INTELLIGENT VEHICLE HIGHWAY SYSTEMS

STRATEGIC DEPLOYMENT PLAN FOR METROPOLITAN BOSTON

NOTE TO READER:

THIS IS A LARGE DOCUMENT

Due to its large size, this document has been segmented into multiple files. All files separate from this main document file are accessible from links (blue type) in the table of contents or the body of the document.

Intelligent Vehicle Highway Systems Strategic Deployment Plan for Metropolitan Boston

Prepared for
The Commonwealth of Massachusetts
Exectiive Office of Transportation
and Construction
and
Massachusetts Highway Department

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EXECUTIVE SUMMARY
IVHS STRATEGIC PLAN FOR METROPOLITAN BOSTON

The Massachusetts Executive Office of Transportation and Construction (EOTC)and the Massachusetts Highway Department (MHD) have developed a strategic plan for implementing an Intelligent Vehicle-Highway System (IVHS) throughout metropolitan Boston during the next decade. The strategic deployment plan covers the roadway and transit network shown in Exhibit 1; and identifies the user services and functions to be provided, the overall system architecture, the supporting technologies and strategies, the operations and maintenance requirements, the implementation priorities, and the associated costs and benefits.

BACKGROUND

The transportation management initiative known as "Intelligent Vehicle-Highway Systems" (IVHS) refers to transportation networks that involve integrated applications of advanced surveillance, communications, computer, display, and control process technologies on the roadway network, in the vehicle, and for transit modes. The goals of IVHS parallel those of EOTC and the MHD -- to improve the efficiency of the transportation network thereby alleviating congestion, reducing fuel consumption and pollution, and improving the timeliness of person movement and goods deliveries; to enhance the safety of the users of the system; and to enhance overall mobility such that productivity and economic competitiveness are maximized.

The strategic planning process for the Boston area focused on the concept of "integrated applications"; that IVHS-based systems are more than the mere implementation of advanced technologies. These systems are provide for coordinated decision making and for the sharing of information such that the transportation network -- consisting of expressways, surface streets, and transit routes: all passing through multiple jurisdiction - is treated as a single "seamless" entity.

User Services

When developing an IVHS strategic plan, it is crucial to think in terms of the services and functions to be provided by the system. Five areas of "user services" were identified for the Boston region as follows:

- Traveler Information
- Traffic Management
- Freigt and Fleet Management
- Public Transportation
- Electronic Toll Collection

Where "users" may be travelers, drivers, transit riders, commercial fleet, operators/dispatchers and transportation management personnel. The various functions associated with these user services were evaluated in terms of their contribution towards the region's transportation goals, including decreased congestion, reduction in single occupancy vehicles improve mobility, economic development, and implementation ease. This evaluation was conducted by a group of policy and decision makers representing MHD, EOTC, Massachusetts Bay Turnpike Authority (MBTA), State Police, Mass Port, FHWA, and resulted

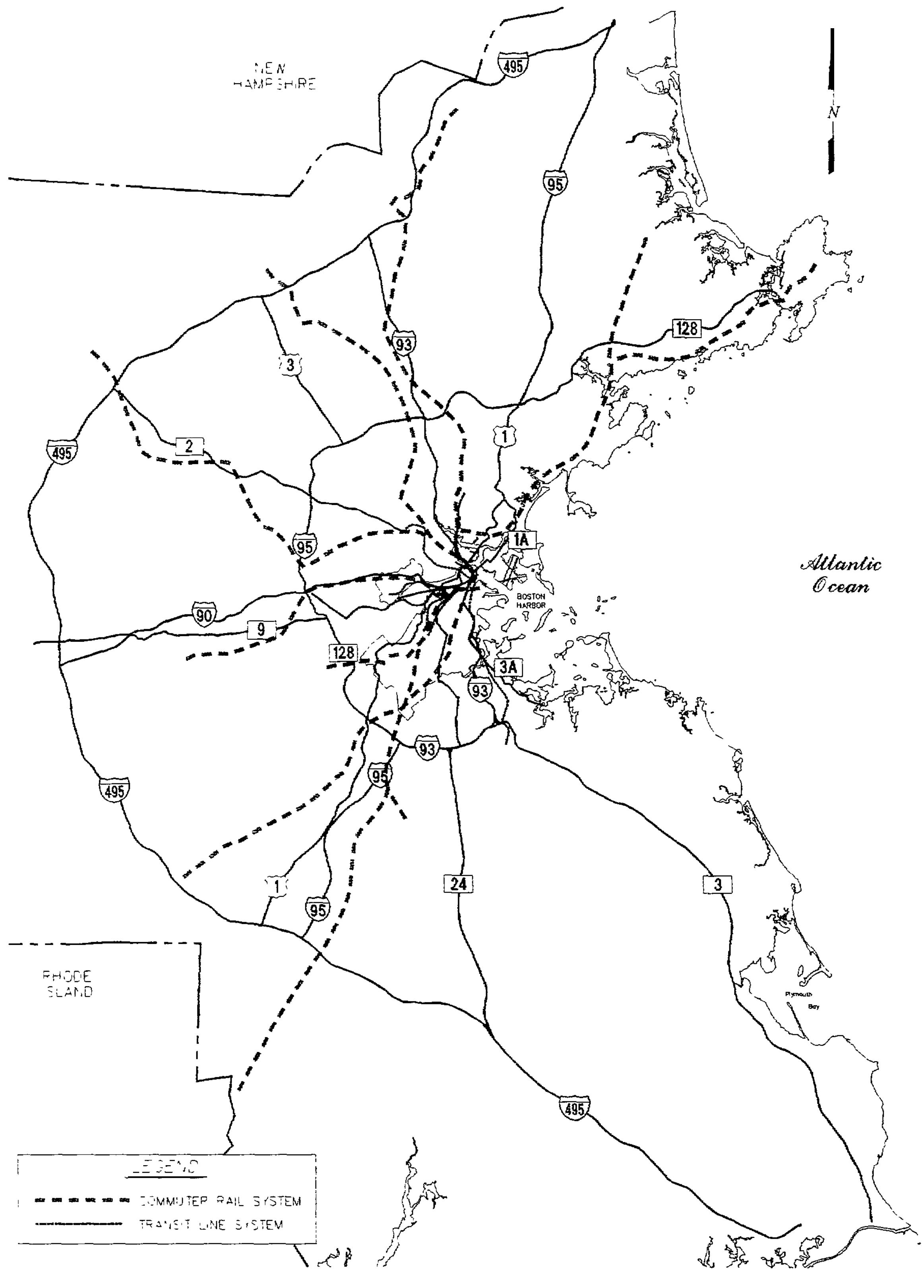


Exhibit 1 ***Project Area & Facilities***

in the identification of several priority IVHS functions as summarized in Exhibit 2. It is emphasized that in developing system goals, defining user-services and associated functions, and evaluating their relative importance, no specific architectures nor technologies were assumed. Bather, it was the prioritized IVHS functions which formed the basis for subsequent analyses and technology recommendations.

REGIONAL ARCHITECTLTRE

One of the key elements of an IVHS strategic plan is the system architecture. An IVHS architecture identifies the functions to be performed by the system, allocates these functions to subsystems, and defines the flows of information and the interfaces between the subsystems and components. In a metropolitan area such as Boston; where the roadway network is managed by several different entities, and additional agencies are responsible for transit (MBTA) and enforcement (State Police); a regional architecture, identifying the various transportation management systems and the linkages between these systems, is necessary.

The regional architecture for the Boston area IVHS network is shown in Exhibit 3. The architecture is "distributed" in that each public agency is responsible for implementing and managing IVHS-based systems for their respective transportation networks. As such, MHD will operate a Freeway Traffic Management System (FTMS); the MTA will operate systems on the Turnpike (I-90) and for the Sumner and Callahan Tunnels; the MBTA will operate a schedule and dispatch system for their trains and buses; local municipalities such as Boston, Cambridge, and Waltham will operate systems controlling their surface-street signals; and so forth. Moreover, it is envisioned that each of these agency-specific systems (or network of systems) will include a separate Traffic Operations Center (TOC)

The concept of a "seamless" transportation network requires that the individual transportation management systems share information so as to create an integrated data base of real-time and multi-modal traveler information, and that the operational and control decisions made within each system (e.g., sign messages, diversion, signal timing, ramp meter rates, etc.) consider the current conditions and potential impacts on the other agencies' facilities. To achieve this necessary integration, the regional IVHS architecture includes a Transportation Information and Coordination Center (TICC) which is connected via two-way links to each and every agency's TOC and with several private entities.

As the name implies, the primary functions of the TICC will involve regional coordination and information. The regional TICC will serve as a centralized clearing house of real-time and static information on transportation conditions (e.g., average speeds, travel times, transit schedules, incidents and congestion problems, construction and maintenance activities, etc.) within the Boston metropolitan area. It will integrate this information into a regional data base of traveler information, covering all modes and routes, which can be accessed by each agency as well as by private concerns.

The other primary function of the regional TICC is to promote and manage coordination between the various transportation agencies and their systems.

Exhibit 2: Boston Area Priority IVHS Functions

- Incident Management - a Traffic Management user service involving a designated subsystem and set of procedures aimed specifically at the rapid detection of roadway incidents, followed by rapidly responding to and clearing those incidents once their existence has been detected and verified.

- Trip Planning - a Traveler Information user service incorporating real-time information on fares, schedule adherence, and travel times for transit networks; and tolls, delays, and travel times for roadways; to aid the traveler in selecting the best route, mode, and departure time.

- Demand Management - strategies to encourage travel during non-peak periods or by alternate modes (e.g., congestion pricing). Strategies to regulate traffic flow access (e.g., ramp metering, surface street signal control) are also included.

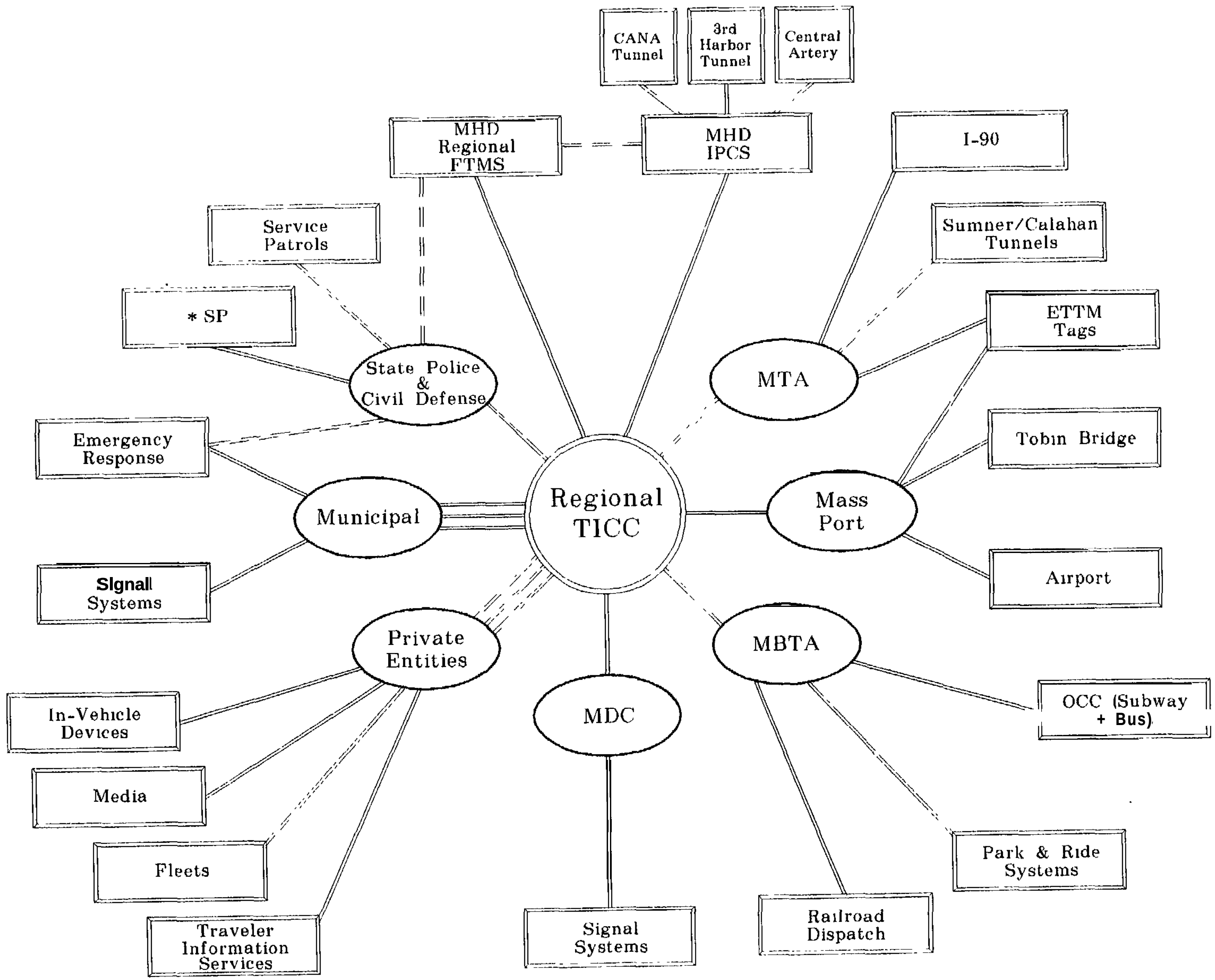
- Electronic Toll Collection - automatic identification of vehicles and automatic debiting of the appropriate amount from a pre-paid account or other billing through another arrangement.

- Advisories - a Traveler Information user service providing real-time information on transportation facility conditions such as congestion, incidents, delays, weather, closures, service changes, parking lot availability, next vehicle arrival, etc -- information which travelers may utilize to plan their trip or modify their trip enroute. The basic information is provided with no travel time nor cost data; (as provided in Trip Planing).

- Route/Mode Guidance - an advanced form of trip planning in that the optimum route or mode may be automatically selected based on traveler-entered parameters (e.g., origin and destination, mode and route preference, cost, etc.).

- Construction Management - scheduling of construction/maintenance activities and setup of construction zones so as to minimize their effects on traffic flow.

Exhibit 3: Recommended Regional Architecture



Most transportation problems can be predicted -- at least in terms of what may happen and where; although not when -- and the corresponding regional strategies, and agency - specific responses to these problems can be pre-arranged, pre-approved, and documented. The role of the TICC will be to develop, implement, and monitor these preplanned region-wide responses as follows:

- TICC is "notified" of a transportation problem (e.g. major incident). This notification may be accomplished manually (e.g., phone call from an agency) or automatically based on real-time information received at the TICC:

- TICC personnel identify the appropriate response plan based on location, type, and severity of the problem. The knowledge base comprising the pre-approved response plans (e.g., type and magnitude of incident, location, entities to be contacted, resources to be allocated, diversions, traveler information displays, etc.) will he used to form a computer-based "expert system".

- The regional TICC contacts the various entities, both public and private, in accordance with the response plan. It is envisioned that initially the TICC will declare that a specific plan be put into effect, with the actual implementation carried out by the individual agencies -- a situation in which the TICC is responsible for "strategic" response, while the various

Public/Private Responsibilities

A major issue in defining and developing an IVHS architecture is the concept of public/private partnerships, and the respective roles of the public and private sectors in implementing, operating, and maintaining IVHS-based systems. A public/private partnership is defined as a relationship in which the private entity provides IVHS services and/or system elements for the public agency; but instead of direct reimbursement from the public agency, some or all of the private entity's costs for these functions are recouped by selling IVHS-based services to other private entities (i.e., collecting a user fee), or by receiving a non-monetary consideration for these services from the public agency (a sort of quid-pro-quo).

As shown in the regional architecture diagram, the private sector plays a major role in the overall IVHS plan for the Boston area. In general, the public side (i.e., the various transportation management and enforcement agencies) is responsible for collecting and integrating area-wide surveillance information, and then developing and implementing control strategies (e.g., incident detection and response, signal/meter timing, etc.) based on this information. The primary role of the private sector is to analyze the integrated data, tailoring the information to meet the unique requirements of the end users (i.e., a "value added"), and then to market and disseminate the traveler information via radio and TV outlets, kiosks located at large travel generators, information. Public-private partnerships may also be utilized to provide communications, incident response, service patrols, and operational support.

BOSTON AREA IVHS NETWORK

The Boston area IVHS network is an array of hardware, software, institutional, and human elements. Several alternative technologies and strategies were analyzed and screened in terms of their ability to provide the priority functions, their compatibility with the regional architecture and with other system components, life-cycle costs, operational and maintenance requirements, and implementation timeframes. Recognizing that IVHS represents a rapidly changing technological field, with new and advanced products being continuously introduced, the system and subsystem architectures were defined to maximize flexibility and modularity and to incorporate accepted technology standards wherever possible. In this manner, the Boston IVHS network can evolve both geographically and functionally, taking advantage of new technologies and strategies as the system matures.

Existing IVHS-Based Systems

The implementation of the Boston area IVHS network is already underway. Several transportation management systems are currently in operation or under construction as summarized below:

Integrated Project Control System The "primary mission of the IPCS is to ensure the safe, efficient flow of vehicular traffic through the CA/T (Central Artery/Third Harbor Tunnel)". In addition, the IPCS will provide support for effectively operating and maintaining all CA/T facilities. This will be accomplished by providing a system to remotely monitor and control all CA/T facilities including buildings and roadways. The IPCS incorporates a fully integrated Traffic Surveillance and Control System (TSCS), including vehicle detectors to gather data and determine traffic flow characteristics in real time, an incident detection system to identify abrupt changes in traffic flow and provide a camera view of the suspect location to an operator, variable message signs, variable speed limit signs, blank-out signs, overheight vehicle detection, and lane use signals. The IPCS will also maintain the internal environment of the facilities by providing control of access, ventilation, power, drainage, and lighting within covered sections.

MBTA Operations Control Center - IVHS is a multi-modal initiative, and the project area also includes the buses, commuter rail, and "T" facilities operated by the Massachusetts Bay Transportation Authority. The MBTA has recently commenced a 5-year $25 million project to upgrade its Operations Control Center (OCC) for the subway and bus lines. When this project is complete, the MBTA will have uniform real-time Automated Vehicle Location (AVL) and schedule adherence information on every light rail and rapid transit trip. Key benefits of the new OCC will include:

- Increased availability and accuracy of vehicle location and schedule adherence information.

- Centralized information processing and operations control in the areas of train control and management, schedule adherence, decision support systems for dispatchers, and reporting.

- Ability to accurately and automatically service real-time passenger information systems (e.g., in-terminal displays as to the arrival of the next train and its destination).

Massachusetts Turnpike Authority (MTA) - MassPike began a comprehensive rehabilitation program for the Sumner and Callahan Tunnels in 1991. As part of this effort, closed-circuit television cameras will be installed in the tunnels and monitored 24 hours-a-day. Both tunnels already have a Highway Advisory Radio (HAR) system transmitting at 530 and 1200 on the AM dial. MassPike is also conducting an Electronic Toll and Traffic Management (ETTM) planning study. This program initiative includes a market study and analysis, system design and procurement, testing, and ultimately integration of an electronic toll collection (ETC) system for use by MassPike patrons. It is expected that the ETC system will be implemented over the entire length of the Turnpike, as well as the Sumner Tunnel.

SmarTraveler - SmarTraveler is a FHWA-sponsored operational test of a privatized traveler information network. SmarTraveler, which is operated by SmartRoute Systems, Inc. of Cambridge, MA, utilizes a "low-tech" infrastructure for collecting traveler information, including cameras on buildings, regularly-scheduled probe trips communicating with the SmartRoute Operations Center via mobile phones or two-way radios, routine monitoring of public agency radio frequencies, aircraft flying over northern and southern sections of the metropolitan area, and direct telephone links to public agencies, (e.g., State Police communications center, MHD radio room, Amtrak dispatch facilities, MBTA operations center, etc.). This information is integrated, and reports are compiled for each route and updated as required. The information and reports are available over the phone -- a traveler calls the system and inputs a code representing the route, area, or mode for which he/she desires information (e.g., 90* for I-90,5* for Logan Airport, 1282" for Rt. 128 south of I-90, etc.)

Traffic Signal Systems - Several computer-based signal systems are operating within the study area. The City of Boston operates a centralized system with approximately 325 intersections on line. Signal control is provided in the City's core and along a series of arterials extending west and south. Within the Route 128 beltway, the Metropolitan District Commission (MDC) controls approximately 250 signalized intersections. A six (6) intersection closed loop system will be in place and operational by spring 1994 along VFW Parkway. Other major municipalities with computerized signal system systems include the City of Waltham and the City of Cambridge

Incident Management - A number of incident management program elements have already been initiated within the Boston metropolitan area by MHD and the Massachusetts State Police. These include service patrols utilizing in-house MHD and contracted resources; and a toll-free highway emergency number (*SP) established by the Massachusetts State Police, working in conjunction with the cellular telephone companies, whereby motorists can report incidents to the Massachusetts State Police communications center in Framingham.

Surveillance Function

Nearly all of the priority IVHS functions depend on collecting, processing, and managing real-time information regarding the transportation network. These data are used by the system for congestion monitoring, incident detection, development of traveler information, and optimizing control strategies. The information on traffic flow may also be processed and stored for planning and historical analyses. The importance of an accurate and reliable surveillance subsystem cannot be overstated. It is truly the "heart" of an IVHS-based system.

The roadway detection subsystem will initially consist of existing loop detectors, new loop detectors, and new overhead-mounted devices (utilizing microwave technology) to measure traffic flow volumes and speeds. Detector stations, covering all lanes, will be located throughout the roadway network. The detectors stations will be spaced at nominal M-mile intervals along those roadway segments which experience the greatest congestion and highest incident rates (e.g., the Southeast Expressway, sections of Route 128, etc.); with longer spacings (1 to 3 miles) for the remaining segments depending on their respective traffic flow characteristics and the availability of power and communications tie-ins. Detection data will be preprocessed in the field using Type 170 controllers on the next-generation version (i.e., Model 2070) of this device.

In the future, the Boston area surveillance subsystem may consist of the vehicles themselves -- being tracked as they traverse the roadway network, and providing real-time information on segment-and direction-specific travel times and speeds. Using vehicles as automated "probes" can be achieved in a number of ways, including AVI tags (which are also used for electronic toll collection), cellular phones, or in-vehicle traveler information devices. In addition to vehicle detection, the roadway surveillance network will also include weather sensors to detect a variety of surface conditions (e.g., wet, ice, snow, salted-slush, etc.) and overheight detectors to provide warnings to vehicles well in advance of the Central Artery/Third Harbor Tunnel.

In addition to monitoring the roadway network, real-time surveillance of transit modes is also an important function of the Boston area IVHS network. Such real-time data on vehicle locations will be used to enhance operations control and passenger information. The transit information will also be integrated with the roadway network data at the TICC to provide a multi-modal traveler information database throughout the region. The MBTA's on-going project to upgrade the "T" lines in terms of surveillance, operations control, and real-time information has already been noted. Given the relatively high priority given to the route/mode guidance function, the strategic deployment plan also includes a recommended expansion and enhancement of this transit surveillance network to ultimately include the commuter rail lines and buses.

Incident Management Function

Non-recurring congestion is the result of "incidents" which block travel lanes or otherwise reduce capacity, thereby impeding traffic flow on the freeway. These freeway incidents are relatively unpredictable and can take on several forms including accidents, disabled vehicles, spilled loads, adverse weather, and special events. The level of nonrecurring congestion in the Boston area freeway network is significant. Statistics developed by the Federal Highway Administration indicate that approximately 78 percent of all freeway congestion in the Boston region is attributable to incidents.

Incident management can be defined as a coordinated, preplanned use of human and mechanical resources to restore full capacity as soon as possible after an incident occurs, and to efficiently manage traffic during the incident. The freeway incident management process involves the following activities:

- Reducing the time required to detect the occurrence of an incident (i.e., awareness)
- Reducing the time required to verify the incident, identify the types of vehicles involved, and to determine the proper response (i.e., identification)
- Reducing the time required to notify the necessary agencies and organizations, and then for the appropriate equipment and personnel to arrive on the scene (i.e., response)
- Reducing the time required for the incident to be cleared from the roadway, restoring full capacity, while exercising proper on-scene management of traffic flow (i.e., clearance)

The Massachusetts Highway Department and the Massachusetts State Police initiated an incident management program throughout the Commonwealth several years ago. The existing features of this on-going effort, plus the additional elements recommended in the Boston area IVHS Strategic Plan, include the following:

Cellular Call-In - As previously noted, a toll-free cellular number (*SP) has been established in central/eastern Massachusetts whereby motorists can report incidents to the Massachusetts State Police communications center in Framingham. The Framingham center currently handles over 20,000 cellular phone calls per month from the 617 and 508 area codes. Cellular phones and the *SP network have undoubtedly decreased the incident detection time -- the State Police estimate that they are detecting the reported incidents within a minute of occurrence. This manual method of incident detection and surveillance is expected to continue. To improve the accuracy of the information provided by callers with respect to incident location, supplemental guide signs -- including 1/10 mile markers and overpass/underpass roadway names -- are recommended throughout the roadway network.

Automated Incident Detection - The *SP incident detection subsystem will be supplemented by automated incident detection along the high-accident/high-volume segments of the roadway network. As previously noted, these segments are being instrumented with detectors at nominal l/2-mile intervals, thereby providing detection of incidents within 3-5 minutes after their occurrence. The purpose of the automated incident detection function is not to improve the detection time provided by *SP; but rather to ensure that no incidents are missed along these critical segments of the roadway network.

TV Surveillance - Closed-circuit television (CCTV) has been used extensively in freeway management systems for incident verification. Cameras are installed along segments of the roadway, and the video pictures are transmitted back to a system control center; thereby permitting operators and police to rapidly confirm a suspected incident (as reported by automated detection algorithms or *SP), to verify the nature of an incident, and to assist responders in quickly determining the appropriate course of action. Full CCTV coverage (i.e. no "blind' spots) is recommended for those roadway segments with %-mile detector spacing -- that is, the areas with automated incident detection. Video surveillance is also recommended in the vicinity of major interchanges and other segments which regularly experience congestion. The CCTV assemblies will consist of color cameras mounted on poles, and will include remote pan, tilt, and zoom capabilities.

Freeway Service Patrols - A freeway service patrol consists of a vehicle (e.g., van, tow truck, etc.) and operator that patrol the freeway network, providing motorist assistance and handling minor incidents (e.g., providing gas, pushing disabled vehicles to nearest exit, changing flat tires, clearing debris, etc.). Freeway service patrols dramatically reduce the incident response and clearance time because the service provider is immediately on the scene, rather than appearing several minutes (or longer) after the incident has initially been detected. MHD has recently awarded a contract to Samaritania, Inc. to provide peak period service patrols (incorporating both vans and pick-ups) throughout Massachusetts, including 16 routes in the Boston metropolitan area. It is recommended that an additional 12 patrol routes be implemented covering most of the roadway segments not included in the initial contract. Moreover, it is recommended that the operation of the service patrols be extended beyond the peak periods to 6:00 AM - 8:00 PM.

Other - Additional elements of the incident management function include:

- **Quick Clearance Policy** - The Massachusetts State Police and MHD have formulated and instituted a Quick Clearance Police, and have entered into an interagency agreement making restoration of normal traffic flow the first priority at an incident site. The policy and supporting legislation enables responding agencies to act quickly in clearing disabled vehicles and debris from the roadway.

Removal of Vehicles - Motorists who are involved in an accident are required to stop at the scene and wait for the police. It is recommended that the Massachusetts law be modified such that, in the case of property-damage-only accidents, the involved vehicles are stopped "without obstructing traffic more than necessary." In this manner, motorists must move their vehicles (if possible) to the shoulder thereby clearing the travel lanes.

Traveler Interface

Traveler interface technologies provide the means by which travelers (and soon-to-be-travelers) are provided with real-time information regarding roadway, transit, and traffic flow conditions, This information can assist the traveler with planning his/her trip, selecting the optimum mode or route, and dynamic decision making during the trip so as to improve the efficiency and convenience of travel (i.e., enhanced mobility). Most of this information is obtained by the surveillance function elements. The traveler interface elements disseminate the information to travelers utilizing a variety of audio and visual techniques.

Traffic Information Broadcasting - The private sector is seen as playing a signigicant role in the dissemination of traveler information. In essence, the public side (i.e., MHD MBTA, MTA, MassPort, etc.) will collect and integrate surveillance information; while the private side will analyze the integrated data, tailor the information to meet the unique requirements of the end users (i.e. a "value added"), and then market and disseminate the traveler information via a variety of outlets including radio and television media, cable TV (e.g., "Traffic Channel"), Highway Advisory Telephone (similar to SmarTraveler), interactive information kiosks at major generators and transfer locations, and in-vehicle devices. The interface between the TICC and private traveler information entities will rely primarily on workstations providing text-based information and color graphics displays, with some use of video from CCTV.

Variable Message Signs - The use of variable message signs (VMS) is seen as an integral part of the traveler information function. Signs will be located in advance of freeway-to-freeway connections, on the approaches to and along those roadway segments which experience the greatest congestion, and in advance of the exits for major intermodal points (e.g., park-and-ride lots). The VMS will incorporate light-emitting technology (e.g., fiber optics with reflective flip disks) to maximize message visibility and legibility.

Demand Management

Solutions for recurring congestion fall into the broad category of "demand management", as their focus is to reduce the demand along roadway segments and at bottleneck locations. Since an incident is a form of roadway bottleneck, the demand management strategies discussed herein may also be applied to the overall incident management process.

Metering - Meters are traffic signals placed at the freeway entrances. They control the rate at which vehicles enter the mainline (i.e., manage the demand) such that the downstream capacity is not exceeded, thereby allowing the freeway to carry the maximum volume at a uniform speed. The proposed metering plan for the Boston area IVHS network includes most of the Route 128 on-ramps (except for the freeway connectors); the Route 3A on-ramp to I-93 northbound; and inbound mainline metering (i.e., signals placed over each lane of a widened segment of the freeway itself) along Route 3 (north and south of Boston), I-95 (north and south of Boston), Route 24, and I-93, with all mainline meter locations upstream of Route 128.

This metering configuration will ensure that nearly every inbound motorist will be metered, thereby reducing recurring freeway delay in an equitable manner. Including HOV bypass lanes, particularly at the mainline meter stations, will also provide an incentive for reducing the number of single-occupancy vehicles on the network and encouraging the use of transit. Additionally, the mainline meter stations may also be modified and utilized in the future for congestion pricing.

Communications

The communications network provides the connecting link for the exchange of information between field hardware and an operations center, and between the various agency-specific TOCs and the TICC. Several communication alternatives and configurations were analyzed in terms of their bandwidths, reliability, expandability, and life-cycle costs. Leased telephone circuits from New England Telephone were determined to be the most cost-effective for the Boston area IVHS network. This communications network will consist of "DIGIPATH" digital data circuits between the control center and the various field elements (e.g., detectors, VMS, camera control, ramp meters, etc.), and "TV-I" analog circuits (i.e., fiber optics leased from New England Telephone) for the transmission of video from the CCTV cameras to the control centers. These circuits will also be utilized for the exchange of information between agency-specific TOCs and the TICC.

Central Hardware and Software

The central hardware and software provide the mechanisms by which the agency-specific TOCs share information and decision support via the TICC. The central architecture -- for both the regional TICC and the MHD-TOC -- is built around the following:

- Real-time data distribution via a "client-server" model, thereby facilitating the communication and integration between potentially disparate systems.
- Region-wide traveler information database based on a geographic information system (GIS), thereby providing a common reference for a large volume of spatial data obtained from multiple sources.
- Integrated workstations -- which incorporate graphic, text, and video displays -- for user access.
- User - selectable information presented through a Graphical User Interface (GUI), supported by audible and/or visual alerts to allow operators to monitor the system while carrying on their other tasks.
- An Expert System (resident at the TICC) which will continuously look for anomalies in the collected information, determine the potential impacts of these problems on the region's transportation network, identify response strategies (in accordance with pre-approved plans), and submit these actions to agency - specific TOCs for implementation.

Control Centers

Control centers, including agency-specific TOCs and the regional TICC, are the focal points of the Boston area IVHS network. These facilities house the central hardware and include space for the system operators, technical staff, and decision makers. Considering the region-wide emphasis and functionality of the TICC, plus the need for easy access by all involved agencies (MHD, MBTA, MassPort, MTA, etc.), this facility will be located at the State Transportation Building at 10 Park Plaza. The MHD-TOC will be located at the State Police facility in Framingham, thereby facilitating coordination for the incident management function. These control centers will initially operate from 6:00 AM to 7:00 PM on each working day, with extended hours in support of special events and weather emergencies. It is envisioned that the TICC and the MHD-TOC will ultimately operate 24 hours-a-day, 7-days-a-week.

Operations and Maintenance

The key to success for the Boston area IVHS program will be an effective program of operation and maintenance. This will require an adequate staff of well-trained personnel, up-to-date documentation on all system components, adequate budget for spare parts and expendables, and a long-term commitment on the part of MHD (and other affected agencies) to utilize the system to its full potential, including keeping the response plans, VMS displays, and system algorithms up-to-date on a continual basis. A "set-it-and-forget-it" policy will & work. It is envisioned that these operations and maintenance activities will be provided by a combination of MHD personnel (in-house), contract services, and public-private partnerships.

IMPLEMENTATION

The various IVHS recommendations for the Boston area transportation network have been designated for inclusion into one of the following implementation scenarios:

- Phase 1 Plan - the initial IVHS network, which is scheduled to be completed and operational within 2-3 years. In developing the Phase 1 recommendations, emphasis was placed on making the maximum use of existing resources, and on deploying technologies which are proven and readily available.

- Year 2000 Plan - a functional, geographic, institutional, and technical expansion of the Phase 1 System. In essence, the year 2000 recommendations, coupled with the Phase 1 Plan, represent the "ultimate" configuration of the Boston area IVHS network.

Exhibit 4 shows the recommended Phase 1 and Year 2000 areas of IVHS implementation. In essence the Phase 1 area incorporates those roadways which experience the largest volumes, the highest volume/capacity ratios, and the greatest number of incidents as compared to the rest of the project area. Moreover, the Phase 1 area includes several existing elements (e.g., detector stations) which can be readily integrated into the NHS-based system. Implementation of the Phase 1 Plan will involve multiple projects, including:

- Early Action Incident Management Program - This project covers the Route 128 corridor between Route 28 in Wakefield in the Route 3/I-93 interchange in Braintree; and includes the deployment of detectors, cameras, and VMS within the corridor the initial MHD-TOC at the State Police communications center, and the associated communications network.

- I-93 Corridor in Medford, Somerville, Cambridge, and Boston - In addition to the installation of detectors, cameras, and VMS along this segment of the freeway network, the project also includes integration with the surface street network (e.g., detectors, signal systems) and MBTA parking.

- Southeast Expressway Corridor - This project includes the installation of detectors, cameras, and VMS in conjunction with the proposed HOV facility.

- Other - One or more projects will be implemented to complete the Phase 1 IVHS network. In addition to the remaining roadway segments, these projects will also include the weather detectors, overheight sensors, supplemental guide signs, and the initial TICC.

- Metering Public Relations - Actual implementation of the ramp and mainline meters is part of the Year 2000 Plan. However during Phase 1, a proactive public relations and information program regarding the recommended metering will be initiated.

SYSTEM COSTS & BENEFITS

The estimated cost for the

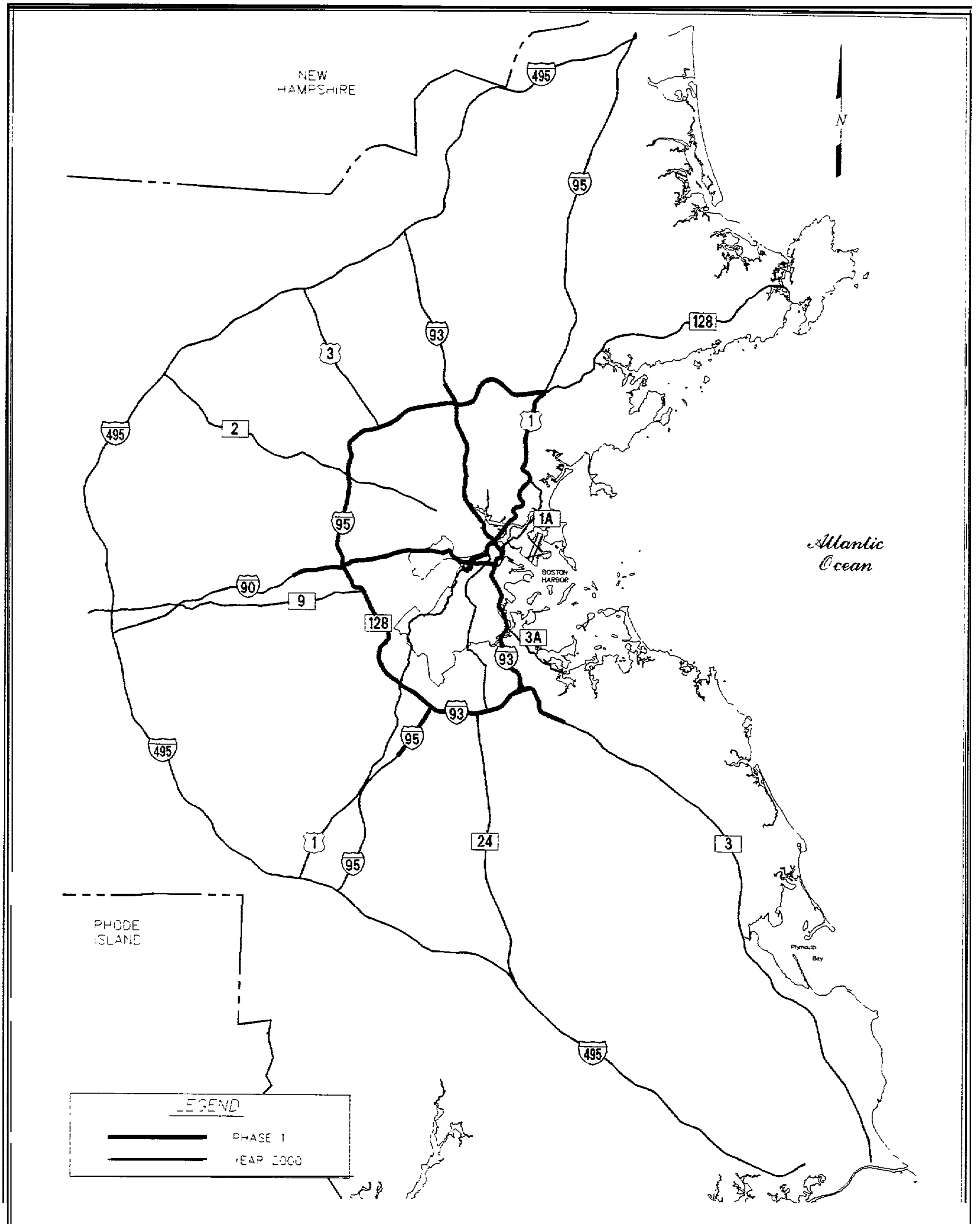


Exhibit 4: Recommended implementation

recommended Boston area IVHS network is approximately $91.5 million in capital costs, with a continuing annual operations and maintenance cost of $12.2 million. Of this total, the Phase 1 implementation represents approximately $40.4 million in capital costs, plus $5.3 million/year for operations and maintenance.

IVHS networks have proven to be one of the most cost-effective methods for reducing congestion and improving the operation of the transportation network. A study by FHWA has identified significant benefits resulting from the implementation of systems such as the one recommended for the MHD roadway network, including an average 37 percent reduction in incident-related delay, an average 28 percent reduction in recurring delay and an average 22 percent reduction in excess fuel consumption. An air quality analysis was performed to assess the potential benefits associated with the implementation of the recommended IVHS program. The results of this conservative analysis for the Phase 1 area indicated a reduction of approximately 190 KG/day in volatile organic compounds, 1000 KG/day in carbon monoxide, and 40KG/day in nitrous oxides. Moreover, these quantitative benefits do not begin to address the improved mobility afforede by the recommended IVHS network.

SUMMARY

The Boston area IVHS Strategic Plan reflects a major commitment on the part of the Massachusetts Highway Department and other agencies to actively manage the day-to-day operations of the region's transportation network. Such a commitment is not only feasible; but it is also necessary if the area is to maintain its economic growth and vitality. Moreover, the expected benefits to taxpayers far outweighs the system's cost.

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LIST OF EXHIBITS (continued)

1. INTRODUCTION

This report documents the results of a study conducted by the JHK & Associates project team for the Massachusetts Executive Office of Transportation and Construction (EOTC) and the Massachusetts Highway Department (MHD). The primary goal of the effort was to develop a strategic plan for implementing an Intelligent Vehicle-Highway System (IVHS) throughout metropolitan Boston during the next decade. The strategic plan is defined herein in terms of the user services and functions to be provided by the IVHS network, the regional architecture for implementing IVHS-based systems, the supporting technologies and strategies required to perform the various functions, the approximate locations of the system components, the operations and maintenance requirements, the implementation priorities, and the associated costs and benefits. In essence, this strategic deployment plan provides the overall framework by which budgets may be established and detailed construction plans and specifications can be developed.

BACKGROUND

The transportation management initiative known as "Intelligent Vehicle-Highway Systems" (IVHS) refers to transportation systems that involve integrated applications of advanced surveillance, communications, computer, display, and control process technologies -- on the roadway network, in the vehicle, and for transit modes. The goals of IVHS parallel those of EOTC and the MHD -- to improve the efficiency of the transportation network thereby alleviating congestion, reducing fuel consumption and pollution, and improving the timeliness of person movement and good deliveries; to enhance the safety of the users of the system; and to enhance overall mobility such that productivity and economic competitiveness are maximized.

IVHS has traditionally been divided into the following six categories:

- <u>Advanced Traffic Management Systems (ATMS)</u> - An ATMS is an array of institutional, human, hardware, and software components which can monitor, control, and manage traffic on a "real-time" basis within an urban highway corridor.

- Advanced Traveler Information Systems (ATIS) - An ATIS provides travelers (and soon-to-be travelers) with real-time information regarding roadway, transit, and traffic flow conditions; as well as navigation and location data. The ATIS information is provided through visual and audio means on the roadway, in the vehicle, at home, and at work.

- Advanced Rural Transportation Systems (ARTS) - ARTS is the application of IVHS technologies to rural and small urban (less than 50,000 population) areas in an effort to improve safety, mobility, and productivity.

- Advanced Public Transportation Systems (APTS) - APTS is the application of the IVHS technologies to enhance public transportation services particularly in the areas of market development, customer interface, vehicle operations and communications, and HOV (High Occupancy Vehicles) facility operations.

- Commercial Vehicle Operations (CVO) - CVO is the application of IVHS technologies for improving the productivity, safety, and regulation of commercial vehicle operations -- including trucks, delivery vans, emergency vehicles.

- Advanced Vehicle Control Systems (AVCS) - AVCS serves to greatly improve safety and potentially make dramatic improvements in highway capacity by providing information about changing conditions in the vehicle's immediate environment, sounding warnings of eminent problems, and assuming partial or total control of the vehicle.

Many aspects of these IVHS categories have similar functional requirements and overlapping technologies. For example, ARTS, APTS, and CVO systems mostly include technologies which are also used to support ATMS and ATIS. Additionally, since ATMS is considered the "umbrella" for the communications, surveillance, and processing technologies required by the other IVHS categories, basing the IVHS planning process on the traditional categories can introduce an inherent bias of implementing a "high-tech" roadway-based ATMS before even considering other needs such as transit and traveler information.

Another concern when developing a comprehensive IVHS strategic plan is the potential impact and influence of technology. IVHS is receiving significant national and international attention at this time. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 emphasizes transportation management activities and related system applications, the development and deployment of advanced IVHS technologies and strategies in these systems. As a result of this increased emphasis and funding, new technologies and devices are being brought to the IVHS area which were not considered, in some cases, as recently as one year ago. Many of these technology enhancements -- particularly in the areas of surveillance, processing, and communications -- appear to offer better and/or more cost-effective methods for achieving the transportation objectives within the Boston region; although it must be emphasized that most of these potential system elements have not yet been proven in an operational transportation management system. This influx of "better" technology, coupled with intense marketing by IVHS product vendors, can lead to a situation where the strategic planning process becomes an exercise of "technology looking for a problem". Instead, the process should concentrate on developing solutions to these problems, and then selecting the appropriate technologies for implementing these solutions.

In essence, the strategic planning process must recognize that the key concept in defining IVHS is the term "integrated applications". This means that IVHS-based systems are more than the mere implementation of advanced technologies. These systems must also provide for the sharing of information, hardware, and/or staff in such a manner that the transportation network -- consisting of expressways, surface streets, and transit routes; all passing through multiple jurisdictions -- is treated as a single "seamless" entity.

IVHS PLANNING PROCESS

In light of the concerns noted above, JHK's approach was to define the Boston area's transportation needs in terms of user services and corresponding IVHS functions; and then to identify the appropriate technologies and system configurations for achieving the required functions in a cost-effective manner. The overall approach is shown in Exhibit l-l and summarized below.

Define Problems

The initiative to improve a transportation system usually results from the recognition of problems with the current operations. Accordingly, the first step of the strategic planning process was to identify and define these problems -- be they roadway congestion, safety, transit operations, etc. Concurrently, existing IVHS-based systems (both existing and proposed) were inventoried to establish their composition and available resources, thereby maximizing compatibility between systems. The results of the problem identification stage are discussed in Chapter 2.

Establish Institutional Framework

IVHS-based systems must fit within the existing organizational and institutional infrastructure. Accordingly, the strategic planning effort must involve numerous public and private organizations, working together as a coalition. This was accomplished via interviews with persons in both the public and private sectors who have interest or responsibilities for the planning, design, construction, operations, or maintenance of transportation management systems. The interviews focused on the current and future transportation needs within the Boston area, the perceived role of IVHS in meeting these needs, existing and proposed IVHS-based systems, the existing organizations involved in transportation management and their respective roles, marketing of IVHS, partnerships for implementing and operating IVHS-based networks, and factors to be considered in evaluating alternatives.

A total of 38 people in 25 organizations were interviewed, as listed in Appendix D (along with a copy of questionnaire). The interviews served to inform the interviewees of the IVHS project; while at the same time giving the project team immediate awareness of the opinions of people who were knowledgeable about policy and other matters related to transportation. This served to include wider input into the IVHS strategic planning process.

An Advisory Committee was also formed to review project documentation, and to discuss a variety of institutional and technical issues related to the IVHS Strategic Plan. The Advisory Committee was comprised of policy-level and operations personnel from transportation agencies in Eastern Massachusetts as listed in Exhibit 1-2. Committee Meetings were held on quarterly basis throughout the project, and offered an invaluable forum for presenting preliminary recommendations and discussing the interagency (i.e., regional) impacts associated with these recommendations.

Exhibit 1-2: Advisory Committee

Agency	Member/Representative
Massachusetts Highway Department	Mr. William T. Steffins Mr. Charles F. Sterling III
Bureau of Transportation Planning & Development	Mr. Daniel F. Beagan
Executive Office of Transportation and Construction	Mr. Michael Swanson
Central Transportation Planning Staff	Ms. Efi Pagitsas
Central Artery/Third Harbor Tunnel	Mr. Dan Kretchmer
Massachusetts Bay Transportation Authority	Mr. David Nelson
Massachusetts Turnpike Authority	Mr. John Judge
Massachusetts Port Authority	Ms. Mary Jane O'Meara
Massachusetts State Police	Lt. Col. Thomas Kennedy
Boston Transportation Department	Mr. Frank Tramontozzi
Metropolitan District Commission	Ms. Julia O'Brien
Federal Highway Administration	Mr. Edward Bates
JRTC	Mr. Dominic D'Eramo

NOTE - Invitations were also extended to the 1000 Friends of Massachusetts organization.

Identify User Services

As previously noted, when developing an IVHS strategic plan, it is crucial to think in terms of the services and functions to be provided by the systems; not which technologies can be utilized

Five areas of user services were identified for the Boston region as follows:

- Traveler information
- Traffic Management
- Freight and Fleet Management
- Public Transport Management
- Electronic Toll Collection

where "users" may be travelers, drivers, transit riders, commercial fleet operators/dispatchers, and transportation management personnel. Exhibit l-3 provides descriptions of these user services and the associated system functions.

Develop System Goals and Define Functional Requirements

This step of the process involved the development of program goals and the prioritization of IVHS functions for achieving these goals. The methodology for evaluating the various functions relative to the system goals and the results of these activities are presented in Chapter 3.

Define System Architecture

An IVHS architecture describes what a system does and how the system functions are provided, creating the general framework within which the various system components are deployed. In a metropolitan area such as Boston, where the transportation network is managed and operated by several different entities, the development of a regional architecture -- identifying the agency-specific transportation management systems, their respective functions, and the information linkages between these systems -- was also necessary.

Exhibit 1-3: Boston Area IVHS User Services and Functions

TRAVELER INFORMATION

- Advisories - real-time information on transportation facility conditions such as congestion, incidents, delays, weather, closures, service changes, parking lot availability, next vehicle arrival, etc -- information which travelers may utilize to plan their trip (i.e., pre-trip) or modify their trip enroute. The basic information is provided with no alternative route or mode information,
- Trip Planning - real-time information on fares, schedule adherence, and travel times for transit networks; and tolls, delays and travel times for roadways; to further aid the traveler in selecting the best route, mode, or departure time. This is differentiated from "Advisories" in that travel time and cost information is provided.
- Route/Mode Guidance - an advanced form of trip planning in that transit and roadway information is combined, and the optimum route or mode may be automatically selected based on traveler-entered parameters (e.g., origin and destination, mode and route preference, cost, etc.).
- Yellow Pages/Services Information - non-transportation related information describing characteristics and locations of services, and their providers (i.e., "yellow pages").
- Location Displays - showing the vehicles current position relative to the transportation network.

TRAFFIC MANAGEMENT

- Traffic Network Monitoring - real-time (and possibly predictive) surveillance of the roadway network to identify traffic flow conditions. (e.g., detectors, vehicle probes, etc.)
- Incident Management - a designated subsystem and/or set of procedures aimed specifically at the rapid detection and verification of roadway incidents, followed by rapidly responding to and clearing those incidents.
- Freeway Ramp Metering/Access Control - strategies on the freeway (or approaches thereto) which call for adaption and response to different traffic patterns and demands as they occur (e.g., ramp metering rates, access control).
- Surface Street Traffic Control - strategies on the surface street network which allow for adaptation and response to different traffic patterns and demands as they occur (e.g., signal timing plans).

Exhibit 1-3: Boston Area IVHS User Services and Functions (continued)

- Demand Management - strategies to encourage travel during non-peak periods or by alternate modes (e.g., congestion pricing).
- Construction Management - scheduling of construction/maintenance activities and setup of construction zones so as to minimize their effects on traffic flow.

FREIGHT AND FLEET MANAGEMENT

- Route Planning and Scheduling - informed routing decisions by fleet dispatchers based on real-time knowledge of roadway conditions and vehicles' locations.
- Vehicle and Cargo Monitoring - real-time information on shipment status (e.g., location delays, temperature of refrigerated cargos, other problems).
- HAZMAT Monitoring and Tracking - coordination of routes, advance notice to appropriate entities regarding vehicle status, and improved emergency response.
- Weigh-In-Motion (WIM) - permits rapid weighing of commercial vehicles such that a full stop is not required.
- Regulatory Support - speeding up the regulatory process and reducing the required number of regulatory stops (e.g., paperless transactions and recording, transparent borders, etc.)

PUBLIC TRANSPORT

- Transit Vehicle Monitoring - real-time information on vehicle locations and schedule adherence (e.g., projected arrival times) to aid the fleet manager in dispatching as well as input to traveler information.
- Transit Vehicle Priority - strategies which reduce transit vehicle delay at traffic control devices (e.g., signal preemption, ramp meter bypass).
- Smart Fare Payment - automatic debiting of the appropriate fare from travelers' pre-paid account, thereby providing quicker fare collection and a flexible fare structure.
- Dynamic Ride Sharing - dynamic information of carpools, matching drivers to travelers.
- Safety/Security Systems - two-way links allowing transit vehicles to communicate with the fleet dispatcher about any problems.

ELECTRONIC TOLL COLLECTION

- Electronic Toll Collection - automatic identification of vehicles and automatic debiting of the appropriate amount from a pre-paid account or other billing through another arrangement.

A discussion of architecture issues and the recommend IVHS architecture for the Boston region are presented in Chapter 4.

Identify and Screen Alternative Technologies

This step focused on screening alternative technologies (i.e., surveillance, traveler interface, control strategies, communications, data processing, etc.) in terms of their ability to provide the priority IVHS functions, their compatibility with other system components and with the system architecture, availability of standards, life-cycle costs, operational and maintenance requirements, and implementation timeframes. The various IVHS recommendations for the Boston area transportation network were designated for inclusion into one of the following implementation scenarios:

- Phase 1 Plan - the initial IVHS network, which is scheduled to be completed and operational within 2-3 years. In developing the Phase 1 recommendations, emphasis was placed on making the maximum use of existing resources, and on deploying technologies which are proven and readily available.

- Year 2000 Plan - a functional, geographic, institutional, and technical expansion of the Phase 1 System. In essence, the year 2000 recommendations, coupled with the Phase 1 Plan, represent the "ultimate" configuration of the Boston area IVHS network.

Strategic Deployment Plan

The culmination of the previous activities is the development of an area-wide Strategic Deployment Plan. This document serves as a "road map" for incorporating IVHS technologies throughout the Boston metropolitan area.

Initial Implementation Project

In addition to the developing the IVHS Strategic Deployment Plan for the Boston region, the JHK project team also developed conceptual engineering documents for an initial implementation project of the Phase 1 Plan. This "Early Action" project covers the 1-93/I-

95/Route 128 corridor between Route 28 in Randolph and Route 28 in Wakefield, and includes the deployment of detectors, cameras, and variable message signs within the corridor, an initial control center, and communications network.

Discussion

The aforementioned advances in technology and introductions of new IVHS products (a trend which is continuing) created a dilemma of sorts in developing the implementation scenarios and the corresponding technology recommendations. On the one hand, the various recommendations could not simply assume that all of the new (and unproven) technologies will function as promised by their suppliers and manufacturers, or that unit costs will decrease over time as such an approach could lead to an overly expensive system which does not function as planned and/or requires a significant maintenance commitment. At the same time, the IVHS recommendations could not rely solely on proven technologies; as this rationale would surely lead to the implementation of a system that is obsolete before its time and is difficult to expand.

JHK'S approach in this regard was to define system and subsystem architectures which maximize flexibility and modularity. This will allow the Boston area IVHS network to evolve both geographically and functionally over time, taking advantage of new technologies and strategies as the system matures. Specific hardware and software recommendations are made, which in many instances include new and innovative approaches. Such recommendations, however, are accompanied with appropriate caveats as to the current status of these newer elements, their potential for success, and possible risks.

The IVHS Strategic Plan for the Boston region as documented herein -- particularly the 2000 plan -- should not be viewed as “etched in stone”. As with all systems which include a strong technology base, change is inevitable. Specific recommendations should be reviewed prior to each implementation project to confirm that the selected technologies and strategies are suitable and appropriate in light of any recent advancements in transportation management systems and control technologies.

REPORT ORGANIZATION

Following these introductory remarks, the report essentially follows the planning process as previously discussed, and includes the following chapters:

2. EXISTING CONDITIONS - This chapter discusses the project area roadways and their respective traffic flow characteristics, accident experience, and problems. The area's extensive transit network is also described. Existing and proposed IVHS - based elements are summarized as well.

3. IVHS FUNCTIONS - The priority functions to be addressed by the IVHS network are addressed in this chapter, along with the methodology used to evaluate and identify these specific functions.

4. REGIONAL IVHS ARCHITECTURE - This chapter describes the overall IVHS architecture which is recommended for the Boston region, and describes the various technical and institutional issues associated with this regional architecture.

The remainder of the report focuses on the priority functions of the Boston area IVHS network, the supporting technologies and strategies required to achieve these functions, the estimated costs and benefits, and the recommended approaches for implementing the strategic IVHS plan. Specific chapters in this regard are as follows:

5. SURVEILLANCE - The technologies and procedures for collecting a wide range of information concerning the transportation network. This chapter discusses available technologies for gathering and processing roadway and transit information, detector spacing, and related issues.

6. INCIDENT MANAGEMENT - This chapter describes the recommended elements of the strategic plan relating to the incident management function -- detection; verification, response, and clearance.

7. TRAVELER INTERFACE - A discussion of IVHS elements which will be utilized by travelers (and soon-to-be-travelers) to obtain real-time information on roadway, transit, and transportation conditions.

8. DEMAND MANAGEMENT - This chapter discusses ramp metering and its potential application in the Boston area.

9. COMMUNICATIONS - The network required to support data and video communications within the IVHS network is described in this chapter, including a discussion of alternatives and analysis thereof.

10. CENTRAL HARDWARE AND SOFTWARE - This chapter includes a description of the database organization, central processing and video monitoring hardware, software functions, decision support mechanisms, and user interface.

11. CONTROL CENTER - This chapter discusses various issues associated with the proposed IVHS control centers, including space requirements, layout, and location.

12. OPERATIONS AND MAINTENANCE - This chapter discusses the staffing levels and qualifications required for an on-going program of IVHS operations and maintenance.

13. SYSTEM IMPLEMENTATION - The estimated costs and benefits, potential funding sources, and approaches for deploying the IVHS network in metropolitan Boston are identified in this chapter.

Appendix A - A list of the freeway segments within the project area, and their corresponding traffic flow characteristics.

Appendix B - Approximate locations of the Phase 1 field hardware (VMS, CCTV, detectors) are shown on 2000-scale plans, along with listings of this hardware for both the Phase 1 and Year 2000 plans.

Appendix C - A list of all on-ramps within the Phase 1 area, and their characteristics for ramp metering.

Appendix D - A list of agencies and persons interviewed during the project, along with a copy of the questionnaire form.

2. EXISTING CONDITIONS

The study area was identified as the primary roadways within I-495, inclusive. As IVHS is a multimodal initiative, the Boston area's extensive transit network was also included in the analyses.

ROADWAY NETWORK

The project area roadways, shown in Exhibit 2-1 and 2-1a include the following facilities:

- I-495 - Interstate Route 495 (I-495) is part of the Federal Interstate system, and is maintained by MHD. Generally, I-495 is a six-lane roadway with a wide median area separating northbound and southbound roadways. The exception to this is a 15-mile segment south of Route 24 where the roadway is four lanes divided.

- I-95 - Between the southerly I-495 interchange and the Route 128 circumferential roadway, this MHD-maintained roadway is a six-lane divided facility. In its circumferential routing between the I-93 interchange northerly to Route 9 in Wellesley it is also a six-lane divided facility, but the use of the shoulder for general travel is permitted during peak periods. I-95 is an eight-lane divided facility from Route 9 northerly to the northerly I-93 interchange in Woburn. From Woburn to Peabody, a six-lane divided section is maintained, with a drop to four lanes through the Route 128 interchange in Peabody -- the point at which its circumferential routing ends. The I-95 corridor widens to eight lanes from Peabody to Newburyport, then to six lanes extending to the northerly terminus of the study area at I-495 in Salisbury.

- I-93 - This MHD facility begins at the I-95/Route 128 interchange in Canton. The southerly five miles of the corridor is part of the Route 128 circumferential roadway, ranging from six lanes divided, with use of the shoulder as a travel lane permitted during peaks, to eight lanes north of Route 24. The I-93 corridor then turns to a north-south alignment at Route 3 in Braintree, where it is referred to as the Southeast Expressway. The Expressway is generally a six-lane divided facility, with the use of breakdown lanes permitted for travel during the peak periods. There are no shoulders between the Massachusetts Avenue interchange in Roxbury and the Route 1 interchange in Charlestown -- the segment which is the focus of the Central

Artery/Third Harbor Tunnel Project. North of the Route 1 interchange, the facility is generally eight-lanes divided to Andover, where it drops to a six-lane divided facility extending beyond the I-495 interchange to New Hampshire.

- I-90 - The Massachusetts Turnpike (I-90) is a 135-mile toll-highway running from the western border of Massachusetts into the City of Boston. It is owned and operated by the Massachusetts Turnpike Authority (MTA) The MTA also operates and maintains the Sumner and Callahan Tunnels which connect downtown Boston with Logan International Airport. Interstate 90 is a six-lane roadway with wide-median areas, except for the segment within I-95 where jersey barriers separate the eastbound from the westbound traffic.

- Route 24- Route 24 is a six-lane divided state highway which runs in a north/south direction, beginning in Randolph intersecting Route 128/I-93 and extending southerly to I-195 in Fall River. The facility is maintained by MHD.

- Route 1 - Route 1 is generally a four-lane to six-lane median and guardrail-divided north/south roadway within the project area. It functions as an urban arterial and is under the MHD's jurisdiction.

- Route 2 - Route 2 is a four-lane suburban arterial operated by MHD and the Metropolitan District Commission. It includes a six-lane divided section through Lexington and eight-lane divided section through Arlington and Belmont; and a four-lane undivided urban arterial under MDC control through Cambridge, Soldiers Field Road, and Storrow Drive to I-93.

- Route 3 - Route 3, which is under the jurisdiction of the Massachusetts Highway Department, runs in a north/south direction beginning in Bourne, running northerly and intersecting I-93 in Braintree. It then follows the I-93/Southeast expressway corridor to Boston where it departs the expressway system to become an arterial street to I-95 in Burlington. There Route 3 resumes as an expressway, running northerly to the New Hampshire border intersecting I-495 in Lowell. Route 3 is a four-lane divided roadway north of I-95. South of I-93, it is a six-lane divided facility through Braintree and Weymouth, where it then narrows to four lanes divided and extends southerly to the Route 6 interchange in Bourne. Within the four-lane section south of Weymouth, the use of breakdown lanes is permitted for travel to Hanover during the peak periods.

- Route 128 - Route 128 is generally a four-lane divided roadway from the I-95 Peabody and extending easterly to Gloucester. Older type interchange designs, rotaries, and signalized intersections are present along sections of this roadway. At the I-95 interchange, Route 128 becomes a circumferential expressway sharing designation with I-95 and I-93 as previously noted.

- Route 9 - Between I-495 and I-95, Route 9 is a four-lane divided roadway maintained and operated by the Massachusetts Highway Department. It functions as an urban arterial with commercial and retail land uses. Signal controlled intersections are present throughout the corridor as are several interchanges of older design.

- Route 3A - The Route 3A corridor as defined in this project extends from the Fore River Bridge at the Quincy/Weymouth line to Nepsonset Circle in Boston. It is an urban arterial which provides a cross section varying from six lanes divided to two lanes with parking in a commercial district. Sections are under control of the Massachusetts Highway Department, the City of Quincy and the Metropolitan District Commission. Capacity is controlled by traffic signal operation (approximately 15, some of which have limited time based coordination) and the presence of/need for parking in the business districts. The level of through traffic using the corridor is limited given the presence of two parallel routes which provide considerably more capacity. These include Quincy Shore Drive to the east and Newport Avenue on the west. Both coverage to the Route 3A corridor at the northerly end access Neponset Circle via the Neponset River Bridge.

CA/T Project

The Massachusetts Highway Department is in the process of planning, designing, and constructing the Central Artery (I-93)Tunnel (I-90) Project (CA/T Project) in Boston, Massachusetts. This CA/T Project will complete the interstate highway system in Boston by extending the I-90 Massachusetts Turnpike to Logan Airport via a Third Harbor Tunnel, and replacing the elevated section of the I-93 Central Artery. The CA/l'Project extends from a point just south of the Southeast Expressway/Massachusetts Avenue interchange to a point on Interstate 93 in Charlestown; and from the Massachusetts Turnpike/Central Artery interchange to a point on Route 1A in East Boston.

The CA/T Project will increase traffic capacity on the Central Artery by depressing and widening the existing facility. Cross-harbor capacity will be increased by construction of a

Third Harbor Tunnel through South Boston linking the Massachusetts Turnpike/Central Artery interchange in Boston with Logan Airport and Route 1A in East Boston.

The Central Artery, from the north portal of the Dewey Square tunnel to the Massachusetts Turnpike area, will segregate northbound traffic in a new cut-and-cover tunnel beneath Atlantic Avenue from southbound traffic in the modified Dewey Square tunnel. This is referred to as the "split alignment". North of Dewey Square, the Artery will be constructed in a cut-and-cover tunnel through downtown. The total length of the Project on the Southeast Expressway and the Central Artery is approximately 3.0 miles.

The depressed and widened Central Artery will have four to five lanes of traffic in each direction (in contrast with the current three) as well as improved ramp connections in the downtown area. The present elevated structure will be removed after completion of the depressed Artery. New ramps will connect with the reconstructed city street system at the surface. The high-level bridge over the Charles River will be replaced as part of this CA/T Project to provide an improved connection between Interstate Route 93, Route 1, and the Central Artery. Improved connections with Storrow Drive and with the Callahan and Sumner Tunnels will also be provided.

The extension of I-90 will include a two-way, four-lane limited-access highway, approximately 3.9 miles in length, with direct connections to the Massachusetts Turnpike, Southeast Expressway, Central Artery, Logan Airport, and Route lA to the north. This highway will extend easterly from the Massachusetts Turnpike/Central Artery interchange, across Fort Point Channel at its southerly point to the Commonwealth Flats area in South Boston, to continue beneath Boston Harbor to a portal at Logan Airport. Connections are provided to Route 1A north as well as to the Airport roadways. An open toll plaza will be located in East Boston.

Traffic Volumes

The annual average daily traffic volumes along the primary roadways within the project area were obtained from the report entitled 1992 Traffic Volumes prepared by the Massachusetts Highway Department, and from recent Environmental Impact Reports for area developments. The traffic volumes for the years 19991, 1994 and 2000 for the major roadways (i.e., expressways) are presented in Exhibit 2-2. A review. of the above reports showed that the growth trends along the major roadways within the project area had very little impact on the future traffic volumes. Thus, a growth rate of 1 percent per year was considered to be a conservative assumption. This growth rate was applied to the 1991 average annual daily traffic volumes to arrive at the existing (1993) and future volumes for the years 1994 and 2000.

Congestion

As noted in the introductory chapter, one of the goals of the IVHS initiative -- in Boston and throughout the nation -- is to reduce congestion on the roadway network. Freeway congestion occurs whenever vehicle demand exceeds the capacity of a section of the freeway. During non-congested conditions -- when volume is less than capacity -- the traffic flows smoothly, with a slight decrease in average speed as the volume increases. When the freeways capacity is reached, the mainline flow becomes "critical" as shown in Exhibit 2-3. While the freeway is operating in this critical area, any additional traffic or a capacity-reducing event (e.g., lane blockage, weaving, etc.) will cause the freeway to "break down" resulting in stop-and-go conditions. Concomitant with this congestion is a significant decrease in the freeway's throughput. Instead of 2000 vehicles/lane/hour traveling at 40 mph (i.e., 80,000 vehicle-miles/hour), the freeway can now only handle 1,600 vehicles/lane/hour traveling at 20 mph (i.e., 32,000 vehicle-miles/hour). In essence, congestion reduces the freeway's efficiency in half.

When examining congestion and potential solutions to the problem, it is important to distinguish between the two basic types of congestion -- recurring and nonrecurring. Each is discussed below.

Recurring Congestion

Recurring congestion is predictable, and typically occurs during the peak hours at the same location on a daily basis. The bottleneck may be the result of heavy traffic flow at an on- or off-ramp, a lane drop, a steep grade, a weaving area, a narrow cross section (e.g., bridge), or some other condition of increased traffic and/or reduced roadway capacity. Regardless of the cause, the effect is that volumes consistently exceed the capacity of the freeway section, resulting in recurrent congestion.

As part of the study, the roadway network was divided into several segments, each with uniform characteristics. Using the available data for traffic volumes, traffic characteristics, geometric, and facility environment, peak-hour volume/capacity ratios were calculated for each roadway segment as a measure of recurring congestion. The results are illustrated in Exhibit 2-4 and summarized in Appendix A.

It is emphasized that the volume/capacity (V/C) ratio calculations were based on the Highway Capacity Manual, and may overestimate the degree of recurring congestion. For example, the Capacity Manual is based on a nominal flow rate of 2000 vehicles/lane/hour; whereas observations within the northeast corridor have indicated stable flow rates of 2300-2400 vehicles/lane/hour. In all likelihood, this phenomenon is also occurring in the Boston area, which would explain the large number of roadway segments which have peak period V/C ratios greater than 1.0 -- a situation which is theoretically impossible. Moreover, recurring congestion is often caused by location-specific anomalies (e.g., weaving area at an interchange) which may not be identified in a macroscopic, segment-based analysis as performed for this study. Based on a review of the V/C ratios, interview results, and local knowledge of the project team, areas of recurring congestion were identified as shown in Exhibit 2-5.

Expanding the analysis to the 2000 design year results in little change. The increasing volume does increase V/C ratios with some movement between the less than 0.70 category to the 0.70 to 0.90 range, and from 0.70 to 0.90 to greater than 0.90. The impact of these increases in volume will be tempered in several corridors with the implementation of several projects identified in the draft report entitled "Transportation Plan for the Boston Metropolitan Region", prepared by CTPS, dated July 30, 1993. The restoration of transit service to the southeast via the Old Colony Branch of MBTA commuter rail is expected to improve conditions in the Route 3 corridor south of I-93. The widening of Route 3 (south) to a minimum six-lane divided facility from Duxbury north to Weymouth will soon be undergoing environmental review. The construction of Route 3 add-a-lane projects, both north and south of the 128/I-95/I-93 circumferential, together with a widening of the I-95 circumferential between Route 9 and Route 24, are part of the proposed program. As previously noted, the CA/T Project will add significant roadway capacity to an area which suffers the worst recurring congestion within the Boston area, if not the entire northeastern U.S.

Nonrecurring Congestion

Non-recurring congestion is the result of “incidents” which block ravel lanes or otherwise reduce capacity, thereby impeding traffic flow on the freeway. These freeway incidents are relatively unpredictable, and can take on several forms, including accidents, disabled vehicles, and spilled loads.

Statistics developed by the Federal Highway Administration indicate that approximately 78 percent of all freeway congestion in the Boston region is attributable to incidents. As a measure of incident-related congestion within the project area, accident reports were obtained from the Massachusetts Highway Department for the most recent year for which data were available (1991). The annual number of accidents along each roadway segment was divided by the lengths of the segments to provide an indication of incident frequency. The results are illustrated in Exhibit 2-6 and summarized in Appendix A.

In general, those roadway segments with a high accident frequency are the same segments with large V/C ratios. This is not surprising since congested conditions, with their stop-and-go flow characteristics, often lead to accidents. It should also be emphasized that the figures contained in Exhibit 2-6 and appendix A represent those accidents reported to the Registry of Motor Vehicles and subsequently added to the MHD accident record system. These reported accidents represent only a portion of the actual number of incidents – albeit the more serious ones – which cause congestion on the roadway network. The primary purpose of such an analysis is to identify, using the number of reported accidents as a measure, which segments experience the greatest incident frequency.

Implementation Areas

As noted in Chapter 1, this IVHS recommendations for the Boston area are designated as part of the Phase 1 or Year 2000 implementation plans. While the 2000 Plan, by definition, encompasses the entire roadway network, a major project issue concerned the coverage area of the IVHS network for the Phase 1 Plan. Even with the exclusive use of well-proven technologies and strategies, it would not be practical to incorporate all the project area roadways into the initial implementation phase, and then expect the system to be operational within 2-3 years. Moreover, it is doubtful that available funding would permit such an approach.

Exhibit 2-7 shows the recommended Phase 1 and Year 2000 areas of IVHS implementation. In essence, the Phase 1 area incorporates those roadways which experience the largest volumes, the highest volume/capacity ratios (i.e., recurring congestion), and the greatest number of accidents (i.e., incident congestion) as compared to the rest of the project area. Moreover, the Phase 1 area includes several existing elements (e.g., detector stations) congestion within the recommended Phase 1 area, the initial implementation of IVHS therein should provide the greatest user benefits for the funds expended (i.e., most "band for the buck"). These early benefits can then set the stage for subsequent expansions of the system to its ultimate configuration by the year 2000.

TRANSIT NETWORK

IVHS is a multi-modal initiative, and the project area also includes the commuter rail and "T" facilities shown in Exhibits 2-8 and 2-9, respectively; as well as the major park-and-ride lots which serve those transit facilities. Moreover, since several bus routes utilize the project area roadways, improvements to traffic flow on these facilities should also benefit transit users.

Existing conditions on transit modes – particularly rail facilities – cannot be examined in the same manner as roadways. Whereas the roadway network is evaluated in terms of congestion levels and accident rates; transit facilities are concerned with customer service parameters such as headways, waiting times, passenger comfort and safety, ease of use, etc. Operations control strategies are employed by transit agencies such as the Massachusetts Bay Transportation Authority (MBTA) to minimize waiting time and riding time, and to minimize the number of passengers who may be impacted by disruptions in service.

From the perspective of IVHS, the operations control process and transit service may be enhanced as follows:

- Automatic vehicle monitoring systems which provide real-time information as to the location and/or identification of all transit vehicles.

- Decision support systems which utilize this vehicle location data and provide dispatchers with information regarding service disruptions, their magnitude, and the potential impacts on other transit routes and transfer points. (For example, should vehicles be held at a transfer point so that transferring passengers can make a connection?)

- Traveler information for transit users as to schedules and fares, schedule adherence, and in-terminal displays providing information on the anticipated arrival times and destinations of the next transit vehcle.

- Electronic ticketing systems (e.g., SMART CARDS) which may be used by passengers to board transit vehicles, thereby speeding up the process and potentially providing the transit agency detailed information regarding passenger origins and destinations.

EXISTING IVHS-BASED SYSTEMS

Several transportation management systems are currently in operation or under construction within the Boston metropolitan area as summarized below:

Integrated Project Control System

As described in the Design Summary Report[1] for the Integrated Project Control System, the “primary mission of the IPCS is to ensure the safe, efficient flow of vehicular

1 C22A1 Final Design Submittal, DeLeuw Cather, November 6, 1992

traffic through the CA/T (Central Artery/Third Harbor Tunnel)". In addition, the IPCS will provide support for effectively operating and maintaining all CA/T facilities. This will be accomplished by providing a system to remotely monitor and control all CA/T facilities including buildings and roadways. An extensive voice, data, and video communication network includes a fiber optics based communications backbone as well radio and telephone equipment. The IPCS includes a fully integrated Traffic Surveillance and Control System (TSCS). The TSCS uses vehicle detectors to gather data and determine traffic flow characteristics in real time. An incident detection system will be used to detect abrupt changes in traffic flow that could be traffic incidents. The incident detection system will notify an operator and provide a camera view of the suspect location of the operator. The operator will either reject the incident alarm, or confirm it and initiate a response plan. The TSCS includes variable message signs, variable speed limit signs, blank-out signs, traffic signal interfaces, overheight vehicle detection, lane use signals and a portal closure station (future mainline metering site). The IPCS will also include the systems necessary to manage roadway toll collection. The IPCS components will be located throughout the CA/T project limits as previously discussed and identified in previous Exhibit 2-1.

The overall goal of the IPCS is to "facilitate the safe and efficient flow of people, vehicles, goods, and services within the CA/T projects". The IPCS will maintain the internal environment of the facilities by providing control of ventilation, power, drainage, lighting, access, fire, and radio frequency energy within covered sections and dedicated buildings. The IPCS includes five major components – Traffic Surveillance and Control (TSC), Facilities Control (FC), Toll Operators (TO), Communications, and the Operations Control Center (OCC). Each of these components is summarized in Exhibit 2-10.

MBTA

The Massachusetts Bay Transportation Authority (MBTA) makes extensive use of vehicle locating techniques to manage its rail operations (including light rail, heavy rail and commuter rail services). The position of a vehicle relative to other vehicles on the same and adjacent lines is critical to the safe operation. Signal control is used to allow speeds where adjacent lines is critical to the safe operation. Signal control is used to allow speeds where the stopping distance of the train is far greater than the viewing distance of the operator.

Exhibit 2-10: IPCS Components

TRAFFIC SURVEILLANCE AND CONTROL

Primary objective is the timely detection of traffic incidents on the CA/T, and the implementation of appropriate signing response to such incidents.

Surveillance and information Gathering

- Loop detectors to measure volume, occupancy, and speed
- Overheight vehicle detectors (infrared-based) to detect vehicles in excess of 13’8” high approaching a tunnel entrance.
- Closed-circuit video equipment, including color and black/white cameras, with pan/tilt/zoom units.
-

Control and Motorist Information

- Variable Message Signs (VMS) – Provide advisory text messages either in support of control or motorist information requirements. (Light emitting technology).
- Variable Speed Limit Signs (VSLS) – Provide a advisory speed indications.
- Lane Use Signals (LUS) – Signals in support of lane and roadway closures.
- Blank-Out signs (BOS) – Signs with limited message capability used to provide advisory information related to road closure and the warning for overheight vehicles.
- Highway Advisory Radio (HAR) – Equipment which provides, via radio, additional and more detailed advisory information to motorist.
- Closure Signals/Devices – Traffic signals for controlling access to the Third Harbor Tunnel (THT) upstream of the eastbound tunnel entrance portal.

Local Field Controller (LFC)

- Microprocessor-based controller – based on Type 170 standard – for detection within the CA/T. The responses to traffic incidents, special events, and facility control events include:

Response

- Uses predetermined response plans to mitigate problems associated with events with the CA/T. The responses to traffic incidents, special events, and facility control events include:
  - Deployment of Emergency Services and Emergency Vehicle Access Routing;
  - General Advisory, and
  - Lane and Roadway Closures.

Exhibit 2-10: IPCS Components (continued)

<u>Response</u>

- Uses predetermined response plans to mitigate problems associated with events within the CA/T. The responses to traffic incidents, special events, and facility control events include:
- Deployment of Emergency Services and Emergency Vehicle Access Routing;
- General Advisory, and
- Lane and Roadway Closures.
- Radio systems consisting of two-way FM communications for various agencies (e.g., Boston Police and Fire, State Police, Boston emergency medical services, MTA, etc.) within the covered sections; and broadcast of local commercial AM/FM radio stations throughout the tunnel.
- Fiber optics backbone networks for voice and data communications, and for video communications.

FACILITIES CONTROL

- Tunnel ventilation
- Tunnel lighting
- Drainage
- Power distribution
- Fire detection and protection (heat/smoke detectors)
- Intrusion detection and access control

TOLL OPERATIONS

- Master computer system
- Lane computer system
- Automatic cash machine
- Electronic toll collection/Automatic Vehicle Identification
- Manual toll collection equipment
- Gate arm control equipment

COMMUNICATIONS

- Switched telephone network (PABX) to provide direct-dial, two-way voice communications between key points within and outside the CA/T system. This will include administration buildings, the Operations Control Center (OCC), ventilation building, toll plazas, maintenance centers, tunnel passages, and off-project access to and from the public telephone network.
- Dedicated, non-dialed point-to-point direct voice communication lines between OCC operators and several agencies (e.g., Boston Fire and Police Departments, State Police, Logan Airport, MHD, MTA, MBTA, MDC, etc.)

Exhibit 2-10: IPCS Components (continued)

- Radio systems consisting of two-way FM communications for various agencies (e.g., Boston Police and Fire, State Police, Boston emergency medical services, MTA, etc.) within the covered sections; and broadcast of local commercial AM/FM radio stations throughout the tunnel.
- Fiber optics backbone networks for voice and data communications, and for video communications.

OPERATIONS CONTROL CENTER (OCC)

- Located in OCC complex in South Boston
- Integrated Central computer – Handles all traffic analysis, logic processing and response plan implementation
- Integrated Workstations - Allow the operator to monitor and control TSCS functions and to observe CCVE images. Other IPCS functions are also available at these integrated workstations.
- Overview Graphical display System – Informs the OCC operator of overall traffic and system status.

Fail-safe intelligent signalling is therefore critical to maintain speeds and operate safely. The Sophistication of the train locating and signalling systems employed on MBTA lines vary widely. While all provide for safe operations, some are more modern than others allowing for greater centralization, automation and flexibility in traffic regulation . For example, on the more recently upgraded commuter rail lines, trains can operate in either direction on either track without degrading speed. This allows greater flexibility in scheduling trains and passing cripples. On older lines and most of the rapid transit system, high speed operation in the opposite direction of normal traffic cannot be allowed due t limits of the signal system. A new AVI (Automatic Vehicle Identification) system has been deployed on the Green Line to help automate train routing and switch control. A new AVI is also being installed on the Blue Line. AVI is more limited on the Red and Orange Lines. There is no AVI on the commuter rail lines. There is no automated tracking of the bus fleet, however each bus is equipped with a two way radio and is in communication with a central bus dispatcher to report problems with traffic, equipment and passengers.

The MBTA has recently commenced a 5-year $25 million project to upgrade its Operations Control Center (OCC) for the subway and bus lines. When this project is complete the MBTA will have uniform real-time automated location and schedule adherence information on every light rail and rapid transit trip. In the new OCC, bus dispatchers will be equipped with GIS tools to help locate buses and evaluate trouble. Eventually, location and schedule adherence information will also be available for all buses. (No specific agenda, timetable, or funding for this bus upgrade ahs been identified at this time). Key benefits of the new OCC will include:

- Increased availability and accuracy of vehicle location and schedule adherence information.
- Centralized information processing and operations control in the areas of train control, traffic control and management, schedule adherence, decision support systems for dispatchers and reporting.
- Ability to accurately and automatically service real-time passenger information systems (e.g., in terminal displays as to next train arrival)

The commuter rail system is dispatched from four separate offices with central control systems of varying sophistication and capabilities. At this time there is no approved plan to consolidate these facilities. One railroad dispatching center will be relocated within the next year and will be incrementally upgraded in subsequent periods. The other three dispatching centers belong to Amtrak or private railroads.

MTA

The Massachusetts Turnpike Authority (MassPike) began a comprehensive rehabilitation program for the Sumner and Callahan Tunnels in 1991. As part of this effort, closed-circuit television camera will be installed in the tunnels and monitored 24 hours-a-day. Both tunnels already have a Highway Advisory Radio (HAR) system transmitting at 530 and 1200 on the AM dial.

MassPike is conducting an Electronic Toll and Traffic Management (ETTM) planning study. This program initiative includes a market study and analysis, system design and procurement, testing, and ultimately integration of the new ETTM system for use by MassPike patrons. It is expected that the ETTM system will be implemented over the entire length of the Turnpike, as well as the Sumner Tunnel.

SmarTraveler

SmarTraveler is a FHWA-sponsored operational test of a privatized traveler information network. SmarTraveler is operated by SmarRoute Systems, Inc. of Cambridge, MA. The “infrastructure” for collecting the traveler information consists of the following elements:

- 44 cameras at 12 location; 15 of which provide full motion video while the other supply “slow-scan” images with a refresh rate of 15 seconds. All of the camera are owned by SmarRoute Systems, with the exception of 3 in East Boston which are owned and operated by the MTA.

- 364 regularly-scheduled probe trips, communicating with the SmarRoute Operation Center under planned schedules and protocols, via mobile phones or two-way radios. Additional probe information is obtained from the Metro Radio System and Logan Express buses.

- Routine monitoring of 300+ publicly-available and public agency radio frequencies on 8 electronic scanners.
- Two fixed-wing aircraft flying over northern and southern sections of the metropolitan area, totaling 15 hours daily.
- Direct telephone links to public agencies, including State Police communications center, Mass Highway Department radio room, two Amtrak dispatch facilities, and MBTA operations center.
- Static information obtained from all the various transportation agencies regarding construction and events.

SmarRoute has also developed the software and information displays, and provides the staff necessary to integrate and manage this real-time information on a daily basis. Reports are compiled for each route and updated (if required) at intervals of no greater than 10 minutes. The information and reports are available over the phone – a traveler calls the system and inputs a code representing the route, area, or mode for which he/she desires information (e.g., 90* for I-90, 5* for Logan Airport, 1282* for Rt. 128 south of I-90, etc.)

Reimbursement for this initial and continui ng investment comes from the sales of the real-time traveler information to other private entities – for example, Channel 5 who does their morning traffic reports form the SmartRoute control center, and the cellular phone companies who provide this information to their customers as a service. The original concept of SmarRoute was to have the incoming calls use a 900 number, thereby generating revenue. However, as port of the SmarTraveler Operational Test (from which Smart Route is receiving $1.5 million of Federal funding as a 50 percent match), these traveler calls at 671-374-1234 are provided at no additional charge. During the first six months of 1993, SmarTraveler averaged approximately 1900 calls per weekday, with a peak of 6136 calls during the March blizzard.

The SamrTraveler Operational Test is currently undergoing a formal evaluation, the objective of which are:

- To assess the quantity and quality of information provided to motorist by the SmarTraveler ATIS operational test project.
- To evaluate the public acceptance and utility of the project information.
- To determine the existing and potential impact of the project on managing traffic congestion.
- To recommend improvements in collecting and disseminating traffic information.

The evaluation is scheduled to be completed by the Spring, 1994.

Traffic Signal Systems

Several computer-based signal systems are operating within the study area. The primary system is the City of Boston's UTCS operation with approximately 325 intersections on line. This system has an ultimate capacity of approximately 450 intersections and the City is currently talking of expansion. The system provides three timing plans with multiple offsets including provisions for emergency program implementation. While control is provided in the City's core, a series of arterials extending west and south are also under control. The City is also experimenting with closed loop corridor control in remote neighborhood corridors. The first such example is the Centre Street corridor in West Roxbury.

Within the Route 128 beltway, the Metropolitan District commission (MDC) is the next largest control agency of traffic signals. The MDC is responsible for approximately 250 signalized location, of which 100 are within the limits of the City of Boston. Some 25 percent of the controllers in use are more than 15 years old. The MDC has relied primarily on time based coordination of its systems. A six (6) intersection closed loop system will be in place and operational by spring 1994 along VFW Parkway, a passenger vehicle roadway which was part of the Route 1 corridor until the redesignation of Route 1 to follow Route I-95 from the Route 1 interchange in Dedham to the Tobin Bridge north of Boston.

Other major municipalities developing systems include the City of Waltham where ten intersections are under full closed-loop operation and twenty more are in various stages of integration. The City's goal is to tie all 50 signalized locations under its control to the system within the next several years. The City of Cambridge has had various types of computerized signal systems in major corridors for over 20 years. These systems are now going the route of closed loop. The balance of communities within the Route 128 area rely primarily on isolated or small time-based system operations. While the City of Malden had an extensive downtown system project 15 to 20 years ago, the system is now operating as a single dial. Outside of Route 128, several communities are developing closed-loop systems for limited areas. Among these communities are Framingham, Danvers and Norwood. Systems are under consideration in other large communities such as Brookline and Newton, although no formal action has yet been taken.

The MHD is beginning the process of signal system development. Through the 1980s, time based coordination was the choice for system development in many of its corridors. Route 3A through Weymouth and the Southern portion of Quincy is a prime example where an eight location system is in place. The prime candidate for a computer monitored system now being considered us the Route 9 corridor in Framingham and Natick. Monitoring capability is also being considered as part of smaller systems including Bell Circle in Revere and Route 3 in Woburn.

Incident Management

A number of incident management program elements have already been initiated within the Boston metropolitan area by MHD and the Massachusetts State Police, including:

- Service patrols, utilizing in-house MHD and contracted resources.
- A toll-free highway emergency number (*SP), established by the Massachusetts State Police, working in conjunction with the cellular telephone companies, whereby motorists can report incidents to the Massachusetts State Police communications center in Framingham.
- Call Boxes (push button devices located at ½ mile intervals) on the southern segment of I-95 between I-495 and Route 128, on I-495, between I-95 (south interchange) and I-90, and on I-93 (northern segment) between Route 128 and I-495.

- Two Massachusetts State Police and one MDC helicopters which provide aerial surveillance.

The *SP network and service patrols are discussed in greater detail in Chapter 7.

3. IVHS FUNCTIONS

The Basic approach used by the JHK project team in developing the IVHS strategic deployment plan for metropolitan Boston was to define the area's transportation needs in terms of user services and the corresponding functions' and then to identify the appropriate technologies and system configurations for achieving the required functions in a cost-effective manner. A crucial element of this process involved the evaluation of the various IVHS functions and their prioritization.

EVALUATION METHODOLOGY

The evaluation methodology for the Boston area IVHS strategic plan was designed to respond to the following requirements:

- Be fully sensitive to differences between IVHS and conventional transportation improvements;
- Recognize that many criteria are measures of the same benefits, therefore requiring to aggregate these evaluation criteria to minimize double counting and misplaced higher implied weights given to the same consequences under different names;
- Avoid underestimating the mobility and other personal and corporate economic benefits from IVHS;
- Emphasize sensible results, subject to face validity checks, rather than (false) precision; and,
- Avoid criteria specific to individual actions which promote their adoption in a "self-fulfilling" evaluation.

Exhibit 3-1 is a flow chart of the evaluation process. It starts with the development of program goals and the criteria for evaluating these goals. The criteria are then weighted to reflect their relative importance. Concurrent with goal development and criteria weighting is the definition of user services and functions for achieving the IVHS goals (refer to previous Exhibit 1-4). These potential functions are then assessed against the evaluation criteria --

Exhibit 3-1: Metropolitan Boston IVHS Evaluation Process

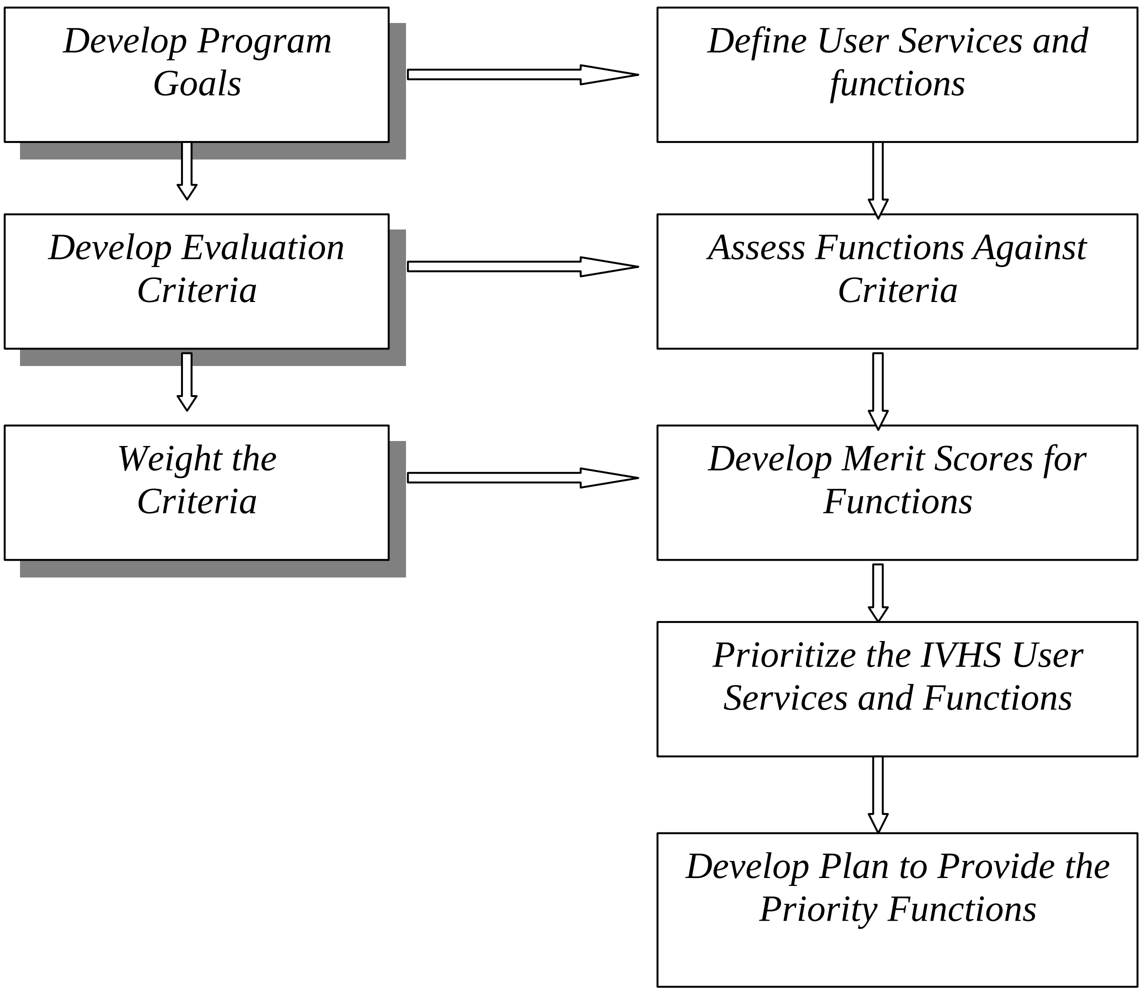


Exhibit 3-1, Metropolitan Boston IVHS Evaluation Process

that is, a determination is made as to how each function impacts the individual criteria. This assessment is based on a scale of –10 to+10, where +10 reflects the maximum positive impact towards meeting a criterion and satisfying a goal; a negative number reflects negative impact; and a 0 indicates no impact. For example, incident management might receive a rating of 5 to 7 for the criterion "decrease congestion", but receive only a 1 or 0 for "reduce single occupancy vehicles".

Merit scores for each function are then developed by multiplying the impact assessment rating and the corresponding criterion weight, and summing across all criteria. This provides the relative importance (i.e., priority) for each IVHS function. This process was applied for the Boston area by a group of policy and decision makers representing MHD, EOTC, MTA, MBTA, State Police, MassPort, and FHWA, with assistance from the project team.

Evaluation Criteria

The complete list of the IVHS evaluation criteria considered for the Boston area is provided in Exhibit 3-2. This structure deals head-on with the confusion between supply and demand impacts in IVHS evaluation. The separation between "efficiency"(1.0 in Exhibit 3-2) and "output" (2.0) means that one can separate the IVHS technology benefits from the individual and corporate demand responses to IVHS that actually increase output (benefits) over those produced by the technology alone. Such an approach reflects the fact that IVHS differs form conventional transportation improvements in the way information is communicated and used to increase the benefits form travel and transportation system operation. Information is communicated in real-time to the traveler on the transportation system status and operation, and on travel services and trip end opportunities. Information is also communicated in real time to the system to improve its operational control capabilities.

When the sole concern was improving the physical transportation infrastructure, improvements were evaluated based on the ***use*** of the network. Vehicle Miles of Travel (VMT) on the network, and congestion, travel times on links were the measures of interest. With the development of a parallel information infrastructure as provided by IVHS, there

Exhibit 3-2: Proposed IVHS Evaluation Criteria

1. Increased Operational Efficiency (supply-side efficiency, meaning more output per unit of input)

 1.1 Short Term: Transportation System Operation

  1.1.1 Infrastructure
  - Increased throughput
  - Increased speeds
  - Reduced stops
  - Reduced delay at intermodal transfer points
  - Reduced operating costs (e.g., from ETTM or information for incident response, etc.)
  - IVHS O&M cost
  -

  1.1.2 Vehicle Efficiency

   1.1.2.1 Private Autos
   - Increase vehicle occupancy
   - Reduced operating costs (including wear and tear)
   - IVHS O&M cost

   1.1.2.2 Transit
   - Reduced operating costs
   - Increased usage (i.e., volume of people moved)
   - Facilitate fare collection and fare reduction/equity strategies
   - APTS O&M cost

 1.2 Medium Term: IVHS Costs
 - Capital costs of IVHS
 - Liability costs of IVHS

 1.3 Long Term: Investment Costs
 - Reduced capital costs of new infrastructure
 - Improved data for more cost-effective transportation investment planning
 - Improved data for concurrency planning

Exhibit 3-2: Proposed IVHS Evaluation Criteria (continued)

2. Increased Output (demand adjustments that further increase output or benefits from IVHS improvements)

2.1 Short Term: Mobility

2.1.1 Personal (passenger)

- Increased travel opportunities (trip end benefits)
- Decreased costs (disutility) of travel (including travel and delays to unfamiliar drivers/travelers). Includes:
  - Increased awareness, and ease of use of transit and ridesharing
  - Travel time (and its various components)
  - Travel time reliability
  - Comfort, stress, fatigue, confusion etc.
  - Safety and personal security
- Increased sense of control over one's own life from predictable system operation (including toll and transit fare charges)

2.1.2 Freight

- Decreased cost of freight (goods) movement to shippers, including:
  - More reliable "just in time" delivery
  - Travel time
  - Travel cost
  - Driver fatigue, stress, etc.
  - Cargo security
  - Safety (e.g., from tracking hazardous material)

2.2 Medium Term: Economic Development

- Increased access to
  - Labor
  - Materials
  - Markets
- Increased industrial output
- Reduced costs
- Increased investment in plant and equipment
- Opportunities for public/private partnerships
- Increased international competitiveness

2.3 Long Term: Personal Adaptations

- Lifestyle changes
- Land use (settlement) pattern changes (to internalize or otherwise be "informed by" congestion and other social costs of private travel and location decisions)

Exhibit 3-2: Proposed IVHS Evaluation Criteria (continued)

3. Safety

- Reduced number of severity (cost) of:
  - P.D. accidents
  - P.I. accidents
- Reduced fatalities
  - Increased personal security

4. Environment and energy (physical impacts)

4.1 Environment
- Reduced vehicle emissions
- Reduced noise pollution
- Reduced right-of-way requirements
- Neighborhood traffic intrusiveness (affecting community acceptance)

4.2 Energy
- Reduced fuel consumption

5. Implementation

5.1 Ease of Implementation
- Technical feasibility
- Financial feasibility
- Availability of staffing/skills
- O&M requirements
- Privacy impacts

5.2 Agency Cooperation/Coordination
- Increased sharing of incident/congestion information
- Increased coordination/integration of network operation, management and investment
- Agency commitment to IVHS system

5.3 Technology Flexibility
- Ability to evolve with changes in system performance requirements and technology

must be a parallel emphasis on the use of the information – how individual travelers use the information to make their personal travel decisions, and how firms use the information to ship their products.

This is "mobility", which is measured by the opportunities for and the benefits from travel. In essence, travel decisions involve a series of tradeoffs between the times and costs of travel on all available alternatives, and the benefits of travel from engaging in activities at the trip ends. Without adding capacity, the traveler information from IVHS will increase the informed nature of these tradeoffs and all of the adjustments people make to minimize their cost of travel (e.g., to avoid congestion). For example, with reliable travel time information, travelers for whom the benefits of certain trips are small may choose to travel shorter distances, change modes, or forego or defer trips when congestion is heavy. Others may choose to travel to destinations that are farther away or to make more frequent trips with the confidence that they will not be caught in heavy congestion. IVHS systems should result in higher-value use of personal time and resources for work and leisure activities, and more productive use of commercial and industrial resources. The net increase in user travel benefits will be substantial, yet aggregate reductions in VMT and travel time resulting from improved mobility are not likely to reflect these benefits. In fact, the aggregate reductions in VMT and travel time are likely to be small. Accordingly, the demand-side criteria (i.e., mobility) were separated from the more familiar supply-side efficiency criteria (i.e., reduced congestion).

It is noted that the six national goals in the 1992 U.S. DOT IVHS Strategic Plan map very well on the criteria structure in Exhibit 3-2. The six national goals (with their corresponding Exhibit 3-2 numbers) are:

1. "Improve the safety of surface transportation". (3.0)

2. "Increase the capacity and operational efficiency of the surface transportation system". (1.0)

3. "Enhance personal mobility and the convenience and comfort of the surface transportation system". (2.0)

4. "Reduce the environmental and energy impacts of surface transportation".(4.0)

5. "Enhance the present and future productivity of individuals, organizations, and the economy as a whole". (2.2)

6. "Create an environment in which the development and deployment of IVHS can flourish". (This is a legitimate national goal, but creating and deploying a technology for its own sake was not considered relevant at the local level).

The extensive list of criteria was grouped to make it more manageable. The grouped criteria and the corresponding weights assigned by the synthesis group are as follows:

- Decrease congestion - 5.0
- SOV Reduction - 4.6
- Improved Mobility (Residents) - 4.0
- Improved Mobility (Non-residents) - 2.8
- Improved Mobility (Commercial) - 3.4
- Economic Development - 3.0
- Land Use Patterns - 2.4
- Safety - 5.0
- Improved Environment - 4.2
- Implementation Ease - 3.4

Function Priorities

Each member of the synthesis group rated each of the IVHS functions noted in previous Exhibit 1-3 against the above criteria. It is noted that some of the functions identified in Exhibit 1-3 were not included in the Evaluation Methodology – specifically traveler information location displays, freight route planning, and vehicle/cargo monitoring, as these were considered to be solely private functions; and traffic network monitoring, which is more of a means to an end rather than an actual function. The composite results are shown in Exhibit 3-3. As indicated by these results, the priority functions and user services for the Boston area IVHS network are as follows:

- Incident Management (Traffic Management)
- Route/Mode Guidance: Pre-Trip (Traveler Information)
- Time/Cost Advisories: Pre0Trip (Traveler Information)
- Demand Management: Congestion Pricing (Traffic Management)
- Electronic Toll Collection

- Advisories: Pre-Trip (Traveler Information)
- Construction Management (Traffic Management)
- Route/Mode Guidance: Enroute (Traveler Information)

Exhibit 3-4 presents a matrix of these priority functions versus potential IVHS technologies and strategies, with an "X" indicating that the particular technology may be applied in support of the required functionality. It is emphasized that in developing system goals, defining user-services and associated functions, and evaluating their relative importance, no specific architectures nor technologies were assumed. Bather, it was the prioritized IVHS functions which formed the basis for the subsequent development of IVHS architectures and technology recommendations.

The rest of this report describes the potential IVHS technologies and strategies in greater detail, and makes recommendations regarding their implementation within the Boston area so as to provide the priority functions in a cost-effective manner. Following a discussion of the regional IVHS architecture in the next chapter, the surveillance functional area -- which is necessary to support the other functions -- is discussed in Chapter 5; the incident management function (i.e., the highest priority) is discussed in Chapter 6; the various traveler information functions (e.g., advisories, route/mode guidance etc.) are described in Chapter 7; and the demand management functions are discussed in Chapter 8. The remaining chapters focus on supporting "technologies" -- communications, central hardware/software, control center and operations/maintenance -- which are necessary to provide a fully-operational and successful IVHS-based system.

Exhibit 3-4: Mapping of Priority IVHS Functions to Technologies and Strategies

	Incident Manage.	Traveler Inform. (Pre.Trip)	Traveler Inform. (En-route)	Demand Manage.	Construct. Manage.	ETC
SURVEILLANCE						
In-Pavement Detectors	X	X	X	X		
Overhead-Mounted Detectors	X	X	X	X		
Video Image Detection	X	X	X	X		
Automatic Vehicle Identification (AVI)	X	X	X	X		X
Automatic Vehicle Location (AVL)	X	X	X			
Manual (Call-In)	X	X	X		X	
Weather/Other		X	X			
CCTV	X	X			X	
TRAVELER INTERFACE						
Variable Message signs			X	X	X	
Highway Advisory Radio			X		X	
Highway Advisory Telephone		X	X		X	
Commercial Media (radio)		X	X		X	
Commercial Media (television)		X				
Kiosks		X				
In-Vehicle Displays			X		X	
CONTROL STRATEGIES						
Automated Incident Detection	X					
Ramp/Mainline Metering	X			X	X	
Signal Control	X			X		
Road Use Pricing				X		X
Service Patrols	X				X	
Quick Clearance Policies	X					
HOV Restriction				X		
Diversion	X			X	X	

Exhibit 3-4: Mapping of Priority IVHS Functions to Technologies and Strategies (continued)

COMMUNICATIONS						
Cellular Phone	X		X		X	
Radio Frequency Media	X	X	X	X	X	X
Satellite	X	X	X		X	
Beacons			X			X
Cable Media	X	X		X	X	X
Leased Telephone	X	X		X	X	X
DATA PROCESSING						
Database (GIS/Data Fusion)	X	X	X	X	X	X
Incident Detection Algorithms	X					
Traveler Information Algorithms		X	X			
Traffic Control Algorithms				X		
Traffic Prediction	X	X	X	X	X	X
Expert Systems	X	X	X	X	X	X
Graphic Displays		X	X		X	
OTHER (Regional Architecture)						
Coordination	X	X	X	X	X	X
Information Sharing	X	X	X	X	X	
Public-Private Partnerships	X	X	X	X		X

4. REGIONAL ARCHITECTURE

This Chapter describes the overall IVHS architecture which is recommended for the Boston region, and presents the various technical and institutional issues associated with this regional architecture.

BACKGROUND

One of the key elements of an IVHS strategic plan is the system architecture. In the context of IVHS, an "architecture" describes what a system does and how it does it, providing the general framework within which the various system components are deployed. It identifies the functions to be performed by the system, allocates these functions to subsystems, and defines the flows of information and the interfaces between the subsystems and components.

Multiple strata or layers of architectures exist within an IVHS network. Each of the individual system elements -- be they hardware devices (e.g., detector, processing cabinet, variable message sign, etc.) or software programs (e.g., incident detection algorithm, transit schedule monitoring, expert system) -- possess their own architecture. These elements are combined into subsystems as required to perform a variety of IVHS functions (e.g., incident detection and response, traveler information, transit fleet management), with the communications and interface between the various elements defined as part of the subsystem architectures. Complete IVHS-based systems, such as the MBTA's proposed OCC and the Integrated Project Control System (IPCS) for the Central Artery/Third Harbor Tunnel, are formed by combining subsystems.

In a metropolitan area such as Boston, where the roadway network is managed and operated by several different entities (refer to Exhibit 4-l and 4-1a), with additional agencies responsible for transit (MBTA) and enforcement (State Police), a regional architecture -- identifying the various transportation management systems and the linkages between these systems -- is necessary to provide a "seamless" transportation network from the perspective of the traveler.

ARCHITECTURE CONSIDERATIONS

Defining an IVHS architecture requires an understanding of the user services to be provided by the IVHS network (as discussed in Chapter 3) the institutional framework and constraints in which the IVHS-based system must function, technology availability, and the relationship between the public and private sectors. Each of these considerations is discussed below.

Institutional Framework

An IVHS architecture -- particularly on the regional level -- must fit within the existing organizational infrastructure. It is unrealistic to demand significant changes or to inipose a new institutional framework on the various jurisdictions and entities who are involved or affected by IVHS, other than to build logical extensions to the existing framework. In essence, the regional architecture must provide for a seamless transportation network while also respecting local autonomy -- a win-win solution.

Technology Availability and Implementation Phasing

Another issue which impacts architecture development is the availability of key enabling technologies. Certain system strategies and functions (e.g., in-vehicle routing) require hardware and/or software which is not yet fully developed or tested, and prerequisite information (e.g., real-time surveillance) which is not currently available. Accordingly, the system architecture must be flexible such that these (and other) enabling technologies may be readily incorporated into the IVHS network sometime in the future.

An IVHS architecture must be "open" to ensure compatibility with existing/proposed systems and with future technologies. Open architectures utilize standards and non-proprietary interface protocols, thereby allowing various (and conceivably dissimilar) systems to interact with one another, and allowing modular replacement and upgrading of system elements and subsystems with minimal impact on other components. Openness allows multiple vendors to supply the same type of element, thereby preventing the operating agency from becoming locked into a single proprietary component. Moreover, standards and protocols typically provide upward compatibility for accommodating new technologies in the future.

Public/Private Responsibilities

An extraordinary issue in defining and developing IVHS-based transportation networks is the concept of public/private partnerships, and the respective roles of each in implementing, operating, and maintaining these systems. To date nearly all IVHS implementations within North America have been based on the philosophy that most, if not all, surveillance, management, and traveler information functions should be provided by government (i.e., the public side). In essence, IVHS has been viewed as an advanced technology/electronic extension of the road signs, street lighting, and traffic control operations which are currently being provided by government. Within this context, "public/private partnerships" have involved the public agency merely hiring a private entity to perform work that it cannot accomplish with in-house staff or resources. The most common IVHS examples in this regard include system design, system installation, construction engineering, system maintenance, and the daily system operations being performed by a private consultant/contractor as an extension of the public agency's staff. This arrangement is really more of a formal contractual arrangement than a partnership since the private entity provides these services in return for complete and full monetary reimbursement from the government agency.

Another type of public/private partnership exists -- one in which the private entity still provides IVHS services and/or system elements; but instead of direct (and presumably complete) reimbursement from the public agency, some or all of the private entity's costs for these functions are recouped by selling NHS-based services to other private entities (i.e., collecting a user fee), or by receiving a non-monetary consideration for these services from the public agency (a sort of quid-pro-quo). Several examples of this latter concept of public-private partnerships are being explored in the United States, including:

- Marketing and sales of in-vehicle and portable devices to provide real-time traveler information and routing.

- The government agency providing access to the highway right-of-way to a private communications firm, in return for which the private entity installs and maintains a communications network (e.g., conduit, cable, and electronics) for the government agency's IVHS network. The private communications firm recoups the cost of this communications system by sizing it to provide telecommunications services to other users (e.g., other private entities), who are then charged.

- Collection, marketing, and sales of real-time traveler information. As discussed in Chapter 2, Boston-based company SmartRoute Systems, Inc., (which is operating SmarTraveler) is an example of a private, IVHS-based surveillance and traveler information network.

The IVHS architecture must define the relationships between the public and private sectors, along with their respective responsibilities. Exhibit 4-2 summarizes the public and private roles in providing the user services and system functions as envisioned for the Boston region.

RECOMMENDED ARCHITECTURE

The recommended regional architecture for the Boston area IVHS network is shown is Exhibit 4-3. The major features and potential issues associated with this architecture scheme are discussed below.

Local Autonomy

The architecture is "distributed" in that each public agency is responsible for implementing and managing MIS-based systems for their respective transportation networks. As such, the MTA will operate systems on the Turnpike (I-90) and for the Sumner and Calahan Tunnels; the MBTA will operate a schedule and dispatch system for their trains and buses; local municipalities such as Boston, Cambridge, and Waltham will operate systems controlling their surface-street signals; and so forth. Moreover, it is envisioned that each of these agency-specific systems (or network of systems) will include a separate Traffic

Operations Center (TOC) located facilities.

As shown on the architecture diagram, two systems exist within MHD -- the IPCS, and a regional Freeway Traffic Management System (FTMS) which will provide similar traffic surveillance and control functions as the IPCS along those roadway segments (e.g., I-495, I-95, I-93, Route 3, etc.) not included in the IPCS or other agency-specific systems.

It is envisioned that the same organization within MHD will be responsible for the overall management and administration of both the Regional FTMS and the IPCS, and that the central control hardware for the two systems will be "linked" (for sharing data and developing traveler information). Nevertheless, it is recommended that the FTMS and IPCS be implemented and operated as separate entities. Such an approach is appropriate given the significant differences in their respective configurations (e.g., type and density of system elements), intended functions, and overall system objectives and priorities. This approach also provides institutional flexibility should the responsibility for IPCS operations ever be shifted.

Regional Coordination

The concept of a "seamless" transportation network requires that the individual transportation management systems share information so as to create an integrated data base of real-time and multi-modal traveler information, and that the operational and control decisions made within each system (e.g., sign messages, diversion and routing, construction activities and closures, signal timing, ramp meter rates, etc.) consider the current conditions and potential impacts on the other agencies' facilities. To achieve this necessary integration, the regional IVHS architecture includes a Transportation Information and Coordination Center (TICC) which is connected via two-way links to each and every agency's TOC and with several private entities.

As the name implies, the primary functions of the TICC will involve regional coordination and information. The regional TICC will serve as a centralized clearing house of real-time and static information on transportation conditions (e.g., speeds and travel times, transit schedules, incidents and congestion problems, construction and maintenance activities, etc.) within the Boston metropolitan area. It will integrate this information into a regional data base of traveler information, covering all modes and routes. In this manner the TICC provides each agency with a single point of contact for disseminating information to the other agencies and private concerns, as well as a single distribution point from which an agency can obtain current information on the transportation network beyond its jurisdictional boundaries.

The other primary function of the regional TICC is to promote and manage coordination between the various transportation agencies and their systems. Examples of this coordination function include:

- Construction management -- planning construction/maintenance activities such that corridor capacity on parallel routes/modes is not significantly reduced.
- Traveler information elements (e.g., VMS, HAR) belonging to one agency describing conditions or problems on another agencies' facilities.
- A system's operational and control parameters (e.g., signal timing plan in effect, number of toll booths open, transit vehicle Headways/frequency of service) being changed in response to a projected increase in demand -- such as travelers diverting from another facility which is experiencing a closure or other severe congestion.
- Sharing of incident management resources (e.g., wreckers, emergency service vehicles, clean-up, portable VMS, etc.), particularly during major incidents.
- Sharing of available communications bandwidth -- both cable and radio spectrum -- for MIS-related transmissions.

A significant issue associated with the Boston-area Strategic Plan is defining the level of coordination between the agency-specific TOCs, and the corresponding role of the regional TICC. Most transportation problems can be predicted -- at least in terms of what may happen and where; although not when -- and the corresponding regional strategies and agency - specific responses to these problems can be pre-arranged, pre-approved, and documented. The role of the TICC will be to implement and monitor these preplanned region-wide responses. It is envisioned that this will be accomplished as follows:

- TICC is "notified" of a transportation problem (e.g. major incident). This notification may be accomplished manually (e.g., phone call from an agency) or automatically based on real-time information received at the TICC.

- TICC personnel identify the appropriate response plan for implementation based on location, type and severity of the problem. It is envisioned that the knowledge base comprising the pre-approved response plans (e.g., type and magnitude of incident and location, entities to be contacted, resources to be allocated, diversions, traveler information displays, etc.) will be used to form a computer-based "expert system" as discussed in Chapter 10.

- The regional TICC implements the appropriate strategies and contacts the various entities, both public and private, in accordance with the response plan. It is envisioned that initially the TICC will declare a specific plan to be put into effect, with the actual implementation (i.e., response call-out, VMS control, etc.) carried out at the specific agency -- a situation in which the TICC is responsible for "strategic" response, while the various TOCs are responsible for "tactical" response. As this regional architecture evolves, the TICC may assume a greater responsibility for regional control and operations -- including interfaces with agency-specific system elements so that the TICC can directly implement a response plan (presumably with agency override capabilities).

The regional TICC should be placed administratively under the Massachusetts Highway Department (MHD). The reasons for this proposed organizational structure are numerous -- MHD is already responsible for much of the highway network within the Boston region. Moreover, MHD is a statewide operating agency as well as an official recipient of transportation funds from the Federal government.

As previously discussed, TICC staff (discussed in Chapter 11) will be responsible for initiating and then managing preplanned and pre-approved responses to a wide array of transportation plans within the network. The development of these response plans will be the responsibility of a regional Operations Committee comprised of representatives -- primarily senior operations staff -- from each public agency involved in or affected by the regional architecture. The Operations Committee will meet on a regular bases (e.g., monthly) to share ideas, to deal with procedural and policy matters regarding management of the transportation network, and to develop (with staff assistance from TICC personnel) the various response plans. Each response plan will include as a minimum:

- Roles and responsibilities of each agency and the TICC.

- Traveler information to be disseminated (e.g., VMS messages, media/private interface, etc.).
- Equipment and resources to be provided by each agency, and the personnel to be contacted.
- Diversion planning (e.g., defining alternate routes and preparing maps, signal timings and ramp meter rates, guidelines for implementing diversion, etc.).
- Guidelines for implementing the response plan by the TICC.

The Operations Committee will perform debriefings following incidents, and modify the corresponding response plans as required. The Committee will also develop guidelines for TICC functions and operations when no plan exists for a particular problem, and the response must be developed "on the fly". The response plans developed by the Operations Committee will be subject to approval by an Executive Committee -- the composition of which will mirror the current Advisory Committee membership.

The coordination requirements go well beyond the study area confines of I-495. There is the I-95 Corridor Coalition (of which MHD is a member) whose recently developed business plan includes such elements as an information exchange network, development of standard operating procedures for notification of incidents and construction/maintenance activities which have multi-member impacts, feasibility of corridor-wide AVI/ETTM technology, feasibility of regional communication centers (e.g., Boston, Providence), and commercial vehicle operations (e.g., standardized permitting). Activities are also underway to develop a national IVHS architecture, with the initial focus on in-vehicle alternatives and issues (e.g., vehicle-infrastructure communications, location of route-selection functions, coupling between route selection and traffic control etc.).

Role of Private Entities

As summarized in previous Exhibit 4-2 and shown in the architecture diagram in Exhibit 4-3, the private sector will play a major role in the overall IVHS plan for the Boston area. In general, the public side (i.e., the various transportation management and enforcement agencies) is responsible for collecting and integrating area-wide surveillance information (e.g., detectors, AVL systems, CCTV, AVI probes, etc.), and then developing and implementing control strategies (e.g., incident detection and response, signal/ramp timing, etc.) based on this information. The primary role of the private sector is to analyze the integrated data, tailoring the information to meet the unique requirements of the end users (i.e., a "value added"); and then to market and disseminate the traveler information via radio and TV outlets, kiosks located at large travel generators, highway advisory telephone, and in-vehicle devices. There are some exceptions to this general rule. For example, the public side will be installing and operating variable message signs and information kiosks at key locations throughout the roadway and transit networks to provide traveler information. Moreover, as discussed in Chapter 13, public-private partnerships may also be utilized to provide communications, incident response, service patrols and operational support.

5. SURVEILLANCE

Nearly all of the IVHS functions depend on collecting, processing, and managing real-time information regarding the transportation network. These data are used by the system for congestion monitoring, incident detection, development of traveler information, and optimizing control strategies, The information on traffic flow may also be processed and stored for planning and historical analyses. The importance of an accurate and reliable surveillance subsystem cannot be overstated. It is truly the "heart" of an IVHS-based network.

ROADWAY TRAFFIC DETECTORS

Traffic flow along a segment of roadway can be described in terms of the following parameters:

- Volume - a measure of traffic demand; the number of vehicles passing a point (i.e., detection zone) during a specified time period.
- Occupancy - a measure of traffic density; the percentage of time that vehicles are present in the detection zone.
- Speed - a measure of the rate of motion of the vehicles (e.g., miles per hour); typically, the average speed of all vehicles passing through the detection zone.
- Average Vehicle Length - a method of classifying the different types of vehicles (by length) passing through the detection zone.

These attributes can be used by the system to define the demand level, the utilization of capacity, potential incident (or other bottleneck) locations, and the level of service or performance on network segments. Additional traffic flow descriptors -- such as vehicle location and identification, vehicle weight, number of axles, etc. -- may be required by a system.

The specific data to be collected by an IVES-based system is dependent on the desired functions and user services, and the algorithms used by the system to perform these functions. For example, the established incident detection algorithms utilize occupancy measurements (although speed-based algorithms are being developed); travel time algorithms for developing traveler information require speed data; permanent count stations typically include volume and classification measurements; and electronic toll collection requires vehicle identification. A detection subsystem which provides all the required traffic flow parameters at each detection location would be preferable, but as shown in Exhibit 5-1 very few surveillance technologies provide this capability.

For most roadway-based IVHS applications, the system will require some or all of the basic traffic flow parameters of volume, speed, occupancy, and average length. The following relationship exists between these parameters:

$$\text{Speed} = \frac{K \times Volume \times Ave.\ Length}{Occupancy}$$

where speed, volume, ave. length, and occupancy are as previously defmed; and K is a "constant" for converting units of measurements (NOTE - The value of K does vary slightly depending on the length of the detection zone -- the longer the zone, the greater the occupancy measurements). If any three parameters are known, the fourth can be calculated using the above formula. Moreover, average vehicle length can generally be "assumed", based on actual measurements at key locations throughout the network; however, such extrapolations must be accurate and reliable.

Given the importance of the time advisory functions, speed data are considered crucial for developing travel time estimates within the IVHS network. Additionally, volume data are necessary for planning purposes as well as to aid in congestion monitoring and developing appropriate control strategies. Thus, as a minimum, the roadway detection subsystem will be configured to provide speed and volume information.

Detector Spacing

The spacing between detector stations has a significant impact on the effectiveness of

Technology	Mounting	V	O	S	C	L	Detection Area	Status
Loop	In Pavement	•	•	o	o	1	Side of Loop	Operational
Self powered	In Pavement	•	•			1	Point	Development
Radar (Wide Beam)	Overhead	•		•		4	Depends on Distance	Operational Testing (CT)
Radar (Narrow Beam)	Overhead			•		1	Depends on Distance	Operational Testing (CT)
Microwave (Forward Looking)	Overhead	•	•	•	•	1	Minimum 7-foot Length	Operational Testing (Toronto, NJ)
Microwave (Side Mounted)	Overhead (to side)	•	•	o	o	4-6	Depends on Distance	Operational Testing (Toronto)
Ultrasonic	Overhead	•	•		•	1	Point	Used in Japan
Infrared	Overhead	•	•	o	o	1	Depends on Distance	Used in Europe
Video Image Detection (VIDS)	Overhead	•	•	•	•	4	User defined	Operational Testing (NJ, MN)
Passive Acoustic	Overhead	•	•			1	User defined	Development

V = Volume
O = Occupancy
S = Speed
C = Classification
L = Number of lanes covered by single detection unit
• = Parameter can be measured
o = Parameter can be measured in a pared-configuration

Exhibit 5-1: Roadway Detector Technoloties

an IVHS-based system. As a general rule, detector spacing should never be greater than 3 miles (i.e., 3 minute +/- travel time between stations under normal flow conditions). This maximum spacing will permit the system to monitor congestion, to estimate travel tunes, and to develop reliable traveler information in a timely manner. Other system functions such as ramp metering and incident detection typically dictate a closer spacing of detector stations. For ramp metering, at least one detector station should be located between each metered entrance ramp. For incident detection, as can be seen in Exhibit 5-2, the closer the detectors are spaced, the more quickly an incident will be detected.

Regardless of the functions to be provided, the greater the level of congestion (e.g., incident, recurring, combination) along a section of roadway, the closer the detectors should be spaced. The logic behind this general rule can be demonstrated by referring back to previous Exhibit 2-3 (Speed-Flow Relationships). When a roadway is operating at or near capacity, any minor anomaly in the traffic stream (e.g., incident, excessive weaving in a merge area, etc.) can cause the flow to break down. Under these volatile conditions, it is important to monitor the traffic flow in a "microscopic" manner -- that is, a closer spacing of detectors such that the impacts of any disturbances in the flow can be identified almost immediately, and the appropriate actions (e.g., incident management response, metering rates, dissemination of traveler information) can be initiated soon thereafter as required to return the traffic flow to a more stable condition. These same anomalies also occur on less congested roadway segments, but their impact on traffic flow is not as great as compared to a segment which is operating near capacity. For example, instead of a breakdown in flow, the average speed may drop from 55 mph to 35 mph. Under these circumstances, traffic flow may be monitored in more of a "macroscopic" fashion -- that is, a larger spacing between detectors -- thereby reducing system costs with no appreciable impact on overall effectiveness.

The freeway segments to be detectorized and the recommended detector spacings for the Phase 1 and Year 2000 Plans are shown in Exhibits 5-3 and 5-4. In general, those segments with nominal 1/2-mile detector spacing experience the greatest congestion and the highest accident rates within the network. The intensive monitoring of traffic flow provided by 1/2-mile spacing will be utilized for automated incident detection along with congestion monitoring for traveler information. The next level of detector spacing -- nominally 1 - 11/2 mile along other relatively congested freeway segments -- will permit the system to monitor congestion levels, to develop reliable traveler information in a timely manner, and to determine appropriate metering rates. This spacing may also be utilized for automated incident detection, but the mean detection time will be significantly longer than that provided by 1/2-mile spacing. Those roadway segments which do not typically experience significant congestion or incident frequency will be instrumented at 11/2-3 mile intervals primarily to provide traveler information.

In addition to the detector spacing logic discussed above, another reason for not providing intensive detector spacing (at 1/2 mile intervals) throughout the roadway network is that a reliable "manual" incident detection system already exists -- specifically, the *SP cellular call-in system. As discussed in Chapter 7, the *SP program is receiving 18,000 to 20,000 calls per month regarding a variety of roadway incidents. Moreover, according to State Police personnel, they are detecting these incidents via *SP within 1 minute of their occurrence. Thus, the emphasis of the strategic plan is to provide intensive detectorization only for those segments with high congestion levels <u>and</u> accident rates so as to supplement the *SP network, and to detectorize the remaining roadway segments with longer spacings as required to provide congestion monitoring, accurate traveler information, and reliable information for developing metering rates.

Finally it is emphasized that the various spacing criteria discussed above are only guidelines. The actual spacing between adjacent detector stations will be dependent on several site-specific factors. These "opportunities" include locations of existing detectors, availability of structures for mounting overhead detectors over each lane, and accessibility of power and communication connections.

Detector Technology

A number of technologies are available (or in development) for collecting the roadway surveillance data.

Inductive LOOP Detectors

The inductive loop detector has been the predominant form of surveillance technology used in freeway management systems. An inductive loop.detector consists of a loop of wire buried in the roadway which is excited with a signal at a frequency ranging from 10 KHz to 200 KHz. The loop functions as an inductive element in the detection circuitry. When a vehicle stops on or passes over the loop, its inductance is decreased, and an electronic device (i.e., amplifier) detects the change in inductance. This on/off output, measuring the presence or absence of a vehicle, is processed to provide measurements of volume and occupancy. When installed in pairs (i.e., "speed-traps"), the loops can provide speed and classification information as well. It is also noted that 3M is now testing a prototype loop amplifier which reportedly will provide speed and classification information -- in addition to volume and occupancy -- from a single loop.

A major concern with loops is poor reliability (as reported by several users>, and the maintenance effort and disruption of traffic associated with repairing (i.e., re-cutting) a loop. It should be noted, however, that most loop detector problems are the result of poor design, improper installation techniques, lackadaisical inspection, or some combination of these, and not an inherent deficiency of the technology itself. Newer installation techniques -- such as loop wire encased in plastic tubing, use of better sealants, and embedding preformed loops (consisting of loop wires in PVC conduit) into the roadbed -- have dramatically improved loop reliability.

The Massachusetts Highway Department (MHD) is in the process of upgrading their loop detector network within the Phase 1 area as shown in Exhibit 5-5. Each station -- most of which are currently being installed -- consists of a loop-pair in each lane, thereby providing the ability to measure volume, speed, occupancy, and length on a lane-specific basis. The loops terminate in ground-mounted cabinets located at the side of roadway. Very few of these stations have power or communication connections, although conduit sweeps have been provided for this purpose. They are currently intended as count stations (using commercially-available traffic counting equipment), but they may be incorporated into the IVHS network.

Self-Powered Vehicle Detector

The self-powered vehicle detector (SPVD) consists of an in-road sensor containing a transducer, an RF transmitter with antennas, and a battery. The in-road sensor operates on the same principle as a magnetometer sensor. It is powered by an internal battery and its connection to the relay is a radio link. The roadside receiver includes a commercially available FM receiver and a tone decoder electronics package. No lead-in or interconnecting cables are needed (refer to Exhibit 5-6).

The battery does need to be replaced approximately every 2-3 years. Thus, the SPVD appears to have a primary application for temporary installations. It is noted that one manufacturer is marketing an SPVD with a solar panel/generator as a part of the embedded detector element, thereby eliminating the need for battery replacement. However, it is unknown what effect road dirt and grime will have on the efficiency of the solar panel.

This technology is still in development -- specifically, the radio link between the in-pavement unit and the roadside processor. Moreover, the unit does not provide speed information.

Overhead-Mounted Detectors

Installation of the detection unit above or to the side of the roadway permits maintenance activities to be performed with minimal disruption to the traffic flow. Moreover, these overhead-mounted detectors can generally remain operational during roadway reconstruction and rehabilitation activities that usually destroy loops and other in-pavement devices. One potential drawback with these technologies is that their optimum placement is (typically) directly over each lane; and for such an installation to be cost-effective, an existing overhead structure (e.g., overpass, sign support, etc.) is required. The location, spacing, and placement of these existing structures can impact the effectiveness of the surveillance subsystem.

Radar Detectors

Radar detectors direct a continuous wave of low-power microwave energy toward an area of roadway at a 45 degree angle. As vehicles pass through the beam, the energy is reflected back to the sensing element which measures the speed based on the Doppler effect. Two types of radar detectors are available, as shown in Exhibit 5-7.

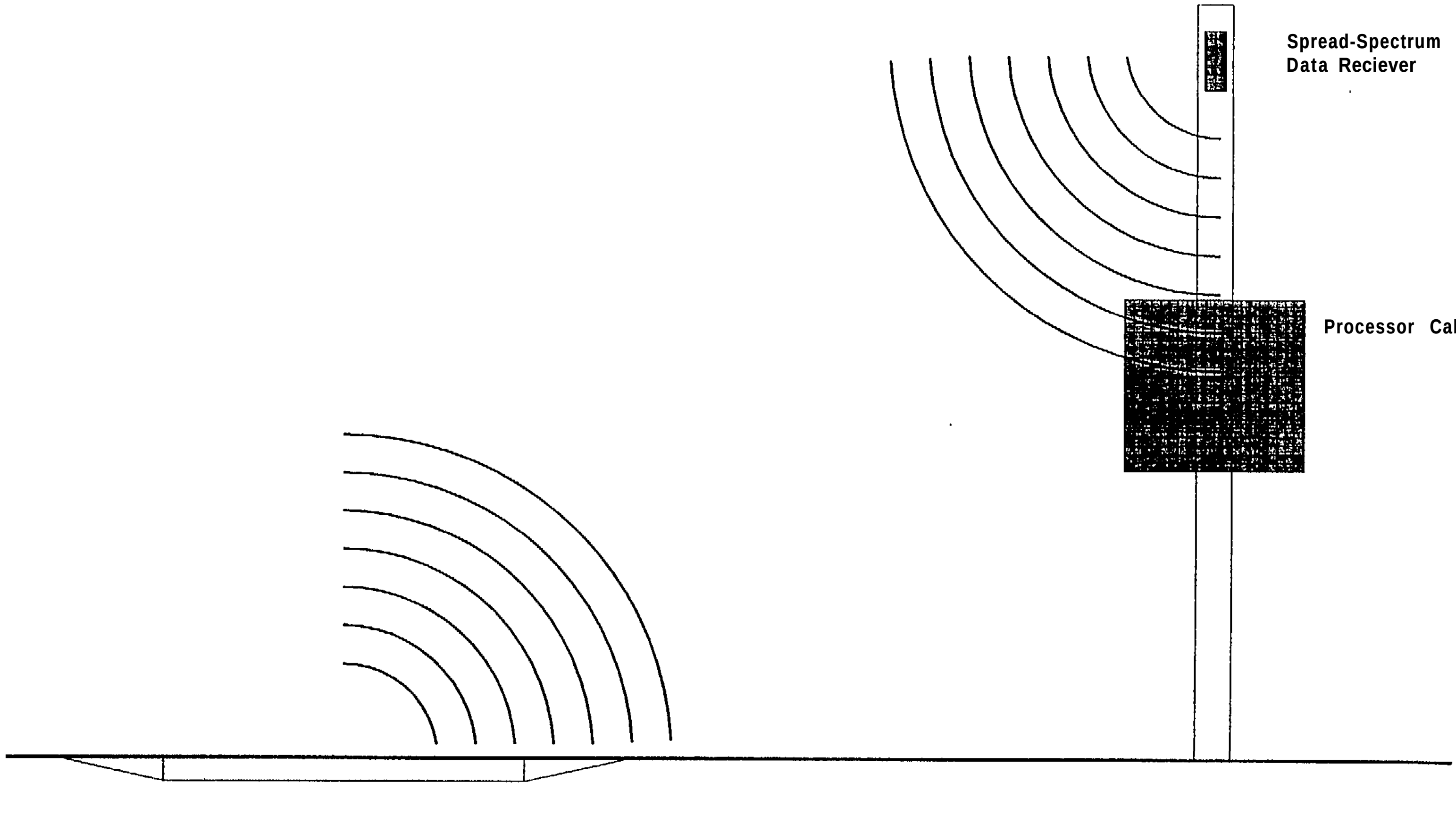


Exhibit 5-6: Self-Powered Detector

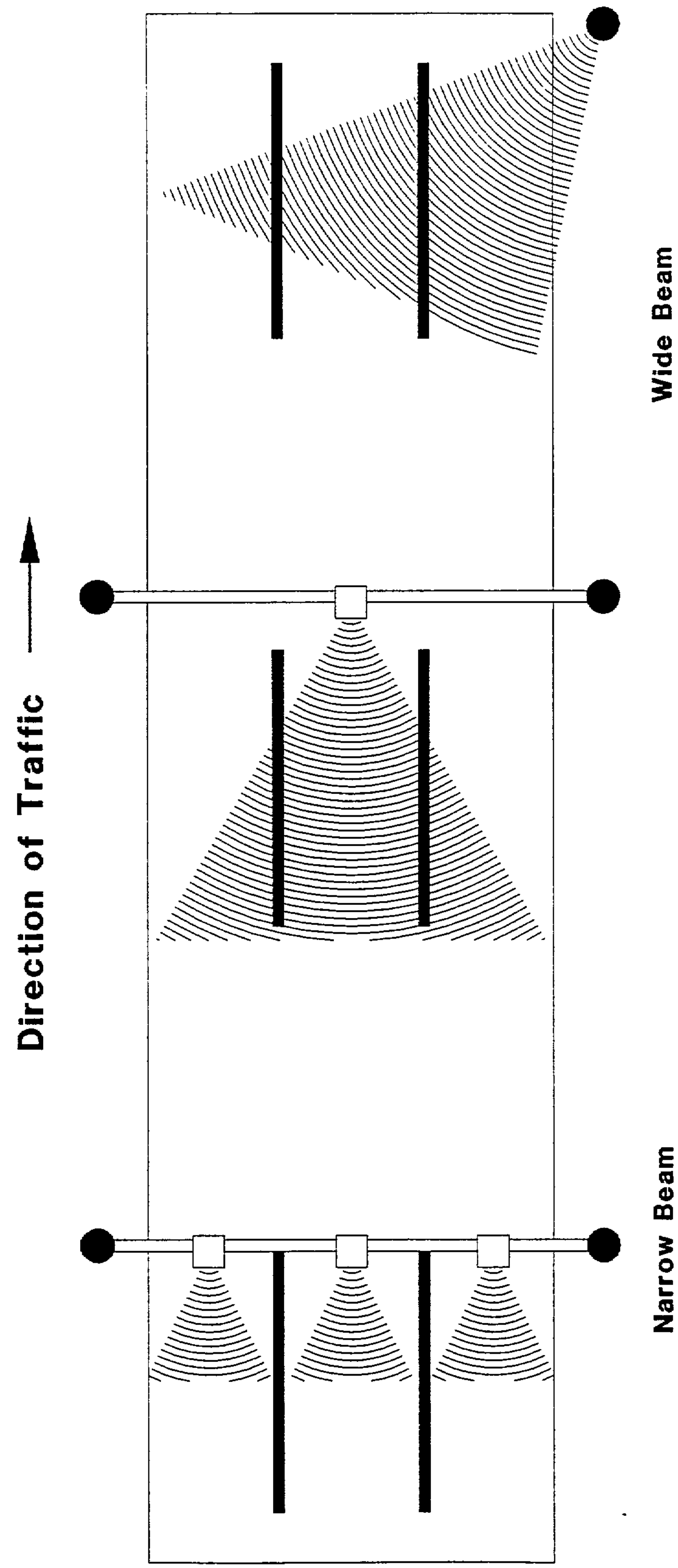


Exhibit 5-7: Radar Detection Operation

- Wide Beam - These units are installed at locations where only the general speed of the freeway flow is necessary. They can be mounted over the center of the freeway or to the side. Whenever a vehicle enters the beam, its speed is measured. If multiple vehicles enter the beam within the same one-second interval, the speed of the largest vehicle is typically recorded.

- Narrow Beam - These units are installed at locations where lane-specific traffic volumes and individual speed measurements are necessary. An individual detector is mounted over the center of each lane.

In addition to the radar unit, one vendor provides a "multiplexer" which provides power to, and collects the real-time speed information from, as many as 8 radar units. The multiplexer also compacts the speed data into a single character string for transmission to a field processor or communications modem via a RS-2232 interface. The character string is updated once every second. This particular radar detector also provides two pulse-type contact closures emulating a loop-pair speed trap. The first closure occurs when a vehicle enters the radar beam. The second is a "dummy" closure -- its occurrence, relative to the first contact closure in time, is calculated based on the direct measurement of the vehicle's speed and an assumed 12 foot spacing (front-to-front) of two 6'x6' loops in a trap configuration.

Radar detectors are being installed in the Hartford, Connecticut, region as part of an IVHS operational project. Initial evaluation results indicate that both the narrow-beam and wide-beam configuration provide accurate speed data. The narrow-beam configuration also appears to offer reliable volume information, but not necessarily in all circumstances. Similar results are being found in a FHWA detector evaluation. The volume counting function of the narrow-beam configuration and their performance during congested conditions (i.e., radar detectors are not able to detect motionless vehicles) requires further analysis.

Microwave Detectors

Microwave detectors are very similar to the radar detectors in that they transmit microwave energy toward an area of roadway from an overhead-mounted device. Instead of measuring a vehicle's speed using the Doppler effect, the microwave detector measures the time it takes for a transmitted pulse to arrive at the road or a vehicle, then be reflected, and return to the detector. The presence of a vehicle is denoted by the difference in the time of arrival of the pulse when a vehicle passes through the field of view, as compared to the time of arrival of the pulse from the road surface.

Several microwave detectors are on the market. One of these devices, developed by a Canadian firm (Electronic Integrated Systems) in concert with the Toronto Freeway Traffic Management System, is reportedly capable of true presence detection (i.e., the specified sampling rate is 100 times a second). The unit is reported to provide 12 detection zones of user-defined length (in 7-foot increments) along a narrow width beam path, with a detection range of 200 feet. Two mounting configurations are possible as shown in Exhibit 5-8.

- Side-Fired: Installation of the microwave detector at the side of the roadway -- at a 20-30 foot height and with no greater than a 50^0 angle to the vertical -- can provide lane specific volume and occupancy data. Speed and classification information can also be obtained if two side-mounted detectors are installed adjacent to one another, emulating a loop-based trap. A detector which can be installed to the side of the freeway will enhance maintenance activities (i.e., lane closures are not required). The potential drawback of the side-mounted configuration is that large vehicles passing through the beam in the outer lanes (i.e., those nearest the detector) may signigicantly reduce the unit's effectiveness at detecting vehicles which are concurrently present in the inner lanes -- a phenomenon known as occlusion. Initial results from testing on a 6-lane freeway in Toronto indicate "reasonable" accuracy (i.e., an average 5 percent error) for the 4 lanes closest to the detector, and very large errors for the two furthest lanes. Moreover, the errors tend to increase as the traffic volume increases.

- Forward-looking: The problem of interference from large vehicles can be eliminated by mounting detector units over the roadway. This configuration provides two detection zones for measuring volume, occupancy, speed, and classification but to obtain this information on a lane-specific basis, a detector must be installed over each lane, significantly increasing the costs as compared to a side-fired installation. This configuration has provided very accurate information along the New Jersey Turnpike.

Ultrasonic Detectors

Ultrasonic vehicle detectors include an overhead-mounted transducer which transmits sound waves (at a selected frequency between 20 and 65 KHz) into an area defined by the

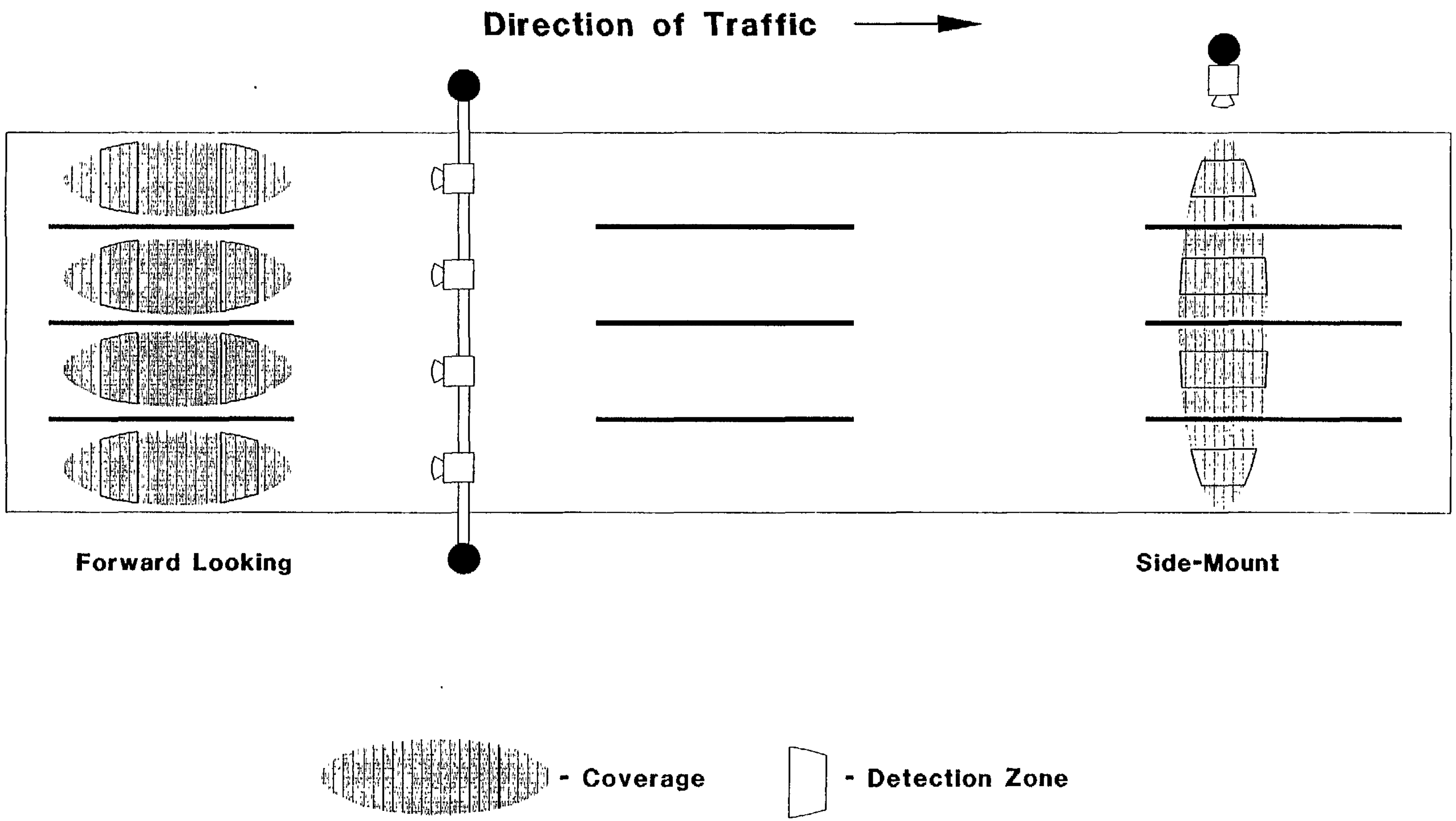


Exhibit 5-8: Microwave Detector Configurations

beam width pattern of the transducer. A portion of the energy is reflected from the road surface or a vehicle in the field of view. The detector transmits a pulsed waveform whose repetition period is typically between 80 and 100 msec, and measures the time it takes for the pulse to arrive at the vehicle and return to the transmitter. As shown in Exhibit 5-9, this permits the detector to measure the height profile of a vehicle, thereby providing classification data in addition to volume and occupancy.

The Port Authority of New York and New Jersey has experimented with ultrasonic detectors for a surveillance and control program at the Holland Tunnel. The ultrasonic detectors were placed in pairs at regular intervals to monitor and track individual vehicles moving through the tunnel, with fairly good results in limited testing. Ultrasonic detectors are used extensively in Japan in keeping with the government policy, which does not permit cutting the pavement. These detectors are a major component in the Tokyo traffic control system, and the Japanese application appears to be the most extensive use of ultrasonic detectors anywhere. A manufacturer in this country has combined the ultrasonic unit with a radar detector to provide speed information in addition to volume, occupancy, and classification data.

Infrared Detectors

Infrared detectors currently marketed consist of both active and passive models. In the active system, detection zones are illuminated with low power infrared energy supplied by light emitting diodes (LEDs) or laser diodes. The infrared energy reflected from vehicles traveling through the zone of detection is focused by an optical system onto a detector matrix mounted on the focal plane of the optics. Real-time signal processing techniques are used to analyze the received signals and to determine the presence of a vehicle. Changes in received signal levels caused by environmental effects -- such as weather, shadows, thermal heating, etc. -- are automatically corrected. Manufacturers, such as Schwartz Electra-Options Inc. report that the infrared detectors have the capability to detect vehicle presence even when the vehicle is stationary, and to provide speed and vehicle length measurements (computed from the measured time interval between the interception of two laser beams). The units are designed to accommodate mounting heights of between 15 and 30 feet. The size of the field

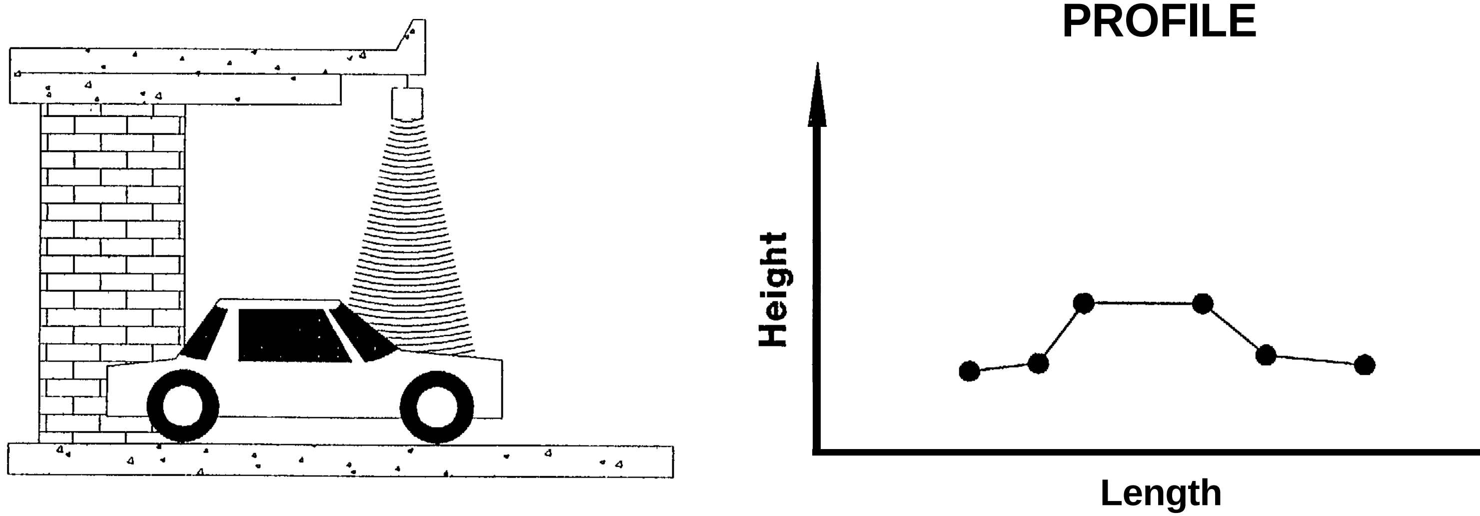


Exhibit 5-9: Ultrasonic Detection Operation

of view (i.e., detection zone) is dependent on the mounting height and the angle.

The passive infrared detector measures similar traffic parameters. It uses an energy sensitive detector element to measure the change in energy emitted when a vehicle enters the field of view. The source of this energy is blackbody radiation due to the non-zero temperature of emissive objects. The detector contains a lens that allows 3 to 7 degree detection zones as a function of focal length. The zone may extend up to 300 feet from the unit. To eliminate adjacent lane detection when detecting vehicles over 100 feet from the unit, a long focal length lens option is used.

Infrared detectors are used extensively in England for signal control and pedestrian crosswalks. Infrared detectors are also used on the San Francisco-Oakland Bay Bridge, where they are side-mounted at 600 feet intervals on the upper deck to establish the presence of vehicles across all five lanes, thus providing an occupancy measure.

Several disadvantages of infrared detectors are often cited. Changes in light and weather will cause scatter of the infrared beam and received energy. The energy reading at the focal plane is sensitive to water from fog, haze, and rain as well as to other environmental obscurants. Their reliability in high traffic flow conditions has also been questioned, but they have been used successfully on the San Francisco-Oakland Bay Bridge to track the end of queues.

Passive Acoustic

A passive acoustic detector "listens" for vehicles as they pass through a detection zone specifically, identifying the unique acoustical signature of engine noise or tires on the pavement. This is a very new detector technology with no installations as of yet. A passive acoustic detector has been developed by AT&T and is currently being tested by the New Jersey Turnpike and the Ohio Department of Transportation. The passive acoustic detector is presently designed for mounting directly over an individual lane, providing volume and occupancy data for that lane. It has also been tested in a side-mount configuration, but can only detect a vehicle's presence in the nearest lane.

It is noted that AT&T hopes to enhance the passive acoustic detector to provide user-definable detection zones and zone-specific presence detection over multiple lanes from a side-fired mounting. Since this technology uses acoustic signatures to detect vehicle presence, occlusion should not be an issue as it is with video- and microwave-based technologies.

Machine Vision

Machine vision technology -- also widely known as video image detection (VIDs) -- uses microprocessor hardware and software to analyze "video" images of the roadway, and to extract real-time traffic flow data (e.g., volume, occupancy, speed, classification, etc.). With current VIDs systems, "pseudo-detectors" are identified within the camera's field-of-vision by the user. Every time a vehicle enters or crosses this detection zone, a detection signal (i.e., presence) is generated which can then be processed to provide volume, speed, classification, and occupancy measurements.

VID offers several advantages -- it does not require installation in the pavement, and multiple detection points covering several lanes can be defined within a single camera's/sensor's viewing area. Potential concerns with VIDs are summarized below:

- Current VID systems emulate loops in that vehicle presence is detected, and then processed to develop volume, occupancy, speed, and classification data. This is not a problem per se, but at night most of these systems function by identifying the movement of headlights. While this method provides accurate volume and speed information, it precludes the processing of occupancy and classification data. In order to obtain this presence-driven information during the hours of darkness, it is necessary to utilize low-light sensitive cameras (e.g., minimum usable illumination at scene of 2 footcandles), and install the cameras along freeway segments with street lighting.

- The accuracy of VID is very sensitive to camera placement. The optimum situation for all VID systems is to have the cameras mounted as high as possible (at least 25 feet), and be centered over the roadway with a steep vertical angle. Conditions which vary from this optimum placement typically result in an increase in errors. A major design concern with camera placement and VIDs is occlusion -- when the image of one vehicle partially or completely masks the image of an adjacent vehicle. (Refer to Exhibit 5-10). Positioning the camera well above the center of the roadway will resolve most occlusion problems, but this may not always be feasible; and even with this type of arrangement, densely-packed or congested traffic may still cause occlusion.

- It is not feasible to combine the functions of vehicle detection and video

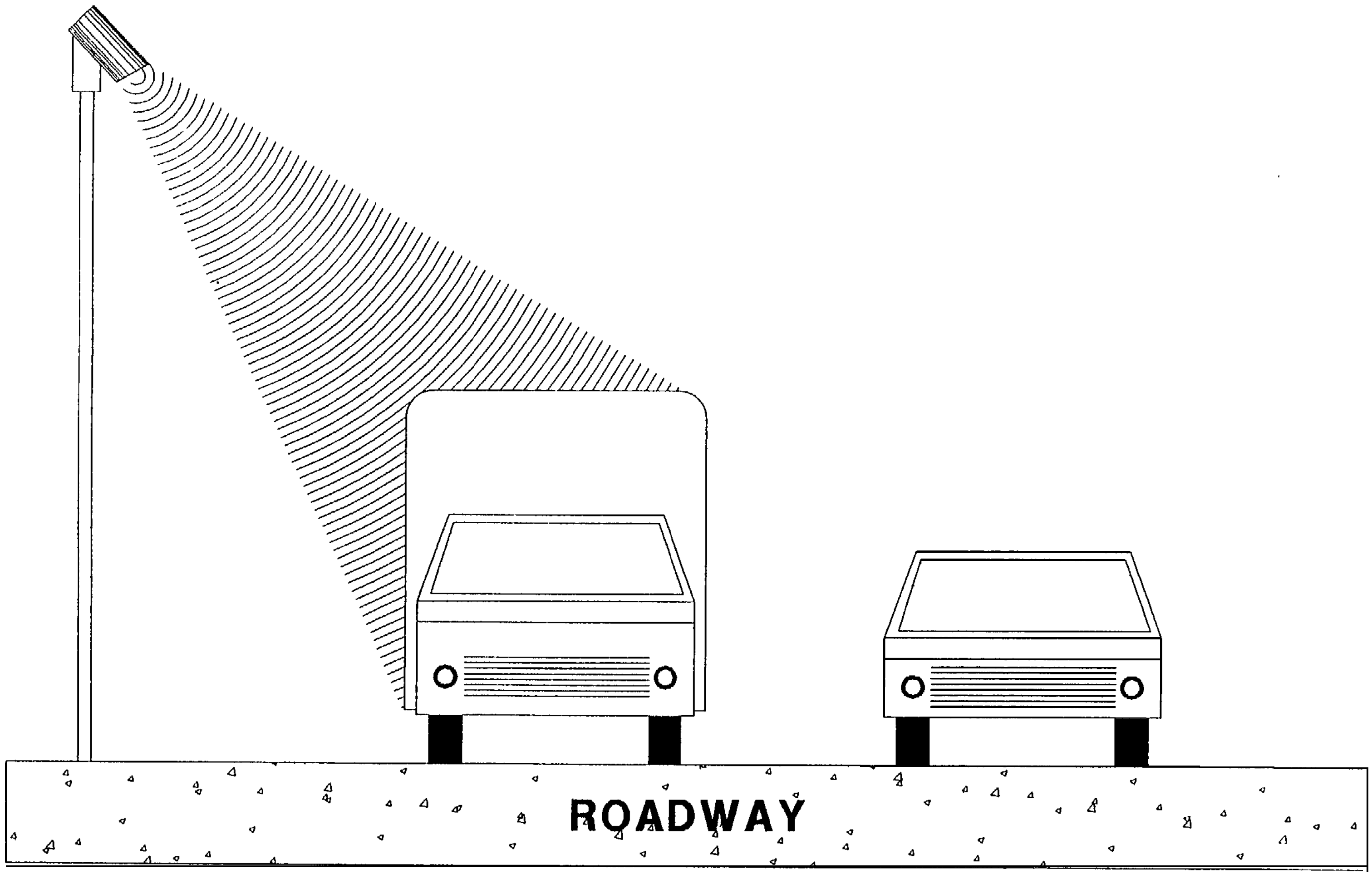


Exhibit 5-10: Example of VID's Occlusion

surveillance into the same cameras. The optimum camera for VID (in terms of accuracy during dusk, dawn, and inclement weather) is a low-light CCD sensor which may not be appropriate for CCTV functions. Moreover, every time the camera is panned, tilted, or zoomed to view an incident or other congestion -- a fairly common occurrence in most freeway systems -- the detection zones are lost. It is technically feasible to reposition the camera at the previously established detection zones after it has been moved, but special pan/tilt units and processing hardware are required.

- The cost of a VID system -- the camera, microprocessor, interconnecting cabling -- is very expensive relative to other detection technologies. The average cost of a single VIDs installation is $40,000-$50,000, although the costs are expected to decrease.

VID is rapidly becoming a "proven technology", with systems now being marketed by several vendors including Econolite, Kentron, and Computer Recognition Systems. Functioning installations include Minneapolis and the New Jersey Turnpike. Recent tests of VIDs show vehicle detection accuracy in excess of 95 percent for all of the conditions studied, provided the camera is in an optimum position. The heavy congestion shadows, poor lighting, and adverse weather conditions that degraded the performance of early VIDs do not appear to be problems in the more modern systems. It is anticipated that future VIDs will provide greater functionality, including tracking of individual vehicles, measuring speeds directly as an output of the vehicle tracking process (as compared to the current method of emulating loop pairs), and identifying congestion and detecting incidents.

Detector Recommendations

The Phase 1 recommendations must be based on proven technology and utilize existing facilities wherever possible. Accordingly, it is recommended that the MHD loop detector network (refer to previous Exhibit 5-5) be incorporated into the IVHS network. These existing loop stations will be upgraded to provide 120 VAC power and communications to the cabinet, along with the installation of a detector processor.

Two substantial gaps exist within the loop detector network -- the Massachusetts Turnpike (I-90) and a section of I-93 between Sullivan Square and I-90 (i.e., the elevated sections of the Central Artery where loop installation is very problematic). New roadway detectors are required along these segments, and also at other locations throughout the network as required to provide the recommended detector spacing.

The use of overhead-mounted detectors -- either narrow-beam radar or forward-looking microwave -- is recommended for those areas wherever an appropriate support structure (e.g., overpass, sign) exists, and the detector spacing requirements are satisfied. A radar or microwave detector will be installed over each lane, and the connecting cables from the detectors will terminate in a ground-mounted cabinet complete with power and communications. At those locations where an existing overhead support does not exist, new loop stations -- consisting of loop-pairs in each lane and a ground mounted cabinet -- will be installed.

The use of new overhead-mounted detectors (wherever possible) is recommended to avoid the lane disruptions associated with repairing (i.e., recutting) loop installations. Of the available overhead-mounted technologies, radar, microwave, and VIDs are the most proven in terms of accuracy and reliability. Given the current high cost of a VIDs installation, this technology is not recommended for the Phase 1 implementation. Radar detectors are currently less expensive than microwave detectors by approximately $2,000 per unit; but there is some concern as to the ability of narrow-beam radar units to provide accurate volume data under all traffic flow conditions. Depending on the results of operational tests and FHWA research, it may be necessary to install microwave units. Functional requirements for both radar and microwave units are summarized in Exhibit 5-11. It is noted that in developing the cost estimates in Chapter 13, the use of microwave detectors has been assumed.

The Phase 1 detector configuration will provide, as a minimum, lane-specific speed and volume data on a real-time basis -- information which is required for developing reliable traveler information, detecting incidents, and providing a historical record. The loop-based stations will also provide classification (i.e., vehicle length) data. The locations of Phase 1 detector stations -- both existing and proposed -- are shown in Exhibit 5-12.

Detector Data Processing

A major issue concerns how and where the data from the roadway detectors are

Exhibit 5-11: Functional Requirements for Radar and Microwave Detectors

Functional Requirements for Radar Detectors

- Operate up to 32 feet above the road surface.
- Detection area on roadway shall not exceed 8 feet in diameter when detector is mounted 32 feet above roadway.
- Detect vehicles traveling at speeds of 5 mph to 80 mph.
- Vehicle direction (traveler detector, away from detector) for detection user selectable.
- Housed in a weather-tight enclosure, with nominal dimensions of 10" (D) x 12"(W) x 10" (H).
- Operate on 11 to 15 VDC. Average current draw not to exceed 160mA.
- Include RS-232C serial data port, providing Transmit Data Receive Data, Carrier Detect, and Ground signals.
- Serial port shall operate at 1200 or 2400 baud, providing vehicle speed in ASCII format.
- Provide two pulse-type contact closures emulating a loop-pair speed trap. The first closure occurs when the vehicle enters the beam. The second is a "dummy" closure -- its occurrence, relative to the first contact closure (in time) is determined based on the direct measurement of vehicle's speed.

Functional Requirements for Microwave Detectors

- Microwave detectors shall use a beam of microwave energy transmitted toward the roadway to detect the presence of vehicles within user-defined zones. Whenever a vehicle enters the detection zone, the microwave detector shall provide an input to a DC isolator within a detector processor assembly.
- The microwave detector shall identify vehicle presence independent of the vehicle's direction of travel through the zone.
- Transmitter power of 10 mW maximum, and a frequency band of 10.525 GHz +/-25 Mhz. The detector shall comply with the limits for a Class A digital device, pursuant to Part 15 of the FCC rules.
- Area of coverage defined by 50 degrees elevation, 6 degrees azimuth, and 120 feet - 200 feet range, selectable.

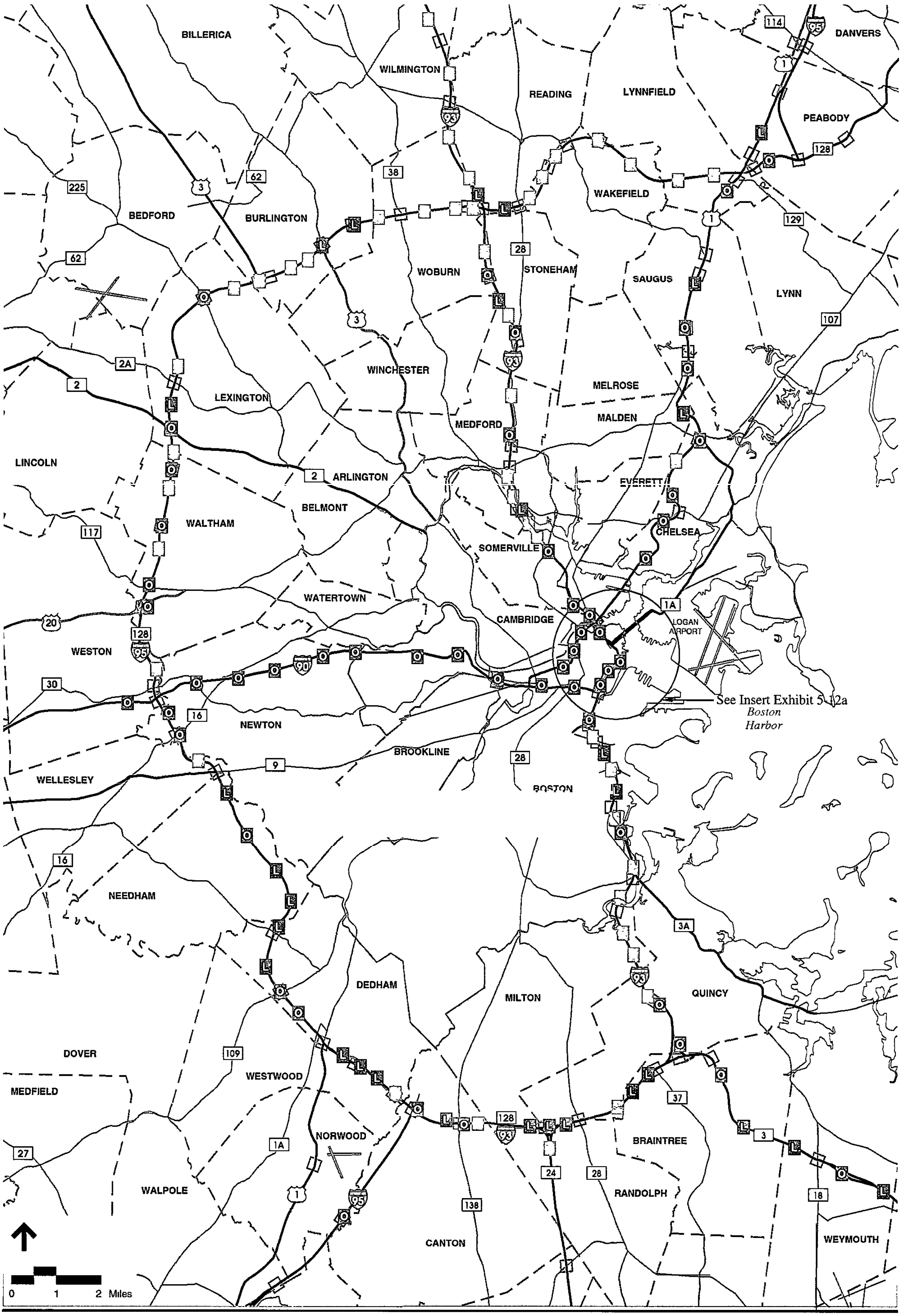
Exhibit 5-11: Functional Requirements for Radar and Microwave Detectors (continued)

- Provide a minimum of 6 detection zones. The size of each zone shall be user defined with a maximum range resolution of 7 feet. Spacing between detection zones shall be user defined with a maximum range resolution of 3 feet.

- Timing resolution of 10 Msec (maximum).

- Interface consisting of a single MS connector which provides power to the unit, output signals for each of the 6 detection zones, and signals for programming and testing.

- Enclosed in a stainless steel or aluminum box and sealed to protect the unit from wind up to 90 mph, dust and airborne particles, and exposure to moisture. The overall dimensions of the box, including fittings, shall not exceed 8-inches x 10-inches x 12- inches. The total weight of the microwave detector shall not exceed 15 pounds.



Existing Loop Detector Stations

Proposed Loop Detector Stations

Proposed Overhead Microwave Detector Stations

Interchange

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 5-12 Phase 1

Detector Locations

Existing Loop Detector Stations

Proposed Loop Detector Stations

Proposed Overhead Microwave Detector Station

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 5-12a Phase 1 Detector Locations (Continued) processed. Several options are available including:

- Have the information transmitted every second, in a format consisting of several data bits, to the central computer for processing.
- Preprocess the data in the field, accumulating speed and volume measurements over a specific time period (e.g., 20-seconds to l-minute), and then transmit the information to central. The processor also performs initial error checking of the collected data.
- Preprocess the data as noted above, but further analyze and store the information, transmitting to central only on an "event-driven" basis. For example, the field processor may execute' automated incident detection algorithms and transmit an alarm whenever a possible incident has been detected; or the processor may calculate and store average speed data, but transmit the information only when this speed value has fallen into a different, predefined speed bins (e.g., 0-20, 20-30, 30-45, 45 mph +).

The first scenario places a major burden on the communications network and requires a large powerful computer, and possibly several computers. The exception basis (i.e., event-driven) places the minimum burden on the communications network allowing "dial-up" communications, but field hardware which possess the required processing capabilities and the associated firmware are just now in the development stage. The middle scenario -- preprocessing the data and transmitting the information on a regular basis -- is utilized by most freeway management systems including the IPCS design. It is also recommended for the Boston area Phase 1 implementation.

Perhaps the most important consideration in this regard is flexibility. Given the rapidly changing detector market, an IVHS-based system must be capable of measuring traffic flow utilizing several different detector technologies, while also providing this real-time information to the control center in a single standard format. In this manner, the system is not locked into a specific technology or vendor. New detector technologies can be integrated into the system as they become available (and proven), while the processing at central remains consistent. Preprocessing the data in the field provides such an "open" architecture for detector data processing.

Detector Processors

A related issue is the type of detector processor hardware. MHD has standardized on NEMA-standard controllers for surface-street signal control; and utilizing this equipment for detector processing in the MHD-FTMS would be the optimum situation in terms of continuity of maintenance procedures and minimizing spare part inventories. Despite these important considerations, it is recommended that Type 170 controllers be utilized within the IVIIS network for detector processing. The primary reasons for this recommendation include:

- FTMS experience - Type 170 controllers are widely used in freeway traffic management systems throughout the country, including the IPCS, New Jersey Turnpike, Milwaukee, California, etc. The JHK project team is unaware of any system which utilizes NEMA controllers for detector processing as described above.

- Capabilities - Perhaps the reason why so many systems utilize Type 170 controllers and not NEMA controllers involves their respective capabilities. The NEMA standard is driven by switching signal lights at an intersection (and this it does very well). NEMA does not address detectors except as inputs to phase selection. On the other hand, with the appropriate firmware (as has been developed for other systems by several entities), Type 170 controllers can accomplish all the required processing tasks. The potential features of such firmware are summarized in Exhibit 5-13.

- Availability and Flexibility - Most NEMA controllers provide some form of enhanced detector processing as part of their vendor specific closed-loop signal systems; although features are significantly less than those listed in Exhibit 5-13. Moreover, the data formats and protocols for these systems are proprietary. Thus, the system might be locked into a single controller vendor for detector processing following the initial Phase 1 implementation. Type 170 controllers are available from multiple vendors, and the firmware for detector processing would be transferable.

- Cost - Recent bid prices in the Northeast (Connecticut, New York, New Jersey) indicate that Type 170 controller assemblies and NEMA controller assemblies (i.e., controller, cabinet, accessories) have equivalent costs -- $4,000 - $6,000 before installation.

The most significant problem with the Type 170 controller approach is that it represents lo-year old technology, and the interface is not particularly user-friendly. This

Exhibit 5-13: Minimum Detector Firmware Features

- Accommodate 20 detection zones per processor (minimum).

- Accumulate traffic flow measurements and compute other parameters over a specific time period (e.g., 20-seconds to l-minute). The data are accumulated and processed based on presence inputs from several types of detectors.

- Perform initial error checking of the data (e.g., comparing the accumulated flow measurements to user-defined over- and under-thresholds).

- Format the pre-processed detector station data and error codes for transmission to the control center. The central computer polls each detector station once every time period, which responds with the accumulated traffic measures. The data format should be consistent between stations, and may include the following information:

  - detector station identification
  - volume by lane (actual count)
  - occupancy by lane
  - average speed by lane
  - average vehicle length by lane
  - cumulative volume by lane (vehicles/hour)
  - occupancy by lane (percent)
  - cumulative average speed by lane (mph)
  - smoothed average volume for mainline (vehicle/hour)
  - smoothed average occupancy for mainline (percent)
  - smoothed average speed for mainline (mph)
  - smoothed average vehicle length for mainline
  - detector failures

is not considered a drawback for the Boston area IVHS network as the next generation Type 170 controller -- the Model 2070 ATMS controller -- is currently being developed by the California Department of Transportation. The 2070 is intended to satisfy the high-end needs of advanced transportation management systems, while providing greater flexibility in terms of communications interface and user programming. The new controller is being designed to maintain physical and electrical interface compatibility with the existing Type 170 cabinet. Thus, the Model 2070 will include a standard Type 170 interface connector (i.e. C-1) and compatible power and communication connections. A summary of the proposed design features for the Model 2070 controller is provided in Exhibit 5-14.

Future Detection

For the purpose of costing the 2000 IVHS Plan, it has been assumed that the same technologies as recommended for the Phase 1 Plan will be incorporated into the ultimate configuration -- specifically, existing loop detectors recently installed as part of the MHD count station program, new microwave detectors installed on existing overhead structures, and new loop stations (loop pairs) as required to achieve the nominal spacing requirements along segments where overhead structures are not present. However, depending on the state of the detector technologies and their respective costs at the time of implementation, it is very possible that segments of the 2000 IVHS Plan will incorporate other types of detectors. Possibilities include:

- Side-Mount Detectors - Installation of detection elements to the side of the roadway is probably the optimum situation in that lane closures are not required to install or maintain the unit. Additionally, depending on its placement, the detector may not be impacted by future freeway reconstruction activities.. The current occlusion problems with video and microwave may be minimized with other technologies (e.g., acoustic) in the future.

- VIDs - As previously discussed, the next generation of VIDs promises to not only detect vehicles, but to track them and, based on this information, identify congestion and detect incidents -- all of this being performed in the field and transmitted to central on an exception basis. It is also envisioned that the cost of VIDs will decrease.

Exhibit 5-14: Design Features of Model 2070 ATMS Controller

General

- Modular construction with interchangeability of modules between multiple manufacturers.
- Chassis will be a 19-inch EIA rack-mountable unit to allow for direct replacement in a Type 170 cabinet.
- Unit chassis and backplane will provide a 3U VME expansion bus, supporting four cards.
- Five basic modules provided -- central processing unit, field input/output module, system communications unit, power supply module, front panel module.

Central Processing Unit

- VMEbus based single board computer that provides the main processing capabilities, as well as control and coordination of other modules.
- Controller firmware shall be resident in an EEPROM supplied with the CPU module.
- Minimum of 7 serial interfaces on the CPU board.
- Processor shall execute the Motorola CPU32 instruction set, and operate at a minimum clock rate of 16 MHz.
- Minimum of 4MB of EEPROM.

Field I/OP Module

- Separate subassembly which will handle the existing Type 170 I/O functionality, providing the interface between the external filed equipment circuits and all other internal modules.
- Support the 44 inputs and 56 outputs of the Type 170 C-l connector.
- Provide an additional connector for expansion of up to 64 inputs and 64 outputs. All inputs may be used as system sensors or status monitors, and all outputs may be used as load switch outputs.

Vehicles probes

It is possible that, ultimately, the Boston area IVHS network may not use roadway detectors (such as loops, radar, microwave VIDs, etc.) at all. Instead, the vehicles traversing the roadway network might function as probes -- being tracked through the network and providing real-time information on segment and direction-specific travel times and speeds. This information can then be compared to expected travel times and speeds (based on historical data) to monitor congestion, detect incidents, implement diversion, and develop traveler information. The data can also be used to examine travel patterns for the expressway network (i.e., automated origin-destination surveys), thereby permitting the system to predict when and where recurring congestion will occur.

As previously discussed in Chapter 2, the SmarTraveler operational test is utilizing "manual" probes for collecting information -- that is, the driver calls in over a cellular phone to report congestion that he/she is experiencing, incidents, and travel times within the network. However, to obtain real-time information on an automated basis (i.e., no action required of the driver), several design elements are necessary.

The population of probe vehicles is a crucial issue. A study being conducted for TRANSCOM on the feasibility of using AVI-equipped vehicles for incident detection indicates that 10 percent of the vehicle population needs to be tagged, with AVI readers spaced at 1 1/2 miles. The requirements for incident detection are probably greater than the probe density required for congestion monitoring and traveler information. Assuming that a 5 percent probe penetration would be adequate for this purpose, 30,000 daily probe trips would be required. (It is noted that the SmarTraveler network of manual probes -- consisting of 364 regularly scheduled daily trips -- constitutes less than one-tenth of one percent of the estimated 600,000 - 800,000 daily trips within the study area.)

Another issue with a probe application is the possible conflict with an individual's right to privacy. Having one's vehicle equipped with an AVI tag or other probe device might be interpreted as "big brother", unless of course it is a voluntary action. In the TRANSCOM project, the reader location, time, and a dummy vehicle ID will be transmitted to a central computer for processing.

Probe vehicles may be achieved under several scenarios:

- AVI - equipped vehicles As previously noted in Chapter 2, the Massachusetts Turnpike Authority anticipates that a new ETC system will be implemented over the entire length of the Turnpike as well as the Sumner Tunnel. MassPort may also incorporate a compatible ETTM system for the Tobin Bridge. Similarly, the Third Harbor Tunnel plans to incorporate AVI tags for electronic toll collection. While these proposed systems will probably provide a sufficient probe population for the Turnpike and the Central Artery, it is uncertain whether an adequate number of probes will be present along other segments of the study area. It is envisioned that AVI-based probes (as a secondary function to ETTM) will not create much of a right-to-privacy issue, as drivers will purchase tags for the express purpose of being identified.

- Cellular Phones - A "Direction Finding Localization System" (DFLS) has been developed by KSI of Annandale, VA. The DFLS, which is currently being tested as part of an operational test, uses the multiple angles of reception of signals from cellular phones to determine the locations of vehicles via mathematical algorithms and digital signal processing. The phones, when turned on but not necessarily in use, are received by more than one cell. Any vehicle with a cellular phone may be tracked, thereby providing average speed information for the various roadway segments, which in turn may be used for traveler information and possibly incident detection. If this technology works, the population of tagged vehicles should not be an issue. New England Telephone reports that 4-5 percent of the vehicles are equipped with cellular phones, and the coverage is increasing. On the other hand, the privacy issue may be a major concern, as well as a potential legal issue.

- In-Vehicle Displays - The national IVHS architecture effort is focusing on, among other issues, the use of in-vehicle displays for disseminating enroute traveler information. Transmission of the real-time information to the vehicle obviously requires an air-path communications medium (e.g., radio/infrared beacons, satellite etc.). If two-way communications are established, the vehicle may act as a probe providing information as to its speed, location, etc. The probe-related issues of coverage, population, and privacy will also apply to the use of in-vehicle devices for this purpose.

WEATHER DETECTORS

MHD is in the process of implementing a monitoring system for winter road conditions. The proposed system, which is being furnished and installed by Vaisala, Inc., includes roadway surface condition sensors which detect the following surface conditions:

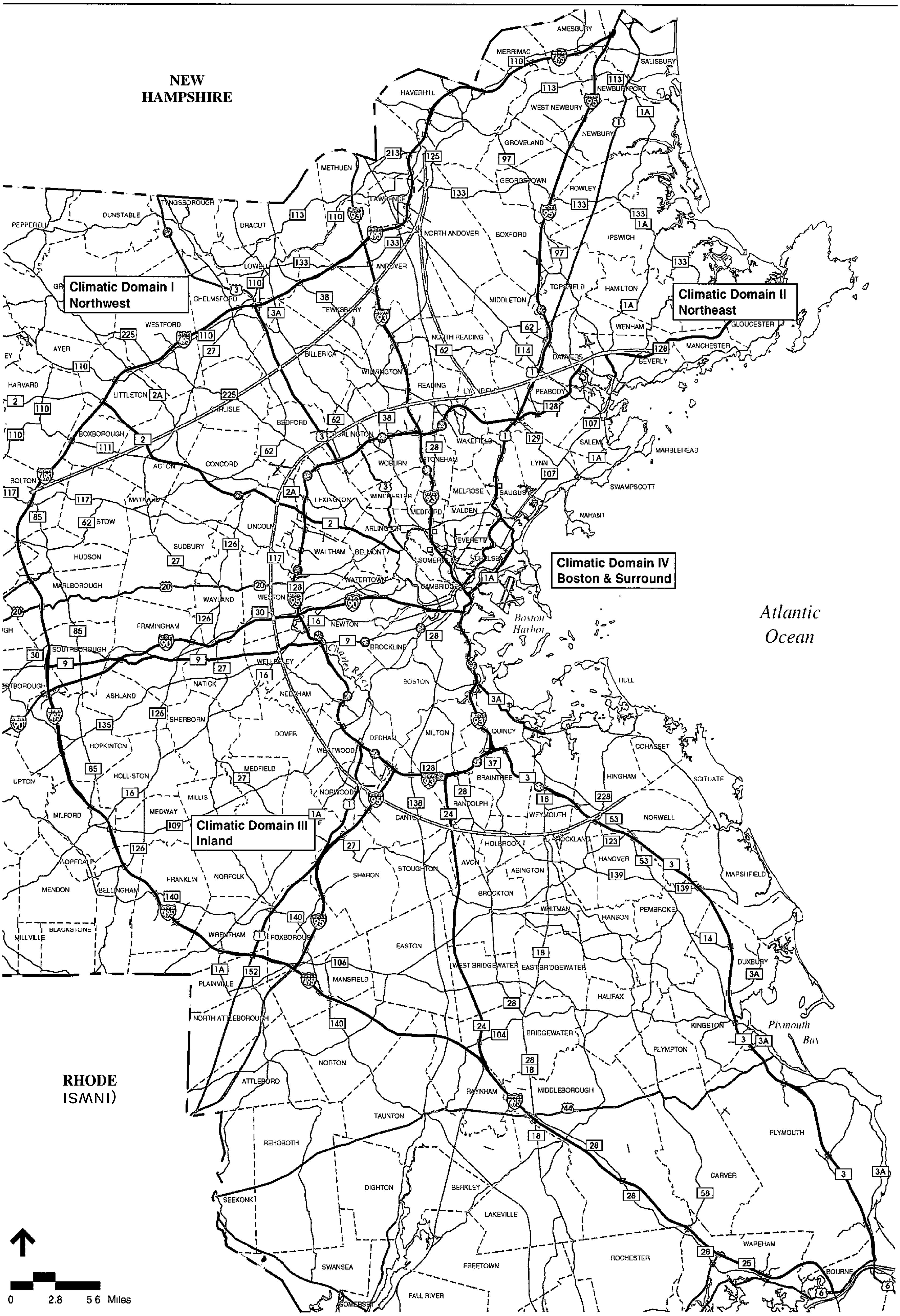
- pavement surface temperature
- dry pavement
- wet pavement
- moist pavement
- wet, but not frozen condition below 32°F
- snowy or icy pavement below 32°F
- dew pavement
- frost pavement
- presence of de-icing chemical
- black ice

Five sensors are being installed. The sensors are connected to remote processing units located in the field which measure, collect and preprocess the environmental data, and then transmit the information to a central PC-based computer for display (map or tabular) and historical storage. Other elements of the MHD weather system include atmospheric condition sensors (e.g., wind speed, wind direction, air temperature) thermal mapping information, and weather forecasting.

As part of the Phase 1 Plan, it is recommended that twelve (12) additional roadway surface condition sensors (with remote processing units) be installed at the locations shown in Exhibit 5-15. The segment-specific information obtained from these sensors will be used to provider enhanced traveler information (e.g., "ICY CONDITIONS AHEAD") and to adapt traffic management and control strategies to better suit the particular conditions. Additionally, the information from these detectors should be coordinated with MBTA commuter rail detectors at all 9 layover facilities.

As part of the Year 2000 IVHS Plan, it is recommended that roadway surface condition sensors also be installed at the following locations:

- I-495 between I-95 and I-93
- I-495 between I-93 and Route 2
- I-495 between Route 2 and I-90
- I-495 between I-90 and Route 1
- I-495 between Route 1 and Route 24
- I-495 between Route 24 and Route 6
- Route 3 (south of Boston) between Route 6 and Route 44
- Route 3 (south of Boston) between Route 44 and Route 228
- Route 24 between I-495 and Route 128



Roadway Surface Condition Sensors

- Existing
- Proposed
- Climate Domain Zone Boundary

The Commonwealth of Massachusetts

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Exhibit 5-15 MHD Phase 1 Weather Sensor Network

- I-95 (south of Boston) between I-495 and Route 128
- Route 1 (south of Boston) between I-495 and Route 128
- Route 3 (north of Boston) between I-495 and Route 128
- I-93 between I-495 and Route 128
- I-95 (north of Boston) between I-495 and Route 128

OVERHEIGHT DETECTORS

Overheight detectors are being installed, as part of the IPCS, on all entrances to the Third Harbor Tunnel and their approach roads. These infrared-based units will detect vehicles in excess of 13-feet, S-inches high approaching a tunnel entrance and will actuate a warning message via blank out signs. It is recommended that additional installations -- including the overheight detector, warning blank out sign (e.g. "VEHICLE TOO HIGH FOR TUNNEL") and processor -- be incorporated into the Phase 1 Plan. These devices will be installed well beyond the IPCS boundaries, thereby providing advanced warning to overheight vehicles and allowing them to divert easily around the tunnel and its approaches. Suggested locations include:

- Eastbound I-90 in advance of I-93
- Northbound I-93 in advance of I-93
- Southbound I-93 in advance of U.S. Rte. 1

PUBLIC TRANSIT MONITORING

In addition to monitoring the roadway network, real-time surveillance of transit modes is also an important function of the Boston area IVHS network. Such real-time data on vehicle locations will be used to enhance operations control and passenger information. The transit information will also be integrated with the roadway network data to provide a multi-modal traveler information database throughout the region.

The MBTAs on-going project to upgrade the "T" lines in terms of operations control and real-time information is discussed in Chapter 2. Given the relatively high rating given to the route/mode guidance function, it is recommended that the Strategic Deployment Plan for Year 2000 include an expansion of the enhanced transit surveillance network to ultimately include the commuter rail lines and buses. There are, however, several unknowns associated with this recommendation. First of all, the aforementioned "T" project is a major undertaking which is on the leading edge of the IVHS state-of-the-art for transit systems. Accordingly, this IVHS-based transit system should be completed, fully operational, and evaluated before addressing the other elements of the transit network.

While implementing automated vehicle locating (AVL) systems for rail systems is considerably easier than for bus systems (primarily due to the communication requirements), an advanced AVL system for the commuter rail network may experience some institutional hurdles -- specifically, the network consists of several separate dispatching systems. For instance, the southern and northern lines are dispatched from different locations. Moreover, they are dispatched by AMTRAK (under contract to MBTA), except for the Framingham line, which is dispatched by CONRAIL from Albany.

With regard to AVL-based systems for buses, the Federal Transit Administration is funding demonstration projects in Baltimore, Dallas, Denver, and Milwaukee to investigate their feasibility and usefulness in terms of operations control and passenger information. Another issue is the considerable expense (up to $10,000/bus) presently involved in developing and implementing these AVL-based systems.

Park-And-Ride Lots

From the perspective of the traveler information functions -- particularly the route/mode guidance elements -- knowing that a roadway is congested (a common occurrence) and that the parallel transit line is running on schedule (also a common occurrence> may not be enough. It is also important to know if parking spaces are available at the nearest park-and-ride lot, and if not, where parking for transit can be found. This requires that the surveillance function be extended to include park-and-ride lots, and that real-time information (i.e., available spaces/full) be integrated with the other transportation information.

It is recommended that all major park-and-ride lots (i.e., greater than 400 spaces) be included in the Phase 1 and Year 2000 plans, depending on their respective locations. The basic surveillance subsystem will consist of detectors at the entrances and exists to these lots;

a Type 170 controller with appropriate firmware to continually compare the inflow with the outflow so as to identify the number of vehicles in the lot (and, accordingly, the number of available spaces); and a communications link to one or more TOC's. As errors accumulate in such an automated process, it will be necessary for the lot operator to manually count the number of vehicles in each lot on an occasional basis and input the actual number.

6. INCIDENT MANAGEMENT

Non-recurring congestion is the result of "incidents" which block travel lanes or otherwise reduce capacity, thereby impeding traffic flow on the freeway. These freeway incidents are relatively unpredictable, and can take on several forms including:

- Accidents - In addition to creating congestion, the initial accident may also cause secondary incidents -- accidents within the queue involving drivers who follow too closely and/or fail to react to the slowing traffic ahead of them.

- Disabled Vehicles - Even when stopped on the shoulder, a disabled vehicle causes side friction which reduces capacity. Additionally, the motorist of a disabled vehicle, if walking along the freeway, can also constitute an incident (and possibly a serious safety concern>. In certain instances, the disablement may be "spectacular" in nature (e.g., car fire), resulting in excessive rubber-necking and further congestion.

- Spilled Loads - A spill can block several lanes; and if it involves hazardous materials, complete closure of the freeway and rerouting of traffic may be necessary.

- Adverse Weather - Eastern Massachusetts receives its fair share of adverse weather (e.g., snow, ice) which often tie up traffic. In some extreme cases, snow and ice may warrant partial or total closure of sections of the freeway.

- Special Events - Fenway Park and Boston Garden are examples of sites which generate significant traffic volumes on the adjacent freeways in a relatively short period of time. In most instances, it is possible to plan and implement traffic management for these events (sports, concerts, etc.) since the start times are known and the end times can be estimated fairly accurately. Different types of events may exhibit variation in the traffic flow distribution and directions.

- Construction/Maintenance - Necessary construction and maintenance activities on freeways represent a form of "planned' incident from the perspective of the transportation agency, but they can be random events to motorists unless adequate advance publicity and warning are provided.

Due to increased side friction weaving to avoid the blocked lane(s), and rubber-necking, the impact of an incident on roadway capacity goes well beyond the simple subtraction of the capacity of number of blocked lane(s). The capacity reduction effect for various freeway cross-sections and incident configurations is shown in Exhibit 6-l.

Given the impact of a single incident on traffic flow, coupled with the number of incidents which occur, the level of nonrecurring congestion in the Boston area freeway network is significant. Statistics developed by the Federal Highway Administration (FHWA) indicate that approximately 78 percent of all freeway congestion in the Boston region is attributable to incidents.

Strategies for minimizing the impact of freeway incidents on traffic congestion are categorized as "incident management". Incident management can be defined as a coordinated, preplanned use of human and mechanical resources to restore full capacity as soon as possible after an incident occurs, and to efficiently manage traffic during the incident. Incident management does not eliminate all congestion caused by incidents; but a study by FHWA indicated an average 37 percent reduction in incident-related delay following implementation of comprehensive incident management programs.

The freeway incident management process involves the following activities:

- Reducing the time required to detect the occurrence of an incident (i.e., awareness)
- Reducing the time required to verify the incident, identify the types of vehicles involved, and to determine the proper response (i.e., identification)
- Reducing the time required to notify the necessary agencies and organizations, and then for the appropriate equipment and personnel to arrive on the scene (i.e., response)
- Reducing the time required for the incident to be cleared from the roadway, restoring full capacity, while exercising proper on-scene management of traffic flow (i.e., clearance)

The Massachusetts Highway Department and the Massachusetts State Police initiated an incident management program throughout the Commonwealth several years ago. The existing features of this on-going effort, plus the additional elements recommended for the Boston area IVHS Strategic Plan are discussed below. (Note - Providing traveler information throughout the process is also an important element. This function is addressed in Chapter 7.)

Exhibit 6-1: CAPACITY REDUCTIONS DUE TO INCIDENTS

FREEWAY CROSS-SECTION (No. of Lanes)				
Blockage	2	3	4	5
Shoulder[1]	20%	17%	15%	10%
l-Lane	65%	47%	42%	33%
2-lanes	---	79%	67%	55%

1 This does not include vehicles merely parked on the shoulder

INCIDENT DETECTION

The Massachusetts State Police, working in conjunction with the cellular telephone companies, has established a toll-free highway emergency number (*SP) whereby motorists can report incidents to the Massachusetts State Police communications center in Framingham. The Framington communications center handles over 20,000 cellular phone calls per month from the 617 and 508 area codes. The State Police estimate that they receive seven to eight calls per incident, and that they respond to over 90 percent of the reported incidents.

Cellular phones and the *SP network have undoubtedly decreased the incident detection time -- the State Police estimate that they are detecting the reported incidents within a minute of occurrence. This manual method of incident detection and surveillance is expected to continue, with possibly a further improvement in detection time as the use of cellular phones in the Boston area becomes more widespread, and with more publicity regarding the *SP system.

Suppemental Signing

A common problem with cellular call-in networks such as *SP is the accuracy of the information provided by the caller (i.e., motorist) with respect to the incident location.

Freeway motorists are often unable to identify their location and direction in any meaningful way. To minimize the potential for misleading communications from the public, thereby enhancing the *SP incident detection capabilities, it is recommended that supplemental signing be installed along all the freeways and toll facilities.

Supplemental signs are categorized in the Manual On Uniform Traffic Control Devices[1] (MUTCD) as an element of Guide Signs. Guide Signs provide motorists with information about their location and route, direct them to various destinations, and identify roadside and adjacent motorists' services and points of interest. The system of supplemental signing should include the following information regarding location (refer to Exhibit 6-2):

- Route markers with direction (shields)
- Roadway overpasses/underpasses
- Railway overpasses/underpasses
- Watercourses
- Jurisdictional boundaries
- Milepost locations

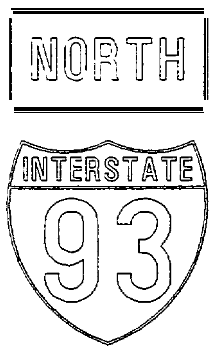
Route Markers

These signs are typically the highway route shields with the route number. On an expressway, they are found on guide signs either overhead (usually at interchanges) or ground-mounted on one or both sides of the traveled highway (between interchanges). The Interstate route shields mounted over the highway will usually have a direction on the sign. The ground-mounted signs will be accompanied by cardinal direction markers identifying the route's designated direction[2].

These signs should be installed along with cardinal direction markers. It is recommended that these signs be installed in both directions between each interchange. The signs should conform to the size and copy specifications for expressways/freeways in the MUTCD.

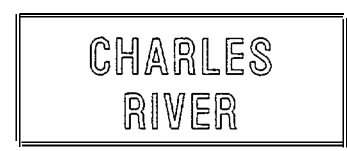
1 Published by the U.S. Department of Transportation, Federal Highway Administration

2 The designated direction (N,S,E,W) will not always necessarily agree with the route's compass direction at a certain point.



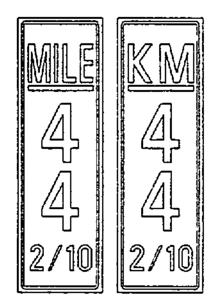
ROUTE MARKERS
WITH DIRECTION

ROADWAY
OVERPASSES/UNDERPASSES

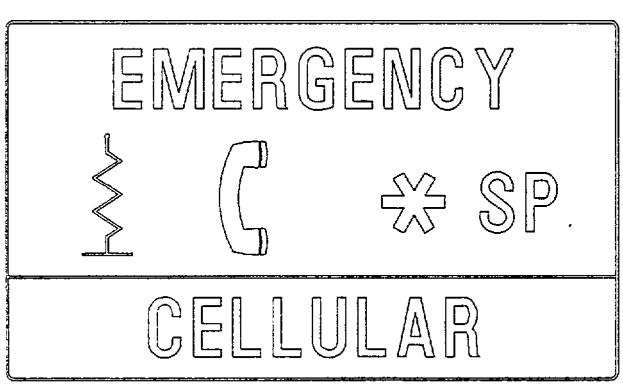


WATERCOURSES

JURISDICTIONAL
BOUNDARIES



MILEPOSTS



CELLULAR CALL-IN
TELEPHONE

Exhibit 6-2: Examples of Supplemental Signs for Phase I Deployment Plan

Roadway Overpass/Underpasses

These general information signs are used to identify the roadway being intersected, either as an overpass or underpass. These roadways are identified by name or route number, depending on how it is commonly known to the local resident. When possible at an overpass, the identifying roadway sign should be mounted on the bridge, directly over the travel portion of the highway. If this interferes with any interchange or higher priority guide signing, the identifying roadway sign should be mounted on the right side of the highway as close to the overpass as possible. In the case of an underpass, the sign should be mounted on the right side of the highway either in the ground as close to the bridge as possible, or attached directly to the bridge wall.

All highways and railways passing under or over the roadway should be identified using street name panels. These signs should use the name and route number (if applicable) of the highway. These signs should be white-on-green, and conform in size to the MUTCD's expressway/freeway specifications. Streets (or railways) which pass over the highway should have signs mounted on the bridge overpass, centered over the travel portion of the road. This location recommendation should be altered if the overpassing structure is skewed such that a sign mounted on the bridge would not be legible to motorists passing under it. Sound engineering judgement is needed in this case, and other possible installation locations may include the right side of the road. In the case of a street or railway passing under the highway, the identifying name panel should be installed on the right side of the roadway.

Railway Overpasses/Underpasses

This general information sign identifies the intersection of the traveled highway with a railway line. It is used in the same manner as that for roadway overpasses/underpasses.

Watercourses

This general information sign is used to identify the watercourse in which the travelled highway is passing over. It typically names the river, stream, etc., and the sign is located on the side of the traveled highway and mounted in the same fashion as the roadway or railway underpass. All watercourses should be identified along the highway. The type, size and installation recommendations for these signs are similar to those for a highway or railway underpass described above. One other option for installation of these signs is on the bridge's approach parapet wall.

Jurisdictional Boundaries

This general information sign identifies the boundaries of political jurisdictions, and should be located on the side of the traveled highway.

Milepost Markers

These markers identify indexed mileage of a routs continuously from the beginning of the route. They are typically spaced at one mile increments, but where incident management programs exist, the spacings can be reduced to one-tenth of a mile. These signs are probably the most important of the supplemental signs in terms of location identification. The unfamiliar motorist who does not recognize another location identifier, such as an overpass or river crossing, is always in sight of a one-tenth milepost marker, and can report the location of an incident if the milepost marker is in place. Likewise, when an incident has been reported, these signs provide location guidance to the responding emergency agency.

Milepost markers should be installed at one-tenth of a mile spacings. The signs should be installed throughout the system where possible. This may not be possible on all parts of the system. This recommended spacing, however, should be adhered to where possible. These signs should include additional information such as the route number and direction. It is recommended that these signs be placed only on the right side of the roadway. (Note - Milepost markers, as described herein, may also be considered kilometer post markers, with recommended divisions of two-tenth kilometer.)

Discussion

Cellular telephones are not an incident detection panacea. There is no guarantee that all incidents will be reported in this manner. Additionally, when incidents are reported by phone, there is no guarantee that the information won't be erroneous or even fraudulent; although receiving multiple calls per incident does provide some degree of verification. The most significant drawback with this manual method of surveillance and incident detection is that cellular telephones are incapable of providing real-time volume and speed data (unless they're used as probes), nor can they identify the areas and extent of freeway congestion -- information which is absolutely necessary for accurate and credible traveler information, for implementing the optimum control strategies (e.g., metering), and for planning purposes. Accordingly, the IVHS Strategic Plan includes automated surveillance (i.e., detectors) as discussed in Chapter 5, and automated incident detection and closed-circuit television for verification as described below.

Automated Incident Detection

The *SP incident detection subsystem will be supplemented by automated incident detection along the high-accident/high-volume segments of the roadway network. As discussed in Chapter 5, these segments are being instrumented with detectors at nominal 1/2-mile intervals, thereby providing detection of incidents within 3 - 5 minutes. The purpose of the automated incident detection functions is not to necessarily improve the detection time provided by *SP; but rather to ensure that no incidents are missed along these critical segments of the roadway network.

The incident detection algorithms must use the same parameters provided by the detection subsystem -- specifically speed and volume. Speed-based incident detection algorithms (i.e., logic which uses only speed as an input) have recently been developed and implemented by JHK for the ConnDOT FTMS in Hartford. Each algorithm uses **a** set of states including Free, Tentative, Confirmed, and Continuing to describe the incident status at a detector station. The algorithms use incoming data to determine transitions between these states. The thresholds that are used for each transition may be selected for each station and modified by the time of day, day of week, or for each 15-minute period in the week. Although rather heavy tuning of thresholds may be required, the flexibility of these simple algorithms is expected to be very powerful. This speed-based logic is summarized below and shown in Exhibit 6-3.

- Mean Speed - Compares the mean speed at a detection station to an incident start threshold and flags an incident when the speed remains below the threshold for the specified incident start time. Terminates the incident when the speed rises above the incident and threshold for a time that exceeds the incident and interval.

- Difference in Speed - Compares the speed measurements of adjacent stations to detect d&continuities. Speed difference, ratio of speeds, and downstream speed tests are used to confirm an incident, similar to the California algorithm occupancy tests. Another variation of this algorithm uses a persistence check on each of the three tests. (Note - California-type algorithms are being incorporated into the IPCS.)

- Standard Deviation - Analyzes the distribution of speeds at each detector station. Just following an incident, the distribution tends to widen before the traffic flow backs down. The standard deviation is a good indicator of this effect. The parameters used for this test are the current speed, the standard deviation of the speed, a spatial standard deviation ratio, a temporal standard deviation ratio, and a trend measurement of the speed. These parameters are tested against a set of thresholds to determine the presence or absence of an incident.

The initial results from evaluation testing of these algorithms in Hartford look promising. Similar speed-based incident detection algorithms are proposed for the MAGIC System in northern New Jersey.

INCIDENT VERIFICATION

Closed-circuit television (CCTV) has been used extensively in freeway management systems for the purpose of incident verification. Cameras are installed along segments of the freeway, and the video pictures are transmitted back to the system control center. It is

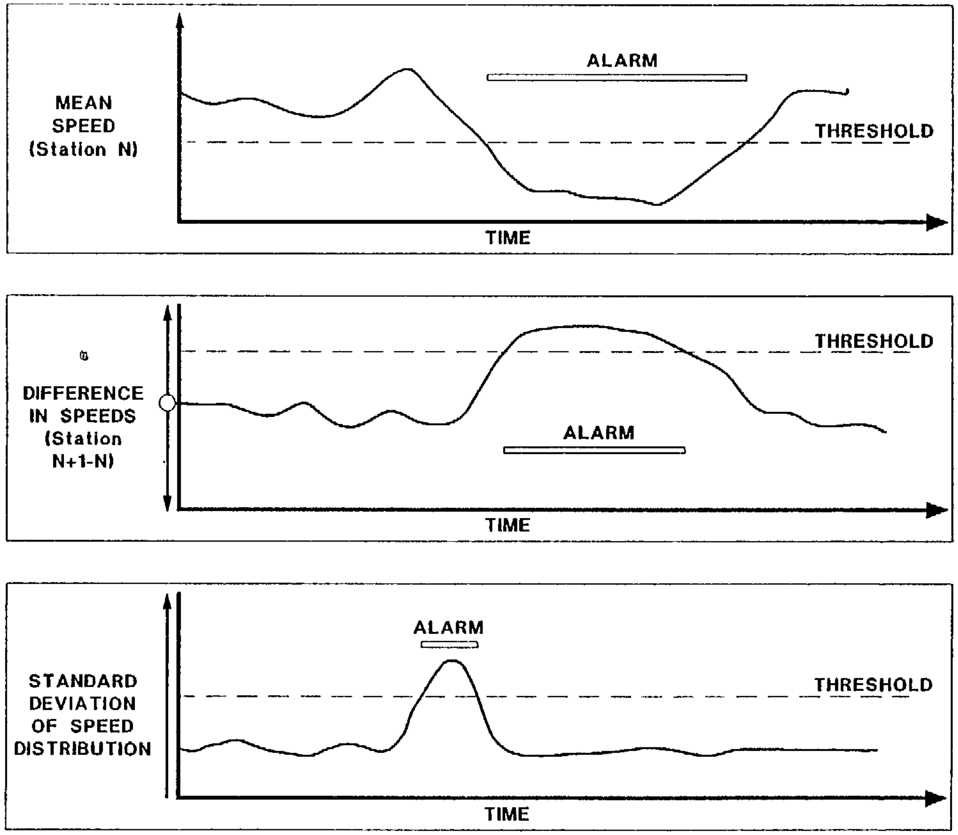


Exhibit 6-3: Speed - Based Incident Detection Algorithms

emphasized that the purpose of CCTV is not to identify the occurrence of an incident (i.e., surveillance) -- it has been found that simply monitoring the video images does not result in early detection. The purpose of CCTV is to rapidly confirm a suspected incident (as reported by detection algorithms or *SP), to verify the nature of an incident, and to assist responders in quickly determining the appropriate course of action.

Closed-circuit television has proven to be one of the most valuable elements of a freeway management system. In addition to its primary task of incident verification, CCTV can also be used for other applications in freeway and corridor management, including:

- Monitoring traffic movements on the mainline, HOV lanes, and the entrance/exit ramps (e.g., driver response to various VMS messages, VMS message verification and fme tuning, HOV/shoulder lane usage, compliance with ramp metering, etc.).
- Identifying and detecting stranded motorists.
- Weather/hazardous condition observations.
- Identifying damage to system equipment resulting from contractors, accidents, storms, etc.

Full CCTV coverage (i.e. no "blind" spots) is recommended for those roadway segments with 1/2-mile detector spacing (refer to previous Exhibit 5-3) and along other segments which regularly experience congestion. These camera assemblies -- complete with pan, tilt, and zoom capabilities -- will be installed on 40-50 foot poles or on buildings as the opportunity exists, at 3/4 to l-mile intervals depending on the horizontal and vertical alignment of the roadway.

Limited coverage video surveillance is also recommended in the vicinity of major interchanges. Each of these monitoring points will be provided with two (2) camera assemblies mounted on 100-foot towers to allow maximum area coverage. The 100-foot high tower will have hydraulic "bend-over" capability for maintenance purposes, or the cameras will be mounted on rings which can be lowered and raised similar to highway lighting. The poles should be designed and constructed as to minimize sway.

The recommend camera locations for the Phase 1 Implementation Plan are shown in

Exhibit 6-4. The areas of CCTV coverage for the Year 2000 Plan are shown on Exhibit 6-5. Exhibit 6-6 identifies the functional requirements of the Phase 1 camera installations. With respect to the camera requirements, color cameras are preferable to black and white images. Black and white cameras do provide better pixel resolution; but for incident verification and related CCTV functions, color resolution is the more important attribute. Moreover, color cameras have sufficient sensitivity for low-light conditions to provide the necessary video clarity.

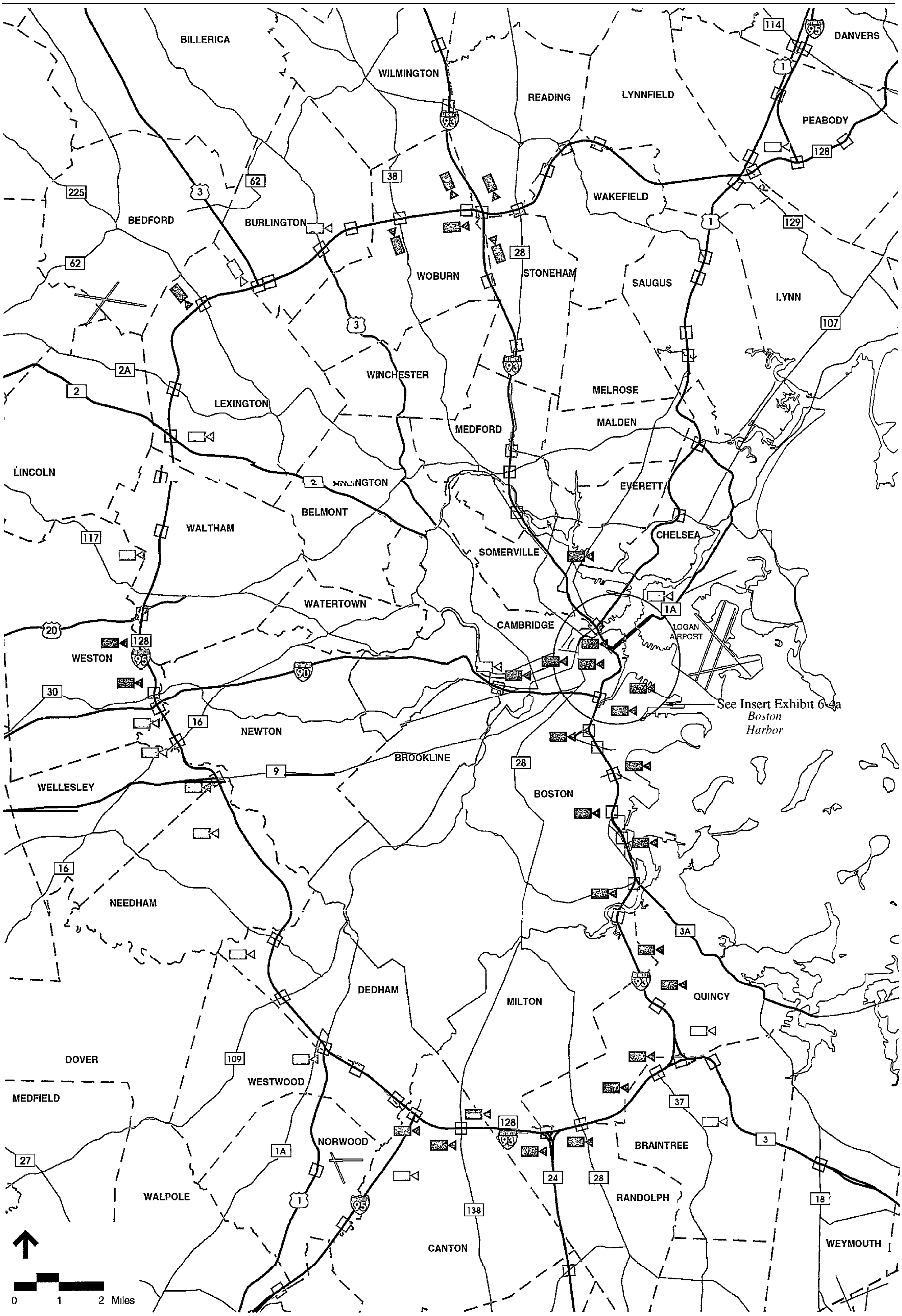
INCIDENT RESPONSE/CLEARANCE

Freeway Service Patrols

A freeway service patrol consists of a vehicle (e.g., pick-up truck, van, tow truck, etc.) and operator that patrol the freeway network, providing motorist assistance and handling minor incidents. Service patrols address many of the incident management elements. The time required to detect an incident may be reduced in some cases -- the number of incidents affected and the time savings being dependent upon the frequency of the service patrols. Incident verification may also be enhanced because of the direct contact in the field.

Most importantly, freeway service patrols can dramatically reduce the incident response and clearance time because the service provider is immediately on the scene, rather than appearing several minutes (or longer) after the initial call has been placed. As an example, studies of service patrols throughout the country indicate benefit-cost ratios of 15:l (Los Angeles) and 17:l (Chicago). The rapid removal of incidents and debris from the freeway travel lanes before they can cause secondary accidents is undoubtedly another benefit -- albeit a difficult one to quantify -- associated with service patrols. Perhaps the most telling evidence regarding the value of freeway service patrols is the multitude of letters, cards, and notes of appreciation that are received each year by the operating/sponsoring agencies from motorists who have been assisted. In essence, freeway service patrols are also a very effective relations tool from the perspective of the operating agency.

The composition and operation of a service patrol program is dependent on the needs and constraints of the local area. Some of the issues which must be resolved in developing



CCTV Mounted on 40' Pole or Building

CCTV (2) Mounted on 100' Tower

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 6-4 Phase 1

Camera Locations

CCTV Mounted on 40' Pole or Building

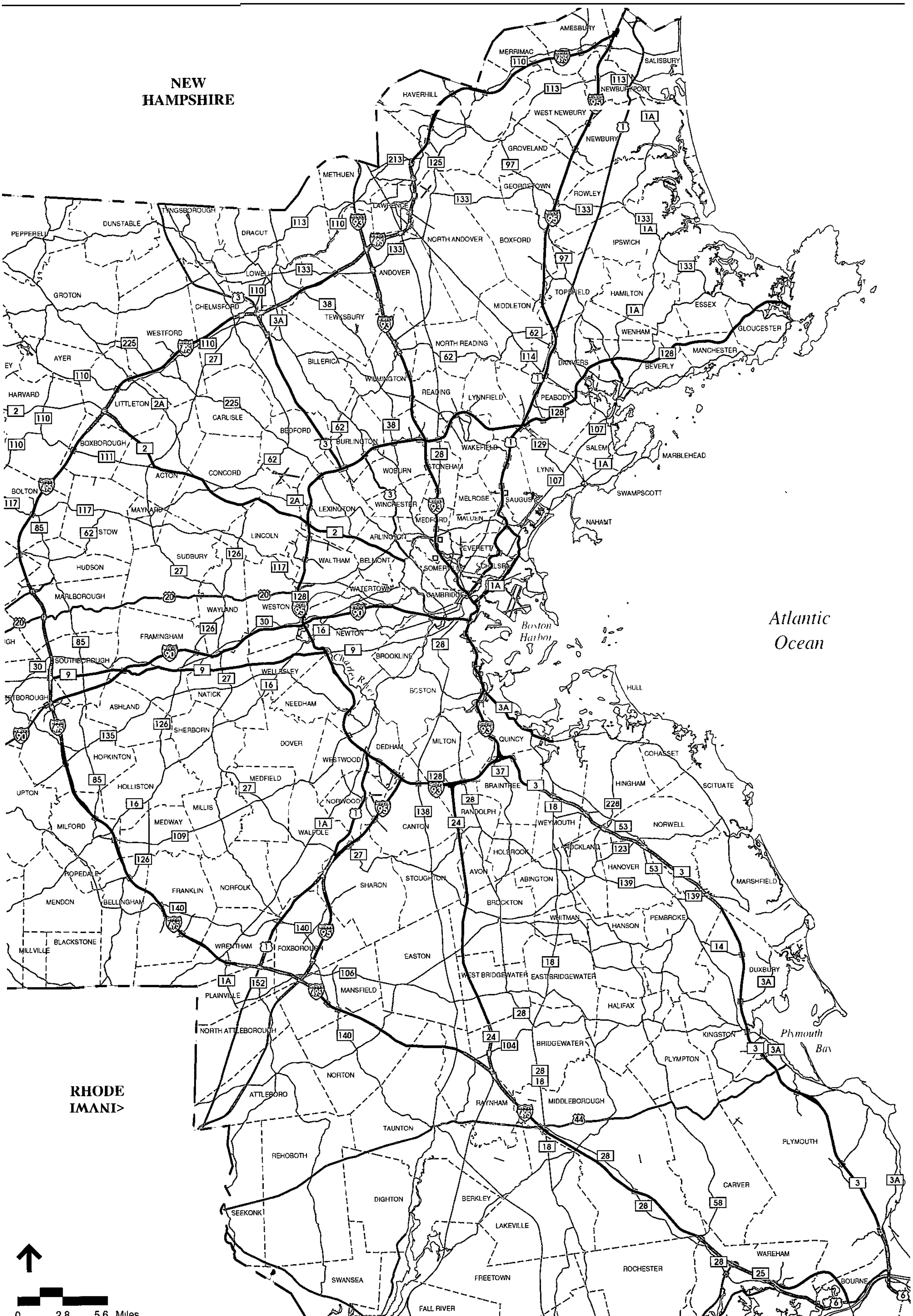
CCTV (2) Mounted on 100' Tower

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 6-4a Phase 1 Camera Locations (Continued)



Closed Circuit Television Coverage

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 6-5 "2000" Plan
Camera Coverage

Exhibit 6-6: CMOS-CCD CCTV Functional Requirements

Camera

• Color system	NTSC Standard
• Image sensor	1/2 inch, blemish free, charge coupled device (CCD) color image sensor Active picture elemen&760(H)x480(V) pixels
• Scan	NTSC; 2:l interlace
• Resolution	350 lines vertical, minimum 460 lines horizontal, minimum
• Contract variation	5 percent overall, or less
• Sensitivity with 3200k illumination	Full video at 1.3 fc faceplate illumination; usable picture at 0.005 fc faceplate illumination
• Automatic color balance	Reference white areas of scene through lens
• Lens mount	C-mount

• Camera and lens installed in an enclosure with windshield wiper.

Zoom Lens

• Focal length	16 to 160 mm (10x) for 40 foot poles - (A longer focal length (320 mm) may be required for high-mount (100 foot) cameras).
• Aperture	f/1.8
• Min. focusing distance	1.3 meter
• Mounting	C-mount
• Format	1/2-inch

Exhibit 6-6: CMOS-CCD CCTV Functional Requirements (continued)

Pan and Tilt Unit

• Pan	0-350
• Tilt	0-90
• Load rating	80 lbs
• Cable guard to prevent entanglement.	

Control Receiver

- The control receiver shall receive data from the camera control unit, decode the command data, perform error checking, and drive pan/tilt unit, camera controls, and other motorized lens.

- The control receivers shall provide the following functions:

  - Zoom In/Out
  - Speed Slow/Past
  - Focus Near/Far
  - Tilt Up/Down
  - Camera Power On/Off
  - Iris Open/Close
  - Pan Right/Left

and implementing freeway service patrols are summarized below.

Type of Vehicle

Service patrols- can utilize pick-up trucks, vans, and/or wreckers. The Chicago Minutemen Fleet, which commenced operation in 1961, includes more than 35 specially designed towing vehicles which are capable of handling almost any freeway incident, including those involving trucks. A number of State DOTS operate pick-up trucks as courtesy patrols to provide gas, water, jump starts, pushes, and other motorist assistance on the freeway. Wreckers are generally considered to be the better choice for service patrol vehicles because of their towing capability, as compared to push bumpers on pick-up trucks. The use of wreckers does require a higher degree of operator skill and commitment. Additionally, the use of agency-owned/operated wreckers is a sensitive issue within the commercial towing industry.

Service Provider

Most freeway service patrols are operated and maintained by public agencies. The Chicago, Minneapolis, and Northern Virginia service patrols are managed by their respective Departments of Transportation. In California, the Highway Patrol.(CHP) oversees the operation of the patrols -- the reasoning being that CHP vehicles are already patrolling the freeways, and are therefore in a better position to direct, monitor, and control the service patrols.

Another option is to contract out freeway service patrols. This has been successfully done on a limited basis, such as patrols in South Florida which were provided by the widening contractor for a roadway reconstruction in accordance with the project's special provisions. To this end, the Towing Recovery Association of America (TRAA) has developed a "Model Plan for Highway Service Patrol System", which in essence is a specification for contract service patrols.

Service patrols may also be provided by private entities. A prime example of this approach is the Samaritan program provided by Samaratania, Inc. of Sutton, MA, which currently operates in various cities throughout the Northeast, including two vehicles in Boston. Samaritan vehicles are specially-made pick-ups or minivans, and are usually sponsored by private corporations (e.g., banks, major drugstore chains, etc.). These vehicles include safety lighting, extensive communications equipment (including police frequencies), a push-bar to remove disabled vehicles from the roadway, and various supplies for motorists assistance (e.g., gasoline, oil, water, hoses, belts, fire extinguisher, tool kit, medical kit, etc.). The vans also have the sponsoring company's logo prominently displayed.

The Samaritan program has proven very successful. Moreover, as part of a public-private partnership, government funding might be utilized to supplement the private funding of Samaritania's (or a similar private organization's) vehicles and activities. In this manner, the required number of service patrol vehicles could conceivably be instituted throughout the Boston region at a fraction of the cost normally associated with dedicated patrols. Under such a joint funding arrangement, both MHD and the supporting private entity (i.e., drugstore, bank, etc.) would have their names on the van.

As to the "best" approach for providing service patrols (i.e., in-house, contract, public-private partnership), a strong argument can be made for in-house management and operation in that it would provide MHD full control over the key element of a successful program-- mainly, the service patrol operators who interact directly with the public. At the same time, in-house service patrols require a significant investment, such as purchasing and maintaining a fleet of State-owned patrol vehicles with accessory equipment, providing garage and maintenance facilities, and hiring and training additional State employees to operate the vehicles. Such as investment may not be institutionally feasible.

Funding availability may be another consideration. A bill recently passed the U.S. House of Representatives (H.R. 3276) which limits the use of Federal-aid funds (authorized under the Federal-aid highway programs) for freeway service patrols to privately-owned or privately operated business concerns. Should this bill be passed by the Senate and signed by the President, the use of Federal-aid funds will be limited to contract service patrols. Publicly owned or operated patrols that are in operation before the dates of the enactment of the act will be exempted from this requirement, but such an exemption may not apply to future expansions of these in-house patrols.

Towing Policy

The commercial towing industry is very critical of freeway service patrols, viewing them as unfair competition. Despite these allegations, service patrols are not in competition with private towing companies. The policy of publicly sponsored service patrols is to provide towing only when it is necessary to relocate a vehicle from the travel lanes; and then the vehicles are towed only to the shoulder, the nearest off-ramp, or similar safe haven. Further assistance or towing from there must be arranged by the motorist or police utilizing commercial wreckers. It is also noted that when service patrols consist of DOT pick-ups (but not wreckers), or are provided by contract (wreckers or Samaritan), the criticism is usually much less.

Number of Service Vehicles

Obviously, the greater the number of vehicles patrolling a freeway section, the more responsive and timely the service will be. A service patrol study conducted by Caltrans determined that the most efficient system was to have 2 vehicles patrolling freeway segments of approximately 4 miles in length for a total roundtrip patrol of 8 miles. In Chicago, a single patrol route covers 3 to 8 miles of freeway, depending on the incident history within the segment. The TRAA model plan recommends a patrol beat length of between 5 and 15 miles one way; with the number of vehicles per beat being established by reference to the average amount of time it should take for a service patrol vehicle to pass a given point every 10 minutes during the hours of operation. For example, if the beat is 9 miles in length and the average speed during the hours of operation is 27 MPH, the number of service patrol vehicles needed in order for a service patrol vehicle to pass a given point every 10 minutes would be four.

A related issue is the hours of the day during which the service patrols operate. Coverage during the peak periods is the absolute minimum, with some systems providing service on a 24-hour-a-day, 7-day-a-week basis. The patrols should operate between 6:00 AM and 8:00 PM. The number of vehicles, (i.e., the coverage area intervals) can be decreased during non-peak periods. These non-peak periods can be used to service and replenish vehicles, personnel training, and report preparation.

Legislation

Appropriate legislation may be required authorizing the service patrols to remove vehicles from the travel lanes and tow them to the shoulder where commercial wreckers can retrieve them. This is an important consideration in terms of liability -- that is, holding the Commonwealth (and its service patrol agents) harmless for any damage to a disabled vehicle during the removal/towing operations. The Section of the Illinois legislation in this regard reads as follows:

> "Whenever the Department finds an abandoned or disabled vehicle standing upon the paved or main-traveled part of a highway, which vehicle is or may be expected to interrupt the free flow of traffic on the highway or interfere with the maintenance of the highway, the Department is authorized to move the vehicle to a position off the paved or improved or main-traveled part of the highway."

Boston Area Service Patrols

MHD has just recently awarded a contract to Samaritania to provide peak period (i.e., 6:30 - 9:30 AM/3:30 - 6:30 PM) service patrols throughout Massachusetts. The equipment and services provided by these patrols are summarized in Exhibit 6-7. The coverage of the 16 specified routes, as well as a recently implemented in-house patrol, is shown in Exhibit 6-8. It is recommended that these patrols be continued as part of the Phase 1 IVHS Plan.

For the Year 2000 plan, it is recommended that an additional 12 patrol routes be implemented covering the segments in Exhibit 6-8. Moreover, it is recommended that the operation of all service patrols be extended to 6:00 AM to 8:00 PM.

Removal of Vehicles

It is generally estimated that accident vehicles can be moved, under their own power, to the side of the road (or other safe location) in at least 70 percent of freeway incidents. This simple act of moving a vehicle from the roadway to the right or left shoulder, thereby

Exhibit 6-7: Minimum Required Equipment List for Contracted Service Patrol Vehicles

Equipment on Service Patrol Vehicle

- Push Bar & Tow Ball
- Public Address System and external speaker
- 12 Volt Jump Start System Front & Rear
- Marine Deep Cycle Batteries for Jump System
- Minimum of 5 Galls each Diesel, Water, Gas & Funnels
- Response & Abandoned Vehicle Cards
- Air Compressor (TERV-Portable air can only)
- Cellular Phone, CB radio, Com/Ops Ctr 2-way radio, Emergency scanner (Communications tree)
- Automatic Fast Idle system for charging
- Roof mounted emergency light bars
- Emergency "Lolli-Pop" lights (SERVE only)
- Directional Arrow light
- 2 rechargeable flashlights
- 3 fire extinguishers-CO2, ABC, & H20
- Street Broom & flat shovel
- Trauma bag (medical kit) & Oxygen (Trauma bag only on TERV)
- Portable air can
- Paper towel dispenser & hand cleaner
- P.V.C. pipe, fittings and clamps
- Flares & Traffic Cones
- Diagnostic test equipment
- Tow chain and "J" hook
- 15 lb. sledge hammer
- Nuts, Bolts, Cotter pins, springs, etc.
- Wire & Electrical repair components
- 6 quarts oil, 6 quarts transmission fluid
- Complete mechanics set of hand tools
- Water and Gas line antifreeze in season
- Brake fluid, Hydraulic fluid
- Assortment of Spare parts, Adhesives
- HazMat Kit (booms and pads)
- Bucket sand or clay absorbent
- Tape recorder for log
- Lockout kit
- Patrol Area Service Directory & Reference Books
- Electrical and Duct tape, Mechanics wire
- Florescent cab lighting
- Hydraulic jacks-floor and bottle to 20 ton

Exhibit 6-7: Minimum Required Equipment List for Contracted Service Patrol Vehicles (continued)

Personnel.

- All patrol drivers must be Massachusetts State Emergency Medical Technicians within first year of operation.

- Drivers must complete training program addressing:

  - Patrol procedures
  - Patrol driver courtesy
  - Tape recorder log
  - Road patrol-observation and practice sessions
  - Paperwork procedures
  - Emergency auto repair
  - Patrol readiness
  - Traffic reporting
  - Vehicle maintenance
  - Radio/telephone procedures
  - Emergency response/accident management
  - Standard first aid (if needed)
  - HazMat response
  - Decision driving

- All patrol drivers must wear uniforms identified with their names and the name of the service provider. Also, a Medical Certification patch must be worn when the patrol driver becomes certified. Outer clothing will have reflectorized striping for night tune visibility.

Services

Cost-free assistance to motorists or other service personnel at a wide variety of transient incidents, including but not limited to:

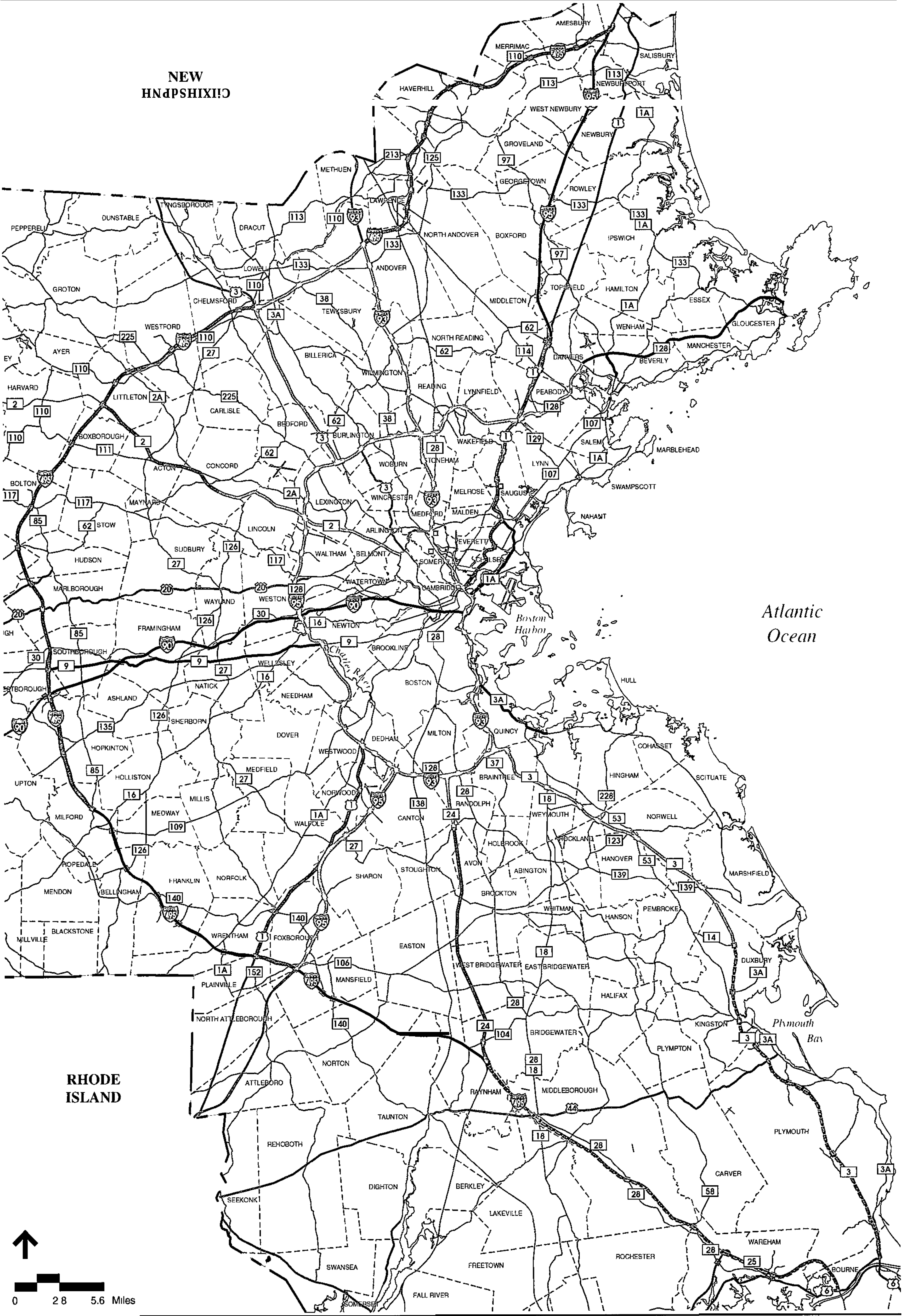
- disabled vehicles,
- accident scenes,
- lost motorists,
- sick or injured motorists,
- pedestrians on roadway,
- live animals on roadway,
- travel or breakdown lane debris,
- vehicle or brush fires,

Exhibit 6-7: Minimum Required Equipment List for Contracted Service Patrol Vehicles (continued)

- fuel leaks,
- other such transient incidents as may be mitigated by use of service patrol vehicle, on-board equipment, and service patrol driver's skills.

There is a 15-minute maximum time limit to diagnose and effect repair. Minor temporary repairs such as, but not limited to:

- giving fuel, oil, water, other essential automotive fluids,
- repairing, changing, inflating flat tires,
- repairing or replacing cooling system hoses,
- replacing fan belts,
- wiring up or removing portions of compromised exhaust systems,
- replacing or repairing such other mechanical or electrical components as may be quickly serviced on site.



Existing Service Patrol Routes

Additional Service Patrol Routes for "2000" Plan (Dashed Line Indicates Seasonal Service)

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 6-8 Service Patrol Routes

opening up all lanes, is a significant step towards relieving traffic congestion. As previously discussed, reducing the time interval between the occurrence of the incident and the removal of the vehiclesis a primary goal of the incident management process.

One solution is to require motorists to immediately remove their vehicles from the travel lanes (if the vehicles can be moved), and exchange information and wait for the police at a location off the travel lanes. State laws generally require the driver of a vehicle who is involved in an accident to stop at the scene of the accident (or as close thereto as possible), and wait for the police. Over half of the states -- although not Massachusetts -- also include the provision that "every stop shall be made without obstructing traffic more than necessary", which is from the National Uniform Vehicle Code. Some state have further expounded on the requirement to minimize the adverse effects of accidents on traffic flow. For example, Texas specifies that when a damage-only accident "occurs on a mainline, ramp, shoulders, medians, and adjacent the nearest suitable cross street, or other suitable location so as to minimize interference with the freeway traffic Any person failing to stop or comply with said requirements under such circumstances shall be guilty of a misdemeanor."

In states where this or similar requirement exists, few motorists move the vehicles out of the travelway on their own volition. One possible reason why these accident vehicles are not being moved out of the travel lanes is that, according to a FHWA Study, "most motorists believe it is necessary to wait for the police to arrive before moving the vehicles so that the insurance policy is not voided". During the aforementioned FHWA study, interviews with insurance company representatives indicated that no insurance company policies would be violated by the removal of a vehicle prior to the arrival of the police. Insurance representatives interviewed by JHK & Associates in Connecticut and Maryland have indicated much the same for property damage accidents. There was, however, some concern on the part of the insurance representatives as to the affect moving vehicles from an injury accident might have on liability and any resulting litigation. The Massachusetts State Police have also voiced a similar concern.

It is recommended that, as part of the Phase 1 Implementation, the Massachusetts law be modified to include the clause noted above (or similar) concerning the removal of vehicle following a property damage accident. However, a law requiring motorists to remove their vehicles from the travelway is not enough. Motorists must be made aware of this requirement, encouraged to abide by it, and also assured that they will not be placing themselves in any jeopardy by doing so. This may be accomplished by:

- The Drivers Manual
- Printed information from the insurance companies. It is also important that any verbal advice from agency/company representatives not be contrary to this policy.
- Public information spots on radio or TV. Use of variable message signs for this purpose is also a possibility.
- Signing on the freeway. For instance, the Florida Department of Transportation has developed a sign detail as shown in Exhibit 6-9, and has installed these signs throughout the State.

Quick Clearance Policy

The Massachusetts State Police and MHD have formulated and instituted a Quick Clearance Policy (QCP), and have entered into an interagency agreement which will make restoring normal traffic flow the first priority at an incident site. The QCP enables responding agencies to act quickly in clearing disabled vehicles and debris from the roadway. The policy becomes applicable when an incident occurs on a state highway and the roadway is totally or partially blocked. The Massachusetts State Police Officer first at the scene, in cooperation with the District representative from the MHD, is responsible for reopening the roadway safely and as soon as possible. Responsibilities include diagnosis of the problem, deciding which experts to draw to the scene (police, fire, ambulance, hazardous materials), summoning the necessary and nearest tow and other equipment and, making sure the operation is carried out with dispatch.

The Police Officer and the MHD District representative share the responsibility for handling traffic around the incident scene. If it is a major incident, the prearranged contingency plan for the area will be adopted to set up the appropriate traffic diversions during clearance efforts. In circumstances where it is determined by the State Police that spilled cargo or personal property is blocking the roadway or endangering the public safety, the State Police Officer may, as authorized by Massachusetts General Law (MGL) Chapter

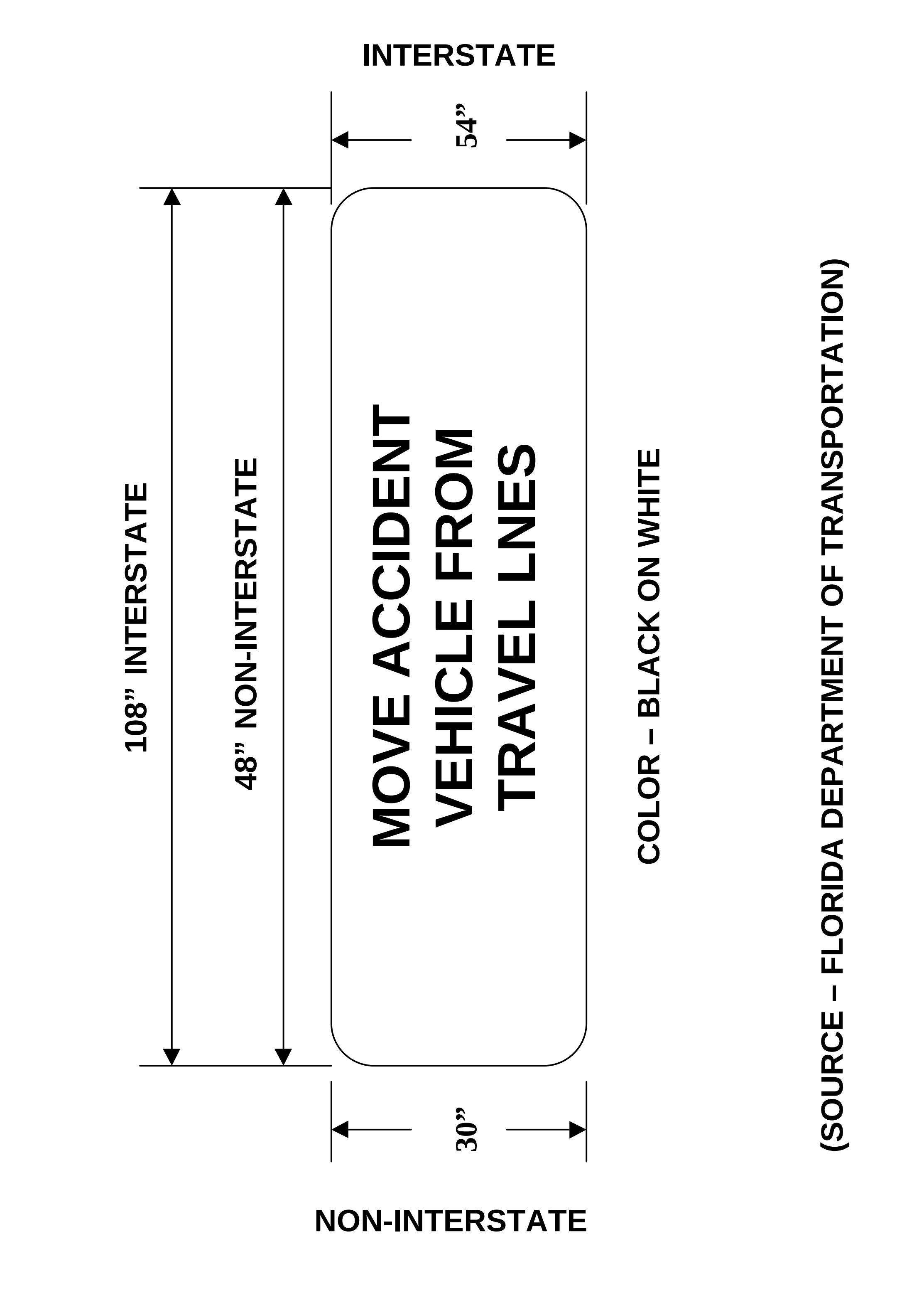


EXHIBIT 6-9: Sign Detail to Inform Motorist t to Move Vehicles from Roadway

85, paragraphs 2A and 2C, and without the consent of the owner or carrier of spilled cargo or other personal property, remove/relocate the cargo or property from the right-of-way or portion of roadway of the state highway system quickly. Moreover, the owner and/or carrier of cargo or personal property so removed/relocated is responsible for reimbursing the state for the cost of these clean-up activities.

Wrecker Service

While the majority of incidents involve vehicles which can be removed under their own power, or removed by service patrol vehicles; there still remains a significant number of accidents in which one or more vehicles will require a tow truck for removal. Under these circumstances, timely response of wrecker services is critical.

The Massachusetts State Police has in place a policy for the use of private tow companies to assist in the clearance of disabled vehicles. Two types of agreements govern towing operations -- rotation lists and contracted franchises. The region is divided into areas of high and low priority. High priority areas have extreme congestion problems and the required maximum response time is less than 15 minutes. Areas of low priority are those in which the removal of disabled vehicles is not urgent and implies maximum response time for the tow truck of more than 15 minutes and not less than 30 minutes. In low priority areas, two companies will be called on an as-needed basis from a rotating list of qualified companies. Companies wishing to be added to the rotation list must initially satisfy the equipment and geographical proximity requirements. In high priority areas, primarily during peak hours, designated tow companies will provide standby service and/or other intensive services along that portion of the highway.

Major Incidents

Major freeway incidents typically involve heavy vehicles and\or spills which require specialized equipment and an extensive clean-up effort. An incident may also be considered "major" if it blocks several lanes for some period of time. For example, the California DOT defines a "major incident" as a situation where the estimated blockage will be two or more lanes for two or more hours. In Pennsylvania, a "serious accident" includes those which meet any of the following criteria:

- Chain reaction collision of 15 or more vehicles
- Tornadoes, landslides, floods, sudden heavy snowfalls, and smoke and fire incidents of a magnitude that highway transportation would be seriously impeded for more than 24 hours
- Incidents which may cause a highway to be closed for 6 or more hours

Regardless of the nature of a major incident, it is very likely that MHD assistance will be required at the site to provide trucks, front-end loaders, or other vehicles; to repair any damage to roadway facilities (e.g., guardrail, sign structure, street lighting); to assist with the traffic control efforts (e.g., set up diversion routes, portable VMS); or some combination of activities.

The Department's ability to mobilize its resources and arrive on the scene of a major/serious incident in a timely fashion is an important aspect of the overall incident management process. One method used by some agencies to provide timely incident response is the establishment of Incident Response Teams. These teams typically consist of DOT (i.e., MHD) employees whose job responsibilities include responding to major incident. The job responsibilities of the team members also include other duties to be performed during their normal hours when not responding to an incident. For some of the team members (i.e., a core group), these other responsibilities generally consist of related freeway management activities such as systems operations, planning, on-going coordination with police and local jurisdictions, alternate route development, data evaluation, etc. Team members are on call at all times, and respond to major incidents as required.

The establishment of Incident Response Teams is recommended for both the Phase 1 and Year 2000 Implementation Plans. During a major incident, team members will contribute traffic engineering expertise at the incident site and perform the following activities in coordination with the on-scene police commander:

- Determine need for route diversion.

- Deploy portable VMS signs to provide diversion information and end of queue protection.
- Close certain on-ramps to reduce freeway traffic demand.
- Assist with incident clean-up and traffic flow control as required.
- Coordinate other MHD activities.

Based on the incident management experience in California, each Incident Response Team will initially consist of four members, with one person serving as a team leader. Team assignments and their after-hour responsibilities should be based, to some degree, on where the personnel live. Each team member will be assigned a DOT vehicle -- either a sedan (e.g., team leader) or a pick-up truck. The incident management team personnel should also have home garaging privileges for these vehicles, thereby allowing the members to respond immediately from their home during off-duty hours. The trucks should be equipped with radios, push bumpers, temporary barricades, flares, cones, hand tools (e.g., shovels), sand, plow blades, (for cleaning moderately sized spills of solid material), portable variable message signs (VMS) and flashing lights to facilitate their movement through congested areas on the roadway network.

COORDINATION

Incident management is a multidisciplinary activity requiring information sharing and collaborative actions. The primary responsibilities for initial response and on-scene management belong to the State Police, with the Massachusetts Highway Department providing assistance as previously discussed. Other entities also have legitimate duties at the incident scene, including:

- Local fire departments and ambulance services, particularly when an incident involves fire and/or injuries.
- Local public works/transportation departments, particularly when freeway traffic is diverting onto local streets.

- Environmental agencies, particularly when hazardous wastes and/or toxic materials are spilled.

It is also important that other transportation agencies within the Boston region be informed of the incident and its impacts so that they can "respond" in an appropriate manner (e.g., Turnpike displaying traveler information on VMS; the MBTA providing additional trains, in the event of a major incident requiring several days of remediation, etc.)

IVHS technology, as is being recommended for the Boston region, can be an extremely effective tool; but it is not an end in and of itself. Without the cooperation, coordination, and commitment of all parties, the traffic and incident management program will never be successful, regardless of how much technology and funds are expended.

The regional architecture described in Chapter 4 provides the technical and institutional mechanisms for developing the necessary coordination. As noted therein, one of the functions of the Operations Committee, with support from TICC staff, will be to develop incident response plans for approval by the Executive Committee and subsequent implementation as conditions dictate. Incident response plans/strategies should be developed for each and every segment of the freeway network, and should include the following:

- Affected expressway segment/direction
- Responsible agencies and contacts
- Participating affected agencies
- Levels of implementation (i.e., different strategies will be required depending on the time of day, the number of lanes closed, and the estimated duration of the incident)
- List of objectives (e.g., local diversion, regional diversion, traveler advisories, on-site flow control, etc.)
- A list of actions associated with each objective and implementation level (e.g., notifications and how accomplished, VMS messages, media feeds, set up of diversion routes etc.)

As discussed in Chapter 10, these strategies will comprise a rules set which will be input into an Expert System to facilitate their implementation and for overall decision support.

7. TRAVELER INTERFACE

Traveler interface technologies provide the means by which the travelers (and soon-to-be-travelers) are provided with real-time information regarding roadway, transit, and traffic flow conditions. This information can assist the traveler with planning his/her trip, selecting the optimum mode or route, and dynamic decision making during the trip so as to improve the efficiency and convenience of travel (ie., enhanced mobility).

It is envisioned that the real-time traveler information for the Boston area IVHS network will include the following:

- Travel times and costs between key points in the network -- by route and by mode.
- Areas of traffic congestion (as may be determined by various thresholds for volume and speed).
- Incident locations and the corresponding delays (including estimated duration).
- Schedule adherence for MBTA rail and buses, and expected times of arrival.
- Construction activities and the resulting lane restrictions.
- Weather conditions which may impact traffic flow (e.g., snow and ice, fog).
- Catastrophic events which close the roadway or transit route (e.g., bridge failure, fire, clean-up of hazardous materials).
- HOV lane status (for Southeast Expressway and I-93).
- Park-and-ride lot status.
- Special events (parades, Garden Events).
- Traveler service information.

Most of this information is obtained by the surveillance function elements discussed in Chapter 5, and processed by the central hardware elements (Chapter 10). The traveler interface elements will disseminate the information to travelers utilizing a variety of audio and visual techniques. These information techniques will include components which are physically present along the roadway network; those external from the roadway (non-roadway based) which may be used to provide the traveler with pre-trip information and in-vehicle techniques.

Regardless of how traveler information is provided, to be effective, the data must be timely, complete and accurate. Any route and mode guidance advice must be credible, and it must be perceived by the individual traveler as providing a personal advantage when followed. Otherwise, the information will be ignored. In general, for each inaccurate bit of information promulgated by the traveler interface elements, it will take numerous occurrences of accurate information to recapture the traveler's faith in the system.

TRAFFIC INFORMATION BROADCASTING

As discussed in Chapter 4 (Regional IVHS Architecture), the private sector is seen as playing a significant role in the dissemination of traveler information. In essence, the public side (i.e., MHD, MBTA, MTA, MassPort, etc.) will collect and integrate surveillance information; while the private side will analyze the integrated data, tailor the information to meet the unique requirements of the end users (i.e. a "value added"), and then market and disseminate the traveler information via a variety of outlets including:

- Radio and television media (i.e., traffic reports as currently provided).
- Cable TV - For "on-demand" information regarding real-time conditions within the Boston area transportation network, the use of a dedicated "traffic channel" over local cable television systems may be incorporated. Similar systems provide local and freeway traffic information (via graphics displays) in Chicago, Los Angeles, and Long Island.
- Highway Advisory Telephone (HAT)/Dial-Up Services - As an enhancement of the SmarTraveler network, information could be presented through the use of voice-digitization techniques. The menus could be expanded to include specific transit routes, "Point A-to-Point B" traveler information as selected by the caller, and visitor/tourist information (e.g. ingress/egress from Logan Airport or Fenway Park). A potential enhancement to the HAT concept might be an automated subscription service in which users are called during subscriber-defined hours to alert them of unusual congestion or delays on subscriber-

defined routes and/or modes. As with most traveler information mechanisms, it is envisioned that the HAT service would be operated by a private entity who would be reimbursed by charging for the calls and related services, or via a public-private partnership.

- Interactive Information Kiosks - The use of interactive kiosks is particularly helpful to travelers away from home -- at an employment, retail, or entertainment center, or at a multi-modal transportation facility. Kiosks could provide traffic information maps (e.g. graphic displays) selectable by a user menu, as well as "best route/mode" information. At transit locations, the interactive kiosks could be coordinated with automated fare collection. It is envisioned that the kiosks would include advertising as a means to pay for their installation and continuing maintenance.

- Bulletin Boards/Videotext - A dial-up bulletin board system, providing map graphics and text information, could be supported by hardware at the TICC. The bulletin board would require only that a PC user have a dial-up modem and compatible communications package. A subscription fee might also be included.

- In-Vehicle Devices - For in-vehicle devices to be useful -- that is, to be more than an expensive road map -- the real-time information contained in the TICC database must be sent to the in-vehicle units. It is also envisioned that the communication link will be two-way, thereby permitting equipped vehicles to be used as detection probes.

The Boston area IVHS network will be a repository for significant amounts of real-time information on traffic flow conditions and incidents, transit operations, and construction/maintenance activities. It is essential that the system (via the TICC) include some form of interface for providing this up-to-the-minute data to private entities (e.g., radio and TV stations) either automatically or upon inquiry. A number of alternatives are possible, including:

- Teletype Network - Text information on current traffic flow conditions (e.g., average speeds, estimated travel times, congested areas, incident locations, etc.) is periodically transmitted to dedicated printers or Fax machines at the various stations. One procedure is called "rip and read", where relatively final copy is provided. Another method is to just provide traffic flow information in a standardized format which can then be used by broadcasters in preparing their traffic report.

- Workstations - This is similar to the teletype network, but now the media stations have workstations and two-way communications which allow them to query the IVHS system directly. It is noted that with this form of media interface, the system must possess the ability to limit the data to which the stations have access.

- Color Graphics - This option is identical to the workstations alternative, except that a high-resolution color monitor is included for showing real-time graphic displays of conditions throughout the roadway and transit network (e.g., different colors representing various speed or travel time thresholds, and adherence of transit routes). These real-time displays can be televised over existing stations and/or a dedicated "traffic channel" (e.g., local access cable), thereby permitting residents to alter their travel plans (if necessary) before they become travelers and commit themselves to a particular route or mode.

- Video Information - If a video inter-tie with media is deemed appropriate, CCTV images can be transmitted for those locations where incidents are present, or for selected freeway locations. The number of images available to the media would depend on the resources available to multiplex the data for transmission to the media and what level of manipulation (switching, number of monitors) the media outlet(s) would have available. A related issue is video communications between the system control center and the various media outlets. In all likelihood, this will entail compressed video (i.e., CODEC) over leased telephone lines.

It is envisioned that the private-entity interface will rely primarily on workstations and color graphics, with limited use of video. Moreover, as discussed in the Chapter 4, the interface will be provided at the Regional Transportation Information and Coordination Center (TICC). In terms of system design, it is important that the central hardware configuration of the TICC include a sufficient number of communication gateways for these connections, and utilize industry-standard software and interface.

Discussion

The concept of utilizing public-private partnerships for disseminating traveler information throughout the Boston region is based on the premise that travelers have an interest in and need for this information; that there is a market value associated with this information (i.e., travelers are willing to pay for it in some manner); and that the market is large enough and/or the information is of sufficient value for the private entities to recoup their costs. This premise is being evaluated as part of the SmarTravel operational test. Assuming that the premise holds true, several policy issues will have to be resolved:

- In nearly all transportation management systems, the information is provided at essentially no cost to the private entities; except for the expense of the printer, workstation and/or color monitor, modems and interface device, and telephone connections. Given the cost of installing the surveillance network and staffing the TICC, perhaps an access fee should be levied for the information.

- Integration of information obtained by the private entities (e.g., probes) with the TICC data base, in terms of who "owns" the data and the access fees noted above.

- The types and level of government rules regarding the "value added" provided by the private entity (e.g. diversion).

VARIABLE MESSAGE SIGNS

There is one major exception to the general rule of the private side providing the traveler interface -- specifically, it is recommended that the public side (MHD) install and operate variable message signs (VMS) as part of the overall IVHS Deployment Plan.

Sign Types

Several different types of variable message signs have been developed. One is the "blank-out" sign in which a single message can be turned on or off as conditions require. If only a few predetermined messages are needed at a particular site, then a rotating drum sign consisting of a three or six-sided prism for each line of the message -- may be applicable. The most flexible type of VMS is the matrix sign, which uses individual pixels turned on/off that combine to portray the desired legend. Matrix options include:

- Character Matrix - An individual module for each character (letter). The letter spacing is fixed.

- Line Matrix - A single matrix for each line. This allows proportional spacing between letters, but limited graphics capability (i.e., primarily arrows).

- Full Matrix - No built-in divisions between letters or lines. This configuration allows the greatest flexibility in the size and stroke of letters, plus graphic symbols.

As noted above, full matrix VMS provides the greatest flexibility. For example, a 28 pixel (V) x 105 pixel (H) full-matrix VMS can display 3 lines of B-inch letters (with 16-21 characters per line), or 2 lines of 24-&h letters (with 12-18 characters per line), depending on the actual characters used and their respective widths. The 2-line message capability of full-matrix VMS -- incorporating larger letters and a broader stroke width -- provides more visual "punch" than the 3-line format, although it also limits the message to fewer characters. The 2-line messages would typically be used for warning purposes, such as;

CAUTION - SLOW
TRAFFIC AHEAD

or during times of the day when the extra punch is need to enhance the legibility and readability of the message (e.g., where the sun is directly behind the sign).

Another advantage of full-matrix VMS is the ability to display graphics, thereby further enhancing message readability. Graphics should be kept simple, be easily recognizable, and be familiar to motorists. The most useful graphics are those which do not require an accompanying explanation on the sign, such as directional arrows, an interstate shield, airplane, or a lane reduction (based on the international diamond sign).

Full matrix VMS are approximately 10 percent more expensive than line matrix VMS. After all, the sign includes more pixel elements and electronics. Thus, if the larger 2-line and graphic capabilities of full matrix VMS will not be used in the system, a line matrix configuration is a more cost-effective approach. It is further noted that character matrix VMS are 5 percent - 10 percent less expensive than the line matrix signs, but the lack of proportional spacing between letters (as occurs with character matrix VMS) is a concern in terms of message readability.

Sign Technology

Several. VMS technologies are available as described below.

Flip Disk

This VMS technology consists of a matrix of disks which are reflectorized (typically yellow) on one side, and flat black on the other. The individual disks are magnetically rotated (i.e., "flipped") to display a pattern of reflectorized disk sides which forms the desired character or pattern. The disk is flipped by applying a brief voltage pulse to a coil, which causes the disk to rotate to its other side.

Since flip disk VMS do not produce their own illumination, visibility is dependent upon the ambient light conditions during the daylight hours. When the sun is shining directly on the disks, this VMS provides excellent viewing. Otherwise, these signs do not generate the bright images that light-emitting signs create, which can make the signs very difficult to read when light levels are low, or during conditions of fog, smog, and rain. During nighttime hours, the signs are illuminated either by lights directed at the face of the sign or black lights inside the housing, but the nighttime visibility is generally less than optimum daytime viewing. In essence, except for conditions of direct sunlight, flip disk signs have very little "punch" to draw attention or to provide conspicuity.

The only power consumption during daylight hours is that used to rotate the disks. No power is required to retain the disks' state. Consequently, power requirements are low, although at night, power consumption increases because of the illumination provided by the external lighting. The signs also have excellent environmental tolerance.

Regarding maintenance of these variable message signs, the disks in older signs have been reported to stick as a result of wear, coupled with dirt and vehicle emissions accumulating in the pivot points. However, newer signs -- which utilize circular disks rotating along a horizontal or diagonal axis on a stainless steel or teflon pivot -- apparently have minimized the sticking problems. Nevertheless, the disks need to be exercised regularly and tested to keep them in good operation. The yellow reflective tape will also eventually be bleached white by the sun, and will need to be replaced.

Fiber Optic

A fiber optic changeable message sign is comprised of bundled fiber optic cables that terminate in "dots" on the front face of the display. Each sign pixel -- analogous to a disk on the previously-discussed VMS -- consists of two such dots. The light source typically consists of a 50 watt tungsten bulb for every three characters (i.e., 5 pixel x 7 modules) in the sign. This bulb is augmented by another 50 watt bulb for an "overbright" mode during bright sun, and to function as a back-up should the primary bulb burn out. The fiber dots and pixels are continuously illuminated -- their visibility being controlled by magnetic shutters which open and close in front of each pixel.

The visibility or "punch" of fiber-optic VMS is excellent under all illumination conditions. A potential problem is that the focused fibers produce a small cone (i.e., 12-degrees) of vision, and off-axis viewing may therefore be somewhat restricted, although proper sign placement (as typically permitted in an expressway environment) will eliminate this concern. Power consumption for the fiber optic VMS is greater than the flip disk, but less than an LED sign (with fan system).

From a maintenance standpoint, the fiber-optic sign has three minor drawbacks:

- The mechanical components (i.e., shutters) are a potential maintenance problem, although the shutters are better sealed from the environment than the traditional flip disk type. Additionally, the shutters do not flip about an open axle -- rather they rotate as a propeller does on a sealed shaft.

- The lamps need to be replaced periodically -- about every 6000 hours of use. In the event of a burn-out, the secondary "overbright" lamp can serve as a back-up. Additionally, lamp burn-outs can be monitored by the system.

- This sign technology is currently available from only one manufacturer using proprietary materials and methods. Moreover, all the sign components are European. Nevertheless, sign users have reported good operational reliability.

Perhaps the greatest drawback of using a fiber optic sign is that the VMS is not available in a line-matrix or full-matrix configuration, although the manufacturer has indicated plans to build a line matrix model.

Light Emitting Diode (LED)

The Light Emitting Diode (LED) changeable message sign is made up of clusters of super bright LED's in a socket mounting. Each cluster forms one pixel of a character or display. The LED clusters can be manufactured in either a light guide cone or a cylinder to protect the display from sunlight washout and to focus the light for optimum visibility.

LED signs provide good visibility under most lighting and weather conditions. A variety of LED colors are available (e.g., red, green, amber), with red providing the greatest brightness. Three types of LED signs are available as summarized below:

- Red Only: As noted above, red LEDs are brighter (i.e., more punch) than amber or green LEDs. However, few agencies use the red only LED VMS because of the color's connotation (regulatory, emergency, etc.) for traffic flow.

- Red-Green Hybrid: When LED VMS were first introduced a few years ago, the amber LED technology did not provide sufficient brightness for message visibility. Thus, in order to obtain an amber display, a cluster of red and green LEDs (e.g., a ratio of 9 red to 55 green) was used. This arrangement yields a "pseudo-amber" display (with a slight trend towards orange) of sufficient brightness when viewed from a distance. However, when viewed close-up or at an angle greater than 10 degrees from center, the individual red and green components are readily visible.

- Amber Only: LED technology has advanced to the point where amber-only LED signs of sufficient brightness have recently been introduced by several VMS manufacturers. There is, however, very little operational experience with these signs to date, and the life-expectancy of the LEDs in a freeway environment is unknown.

LED changeable message signs are completely solid-state with no moving parts. This, coupled with the fact that LED's have a specified life of 10-12 years, make this VMS technology nearly maintenance-free A major concern with LED technology, however, is its sensitivity to heat and humidity. High temperatures adversely affect the quality of the light output, and operation above 120°F will shorten the useful life of LEDs. Accordingly, auxiliary cooling -- fans, heat exchangers and, in some instances, air-conditioning -- is required, thereby increasing maintenance requirements and utility costs.

Hybrid

The hybrid VMS is a mixture of the technologies previously discussed -- flip disk and a light emitting source (fiber or LED). The sign is made up of standard flip disks, with a small hole placed in the center of each one. Behind each hole is a fiber optic bundle, or a green or amber LED. When the disk is in the "on" (i.e., reflective) position, the light shines through the hole in the disk. When the disk is in the "off" (i.e, black) position, the fiber optic bundles (which are constantly illuminated) are covered from view, while an LED light source is turned off.

The fiber/LED enhances disk readability, particularly during low light conditions, giving the VMS the "punch" that the reflectors alone lack. Less light is required from the emitter because the signs don't attempt to overcome the direct sun. Because of the light-emitting component of the disk mechanism, external illumination is not required at night.

The hybrid VMS has many of the same advantages and disadvantages of the two technologies it combines. On the plus side, the VMS marries the best visibility characteristics of both sign groups. On the minus side, the lamps will require replacement and, as previously discussed, flipped disks may be a maintenance problem.

Discussion

Message visibility and legibility under all lighting and weather conditions is the most important attribute of a variable message sign. The chance that a driver will be confused by a display, or miss a sign altogether, must be minimized. As shown in Exhibit 7-1, the purely reflective signs do not provide the necessary quality or visual conspicuity (or "punch"). Accordingly, light-emitting VMS technology -- LED, fiber, and/or hybrid -- is recommended for the Boston Area IVHS System.

As to which of the light-emitting technologies is "best", recent VMS evaluation studies (refer to Exhibit 7-l) provide somewhat contradictory conclusions. All three are very similar in performance with respect to target values and mean legibility distances under various lighting conditions. However, none have been in operation for a sufficient period of time to determine their respective reliability and life-cycle costs. The use of a generic protocol and

Exhibit 7-1: Summary Results of Comparisons of VMS Technologies

ARIZONA DOT (July, 1991)

Target Values (% of maximum possible)

Sign	Night	Day	Backlight	Washout
Flip Disk	31	91	50	60
Fiber Optics	86	90	58	82
LED	78	89	50	75
Conventional	57	61	35	54

Average Legibility Distance (Ft-/Ability to read message)

Sign	Night	Day	Backlight	Washout
Flip Disk	360	700	220	410
Fiber Optics	680	990	660	850
LED	690	750	500	490
Conventional	750	880	460	910

NOTE: Backlight is sun behind sign.
Washout is sun behind driver.

BRITISH COLUMBIA MINISTRY OF TRANSPORT

Field Visibility Bankings at 3 Distances (Day)

	Hybrid (fiber)	LED	Fiber
100M	(2) Best luminance	(3)	(1) Best definition and resolution
200M	(1) Good resolution Best luminance	(3) Difficulty resolving the letter	(2) Smaller size than disks
300M	(1) Best luminance and resolution	(3) See only flashing (test unit was set to change letters every few seconds)	(3) Hardly see to resolve letter

format for VMS control will permit all of these technologiesto be installed in the Boston area.

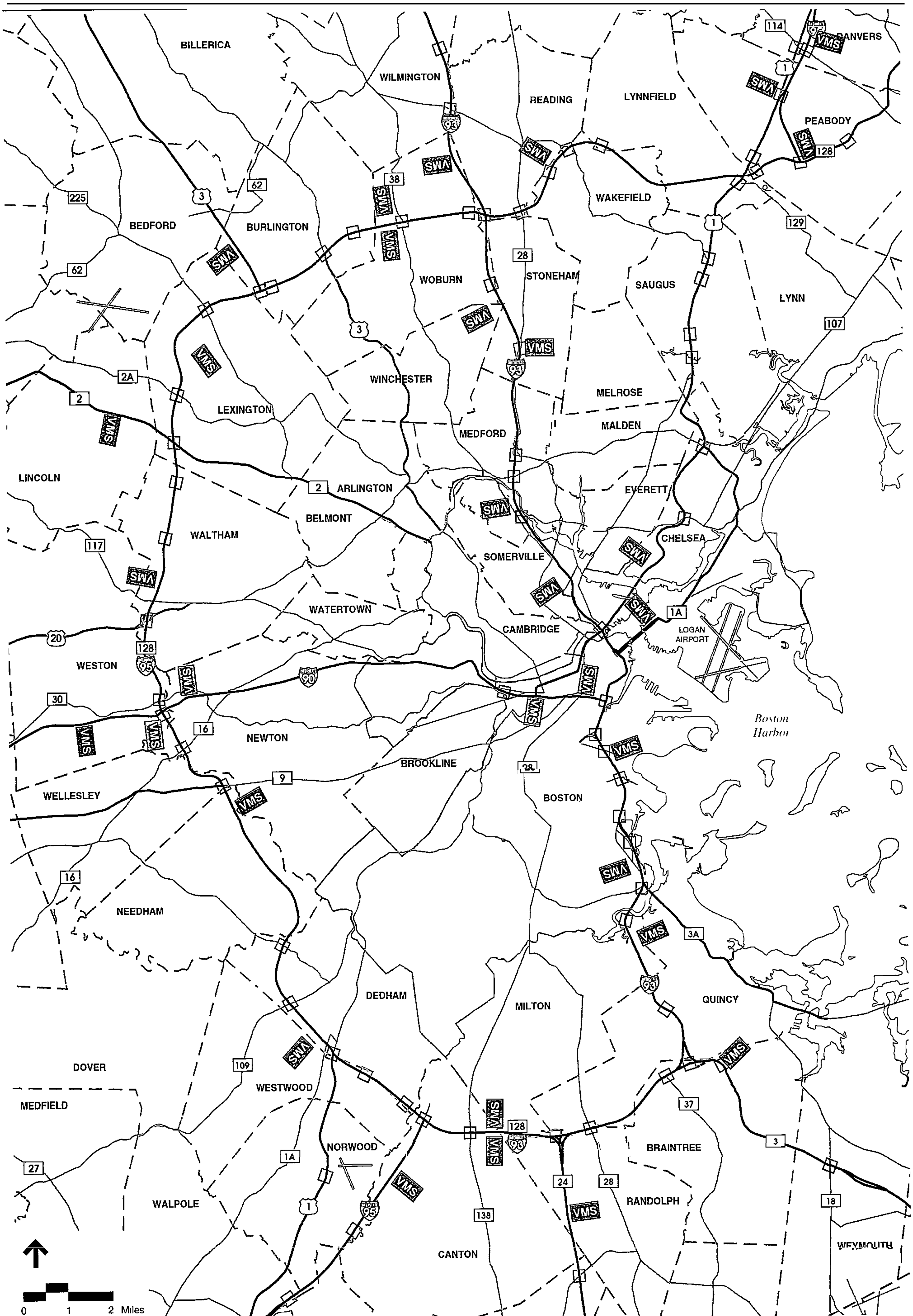
It is also recommended that a VMS demonstration be conducted so that MHD personnel can. view the different sign types from various distances, and determine the appropriate technology. In Milwaukee, Wisconsin, JHK prepared an evaluation procedure for the Wisconsin Department of Transportation to rate numerous VMS technologies and vendors. The procedure evaluated three LED-only signs, two flip/LED hybrid signs, and one each, fiber-optic only and flip/fiber-optic hybrid signs. The evaluation criteria included visibility, intensity, and color. These criteria were evaluated from different distances (linear feet upstream), locations (directly in front of sign or offset), and in different ambient light conditions. (It should be noted that in the Milwaukee evaluation, flip/fiber-hybrid technology was rated the highest.)

Based upon our experience throughout the country, taking into account cost, known reliability, flexibility, and the number of vendors, JHK recommends the use of a hybrid sign composed of flip disk and fiber optic technologies. While LED poses interesting possibilities, its potential intolerance of the weather is still of concern.

VMS Locations

The recommended VMS locations for the Phase 1 and Year 2000 Implementation Plans are shown in Exhibits 7-2 and 7-3, respectively. In general, signs have been located in advance of freeway-to-freeway connections, on the approaches to and along those roadway segments which experience the greatest congestion, and in advance of the exits for major intermodal points (e.g., park-and-ride lots).

At a minimum, the signs should use a line matrix format. The signs should be mounted directly over the center of the directional roadway; and the VMS support structures should include a walkway between the end of the structure and the sign enclosure door/catwalk, thereby permitting maintenance personnel to gain access to the sign and perform their activities without closing a lane(s). Signs with moving parts (e.g., flip disks, shutters) will require a sign face to protect the mechanisms from dirt -- most likely several sheets of Lexan with carefully placed seams so as to not affect message readability.



VMS Existing Variable Message Sign

VMS Proposed Variable Message Sign

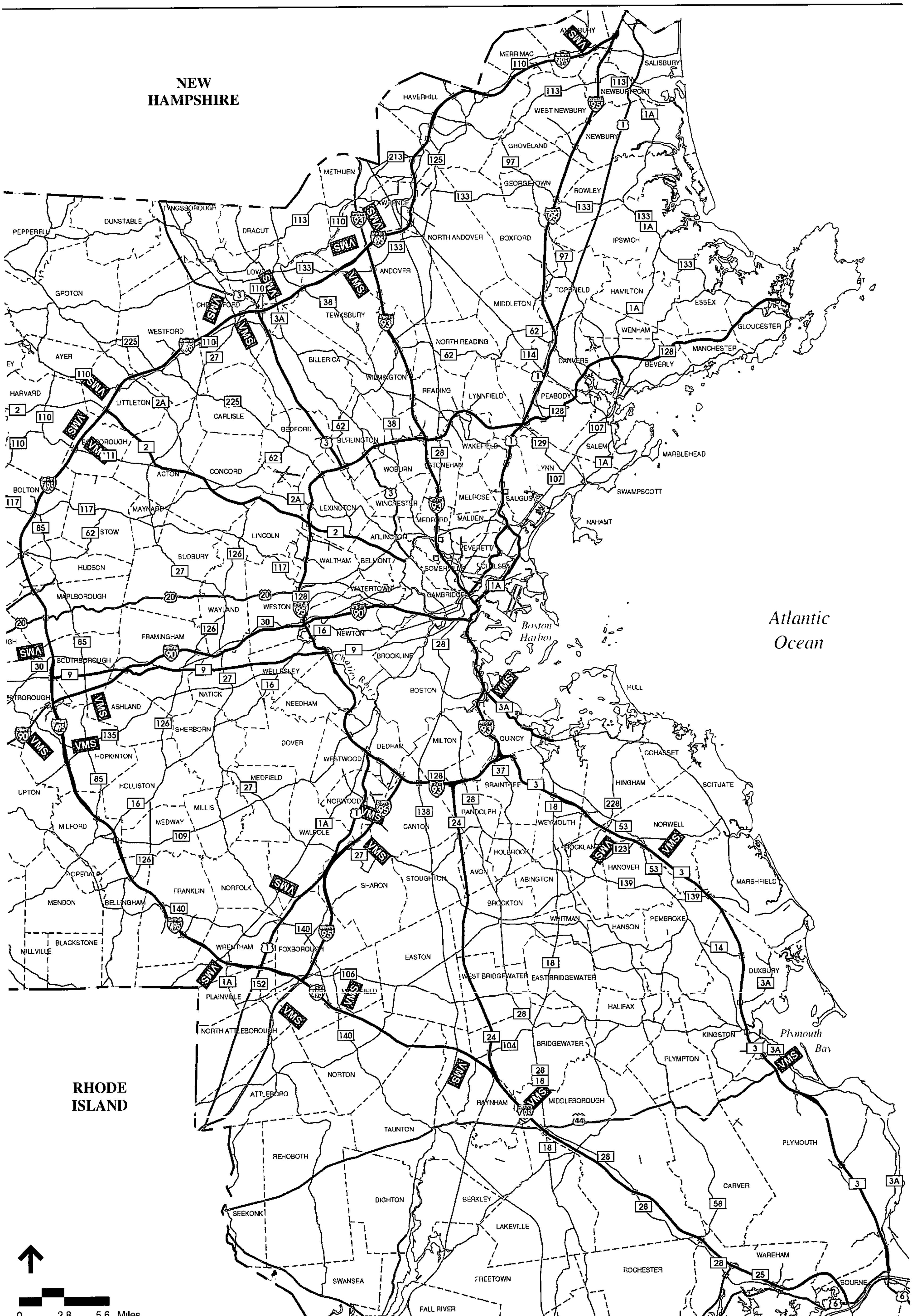
The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 7-2 Phase 1

VMS Locations



VMS Variable Message Signs

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 7-3 "2000" Plan

VMS Locations

Sign Controller and Firmware/Central Software

VMS manufacturers can provide a complete and fully operational sign system. But the sign controllers, local firmware, central software, and communications interface are generally proprietary. This means that when MHD expands the sign system, they will essentially be "locked" into the original manufacturer. To avoid this predicament, it is recommended that during the initial system design, the sign formats and communications protocol be specified. It will be the sign manufacturer's responsibility to provide a sign and sign controller conforming to these specifications, thereby eliminating any proprietary hardware or software which might tie the MHD-FTMS to a specific vendor during future system expansions. The functional requirements of the communications protocol, VMS firmware, and central software are summarized in Exhibit 7-4.

Sign Usage

The purpose behind variable message signs is to provide dynamic information regarding existing traffic conditions such that motorists can make intelligent route choices. It is also envisioned that selected VMS -- particularly those in advance of intermodal facilities -- will be used to provide dynamic information regarding the availability of park-and-ride lots and arrival of the next train. VMS should not merely be used to convey information that could also be displayed by static signing. Rather, these signs should provide timely and accurate information which reflects the current conditions, and which can be used by the travelers to improve their trip time. VMS should not provide trivial information -- telling drivers something they already know. Sign messages themselves should be composed of words that are used in everyday conversation by the motoring public in the geographical location of the system. One of the responsibilities of the TICC Operations Committee may be to formulate and periodically review sign usage policies such that consistent and effective sign messages are always displayed. As an example, some of the wording issues addressed by the sign committee for the INFORM System on Long Island include[1]:

1 Changeable Message Signs for Freeway Operations; JHK & Associates; May, 1989

Exhibit 7-4: Recommended Functional Requirements for VMS Firmware, Central Software, and Protocol

Central Software

- Control and monitor 100 signs.
- 32 standard messages (stored) and one "on-the-fly" message (non-stored) may be compared for each sign controller. Message and font composition is accomplished in a graphic format which will allow exact "What-You-See-Is-What-You-Get" composition and editing of messages and fonts, visible proportional spacing, and autocentering.
- A Time-Of-Day (TOD) Scheduler provided to allow time-based message scheduling. Scheduling options shall include commanding all signs to the same message (global control), selecting a message plan (sectional control), or selecting a single message for a single sign.
- Manual message selection provided in both "locked" and "unlocked" states. A sign with a "locked" manual message will not accept TOD-scheduled message changes until "unlocked", or until the "locked" message is manually removed.
- Access control provided as follows:
  - Level 1 - Status monitoring/message review only
  - Level 2 - Level 1, plus selection of programmed message display and TOD Schedule maintenance
  - Level 3 - Level 2, plus message composition
- All critical information automatically stored as log records on the hard disk. A log record shall provide the following information:
  - Action or event
  - Time and date stamp (24-hour clock)
  - Originating terminal
  - Operator name
  - Message and sign name

Sign Controller/Firmware

- Sign is viewed as 3 lines, each line a matrix consisting of 7 pixels high and 105 pixels wide (for line matrix technology) or sign is viewed as a continuous matrix consisting of 28 pixels high and 105 pixels wide (for full matrix).
- A minimum of 32 messages can be stored in each sign. Messages are stored in the form of ASCII text with special formatting characters embedded in text for executing special functions (flashing, inverse character, go to new line, etc.).

Exhibit 7-4: Recommended Functional Requirements for VMS Firmware, Central Software, and Protocol (continued)

- In addition to stored messages, a message may be developed at a central VMS computer and downloaded to VMS for immediate display. This "custom" message will remain in the controller's memory only as long as the message is being displayed.

- All messages not capable of being shown in a single display are shown in two phases (alternating messages). The operator specifies the message for each phase and the length of time each phase of the message is displayed.

- Proportional spacing and message-in-line autocentering is provided.

- User interface support provided via the front panel of the sign controller to allow for the selection of pre-programmed (i.e., stored) messages in the event of a communications failure. Diagnostic routines and associated sign messages are also to be selectable from the front panel.

- In addition to download from central, messages may be downloaded to VMS in the field using a laptop computer via an RS-232 port on sign controller.

Communications/Protocol

- Communications provided via serial communications over leased telephone facilities(including commercial dial-up), twisted-pair cable, and spread-spectrum radio.

- The following five message types are supported. For each type, there is a specific format including address, message type, command/response information, and checksum.

  - Message Selection (select pre-stored message (l-32), and verify display)
  - Immediate Message (display message not previously stored in memory, and verify)
  - Parameter Download (store messages and configuration data in sign controller)
  - Parameter Upload (review stored messages and configuration data from central)
  - Time Broadcast

- All sign command requests, changes in sign status (e.g., displayed message, failure, operating mode), and edits or changes to the messages, sequences timetables, and libraries result in an appropriate entry in the activity log. Message texts shall be included in the log for all message display requests or message edits.

- Capable of remote message selection by external computer system.

- Use of the word "Delays" rather than "Congestion".
- Descriptions like "CAR FIRE" are not used in that these may make the incident interesting, and motorists might choose to see it instead of diverting.
- Alternating messages are not used.
- Use of exit numbers instead of mileage to identify geographic location and extent of delays.
- Displaying "NORMAL TRAFFIC AHEAD" when no delays exist between the sign and the next downstream sign.

The latter usage is an important issue. The policy of some freeway management systems is to not display any message on the sign unless something out of the ordinary (e.g., an incident) is in progress. The logic of this policy is that when the signs are activated in response to an incident, it will command the motorist's attention. One potential problem with this policy is a large number of complaints from motorists that the "signs are broken".

It is noted that since the INFORM System implemented the "NORMAL TRAFFIC AHEAD" messages, people ceased complaining that the signs "don't work". At times, the media and public have struggled with the definition of "normal traffic"; but have not complained about its use. The Toronto system displays guidance information (e.g., identifying a particular route for the airport) as its non-event messages. An additional example is Virginia, which displays the date and time.

8. DEMAND MANAGEMENT

Solutions for recurring congestion fall into the broad category of "demand management", as their focus is to reduce the demand along freeway segments and at bottleneck locations. Since an incident is a form of roadway bottleneck, the demand management strategies discussed herein may also be applied to the overall incident management process.

RAMP METERING

Ramp metering is currently the primary IVHS element for addressing recurring congestion on freeways. Ramp meters are traffic signals placed at the freeway on-ramps. They control the rate at which vehicles enter the mainline (i.e., manage the demand) such that the downstream capacity is not exceeded, thereby allowing the freeway to carry the maximum volume at a uniform speed. Though it may seem paradoxical, by controlling traffic at the ramps such that the freeway's throughput is maximized, more vehicles can enter from the ramps than if the mainline flow was permitted to breakdown.

Another benefit of ramp metering is its ability to break up platoons of vehicles that have been released from a nearby intersection. The mainline, even when operating near capacity, can accommodate merging vehicles one or two at a time. However, when groups (i.e., queues) of vehicles attempt to force their way into freeway traffic, turbulence and shockwaves are created, causing the mainline flow to breakdown. Reducing the turbulence in merge zones can also lead to a reduction in the sideswipe and rear-end type accidents that are associated with stop-and-go, erratic traffic flow.

Ramp metering can serve other purposes, as well, including:

- To discourage drivers from using the freeway for very short trips. Ramp metering is more likely to divert short trips to the arterial streets rather than long trips because the time savings resulting from improved freeway flow will be smaller (or non-existent) for short trips as compared to longer trips.
- To provide incentives for bus ridership and carpooling by allowing HOVs to bypass the ramp meter. Typically, the time savings is one to three minutes.

In essence, ramp metering redistributes the freeway demand over time -- storing any excess demand on the ramp, instead of on the freeway in the form of stop-and-go traffic. While this mode of control is used primarily to reduce the impacts of recurring congestion during peak traffic periods, ramp metering can also be implemented to combat nonrecurring congestion. For example, meters upstream of the incident area would operate at low metering rates, limiting the number of vehicles entering the freeway, while downstream on-ramps would operate with relaxed metering rates (or no metering) in order to handle the increased demand.

Ramp metering has been proven to be a very effective tool for increasing average freeway speeds while also reducing accidents. A study by FHWA indicated that ramp metering systems reduce recurring delay by an average 28 percent. Another measure of ramp metering effectiveness is the fact that every existing ramp metering system in this country has been, or is proposed to be, expanded.

Ramp Meter Configuration

A schematic of a typical ramp meter installation is shown in Exhibit 8-1. Most locations use single-entry metering -- that is, only one vehicle per lane is released during each red-green cycle. The demand detector indicates (to the ramp controller) that a car has arrived at the stop bar and that the metering cycle should commence. Without demand at the stop bar, the ramp signal indication remains red. The output detector senses that the vehicle has passed the stop bar, indicating that the ramp signal should go back to red for the next vehicle. Additionally, the output detector can be used to monitor meter violations (i.e., drivers who ignore the red light) and provide historical data on the violation rate at each ramp. A merge detector may be used as a feedback mechanism to prevent additional metering if vehicles are stopped in the merge area. The queue detector is used at locations where ramp backups may impact surface street operations. The mainline detectors provide volume and occupancy data for traffic responsive operation of the ramp metering.

It is noted that the MUTCD does not contain any standards for ramp metering signals. Most systems use a signal consisting of red and green lights. When metering is not in operation, the signal rests in green; or in some systems the displays are completely turned

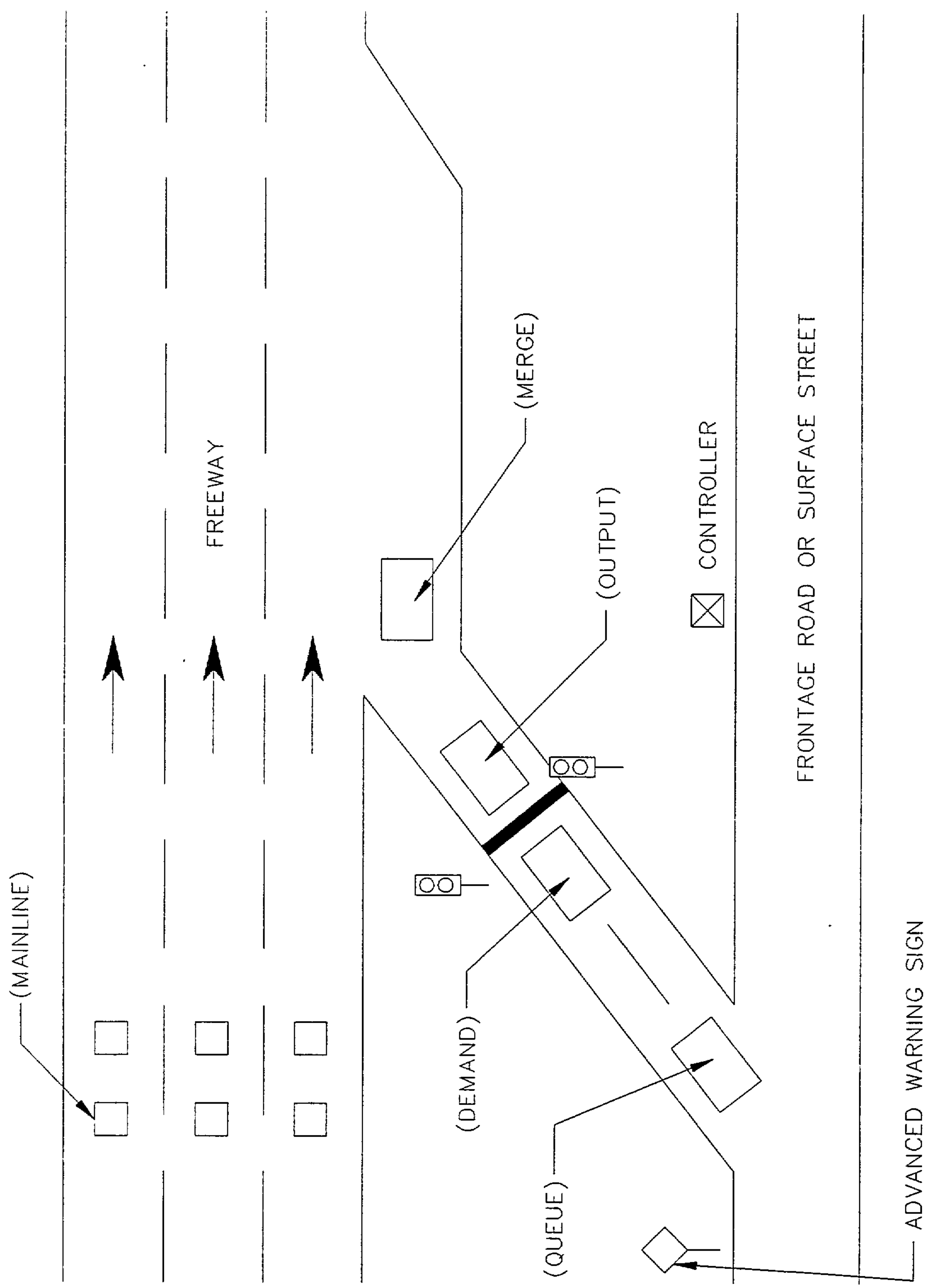


Exhibit 8-1: Typical Meter Installation Layout

off. Some metering systems (e.g., Minneapolis) utilize a red-yellow-green signal head. The yellow indication is briefly displayed during each cycle, and is also flashed whenever metering is not in operation. Most systems also use some sort of advanced notice that the ramp signal is operating -- for example, a warning beacon, blank-out signs, and a strobe light in the red lens of the ramp meter signal.

Ramp Metering Issues

Properly designed and well managed ramp metering has proven to be an extremely cost-effective strategy in reducing congestion. Metering is not appropriate for every location, and several design, operational, and institutional issues must be considered before implementing ramp metering within the Boston area.

Metering Rates

Metering rates have definite upper and lower limits which can affect the feasibility of ramp metering. The minimum reasonable length of the red-green cycle is 4 seconds (i.e., 2.5 seconds of red and 1.5 seconds of green). This yields a (theoretical) maximum metering rate of 900 vehicles per hour for a single metered lane. A practical minimum rate also exists. It has been found that if a ramp signal displays a red indication for more than 15 seconds, most drivers will ignore the signal and enter against the red. Thus, the most restrictive discharge rate is about 240 vehicles per hour.

Control Mode

Ramp metering can be implemented using various forms of operation including:

- Pretimed - This is the simplest form of control. The metering rates are fixed, and change only in accordance with a preset time-of-day/day-of-week schedule (e.g., time clock).
- Traffic Responsive - The metering rate is varied to reflect the freeway

conditions in the immediate vicinity of the ramp. This approach utilizes nearby detectors (on the freeway and the entrance ramp) and a microprocessor-based controller to determine an appropriate metering rate.

- System Control - This is a form of traffic responsive control; but the metering rates for each ramp are determined by a central computer, and are dependent on mainline and ramp flows throughout the network. A significant feature of system control is a more unified and equitable distribution of metering rates -- the ramps nearest the heaviest mainline volumes do not necessarily suffer the most restrictive rate as would occur with the traffic responsive mode.

As previously discussed (Chapter 51, the IVHS system will collect and process real-time surveillance data for the entire roadway network. This will permit system-wide control of any metering, thereby ensuring an equitable assignment of delays at the various metered locations.

Ramp Geometries

Ramps should possess characteristics suitable for metering. One consideration is an adequate acceleration and merge area beyond the meter. Cloverleaf designs, in which the merging area for the curved on-ramp is in close proximity to the off-ramp, are a major concern in that vehicles accelerating from the ramp meter must merge with decelerating vehicles which are exiting the freeway. The tight radii of these curved ramp sections may also create sight distance problems for vehicles entering the queue from the surface street (i.e., inability to observe the stopped vehicles in queue as the vehicle is entering the ramp).

Another major concern is the availability of storage behind the meter. A general rule of thumb used in other systems is that any impacts (i.e., back-ups onto the surface street) are considered negligible if the available ramp storage exceeds 10 percent of the premetered peak hour volume. Storage between 5 percent and 10 percent may be adequate, but more detailed analysis is necessary. Less than 5 percent requires mitigating measures. The Ramp Meter Design Guidelines developed by California DOT address storage requirements as follows:

Peak Hour Volume	Recommended Storage Length (Lane-Feet)
200	1000
400	1700
600	2500
800	3400
1000	4200
1200	5000
1400	5800
1600	6600

The most common technique for increasing storage space is to increase the number of lanes on the entrance ramp prior to the meter. This can be accomplished by restriping or reconstructing (i.e., widening) the ramp to provide two or more lanes. The vehicles are released -- alternating between the right and left lanes -- then merge into one lane before reaching the mainline. Storage is not necessarily limited to the ramp proper. For example, in San Diego a portion of the surface street approach is used to store vehicles -- in one location, as far as 2000 feet from the ramp. This arrangement may require widening and/or channelization of the surface street to reduce any impact the ramp queue might have on nonfreeway-bound traffic.

Impact on Surface Streets

A major issue that is raised in connection with ramp metering is its potential impact on the surface street network. The development of queues which back up onto surface streets is often a primary concern of local jurisdictions. Mitigating measures include:

- Increasing ramp storage as discussed in the previous section.
- Areawide system control of metering such that back-ups are balanced between many ramps.
- Installing a queue detector at the top of the ramp. If back-up is detected (i.e., occupancy exceeds a specified threshold), the metering rate is increased to clear out a portion of the queue. In the event the queue still continues to grow, the ramp meter may be turned off.

Another issue that is raised is the potential diversion of freeway trips to adjacent surface streets. Extensive evaluations of existing metering systems show that some adjustments in traffic patterns do occur after metering, but they are usually not significant. As previously noted, ramp metering may divert some short trips from the freeway. In concept, however, freeways are not intended to serve very short trips; and diverting some of these trips is desirable, particularly if there are alternate routes which are underutilized.

Enforcement

The effectiveness of ramp metering, like any traffic regulation, is largely dependent on voluntary driver compliance. Being a new form of traffic control, there is the potential that drivers will not obey the ramp signals. It should be made clear, as part of an extensive public information effort, that ramp meters are traffic control devices which must be obeyed. The laws and penalties should also be clearly explained. In systems where the advance publicity was positive and plentiful, violation rates were lower.

As is the case with any traffic regulation, enforcement is needed. A high level of enforcement activity is required during the initial ramp metering operation; and continuing spot enforcement should be provided throughout the life of the system, particularly at ramps with excessive violation rates. Coordination and cooperation with State and local police is essential. Representatives from these agencies should be included in the planning and design of any ramp system -- particularly with regard to enforcement issues such as access, area to cite violators, signs, and staffing needs.

Metering Policy

A major policy issue in operating ramp metering is the extent to which the freeway w-ill be kept free-flowing at the expense of ramps and surface streets. One method of avoiding freeway breakdown is to reduce the metering rate at the ramps -- permitting fewer cars to enter the freeway -- such that the mainline capacity is never exceeded. However, such a strategy will increase the motorists'wait at ramps, cause larger queues that might back up onto the surface streets, cause more traffic to divert, and/or increase violations of the ramp signal.

An alternative policy is to regulate the meter rates such that severe ramp back-ups and diversion are minimized. This can be accomplished with a less-restrictive metering rate, queue detector override, or some combination. Significant benefits in freeway flow and accident reduction still result from this "nondiversionary" strategy. The onset of mainline congestion consistently begins later in the peak period and ends earlier. Many days the mainline does not break down at all; while accidents are also reduced. (Note: Nondiversionary metering is utilized in the Denver, Northern Virginia, Chicago, INFORM and several other systems.)

Freeway Connector Metering

Another means of providing better entry control within the freeway network is to meter freeway-to-freeway connector ramps. Experience in Minneapolis and San Diego indicates that significant benefits can be achieved with connector metering under the appropriate conditions. These conditions essentially parallel the following issues associated with surface ramp metering:

- Metering Rates - Freeway connectors often have volumes greater than 900 vehicles per hour per lane (the maximum possible with single entry metering). Metering rates in excess of this maximum figure can be achieved by platoon metering, in which two or three vehicles are allowed to pass on each green phase. Theoretically, based on a minimum cycle length of 7.5 seconds and three vehicles per cycle length, a metering rate of 1,440 vehicles per hour per lane is possible; although no practical application of this magnitude has been reported. There is also the potential issue of consistency in the metering regulations -- limiting surface ramps to one car per green, while permitting two or more vehicles per green at the freeway connector ramps.

- Storage Capacity - The ramp storage must be capable of handling the anticipated queuing which will occur with connector metering. As previously discussed, this may require additional lanes (e.g., widening, restriping).

HOV Bypass Lanes

Another strategy that is frequently used in combination with ramp metering is a HOV bypass lane. This is a parallel ramp or ramp lane that is reserved for HOVs to bypass the meter (refer to Exhibit 8-2), and thus provide a travel time incentive for carpools, vanpools, and buses. If the number of HOVs is too large, the occupancy rule can be modified or the HOV lane can also be metered, but at a more favorable rate. A potential concern with HOV bypass lanes is an increase in violations -- that is, single-occupancy vehicles using the HOV lane to avoid the metered queue. As discussed, an active enforcement program will minimize such violations.

Freeway Mainline Metering

The techniques of freeway mainline metering differ from conventional ramp metering in several respects. Upstream of the meters, blank-out message signs with flashers warn of metering operation during the metering periods. These must be placed well in advance of the expected operational queue. Rumble strips and changeable delineation (such as that used on airport runways) can warn and direct approaching motorists into the metering manifold. Programmed Visibility signal heads focused on each lane are mounted on a sign bridge downstream of the stop bar. A second sign bridge upstream of the metering manifold could use lane control signs to open and close lanes, increasing the range of metering control. It is noted that speeds on the freeway will be quite high outside of the metering periods. A startup phase, when illuminated "Metering Ahead" message signs light up and the meters cycle through their first greens and yellows to their first reds, is required to begin metering operation. Once queues block passage, approach speeds to the meters are lower and operations smooth.

It is generally desirable to meter mainline volumes to some limit such that downstream capacities are not exceeded. If the capacity of a bottleneck requires that existing mainlines supply no more than about 1000 vehicles per lane per hour, the metering area must be widened and restriped to allow more metered lanes to contribute as shown in Exhibit 8-3. A system of lane use markers upstream of the signal heads can close and open lanes to

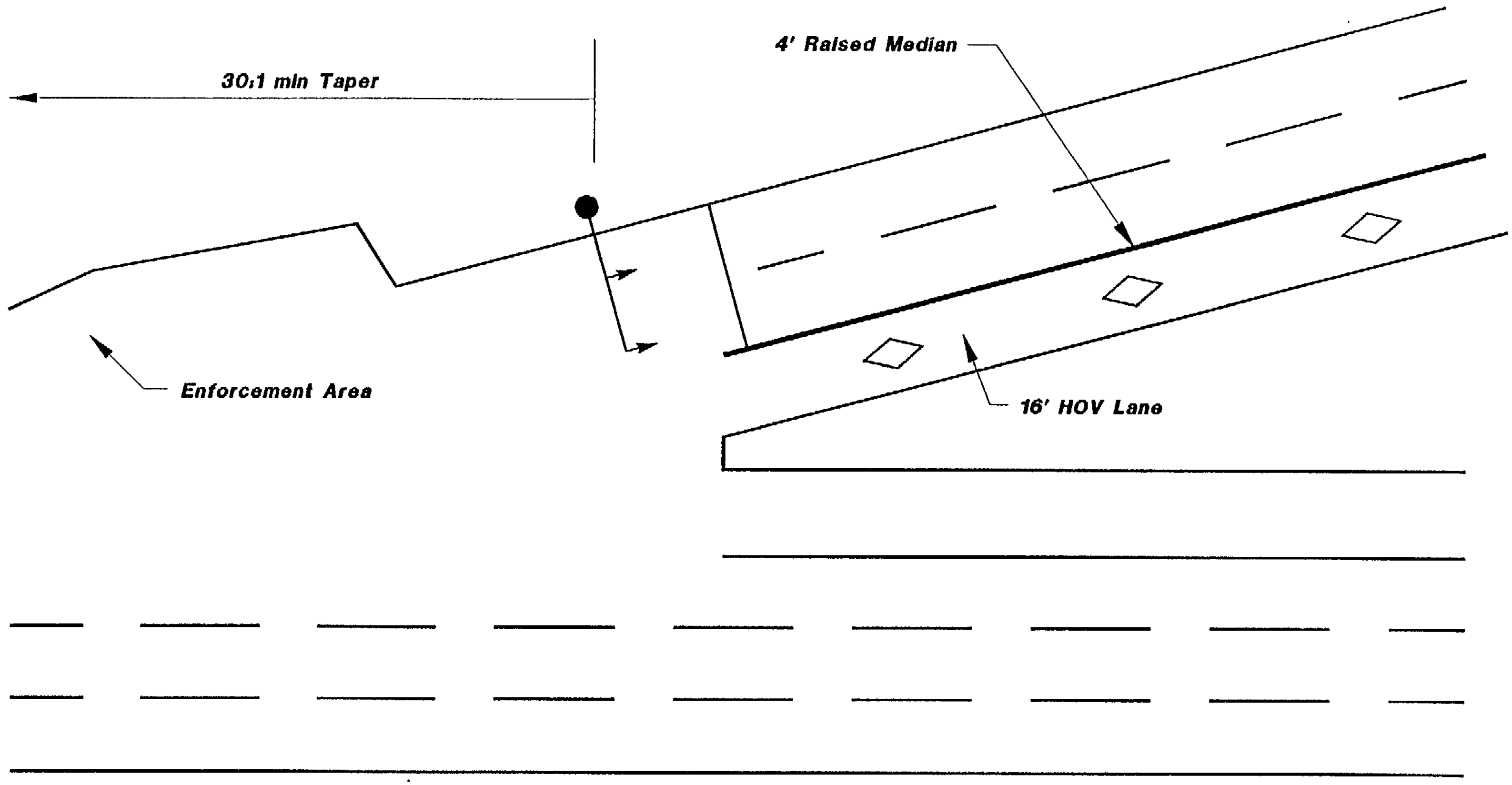


Exhibit 8-2: Ramp Design Guidelines for HOV Bypass

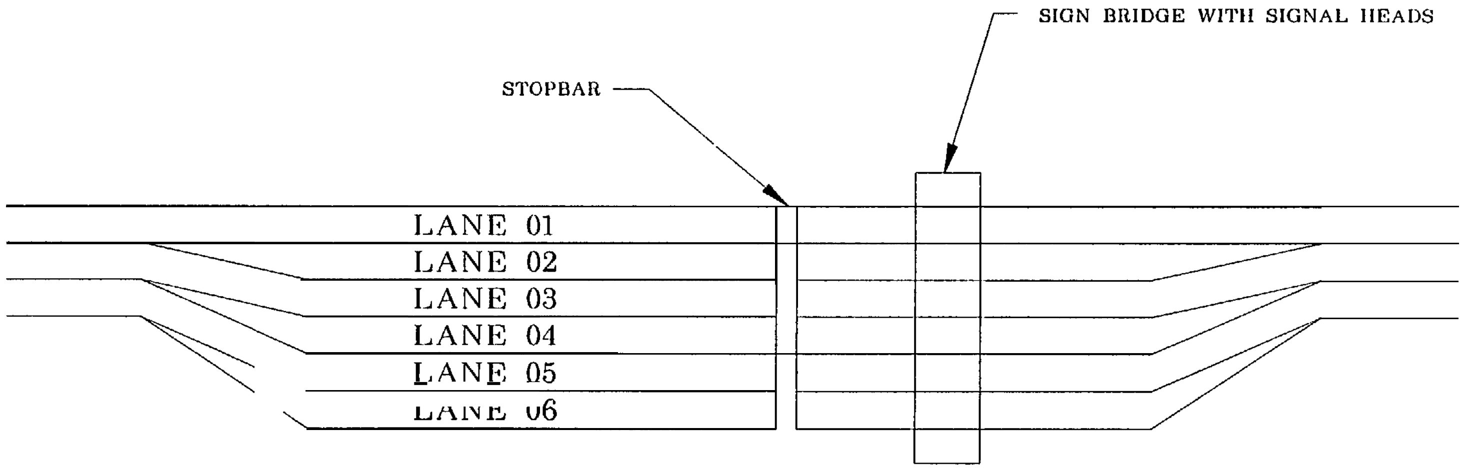


Exhibit 8-3: Mainline Metering

expand the span of control, since the useful operational range of each ramp is between 500 and 1000 vehicles per metered lane per hour. An enforcement area for police use must be provided to ensure effective operation. HOV bypass lanes may also be included.

Operational experience with several facilities (e.g., Bay Bridge in San Francisco, Route 94 in San Diego) has shown that mainline metering can benefit safety while reducing and equalizing delay.

Public Acceptance

Perhaps the most critical metering issue is gaining public and political support. To the public, ramp and mainline meters are often seen as a restraint on a roadway normally associated with a high degree of freedom -- a new form of control where before there was none. As previously discussed, definite benefits can be achieved by metering, and the improvements can be demonstrated statistically. Nevertheless, even though the 2 to 5 minute wait at the ramp or mainline is typically more than compensated for by the improved travel time on the freeway, motorists may only notice the waiting time.

A related concern, and potentially an area of significant controversy is a perceived "inequitable" treatment of trips -- that ramp metering favors longer trips at the expense of shorter trips. Based on experience in other systems, if metering were applied within Route 128 (inclusive), residents who live within the Route 128 beltway might argue that they are deprived of immediate access to the freeway, while long-distance commuters can enter the radial expressways beyond the metered zone and receive all the benefits without the ramp delays. This potential controversy alone should not deter MHD from pursuing a ramp metering program. Nonetheless, the Department should be prepared for some negative public reaction and criticism.

From an institutional perspective, implementation of ramp metering can be a smooth process by considering the following guidelines and strategies:

- Involve all of the affected agencies and institutions in the process from the very beginning. This would include State Police and engineering and enforcement personnel from local jurisdictions.

- Implement metering over the widest possible area, and in such a manner that a large majority of commuting motorists are metered, thereby distribution the delays in an equitable manner.

- Institute a proactive public relations program. In announcing the plans for a ramp meter system, inform the public and institutions about the basic reasons for initiating ramp metering; how metering works and the public's legal responsibilities; a realistic expectation of the system's benefits to users (reduced delays and increased safety); the alternative choices that are available to the motorists; and how the system will respond to the allocation of available capacity in an equitable manner. Various tools can be used to convey this information including distributing brochures, holding public meetings, utilizing government cable TV channels, appearing on radio talk shows, etc.

- Discuss with local governments how the metering will be operated (e.g., rates will be adjusted so as to prevent severe back-ups on City streets). Also discuss the differences between diversion and nondiversion strategies, and what changes will be incorporated within the freeway corridors and the metering operation to minimize the impact caused by any diverted traffic.

- Whenever possible, install ramp meters in conjunction with freeway rehabilitation projects.

- Closely monitor ramp meter operation during start-up, and make appropriate adjustments should problems occur. Additionally, provide brief updates of the metering system at frequent intervals (e.g., accident experience, flow improvements, cost effectiveness).

Ramp Meter Analysis

Each on-ramp within the Phase 1 area was analyzed to determine the extent (if any) that ramp metering could be included in the initial IVHS area. Evaluation criteria included the following:

- Peak hour volume of less than 900 vehicles per lane.

- Minimum storage length of 10 percent of peak hour volume.

- Adequate acceleration area.

- Non cloverleaf design (Note - This criterion affects the straight on-ramp of a cloverleaf interchange as well. It is not feasible to meter one on-ramp at an interchange and not the other; otherwise U-turns on the surface street may become troublesome).

- Not a freeway-to-freeway connector.

These criteria are very conservative. However, this was considered to be the appropriate approach for the Phase 1 implementation -- the premise being any condition which is less than perfect will create institutional and political problems with respect to metering; and such a situation would significantly delay the implementation of the other high-priority Phase 1 elements (e.g., incident management, traveler-information). The results of the analyses are shown in Appendix C.

Very few ramps within the Phase 1 area meet all the aforementioned metering criteria _ for example, only 11 percent of the ramps along the Route 128 circumferential road are currently suitable. Installing a few isolated ramp meters will provide little benefit, while possibly causing significant institutional problems affecting other IVHS functions. Accordingly, ramp metering, per se, is not included in the Phase 1 Plan.

There are several considerations regarding the possible inclusion of ramp metering in the Year 2000 IVHS Plan. The extended implementation timeframe offers the opportunity for "teaching" Boston area motorists about ramp metering, so that they accept and have confidence in this function. Moreover, motorists will have observed the early benefits associated with the Phase 1 implementation, and ramp metering can be marketed as a "next step" in the process. It is also noted that several locations in the United States have metered ramps which violate generally-accepted metering guidelines, yet operate successfully. Many of the ramp meter criteria may therefore be relaxed (e.g., require less than 10 percent storage) and/or geometric improvements (e.g., additional storage) can be introduced. Accordingly, metering is a recommended element of the Year 2000 IVHS Plan.

Several metering scenarios (and combinations thereof) may be considered:

- Meter Route 128 Ramps - Motorists living outside this circumferential route make the greatest use of the roadway network in terms of vehicle-miles travelled. Metering the Route 128 ramps will essentially assign delay to the local motorists (i.e. living in the vicinity of Route 128); as the long distance commuters use either the radial expressways, or enter

Route 128 from the radial connections.

- Meter freeway-to-freeway connectors between Route 128 and the radial routes (I-93, I-95, Route 3, Route 24, etc.) - This will improve circumferential flow on Route 128; but contributions to radial freeway congestion within Route 128 will be slight.

- Meter all ramps on all the radials -- This addresses the congestion on the radial roadways and provides a more equitable distribution of delay, but at a significant cost considering the number of ramps involved.

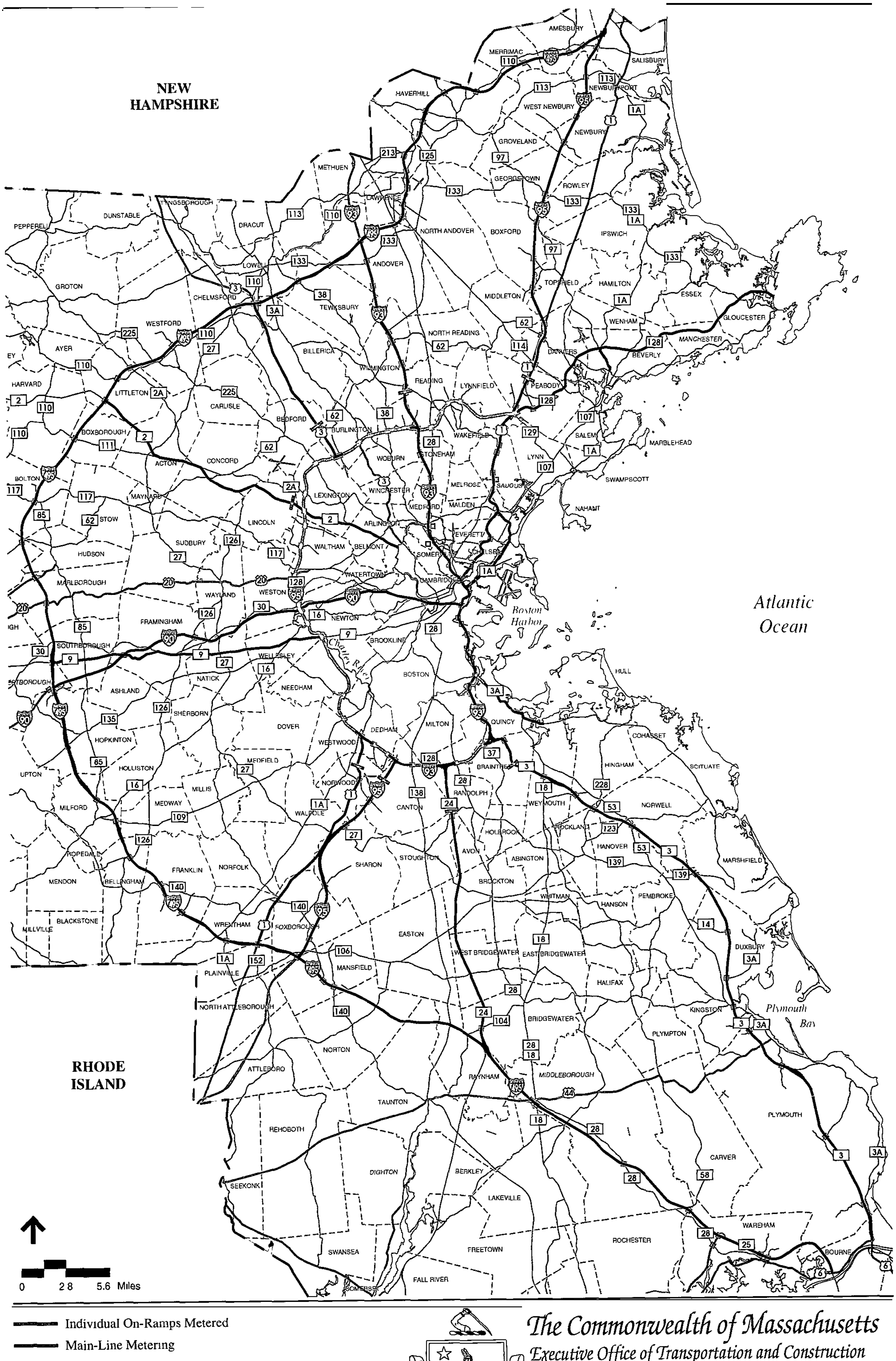
- Meter the mainline of all radial freeways upstream of Route 128. This avoids the high costs of metering all radial ramps and the potential problems of direct connector metering, while assigning delay to the users who contribute the most to VMT and congestion. The Turnpike toll plaza at I-95 (Route 128) essentially provides mainline metering today.

It is recommended that metering be include in the Year 2000 Plan, as shown in Exhibit 8-4. This includes most of the Route 128 ramps (except for the freeway connectors); the Route 3A on-ramp to I-93 northbound; and inbound mainline metering (approximately 5 miles upstream of Route 128) on Route 3 (north and south of Boston), I-95 (north and south of Boston), Route 24, and I-93.

The proposed metering configuration will ensure that nearly every inbound motorist will be metered -- the exception being those motorists who live within the Route 128 circumference and do not use Route 128 -- thereby reducing recurring freeway delay in an equitable manner. Including HOV bypass lanes, particularly at the mainline meter stations, will also provide an incentive for reducing the number of single-occupancy vehicles on the network and encouraging the use of transit. Additionally, the mainline meter stations might also be modified and utilized in the future for congestion pricing.

Metering should be introduced in stages, starting with the Route 128 ramps between Route 9 and Route 24 -- these initial installations being included as part of the proposed lane additions along these segments. This will be followed by the remaining ramps and mainline metering.

It is recommended that the ramp meter controller be a Type 170 (or 2070) controller. These 170 controllers should be identical to the 170's used for detector processing, except that



Individual On-Ramps Metered

Main-Line Metering

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 8-4 Ramp Metering Locations

the PROM module will be programmed for ramp metering. The ramp meter control firmware should provide the following minimum functionality:

- Process mainline detector data as previously discussed.
- Sequence the signal in response to ramp detector actuations and the selected meter rate.
- Alter metering operation (i.e., relax rate/turn-off) in response to occupancy measurements at queue detector.
- Provide various methods for selecting meter rate, including (in priority order) manual; remote (as selected by FTMS computer); traffic responsive; (mainline volumes, occupancy, and speed); and time-of-day/day-of-week (with exception days).
- Provide a minimum of 6 different metering rates, plus non-metering condition.
- Control advance "Metering On" display.
- Measure and count violations (i.e., vehicle actuates passage detector during the red portion of cycle).
- Provide two-lane metering and HOV metering (with separate HOV lane detector).

ROADWAY PRICING

Another form of demand management is roadway pricing, in which motorists are charged for the use of the facility. It is envisioned that any roadway pricing scheme in Boston will utilize AVI technology and electronic toll collection. Instead of standard toll booths, individual vehicles are charged and subsequently billed for their use of the roadway (or some form of prepayment and debit system may be used) based on a variety of factors, such as the number of miles driven, the origin an&or destination of the trip, the time-of-day/day-of-week when the trip was made, and/or where the vehicle was parked. Such information can be readily obtained from widespread application of AVI technology coupled with an appropriate real-time database. A surcharge might be added to the roadway pricing scheme whenever congestion was predicted to be especially heavy, or during periods when air pollution standards were being exceeded. The surcharges could be established in real-time, and then communicated to the public via the traveler information elements.

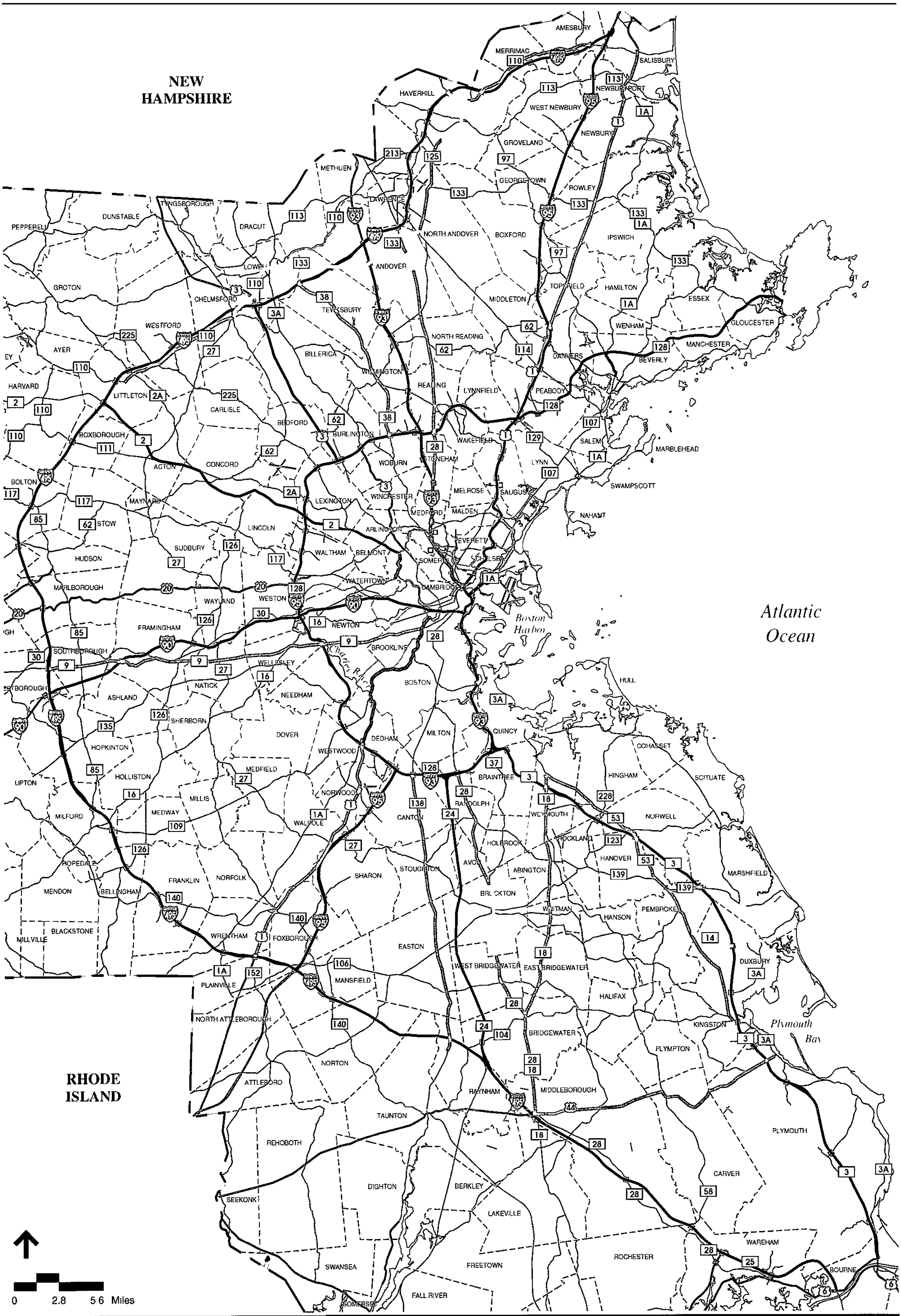
There will probably be significant institutional constraints to resolve before roadway pricing can be implemented. The potential "invasion-of-privacy" issue with AVI has previously been noted. Another issue may involve the equitable treatment of the economically-disadvantaged driver relative to the wealthy driver. As previously noted, the installation of mainline metering may form the basis for the subsequent implementation of roadway pricing.

ARTERIAL TRAFFIC CONTROL

Vehicle movements on the surface street network are controlled by adjusting the signal timing -- a combination of cycle length, split between phases, and offset relative to some common reference -- such that traffic moves with minimal delay and stopping. Computer-based signal systems allow a large number of timing plans to be developed, stored, and implemented by a central computer. Timing plans can be developed for all of the normal traffic conditions, as well as those found during special events and diversion. Another feature of computer-based signal control is that the signal timing plans may be implemented from the central control room, or from a remote workstation which has dial-up access to the central computer.

Existing and proposed signal systems within the Boston area are described in Chapter 2. Corridors for future signal systems are identified in Exhibit 8-5. These corridors were selected due to the potential for processing diversionary route traffic based on the incident occurrence in the parallel highway corridor. While spacing of signalized intersections or major generators may not normally require system control and operation (especially in the radials between Route 128 and I-4951, the availability of communications between a control center and the local intersection to effect an emergency timing plan is desirable. As locations within these corridors are upgraded, whether they be insulated or part of a system, closed loop technology in some form should be implemented or provisions for future implementation acknowledged.

Given the crucial role that arterial signal timing plays during diversion, and the



MDC

MHD

MDC And MHD

Municipalities

The Commonwealth of Massachusetts

Executive Office of Transportation and Construction

IVHS Strategic Deployment Plan for Metropolitan Boston

Exhibit 8-5 Signal System Corridors

general relationship between events on the freeway and the traffic flow on surface streets,interties should be established between the TICC and the various computerized signal systems (e.g., Boston, MDC, MHD etc.). As an example, if diversion was to be implemented as part of a regional strategy, the TICC would "request" that a special timing plan -- designed specifically to handle the additional traffic diverted from the freeway -- be initiated by the signal system; and if the alternate surface street route had spare capacity (as measured by system detectors), the signal system would implement that timing plan. In a similar fashion, if multiple diversion routes were available, the TICC would review the current surface street traffic flow data from the signal system and determine the optimum diversion route. In the event diversion would be required for some time (i.e., major incident), this interaction would be a continual process.

This freeway -- surface street coordination will be addressed in the various response plans and included in the Expert Systems rules base (as discussed in Chapter 10). The process will involve the TICC and the signal system owners developing and agreeing to a series of plans of action to be taken (or not taken) in the event of certain specified conditions (e.g., levels of congestion on both the freeway and surface street network, diversion, freeway closure, etc.). When these conditions occur, the TICC will request -- either manually or automatically -- a corresponding action by the signal system(s). The final decision as to the implementation of the request would depend either upon an operator intervention or upon the status of the system at the time. Various levels of automation and required operator intervention are possible, depending on the scenario and the agreement between the TICC (via MHD), MDC; and local jurisdictions. The primary issue is that coordination and a continuous information exchange must be maintained between the freeway and surface street networks if strategies and responses are to be coordinated.