
16	Cleveland--Akron, OH CMSA	Cleveland	9	89	78	176	31	15	5	51	227	171	86	70	327	212	189	153	554	
16	Cleveland--Akron, OH CMSA	Akron	8	27	26	61	10	9	5	24	86	81	43	26	151	99	80	57	236	> 75 cm
16	Cleveland--Akron, OH CMSA	Lorain-Elyria	9	19	5	33	10	7	-	17	50	47	1	4	53	66	27	9	102	
17	San Diego, CA MSA	San Diego	8	65	65	139	43	15	50	108	246	50	146	55	251	102	226	170	498	< 12.5 cm
18	St. Louis, MO--IL MSA	St. Louis	48	96	101	244	21	23	31	75	319	336	159	44	540	405	278	176	859	12.5 < X < 75 cm
19	Denver--Boulder--Greeley, CO CMSA	Denver	22	29	47	97	30	24	57	111	209	129	125	178	432	182	177	282	641	> 75 cm
20	San Juan--Caguas--Arecibo, PR CMSA	San Juan	5	17	21	43	8	5	9	23	66	24	49	42	116	38	72	72	182	< 12.5 cm
20	San Juan--Caguas--Arecibo, PR CMSA	Caguas	5	1	6	13	1	8	3	12	25	8	7	7	22	14	16	16	46	
21	Tampa--St. Petersburg--Clearwater, FL MSA	Tampa-St Pete-Clearwater	17	37	36	90	31	3	1	35	124	115	154	58	326	163	193	94	451	< 12.5 cm
22	Pittsburgh, PA MSA	Pittsburgh	71	71	23	166	83	32	3	118	283	301	169	36	506	455	272	62	789	> 75 cm
23	Portland--Salem, OR--WA CMSA	Portland-Vancouver	15	12	58	85	7	16	25	48	133	127	94	51	271	150	121	134	404	> 75 cm
24	Cincinnati--Hamilton, OH--KY--IN CMSA	Cincinnati	5	45	97	147	11	6	11	29	176	108	42	82	232	124	94	191	408	12.5 < X < 75 cm

Rank	Area Name	URBANIZED AREA	< 0.50	0.50-0.75	> 0.75	Interstate	< 0.50	0.50-0.75	> 0.75	other	EXPRESSWAY		0.50-0.75	> 0.75	ARTERIAL	< 0.50	0.50-0.75	> 0.75	TOTAL	ANNUAL SNOW
															MILEAGE					
25	Sacramento--Yolo, CA CMSA	Sacramento	-	20	31	50	1	11	43	55	105	188	95	74	356	189	126	147	462	< 12.5 cm
26	Kansas City, MO--KS MSA	Kansas City	54	52	95	201	82	60	31	173	374	211	57	51	320	347	169	178	694	12.5 < X < 75 cm
27	Milwaukee--Racine, WI CMSA	Milwaukee	4	32	38	75	20	8	9	37	111	203	79	113	396	227	119	160	507	> 75 cm
28	Orlando, FL MSA	Orlando	-	12	32	44	52	60	-	112	156	64	139	52	256	116	212	84	412	< 12.5 cm
29	Indianapolis, IN MSA	Indianapolis	34	53	29	116	6	1	7	14	130	87	106	62	255	126	160	98	385	12.5 < X < 75 cm
30	San Antonio, TX MSA	San Antonio	46	34	55	135	14	35	27	76	211	119	87	59	265	179	156	141	475	< 12.5 cm
31	Norfolk--Virginia Beach--Newport News, VA--NC MSA	Norfolk-VA Beach-Newport News	20	53	41	115	43	16	-	58	173	157	82	38	276	220	151	79	449	12.5 < X < 75 cm
32	Las Vegas, NV--AZ MSA	Las Vegas	7	10	29	47	13	5	12	30	77	44	40	31	114	65	55	72	191	12.5 < X < 75 cm
33	Columbus, OH MSA	Columbus	6	56	52	114	2	25	0	28	142	56	44	59	160	65	125	111	302	12.5 < X < 75 cm
34	Charlotte--Gastonia--Rock Hill, NC--SC MSA	Charlotte	2	15	38	56	8	21	25	53	109	36	16	42	94	46	52	105	203	12.5 < X < 75 cm
35	New Orleans, LA MSA	New Orleans	5	18	21	44	7	-	1	8	52	81	62	76	219	93	80	98	271	< 12.5 cm
36	Salt Lake City--Ogden, UT MSA	Salt Lake City	28	38	7	73	3	1	2	6	79	66	27	23	116	97	65	33	195	> 75 cm
36	Salt Lake City--Ogden, UT MSA	Ogden	10	27	-	37	-	-	-	-	37	28	13	7	48	38	40	7	84	
37	Greensboro--Winston-Salem--High Point, NC MSA	Winston-Salem	-	13	3	16	3	25	13	42	58	3	4	7	14	6	42	23	71	12.5 < X < 75 cm
37	Greensboro--Winston-Salem--High Point, NC MSA	Greensboro	8	7	11	26	13	10	6	29	55	19	16	1	36	40	33	18	91	
38	Austin--San Marcos, TX MSA	Austin	-	10	18	28	7	23	46	77	105	54	80	50	184	62	114	114	289	< 12.5 cm
39	Nashville, TN MSA	Nashville	10	36	54	100	15	16	9	40	139	58	72	40	170	82	125	103	309	12.5 < X < 75 cm
40	Providence--Fall River--Warwick, RI--MA MSA	Providence-Pawtucket	18	24	30	72	19	14	14	47	119	197	76	49	322	235	114	93	441	> 75 cm
41	Raleigh--Durham--Chapel Hill, NC MSA	Raleigh	9	9	32	49	4	2	7	13	62	24	36	55	116	38	47	93	178	12.5 < X < 75 cm
41	Raleigh--Durham--Chapel Hill, NC MSA	Durham	5	3	18	26	4	15	4	22	48	24	21	11	55	33	39	32	103	
42	Hartford, CT MSA	Hartford-Middletown	10	32	26	67	11	27	3	41	108	49	42	44	136	70	100	74	244	> 75 cm
43	Buffalo--Niagara Falls, NY MSA	Buffalo-Niagara Falls	19	25	29	73	47	15	3	65	138	131	138	24	293	197	178	56	431	> 75 cm
44	Memphis, TN--AR--MS MSA	Memphis	26	17	35	78	4	6	4	14	92	93	92	32	217	123	115	71	308	12.5 < X < 75 cm
45	West Palm Beach--Boca Raton, FL MSA	West Palm Beach-Boca Raton-Delray Beach	-	9	37	46	-	38	3	41	87	65	72	21	158	65	119	62	245	< 12.5 cm

Rank	Area Name	URBANIZED AREA	< 0.50	0.50-0.75	> 0.75	Interstate	< 0.50	0.50-0.75	> 0.75	other	EXPRESSWAY		0.50-0.75	> 0.75	ARTERIAL	< 0.50	0.50-0.75	> 0.75	TOTAL	ANNUAL SNOW
												MILEAGE								
46	Jacksonville, FL MSA	Jacksonville	2	36	44	83	28	36	9	74	156	57	51	24	132	87	124	77	288	< 12.5 cm
47	Rochester, NY MSA	Rochester	24	9	26	59	18	12	9	40	99	18	22	13	53	61	42	49	152	> 75 cm
48	Grand Rapids--Muskegon--Holland, MI MSA	Grand Rapids	24	20	4	47	2	14	4	20	68	79	40	33	152	105	74	40	220	> 75 cm
49	Oklahoma City, OK MSA	Oklahoma City	112	9	-	121	27	1	-	29	150	251	13	-	264	391	24	-	414	12.5 < X < 75 cm
50	Louisville, KY--IN MSA	Louisville	19	46	51	117	4	13	3	20	137	40	50	93	184	64	110	147	321	12.5 < X < 75 cm
																12,751	11,871	12,518		
		TOTAL				7,255				5,128	12,383				24,757				37,140	

APPENDIX D – UNIT COSTS

Traffic Flow Detector Station

6-year cost = $45, 000

Includes 2 overhead detector units, poles / foundations for mounting the units, processor / cabinet / foundation / power, connecting cabling and conduit, CDPD communications, and maintenance (15 % of electrical items per year).

Video (Low Bandwidth)

6-year cost = $70,000

Includes camera, pan / tilt / zoom unit, pole / foundation for mounting the camera, video conversion unit (a few frames per second) / cabinet / foundation / power, connecting cabling and conduit, communications, and maintenance (15 % of electrical items per year).

Video (Medium Bandwidth)

6-year cost = $85,000

Includes camera, pan / tilt / zoom unit, pole / foundation for mounting the camera, video conversion unit (10 to 15 frames per second) / cabinet / foundation / power, connecting cabling and conduit, communications, and maintenance (15 % of electrical items per year).

Video (High Bandwidth)

6-year cost = $125,000

Includes camera, pan / tilt / zoom unit, pole / foundation for mounting the camera, video conversion unit (full-motion / broadcast quality) / cabinet / foundation / power, connecting cabling and conduit, communications, and maintenance (15 % of electrical items per year).

Weather Station

6-year cost (complete) = $ 50,000
6-year cost (partial) = $ 40,000

Includes road condition - weather measuring units, pole / foundation for mounting the atmospheric condition elements, processor / cabinet / foundation / power, connecting cabling and conduit, communications, and maintenance (15 % of electrical items per year).

Bus AVL Tracking

6-year cost = $ 20,000,000 per CMSA

Includes GPS logic units and communications (for 1000 buses) and central monitoring hardware and software.

Infrastructure Security

6 – year cost = $ 2,300,000 per site

Includes traffic flow monitoring at 1/2 – mile intervals, full-coverage video (high – bandwidth) plus video to monitor off – roadway events, monitoring software, communications, and maintenance.

Data Integration

6 – year cost = $ 1,000,000 per urban “center”
6 – year cost = $ 500,000 per rural (statewide) “center”

Assumed Level of Existing Deployment

Freeway Traffic Flow and Video = 25 %
Arterial Traffic Flow and Video = 5 %
Freeway Weather Station = 15 %
Arterial Weather Station = 5 %
Bus AVL System = 30 %
Data Integration (urban centers) = 15 %
Data Integration (rural centers) = 5 %

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Toll-Free "Help Line" 866-367-7487
www.its.dot.gov
EDL Document No.: 13812
Publication No.: FHWA-OP-03-096