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ATMS Concept of Operations and Generic System Requirements

Task B Final Interim Report for Design of Support Systems for Advanced Traffic Management Systems
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1.0 INTRODUCTION

This document is the second in a series describing the results of a five-year research program entitled the ***Design of Support Systems for Advanced Traffic Management Systems.*** The purpose of this work is to define, design, prototype, and evaluate the baseline support systems for the implementation of Advanced Traffic Management Systems (ATMS).

1.1 Scope

This document describes the Concept of Operations and Generic System Requirements for the next generation of Traffic Management Centers (TMC). Four major steps comprise the development of this Concept of Operations. The first step was to survey the state-of-the-practice to develop a thorough understanding of how traffic networks are currently managed. This review was conducted through interviews with TMC managers, TMC inspection visits, and a literature search and review. The results of this review are documented in a previous report entitled, "Traffic Management Centers - The State-of-the-Practice". Using the review's results as a foundation, the second step was to develop a comprehensive list of ATMS functions that would meet the objectives of the Intelligent Vehicle Highway System (IVHS). This list was then used to derive ATMS functional requirements. The functional requirements encompass the generic system requirements, which are higher level requirements identifying critical areas where support systems are essential for effective management and operation of ATMS. The functional requirements served as the baseline for a top-down analysis, the third step, in which each function was analyzed to determine requirements for the information to be input, the necessary processing, and the output information to be produced. Using this list, more detailed analyses were performed to identify ATMS boundaries, the role and assets of ATMS itself, identification of external entities, data and information exchange between ATMS and external entities, and the decomposition of functions within ATMS. A by-product of these analyses, was the identification of ATMS subsystems and support systems and their interrelationships. Finally, the last step was to develop a set of operational scenarios to exercise each of the identified functions in the subsystems. The result of these analyses provides a framework for the design of ATMS support systems.

1.2 System Overview

The purpose of an ATMS, in the context of IVHS, is to promote the efficient movement of people, goods, and services by optimizing the operation of a traffic network. To effectively perform these tasks, ATMS must cooperatively and pro-actively interact with its internal and external entities. Real-time sensor data from a surveillance system (e.g., loop detectors, probe vehicles, video cameras, etc.); policy data in the form of jurisdictional, legal, or system policies; event planning data in the form of construction plans and other special events (e.g., sports, concerts, etc.); incident report and equipment malfunction data; information requests and requirements; network status and performance data; and other types of data must be collected, processed, and analyzed to issue directives to control devices, such as signals and Changeable Message Signs (CMS), and to disseminate traffic and network status data to IVHS External Systems to effectively manage the network. For more comprehensive coverage of external entities and information flow, refer to Section 2.1.

1.3 ATMS Vision, Goals, and Objectives

The ATMS vision must be consistent with, and responsive to, the larger vision of IVHS. This larger view is essential to setting the context for ATMS, which will serve as the basis for developing an ATMS operations concept and system architecture concept.

1.3.1 A Vision for ATMS

IVHS is a system suite of technologies and processes. Its goal is the efficient and safe movement of people, goods, and services in our surface transportation system. IVHS will apply technologies in surveillance, analysis, control, communications, display, and data management to assist in optimizing the traffic carrying performance, with appropriate safety, of our surface transportation infrastructure. IVHS services individual travelers and their vehicles; commercial fleet companies, their vehicles, and operators; public transit organizations, their vehicles, and operators; public traffic management organizations, their monitor and control systems; and private firms investing to develop products and services for the IVHS market. IVHS provides a systems approach to monitoring and managing traffic and traffic infrastructure; to providing information and services to individual travelers, to commercial fleet organizations, and vehicle operators; and to transit operations centers and vehicle operators. This is all done to achieve a balance of optimal traffic system performance and to satisfy individuals using the surface transportation system.

This report ***will*** use ***the Strategic Plan for IVHS in the United States,*** dividing IVHS into major segments that serve the goals of IVHS constituents. These segments are Advanced Traveler Information Systems (ATIS), Advanced Public Transportation Systems (APTS), Commercial Vehicle Operations (CVO), Advanced Vehicle Control Systems (AVCS), and of course, ATMS. These segment concepts have been described in many papers, are well known in the IVHS community, and will not be described further here except to note that this report assumes a vision consistent with the description of these segments as described in the IVHS Strategic Plan. Later sections of this report will refine considerably our view of these IVHS segments as we define the requirements they impose on ATMS, and the information interactions between ATMS and the segments.

This ATMS vision assumes a mature IVHS environment in which vehicles are fully equipped with navigation capabilities and have the ability to interact with ATMS, communicating probe information as well as receiving dynamic traffic state information and route guidance. In this vision, transit operations centers have advanced planning and scheduling capabilities to effectively employ traffic state and infrastructure status information from ATMS. ATMS also communicates directly with transit vehicles on the roadways, employing this information using ATIS-like technologies. This interaction allows APTS transit operations centers to optimally achieve the goals of efficiently moving the vehicles and enhancing multi-modal transportation. Similarly, CVO fleet operations centers interact with ATMS, employing traffic and traffic infrastructure information to plan and execute commercial trips in the most efficient manner possible. The intended goal is to provide an environment in which these commercial vehicle entities can operate as prospering businesses, while ensuring that their operations are coordinated with the overall system goals of the traffic network. ATMS will provide basic traffic infrastructure and environmental information to AVCS elements so that AVCS subsystems, using vehicle-to-infrastructure interactions, can achieve enhanced/automated vehicle control.

In this vision, ATMS is the information management, coordination, and control element that allows IVHS to work as a system, achieving its goals in an integrated manner. ATMS performs this primarily through traditional monitoring and control of the traffic network, and through the development of new, more sophisticated technologies. These technologies are integrated with operation processes designed to more effectively interact with other IVHS elements.

In this mature environment, ATMS will play a significantly more interactive role with the day-today transportation operation than today's TMCs. To begin with, ATMS will be in a significantly more data intensive environment, A TMC within an advanced ATMS, will be continuously receiving high-resolution surveillance data from a number of sources, including traditional (but improved reliability) loop detectors; electronic spectrum sensors [microwave, Infrared (IR), and optical bands]; probe vehicles; as well as information in the form of text reports from observers on the roadways. ATMS will need large volumes of high-quality data in order to accomplish adaptive and predictive traffic control strategies. ATMS will continuously monitor these large volumes of data, scanning to identify the onset of traffic anomalies and predicting traffic anomalies prior to their occurrence. ATMS will employ advanced data management techniques to store the data, so that it can be readily recalled when required to analyze a traffic situation. In this intense operations environment, a mature ATMS will monitor and manage traffic operations with layered techniques that "hide" the complexity of underlying operations from the operator. This is necessary, because it is not economically feasible to have human operators continuously dealing with these underlying processes. It is desirable, because ATMS operations require synthesized and abstracted information items, not a mass of raw data, much of which is meaningless until abstracted. A mature ATMS will employ a number of techniques to accomplish this abstraction, all leading to the goals of allowing ATMS to understand the complexities of traffic network states; to quickly develop and implement effective traffic management strategies; and to provide information support to external IVHS segments.

In this environment, ATMS will also assume responsibilities beyond those of current traffic management systems as an influential participant in new areas. These new areas include demand management, in which ATMS will not only sense current roadway demand, but will employ strategies to influence individual demand to optimize the traffic network system. ATMS will have two-way communication (i.e., via ATIS) with travelers in their vehicles, a significant change from today. Another new role for ATMS will be to exchange information and control strategies through interactive cooperation with transit operations centers to further the viability of multi-modal travel for many urban travelers. ATMS will develop similar interactions with commercial fleet operations centers, ATMS will have a dynamic role in managing the availability of urban parking resources and in providing this information to travelers.

Given the complex functionalities, the demanding data management requirements, and its many new roles, ATMS can become a complex and expensive system to maintain and operate. The nature of the technologies and processes that ATMS will employ will ensure that this does not happen. To begin with, ATMS will employ advanced system management technologies permitting autonomous monitoring for many systems management functions. Self-sustaining functions include the ability of ATMS to monitor its own internal systems and interfaces, identifying when subsystem components require regular maintenance, as well as identifying and suggesting solutions for system malfunctions. From a human operator perspective, ATMS will employ embedded training capabilities and operator assist capabilities, allowing ATMS, even though significantly more complex than today's traffic management systems, to be operated with minimal operations staff. ATMS will employ analysis and decision support strategies using intelligent computation techniques, to allow operators to carry out complex procedures, perhaps several simultaneously, without getting lost in the task's complexity.

1.3.2 Goals and Objectives

Our stated goal for ATMS is consistent with the preceding vision. The goal of ATMS is to satisfy the needs of society to efficiently move people, goods, and services on the nation's surface transportation system. From this goal we derive the following objectives for ATMS:

a. ATMS will provide the capability for integrated, dynamic, real-time, and pro-active traffic management to combat congestion and optimize traffic operations.

b. ATMS will provide the capability to integrate traffic management across adjacent or otherwise related political jurisdictions.

c. ATMS will ingest and process data from advanced sensors over wide-area networks, including data from new types of sensors, alternative technology sensors, and probe vehicles.

d. ATMS will support detection of, and rapid response to incidents and collaborative action on the part of various organizations to provide integrated responses.

e. ATMS will provide information and functional capabilities to accommodate multi-modal transportation management strategies.

f. ATMS will accommodate the various deployment requirements and operational needs of different jurisdictions.

g. ATMS will be deployable consistent with existing facilities and state-of-the-practice in traffic management. This will be done so that investments in systems, policies, and procedures will be preserved to the maximum extent possible.

h. ATMS must be designed to be modular and flexible, so that it can be deployed over time, integrated with existing designs, and deployable in heterogeneous environments.

i. ATMS will provide information management and communications capabilities to ensure the integrated operation of all IVHS elements. These capabilities will also be applied to ensure successful interaction with non-IVHS elements.

j. ATMS will support the maintenance of the transportation infrastructure.

k. ATMS will enhance the safety of operations in the traffic network.

l. ATMS will create and maintain public confidence in ATMS.

m. ATMS will employ techniques and technologies to control traffic demand

1.4 Assumptions

The operations concept and architecture defmition described in this report are derived from the preceding objectives, consistent with the following assumptions.

a. It is assumed that the ATIS, APTS, and CVO segments of IVHS will all have the capability to communicate with ATMS to provide and receive traffic-related information. These segments will have the capability to use this information to perform their functions of trip planning (suggested modes, schedules), route selection, vehicle scheduling, etc., appropriate to each segment. This assumption implies that these IVHS segments will not require trip planning, route selection, etc., from ATMS to meet their own objectives (although ATMS may have versions of these capabilities to meet traffic network management goals).

b. The ATMS role in routing is to assist ATIS/CVO entities in route determination and selection. More specifically, the ATMS role is not to determine routes for individual vehicles, but rather to ingest aggregated (or to aggregate) Origin-Destination (O-D) data pairs, to generate suggested routes for groups of vehicles sharing commonalties in O-D data, and to disseminate this information along with the traffic network status to IVHS. It is understood that ATIS will actually further compute/select particular routes for individual vehicles, however, ATMS must play an active role in routing to better manage the traffic network (i.e., traffic demand). This assumes a hybrid approach, combining the benefits of centralized and distributed routing.

c. Emergency and HAZMAT vehicle routing can be performed by ATMS. These are the only cases where ATMS performs individual vehicle routing. This assumption implies that route selection is done on a special case basis (e.g., emergency vehicles).

d. It is assumed that advanced capability sensors will be available, within reasonable technology forecasts, appropriate to the needs of advanced traffic surveillance and control.

e. It is assumed that a sufficient number of private, commercial, and transit vehicles will be equipped as probes in order to provide adequate data to ATMS to support advanced traffic surveillance and control.

f. It is assumed that during the time frame of this version of ATMS (the year 2002) early versions of AVCS will be available, providing enhanced driver assistance through vehicle-to-roadway interactions, and that these interactions will not require dynamic interactions with ATMS or any special data types other than basic traffic and traffic infrastructure conditions.

g. It is assumed that the ATMS role in multi-modal trip planning is limited to information correlation and dissemination, and that ATMS will not perform the actual multi-modal trip planning and management functions. In this concept, ATMS would maintain information - primarily ATMS traffic data - and provide this information to ATIS/APTS elements that would determine actual multi-modal parameters and options.

h. Assets of the traffic network having primary or secondary surveillance functions are assumed to be internal (organic) to ATMS, not external entities. Examples include loop detectors, parking utilization sensors, Electronic Toll and Traffic Management (ETTM) components [assuming the ETTM entity has Automatic Vehicle Identification (AVI) from which traffic volumes can be derived], etc.

i. In-vehicle signing is assumed to be part of other IVHS elements (i.e., ATIS).

j. ATMS will support the development of various demand management strategies which are mostly implemented by external organizations. Although the implementation of demand management strategies is done by external organizations, ATMS can support the analysis to determine effective strategies (e.g., congestion pricing, parking pricing, road pricing, impact fees, zoning restrictions, truck-free zones). Direct participation in the implementation of demand strategies is limited to aggregate routing information embedded in the dynamic network data, and control strategies for organic ATMS components (i.e., signals, CMS, ramp meters, etc.). This includes route diversion information in the case of incidents and congestion.

k. ATMS will provide data on violation rates, but not for individual vehicles. Individual vehicle violation determination is not a necessary function of ATMS, although ATMS does not preclude functionality for this purpose.

1. ATMS will provide integrated (i.e., freeways and surface street) traffic management at a regional (wide-area) level. To do this, ATMS must implement traffic management strategies across different traffic jurisdictions.

m. ATMS will exchange regional traffic data with adjacent ATMS entities through an external interface.

n. The ATMS role in incident management is limited to incident detection, initial incident notification to emergency units, and routing and coordination of emergency vehicles. Once emergency units arrive at the scene, they assume responsibility for coordinating the incident's resolution. It is assumed that ATMS may not actually manage the incident scene. ATMS does however, assume responsibility for managing traffic operations including CMS updates, alternate routing, and information dissemination.

0. The ATMS role in parking management is limited to collecting and disseminating parking surveillance data. Garages equipped with appropriate sensors will transmit utilization levels to ATMS, where the data are collected and transmitted to ATIS. ATIS then uses this information to assist travelers in efficiently carrying out multi-modal (and single mode) trips requiring a modal transition near a parking facility. For example, a traveler wishing to park their car and board a subway system can use this information to go directly to subway stations where parking is currently available, and avoid stations where parking facilities are full.

1.5 Design Issues. and System Policies

Three major issues affect the development of ATMS support systems. The first is the impact of technological change on the functionality and capabilities of an ATMS. The second design issue is that ATMS support systems will be designed for operation in small-to-large urban areas and along major corridors. The final design issue that merits consideration is that many localities have already made significant investment in existing traffic management facilities.

Because of rapidly changing technology, it is reasonable to anticipate that the following elements will undergo tremendous evolution in the future:

a. ATMS data sources (e.g., detectors).

b. ATMS output targets (e.g., CMS, signals, in-vehicle displays).

c. Modes and bandwidth of communications.

d. Computer technology.

e. Graphical display.

f. Traveler guidance and control algorithms.

The impact of changing technology on the design of support systems is felt in two ways. First, because predicting the availability of a particular technology at a particular time is an inexact science, the system must be robust enough to accommodate changes. Second, new technologies are deployed unevenly. This introduces the possibility that while a particular technology is feasible, it may not be available at a location where it could be used. Because the implementation of ATMS will be a gradual and evolutionary process, provisions must be made for the additions and modifications forthcoming in the constantly evolving IVHS world.

It is desirable that the system be robust enough to address the requirements of small-to-large urban areas and major corridors. The scope of prototypes to be built by this effort is defined by the requirement that the systems are intended for mid-size to large urban areas. This requirement's impact is twofold. The first impact is that the support systems need to be engineered to support variability in size and deployment of hardware capabilities. The second impact is that jurisdictional concerns and differences need to be considered during the design process. For the support systems to be successful, they must be capable of accommodating these differences in a direct manner.

The third major issue in support system design is addressing existing investments in traffic management systems. Investments by state and local governments in traffic management infrastructure must be preserved. In order to make ATMS viable, it is imperative that the support systems limit the need for infrastructure reinvestment. The support systems should promote system evolution for implementing agencies. This issue is particularly relevant from the perspective of eventual deployment.

The key element of all the preceding concerns, is that ATMS support systems must support variation. Therefore, ATMS support systems must be designed to accommodate state-of-the-practice (past) technologies. This must be done to maximize use of existing systems, while not sacrificing available state-of-the-art technology. With this in mind, the following policies have been identified for developing support systems:

a. Modularity: An ATMS support system will be modular; not all implementations will require all of the functionality provided. It is anticipated that different areas will have different needs. For example, the needs of a large urban area will differ from the needs of a mid-size urban area. Because of this, inter-dependencies between the support systems must be minimized, and standard interfaces must be used so that support systems may be combined when necessary.

b. Flexibility: To the extent possible, variations in the system will be input parameters, typically read in during system initialization. Parameterizing these variations will be promoted through the use of Object-Oriented Design techniques. The advantage that this process provides is that these parameters become data to the system, and hence the need for redesigns and recompilations is minimized

c. Standards: Modularity and vendor independence will only be achieved using standard interfaces communicating through standard protocols.

d. Interoperability: It is desirable to minimize the impact of jurisdictional boundaries at a minimum, promote the free exchange of information between centers.

e. Maintainability This key element will contribute to the success of the support systems. Maintainability will be promoted through modularity, high-level programming languages providing support for state-of-the-art software engineering principles and practices, standard operating systems, and general purpose processors.

1.6 Document Organization

Section 1 of this report provides introductory information concerning the project, including the ATMS vision, goals, objectives, assumptions, design issues, and system policies. Section 2 provides an ATMS context diagram that delineates between internal and external entities and their information interface. Included in this section are both derived functional requirements and generic system requirements. The conceptual system is detailed in Section 3 and describes ATMS capabilities and components. The vehicle for describing the system is a set of data flow diagrams which are a product of the structured analysis methodology employed (refer to Appendix A). Section 4 validates the system analysis performed in Section 3 through the use of operations scenarios. Section 5 describes subsystems that will become elements of support systems. Finally, Section 6 describes future directions.

1.7 Applicable Documents

a. Georgia Tech Research Institute (GTRI), “System Objectives and Performance Requirements for an Ideal Traffic Management System - Interview Transcripts”, February 1993.

b. Georgia Tech Research Institute (GTRI), Technical Memorandum A9309-140-04, "Initial Function Allocation on Task D", February 1993.

c. Federal Highway Administration (FHWA), Alberto J. Santiago et al., "ATMS Laboratories: A Requirement for Program Delivery", Third Annual Meeting of IVHS America, March 1993.

d. Kimley-Horn & Associates, Technical Memorandum, "Demand Management Strategies", June 1993.

e. Strategic Plan for IVHS in the United States. Report No. IVHS-AMER-92-3, IVHS America, May 1992.

f. Loral AeroSys, ATMS Consortium' "Traffic Management Centers - The State-of-the-Practice", February 1993.

g Wiener and Nagel, "Human Factors in Aviation", 1988, Academic Press.

2.0 SYSTEM OVERVIEW AND DERIVED REQUIREMENTS

This section describes the context in which ATMS operates and the derived requirements for the system. The system context is depicted in a context diagram that identifies system boundaries and external entities. Information flow between the external entities and ATMS is described and illustrated. This context sets the stage for further analysis that includes the development of derived functional requirements, including generic system requirements at the highest level, and the functional decomposition ATMS.

2.1 ATMS Description

The ATMS mission promotes the IVHS goal of satisfying the transportation needs of society by efficiently moving people, goods, and services. The category "people" includes individuals (e.g., passenger vehicles), small groups (e.g., car pools), large groups (e.g., subways, buses), livery, and pedestrians. "Goods and services" refers to small (e.g., messengers), medium (e.g., UPS), and large carriers (e.g., freight). A special class of goods is hazardous materials which are treated differently than other goods. From a high-level, functional perspective, ATMS is the information management, coordination, and control element that allows for effective and efficient operation of the traffic network by managing external interfaces. To operate effectively and efficiently, the system must be reliable, timely, safe, comfortable, economical, and ecologically sound.

Figure 2-l illustrates a logical grouping of internal and external ATMS physical elements. The fundamental function within ATMS is to collect, process, and disseminate all types of traffic-related data to effectively manage the traffic network. To accomplish this, ATMS uses its internal physical elements consisting of a TMC (conceivably multiple TMCs), surveillance equipment, and control and signaling equipment.

A TMC includes: software and hardware to command and control information management systems; communication systems (for both internal and external entities); decision support systems; system management systems (i.e., management of hardware, software, databases, people, and other assets); training systems; and various systems for monitoring, analyzing, and controlling the traffic network within the ATMS regional area. An ATMS region is defined as a specific geographical region, such as a metropolitan area (e.g., the Baltimore Metropolitan area). No specific area size is associated with an ATMS region, since this is a context-sensitive issue. Within an ATMS region there may exist several TMCs cooperatively managing the traffic region. Integrated approaches are used for managing area-wide (i.e., freeway and surface street) traffic across various jurisdictions. ATMS will accommodate and manage the TMCs to ensure that coordinated and integrated control is obtained.

The Surveillance Equipment element includes communications hardware and software, and various types of sensors. Examples of sensors that may be used include:

a. Loop detectors.

b. Closed-Circuit Television (CCTV).

c. Parking utilization sensors,

d. Visibility detectors.

e. Roadway condition detectors.

f. Automated Vehicle Identification.

Also included in this element are ETTM entities that have surveillance equipment producing data that would be useful to ATMS (i.e., AVI sensors used to derive volumes).

The Control and Signaling Equipment element includes CMS, ramp meters, signals, and other types of signs.

It is important to recognize that although surveillance, control, and signaling assets are considered internal (organic) to ATMS, they are not external entities. Later in this section the ATMS context will be detailed, and the distinction between internal and external entities will be fully developed. This will set ATMS system boundaries. The data and information exchanged between the internal and external entities will also be addressed.

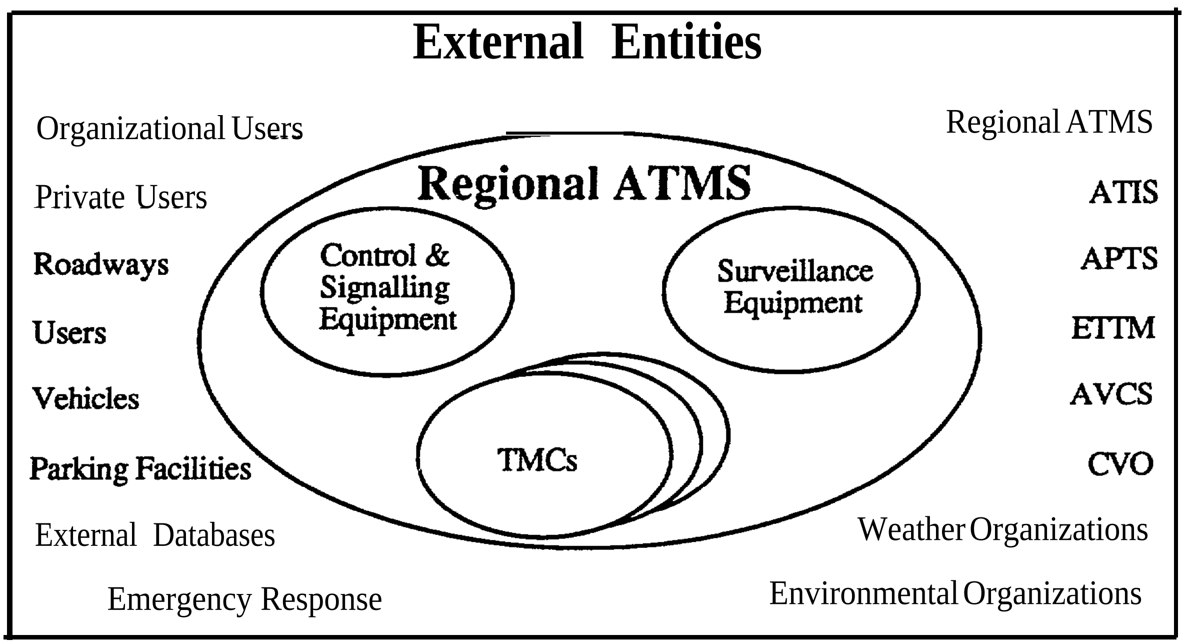

Figure 2-1. ATMS Physical Elements

2.2 Description of External Elements and Data and Information Management Requirements

To effectively manage the traffic network ATMS must dynamically, cooperatively, and proactively interact with external entities. Figure 2-2 illustrates the ATMS environment. ATMS interacts with the following five external entities:

a. Organizational Users.

b. Individual Users.

c. IVHS External Systems.

d. Non-IVHS External Systems.

e. Emergency Response Systems.

The following discussion identifies potential interactions between ATMS and each external entity. Specifically, this discussion focuses on describing the functions and input/output of each external entity as related to ATMS. The discussion will be from the ATMS perspective, not the external entities. The input/output discussed collectively imply the data and information management requirements that the external entities impose on ATMS. More detailed, internal data and information requirements will be presented in future reports documenting this research.

2.2.1 Interaction Between ATMS and Organizational Users

Organizational Users are those users influencing policy and decision-making relating to management of the traffic network. This entity also makes information requests and receives traffic information (e.g., historical data) and analysis data in return. Thus, this entity could also encompass private users, such as UPS or Federal Express, that would employ the traffic information and analysis data for planning purposes. Organizational Users include, but are not limited to:

a. Local, State, and National Department of Transportation (DOT) organizations.

b. Metropolitan Planning Organizations (MPO).

c. Federal Agencies (e.g., EPA).

d. Research Organizations (e.g., FHWA Turner-Fairbank).

e. Political Groups (e.g., city council, state and county officials, Senators, Congressman, etc.).

f. Law Enforcement and Emergency Response Agencies.

g. Universities.

h. National Databases (e.g., maintenance of nationwide statistics).

i. Private Organizations and Commercial Interests.

j. Transit Agencies.

k. Citizen Groups (e.g., AAA).

Organizational Users are primarily characterized by their power to control the overall management of the traffic network. Their main input into ATMS is non-real time, policy-and standards-type data. Organizational Users provide the following input into ATMS process:

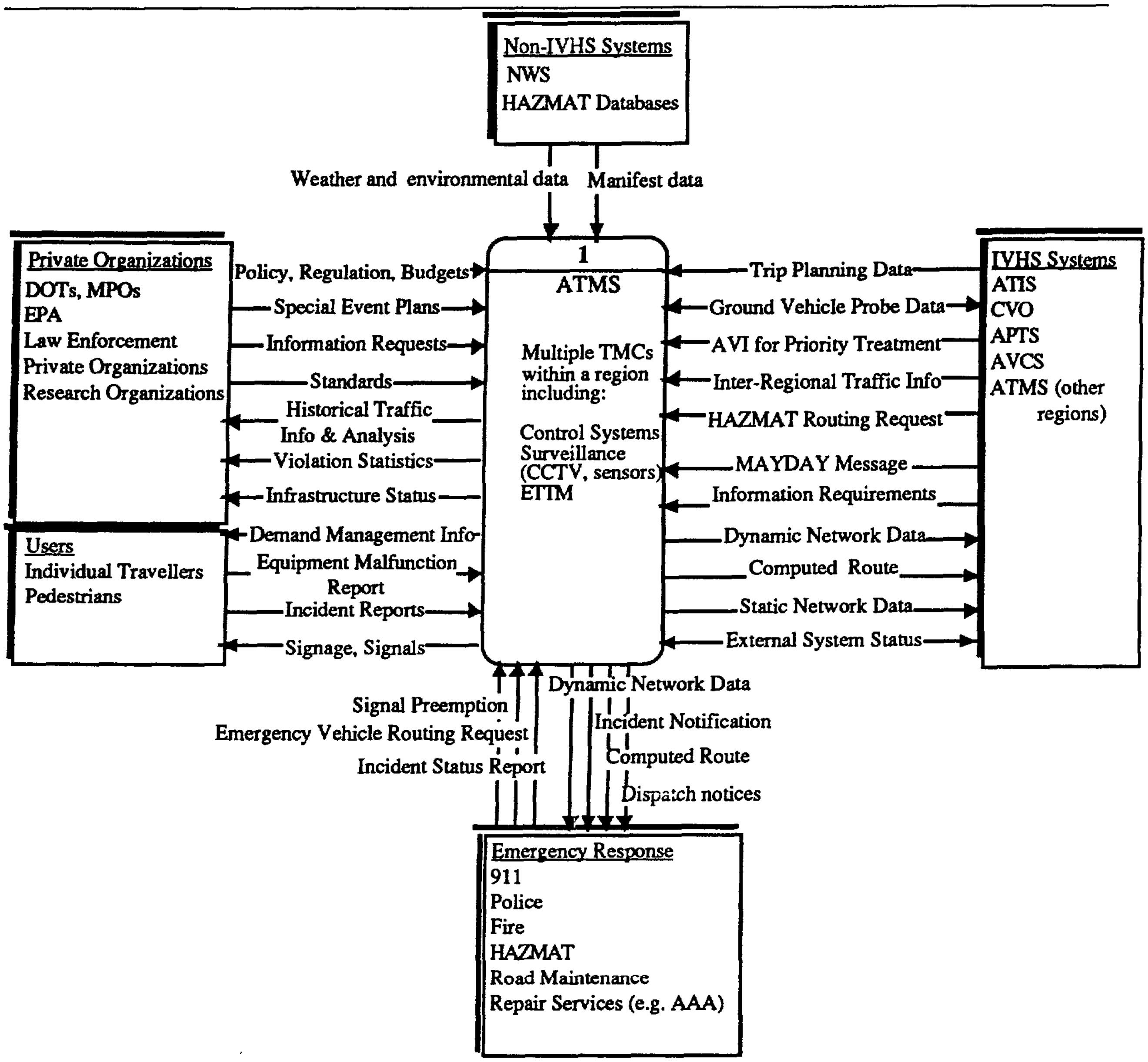

Figure 2-2. The ATMS Context Level Diagram

a. Policy, Regulation, Budgets, such as:

1. Traffic priority schemes (e.g., public transportation before private, allowable pollution levels per geographic region).
2. Legal restrictions (e.g., arterial usage for HAZMAT carriers).

3. Operational policy (e.g., how to respond to given events, lane usage, etc.)

4. Budget and funding for ATMS operations and maintenance.

b. Special Event Plans, such as:

1. Upcoming games, parades, rallies, etc.

2 Planned construction.

c. Information requests for historical data, statistics, or simulation studies.

d. Standards for use in operating ATMS. For example, a standardized digital map for use in managing traffic operations.

Organizational Users receive the following non-real time output from the ATMS process:

a. Historic traffic information and analysis (e.g., past accidents, volume, link times, queue lengths, area congestion, events, traffic statistics, etc.).

b. Violation statistics (not vehicle specific) for compliance with speed limits, High Occupancy Vehicle (HOV) regulations, etc.

c. Infrastructure status indicating roadway infrastructure condition (e.g., deterioration, potholes, etc.).

d. Demand Management Information from which policy decisions and strategies will be derived. For example, historical information will be provided specific to a ATMS element that will allow Organizational Users to derive:

1. Pricing Strategies (i.e., parking pricing, toll pricing, congestion pricing, road pricing, impact fees, parking taxes).

2. Regulatory strategies (i.e., trip reduction ordinances, truck-free zones, proximity fees).

3. Parking strategies (i.e., preferential parking for Carpools, Vanpools).

4. Shared-Ride Strategies (i.e., carpooling, vanpooling, paratransit, buspooling).

5. Employer Strategies (i.e., staggered work hours, subsidized transit passes).

6. Ideas for new technology (i.e., AVI, telecommuting, electronic permits).

7. Zone-Based Strategies (i.e., auto-free zones, peak-hour restricted zones).

2.2.2 Interaction Between ATMS and IVHS External Systems

The IVHS External Systems are automated systems that other users will interface with directly. They include the following:

a. Advanced Travelers Information Systems (ATIS) - provides individual users with processed network traffic data to suit their unique transportation needs. This includes trip planning, vehicle scheduling, route selection and guidance, travel advisories, parking availability, in-vehicle signing, etc.

b. Advance Public Transportation Systems (APTS) - provides public transportation users (e.g., mass transit) with processed network traffic data to suit their unique transportation needs. This includes transit planning and scheduling, route scheduling, travel advisories, in-vehicle signing, etc.

c. Commercial Vehicle Operations (CVO)- provides commercial transportation users (e.g. Federal Express, UPS) with processed network traffic data to suit their unique transportation needs. This includes vehicle planning and scheduling, route selection and guidance, travel advisories, in-vehicle signing etc.

d. Advanced Vehicle Control Systems (AVCS) - systems internal to transportation vehicles that interact with automated highways to provide partial or fully automated "hands off' control.

e. Other Regional ATMSs - interfaces to other ATMSs to support coordinated traffic management between freeways and surface streets, and among adjacent traffic network jurisdictions. This data implies an important data requirement. That is, ATMS will operate in a regional context where multiple TMCs will operate in concert for a coordinated response.

The IVHS External Systems are collectively referred to as other transportation information and control systems that directly interface to ATMS and possibly to individual users. The following arc received from IVHS External Systems:

a. Trip Planning Data - asynchronous data. For example, ATIS, CVO, etc., as a possible long-term function, could provide scheduled trip data to ATMS for planning (i.e., demand determination and aggregate routing information) purposes. Trip Planning data consist of, but are not limited to:

   1. Origin-Destination (O-D) data.

   2. Vehicle identification codes.

   3. Planned parking location or region.

b. Ground Vehicle Probe Data - real-time data from individual users or from IVHS users that have a secondary function of transmitting traffic data back to ATMS. Probe data could consist of:

   1. Link times.

   2. Vehicle location.

3. Vehicle identification codes.

4. Environmental conditions.

5. Route segment travel times, number of stops, average delay, etc.

6. Incident location,

7. Incident type, severity and duration estimates.

8. Weather conditions.

c. AVI priorities - this is data that ATMS uses for altering signals in special cases to travel mom efficiently. For example, coordinated greenways may be used for approaching buses and HAZMAT carriers.

d. Interregional Traffic Information from other regional ATMSs.

e. HAZMAT routing requests - one of the two special cases (the other is emergency vehicles) for which ATMS may perform routing on an individual vehicle basis. For example, a CVO HAZMAT carrier could receive the route it should travel when passing through an ATMS region.

f. MAYDAY message for transmitting incident data when an ATIS-equipped vehicle is grounded (i.e., disabled, crashed).

g. Information Requirements for historical data, statistics, simulation studies, or traffic information. These types of requests may be generated automatically and manually and may be received asynchronously in real-time. Examples of information requirements, in the IVHS external system context, would be requests for transmission of specific traffic related data and associated requirements. ATMS should have the flexibility to accommodate specific needs of various IVHS External Systems.

h. External System Status, generated by IVHS elements, provides feedback to ATMS describing the behavior of External Systems. These messages may include the operational status, errors, and problems. These messages describe the External System's capability to receive and process ATMS data.

External System entities ingest and process traffic network information to derive schedules, compute individual vehicle routes, generate travel advisories, and provide guidance to their customers. The IVHS External Systems receive the following output from ATMS:

a. Dynamic Network Data (real-time), such as:

1. Real-time traffic information in the form of: link times,. road restrictions, environmental conditions, queue lengths, parking utilization levels for garages; and incident locations, types, severities, and estimated durations for the ATMS region. This data flow includes both raw data and derived data products.

2. Suggested routes for aggregate O-D pairs - the suggested route information contains update information on routing, based on the current state of the traffic network. Suggested routes are not for individual vehicles, but rather

for aggregate O-D data pairs. For example, assuming the ATMS region is divided into zones, the suggested routing information will contain the recommended route between two zones, not individual O-D endpoints.

b. Computed routes for special vehicles - for example, a CVO HAZMAT carrier may receive the route to travel when passing through an ATMS region. This is a special case for which ATMS performs routing of an individual vehicle.

c. Static Network Data - describing network geometry and historical data (e.g., lane utilization, time of day volumes, etc.) to be used by IVHS External Systems.

d. External System Status - generated by ATMS, for relaying IVHS failures to IVHS External Systems. This data flow for example, might indicate that the ATIS trip planning data being transmitted into ATMS is invalid (e.g., format error, etc.).

e. Interregional Traffic Information from other regional ATMSs - this will include some superset of the dynamic network data flow, plus attached regional identification data.

2.2.3 Interaction Between ATMS and Individual Users

Individual Users are those who currently manually report such things as incidents, environmental conditions, and defective devices within ATMS. Individual Users include, but are not limited to:

a. The traveling public (individual travelers).

b. Aerial surveillance.

c. Passenger vehicles.

d. Pedestrians.

Individual Users are primarily characterized by their manual interaction with ATMS. This normally consists of telephone calls and visual interaction with ATMS components, such as traffic lights and VMSs. Individual Users provide the following input to the ATMS process:

a. Incident Reports, such as:

   1. Traffic accidents - including involved vehicles, location, severity, emergency units, etc.

   2. Environmental conditions (e.g., icy bridge, etc.).

   3. Complaints.

b. Equipment Malfunction Notices, such as:

1. Faulty traffic light.

2. Power outage.

3. CMS malfunction.

The Individual Users indirectly receive output from ATMS upon which they act. Output from the ATMS process to the Individual Users includes control data, such as signals and CMS.

2.2.4 Interaction Between ATMS and Non-IVHS External Systems

Non-lVHS External Systems transmit environmental, weather, and manifest data to ATMS. Examples of Non-IVHS External Systems include, but are not limited to:

a. Current weather and forecasted weather organizations (e.g., National Weather Service, TV and radio stations).

b. Environmental organizations conducting pollution monitoring (e.g., EPA.).

c. External databases (e.g., HAZMAT external databases from which the manifest data, current location, etc., could be extracted).

Non-IVHS External Systems provide the following input into the ATMS process:

a. Weather and environmental data, such as:

   1. Real-time current and forecasted weather conditions.

   2. Real-time pollution levels.

b. Manifest data for HAZMAT carriers and data from other external databases.

The Non-IVHS External Systems, in their current capacity, do not directly receive any output from the ATMS process. It is likely, however, that a mature ATMS will post queries and updates to external databases. This is not represented because at present, the role of external databases in the operation of ATMS is not well-defined.

2.2.5 Interaction Between ATMS and Emergency Response Systems

The interaction between Emergency Response Systems and ATMS is to coordinate responses to incidents to quickly restore personal safety and normalcy to the traffic network. Emergency Response Systems assist in resolving traffic accidents and other types of emergency activities, such as fire, spills, and sickness. Emergency Response Systems include, but are not limited to:

1. Police, ambulance, fire (i.e., 911).

2. HAZMAT units.

3. Repair service/AAA (i.e., tow trucks).

4. Highway repair crews for road maintenance.

The Emergency Response Systems provide the following inputs to ATMS:

a. Signal Preemption data, which is data to ATMS that allows a fire truck, for instance, to more rapidly arrive at the accident scene by altering signaling en route, reserving lanes, etc.

b. Incident Status Reports, such as:

    1. Traffic accidents and status (e.g., location, severity, expected delay, etc.).

    2. Environmental conditions (e.g., icy bridges, etc.).

C. Emergency vehicle routing requests (i.e., ATMS can route, track, and alter signals for emergency vehicles).

For the Incident Status Input, it is important to recognize that Emergency Response Systems play a larger role than Individual Users. For instance, they have the capability to not only report incidents to ATMS, but they can also more reasonably estimate accident duration.

The Emergency Response Systems receive the following output from the ATMS process:

a. Incident Notifications, in may instances ATMS will be the first organization detecting an incident. ATMS will then alert the appropriate organizations.

b. Dynamic Network Data (real-timej, as previously described, this data describes the existing state of the traffic network.

C. Computed routes for emergency vehicles - for example, a fire rescue squad will receive the route he should travel to the accident scene. This is a special case for which ATMS performs routing of an individual vehicle.

d. Dispatch notices for ATMS externally controlled repair resources - for example, ATMS will have control over the dispatching of road repair and maintenance crews.

2.3 Rationale for Automation

The functional requirements for ATMS are the basis for allocation of functions to a logical system architecture, from which ATMS support systems can be defined and, in Task C specified. A key aspect of this system definition process is the allocation of functions to machine or human performer roles. In this section we describe the rationale for this allocation.

This section examines several of the issues surrounding the use of automation for ATMS. Although taken as a given in today's technological environment, the rationale for incorporating automatic features requires an examination so as to effectively partition the workload between humans and equipment while at the same time incorporating the partitioning into an integrated system. The advantages and pitfalls of automation will be discussed along with an initial estimation of the degree of automation in each of the ATMS support systems. Finally a vision of the role of automation in a future ATMS is described.

Four roles for human operator have been defined for consideration in ATMS operations with varying degrees of operator and computer involvement. For the purpose of this effort, we have adapted the definition of operator roles developed through parallel research being conducted under by the Georgia Tech Research Institute under FHWA contract (GTRI, 1993). Table 2 - 1 summarizes each of the four roles.

Table 2 -I. Human and Computer Rote Definition

Designation of Human as:	Human Role	Computer Role
Direct Performer	Human performs all functions	No involvement
Manual Controller	Responsible for decision making and implementation	May play a major role in sensing environment or in executing actions designated by human
supervisory Controller	Monitors computer performance and may intervene performing functions, adjusting parameters and overriding computer decisions	May make decisions about control actions to be taken, under supervision of human
Executive Controller	Can enable or disable the function	Capable of decision making and implementation

An effective ATMS will require a certain level of automation that will be a melding of the capabilities of both human controllers and computer technology. The processing subsystems are more computer intensive with less human involvement than the management subsystems. In general there is no one-to-one correlation between subsystems and the roles of human and computer technology, but rather a blending of roles for each subsystem.

2.3.1 Advantages of Automation

The rationale for incorporating automation is based on the assumption that automation will provide a more efficient and effective system. The specific reasons include:

a. Reduction in the operators workload. By having a computer perform certain functions, the operator's workload can be reduced, requiring fewer operators and a less stressful working environment.

b. Performs functions that humans cannot. There are certain functions, such as counting and calculating that are best performed by computer-based systems.

c. Obviates the need for tedious, repetitive and routine functions. There are certain functions that are tedious, repetitive and routine, that the operator should not be burdened with, as they can be performed by a computer.

d. Increases capacity and productivity. By freeing the operator from routine functions, the operator can perform more intricate and productive functions.

e. Reduces human error. A computer based system can perform validity checks on the decision-making process to minimize the chance of error, such as opening both sides of a high occupancy lane to oncoming traffic.

f. Dampens individual differences. By using a standard computer algorithm, different decisions based purely on individual styles can be narrowed, resulting in a more uniform operational environment.

2.3.2 Pitfalls of Automation

While in the abstract, automation appears as the method of successfully augmenting a human operator for increased efficiency, there are numerous pitfalls in automation.

a. Human as a system monitor. Removing the human from the control loop and making him/her a system monitor to ensure that all systems operate effectively is a standard procedure in many automated systems. However, humans do not make effective monitors. Having a human sit in front of a bank of computer screens is a tiring, boring and non-motivating job, that can result in a severe vigilance problem. Attention wanders and critical responses to situations may be late or not taken. In some applications, operator may do nothing for weeks or even months. Yet if something goes wrong they are required to accurately respond in seconds to a critical situation. Systems must be designed so that vigilance degradation does not become a problem.

b. Reduction in workload. While automation is supposed to reduce workload, cockpit automation in modem aircraft has not had that effect. When pilots were asked if automation (as in the ‘glass cockpit’) reduced their workload, an almost equal number agreed and disagreed with the statement. By and of itself, automation does not necessarily reduce workload. There arc usually more items to monitor such as the function itself, the sensor and the indicator. The increased number of components reduces overall system reliability. In addition the increase in complexity that accompanies automation can result in an increase in false alarm rate. This in turn translates to greater workload for the operator in analyzing the accuracy of alarms.

c. Overtrust and undertrust. Operators tend to develop a certain degree of trust in an automated system, referred to ***as the calibration*** of trust. Automated systems that operate perfectly should be trusted and those that are unreliable should not. Humans however are not very good at calibrating systems. They may flip rapidly from trust to mistrust or they may develop a sense of overtrust, despite evidence to the contrary. For example, overtrust in an autopilot resulted in the fatal crash of an Eastern Airlines plane, while the crew were attempting to diagnose a malfunctioning landing-gear indicator (Wickens, 1992).

d. Reduction in Familiarity. Automation is usually associated with less direct operator involvement in a system. This can result in a reduction of familiarity with the system. There is evidence from the aircraft industry that when a malfunction occurs, such as an engine failure, the operator in an automated system is slower to detect the problem and requires a longer time before taking corrective action. In addition, the reduction in familiarity may make it more difficult to handle unique problems as the operator's mental model of the system is not as complete.

In designing ATMS, it is important to consider all of the potential benefits of automation while recognizing and avoiding the potential pitfalls.

2.3.3 Automation in ATMS

The remainder of this section, discusses the rationale for selecting which of these four roles is assigned to ATMS functions. Central to this discussion is the assumption of a general objective of maximizing automation levels, with the goal of reducing human resource requirements to minimize recurring operations and maintenance expenses. We also state a goal related to the qualitative nature of human roles when they are assigned to ATMS functions. Generally we will be seeking to assign human roles in which the performer plays a "significant" role, and not a superficial role. The rationale here is that if ATMS is not fully automated, and if human roles are required at all, then those roles should allow the individual to sense her/his importance to the effective operation of ATMS. It is our belief that this objective is consistent with the findings in studies and evaluations in human performance over the last several years. It is also our belief that this rational is consistent with GTRI's human factor's analysis currently being performed in a related contract.

Two critical aspects of incorporating automation within ATMS, and in turn within the support systems, involves analysis and synthesis. The actual determination of which of the four performer roles to assign to system functions require analysis to determine where automation can be of value and the level of automation. A synthesis is then required so as to generate an integrated design that capitalizes on the benefits of automation, while minimizing the pitfalls.

To perform analysis, we first examine what it is physically possible for machines and humans to perform, generally a quantitative consideration. For example, does a task require many operations in short periods of time that exceed the physiological capability for humans to perform, and exceed the technological capability for machines to perform at a reasonable cost? Generally, quantitatively challenging tasks such as this are scalable in nature and machine capability is purely a performance and cost issue. For example, if technology provides computer sufficiently fast processors, then the task can be performed, although the cost in some situations may be prohibitive.

A related aspect of the quantitative nature of tasks is complexity. A task may not just have many operations in time, but the operations may be very complex. This is especially significant if tasks have complex operations in which the underlying relationships of the operations are not well understood, and it would be very difficult to write an algorithm to guide machine performance. A human may do well at many complex tasks of this nature if there is sufficient time to perform. However, a machine may have difficulty with ill-defined complex tasks, although new paradigms of machine capabilities, such as neural networks, allow machine performance on complex tasks in which the underlying relationship is not understood and for which it would be difficult to write an algorithm describing the correct performance.

The preceding considerations relate to what is possible for machines and humans to perform in terms of individual tasks. But it is also important to consider what should machines and humans do in terms of ATMS functions. A synthesis is required here to capture the benefits of automation, while minimizing the pitfalls. For example if a task is capable of being performed by both a machine and a human, to which performer should the task be assigned? First we consider the tasks in isolation. If the task is performable by both machines and humans, we will assign it to the role that captures the most advantages and least pitfalls. However, this decision will generally be made not in terms of the task in isolation, but the task in context of the total system. What happens before and after the task in question could be very important in this consideration. For example, considering tasks as parts of larger "chunks" of self-contained accomplishment will provide the context in which analysis can be evaluated. Other considerations may play a part in this analysis as well, such as, cost and system performance.

There is a "qualitative" consideration of importance as well as the quantitative aspects we have just discussed. The qualitative considerations generally apply to human performers, who, because they are self-reflective, their performance can not be determined solely in terms of their ability to perform the task. How people feel about themselves in work and other activities has been shown to have a considerable affect upon their effectiveness in their work. Put more bluntly, people do not perform well in "throw-away" jobs, where they do not perceive their role as important to the outcome of the endeavor. These are very important considerations in what drives people to high performance. Calling this a "value" consideration is quite appropriate, because human performance is often affected by how valuable an individual feels that she/he is to tasks being performed.

We may sum up our rationale as follows. We will examine quantitative aspects of the function to determine if the task is performable by machine or human components. We will evaluate the advantages/disadvantages relevant for each function between human and machine performers when both can accomplish the task and in general strive to achieve the benefits of automation and avoid the disadvantages. When human performer roles are indicated, we will seek roles that provide a context of "value" for the human.

Table 2-3 lists the identified system functions arrayed against operational personnel functions. For each major function, the role of the operator is noted along a continuum from Direct Performer through Executive Controller. As seen from the number of boxes where Executive Controller, Supervisory Controller and Manual Controller play a part, automation obviously has a role, and the definition and design of the support systems should reflect that fact.

Table 2-2. Matrix of System Versus Operational Personnel Functions

SYSTEM FUNCTIONS	SURVEILLANCE AND MONITORING									
	Receive Briefing	Review Events Schedule	Select Items and Areas for Close Observation	Set Alarms	Review Weather Situation	Monitor Ongoing Traffic Situation	Monitor Police, Emergency Etc. Communications	Detect Traffic Incidents	Receive Specific Reports	Verify Incidents and Reports
1. PROCESS SURVIELLANCE DATA **Perform Validity and Integrity Checks** - Accept Incoming Data - Perform Limit Checking - Check Expected Values and Trends						E				
Collect ATMS Surveillance Data - Sensor Data Collection - Data Conversion and Processing - Simulate Senso r Devices and Processing						E				
Generate Derived Data - Compute Time Average - Compute Period Count - Fuse Data Source - Extract Probe and Vehicle Data - Generate Aggregate Counts by Link or Area	S	S	M	D						
2.MANAGE TRAFFIC OPERATIONS **Assess Current Network Traffic Condition** -Detect Anomaly - Classify Anomaly - Incident Verification **-Incident Detection under Low-Volume Conditions**	S			D	M	E	S	S	D	M
Predict Conditions- Assess Current Strategy - Determine Regional Network Traf fic Loads - Medium-Term Prediction of Subnetwork Link Volumes - Specify Effected Subnetwork - Compute MOEs - Short-Term Prediction of Intersection Approach Volumes		E			M					
Generate Traffic Management Strategies - Retrieve Alternate Strategies - Adopt Strategies to Predicted Conditions										
Evaluate Strategies - Select Evaluation Models - Prepare Evaluation Models - Run Models - Assess Results o f Model Runs										
Implement Management Strategies										
Incident Management - Process Incident Reports/Verification - Classify Incident Severity - Dispatch Emergency Services - Generate Routing Request - Maintain Incident Log - Estimate Incident Duration and Capacity Impact						E		S	M	
3. MANAGE ATMS **Monitor Databases** Maintain **Maintenance Log** **Provide Equipment Status** **Maintain Configuration and Inventory Control** **Schedule** Maint**enance and Repair Activities** **Manage Databases**										
4. DISSEMINATE INFORMATION **Process Request for** Information **Schedule Event for Data Outputs**										

LEGEND: D Direct Performer M Manual Controller S Supervisory Controller E Executive Controller

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Table 2-2. Matrix of System Versus Operational Personnel Functions (Cont'd)

SYSTEM FUNCTIONS	DECISION MAKING									
	Formulate Control Strategies and Tactics	Re-call Historical Data	Forecast Trouble Spots	Activate Decision Support System	Fuse Data	Compare Alternatives	Predict Consequences of Actions	Request Additional Info	Establish Alternative Strategies	Re-plan Operations
1. PROCESS SURVIELLANCE DATA **Perform Validity and Integrity Checks** - Accept Incoming Data - Perform Limit Checking - Check Expected Values and Trends										
Collect ATMS Surveillance Data - Sensor Data Collection - Data Conversion and Processing - Simulate Sensor Devices and Processing									D	
Generate Derived Data - Compute Time Average - Compute Period Count - Fuse Data Source - Extract Probe and Vehicle Data - Generate Aggregate Counts by Link or Area										
2.MANAGE TRAFFIC OPERATIONS **Assess Current Network Traffic Condition** -Detect Anomaly - Classify Anomaly - Incident Verification **-Incident Detection under Low-Volume Conditions**					S				D	
Predict Conditions- Assess Current Strategy - Determine Regional Network Traffic Loads - Medium-Term Prediction of Subnetwork Link Volumes - Specify Effected Subnetwork - Compute MOEs - Short-Term Prediction of Intersection Approach Volumes	M	M	S		E	S				
Generate Traffic Management Strategies - Retrieve Alternate Strategies - Adopt Strategies to Predicted Conditions	M						S	S		M
Evaluate Strategies - Select Evaluation Models - Prepare Evaluation Models - Run Models - Assess Results of Model Runs	M						S	S		M
Implement Management Strategies				M						M
Incident Management - Process Incident Reports/Verification - Classify Incident Severity - Dispatch Emergency Services - Generate Routing Request - Maintain Incident Log - Estimate Incident Duration and Capacity Impact								D		
3. MANAGE ATMS **Monitor Databases** Maintain **Maintenance Log** **Provide Equipment Status** **Maintain Configuration and Inventory Control** **Schedule** Maint**enance and Repair Activities** **Manage Databases**								D		
4. DISSEMINATE INFORMATION **Process Request for** Information **Schedule Event for Data Outputs**										

LEGEND: D Direct Performer M Manual Controller S Supervisory Controller E Executive Controller

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Table 2-2. Matrix of System Versus Operational Personnel Functions (Cont'd)

SYSTEM FUNCTIONS	CONTROL SUBSYSTEM				
	Divert Traffic	Set Traffic Light Sequences	Command Actions	Dispatch Control Personnel	Provide Multi-Modal Coordi-nation (As Appropriate)
1. PROCESS SURVIELLANCE DATA **Perform Validity and Integrity Checks** - Accept Incoming Data - Perform Limit Checking - Check Expected Values and Trends					
Collect ATMS Surveillance Data - Sensor Data Collection - Data Conversion and Processing - Simulate Senso r Devices and Processing					
Generate Derived Data - Compute Time Average - Compute Period Count - Fuse Data Source - Extract Probe and Vehicle Data - Generate Aggregate Counts by Link or Area					
2.MANAGE TRAFFIC OPERATIONS **Assess Current Network Traffic Condition** -Detect Anomaly - Classify Anomaly - Incident Verification **-Incident Detection under Low-Volume Conditions**	M	M	D	D	
Predict Conditions- Assess Current Strategy - Determine Regional Network Traffic Loads - Medium-Term Prediction of Subnetwork Link Volumes - Specify Effected Subnetwork - Compute MOEs - Short-Term Prediction of Intersection Approach Volumes					
Generate Traffic Management Strategies - Retrieve Alternate Strategies - Adopt Strategies to Predicted Conditions					
Evaluate Strategies - Select Evaluation Models - Prepare Evaluation Models - Run Models - Assess Results o f Model Runs					
Implement Management Strategies					
Incident Management - Process Incident Reports/Verification - Classify Incident Severity - Dispatch Emergency Services - Generate Routing Request - Maintain Incident Log - Estimate Incident Duration and Capacity Impact	M	M	D	D	
3. MANAGE ATMS **Monitor Databases** Maintain **Maintenance Log** **Provide Equipment Status** **Maintain Configuration and Inventory Control** **Schedule** Maint**enance and Repair Activities** **Manage Databases**					M
4. DISSEMINATE INFORMATION **Process Request for** Information **Schedule Event for Data Outputs**					

LEGEND: D Direct Performer M Manual Controller S Supervisory Controller E Executive Controller
LORAL A

Table 2-2. Matrix of System Versus Operational Personnel Functions (Cont'd)

SYSTEM FUNCTIONS	INFORMATION DISSEMINATION: Provide Incident Info to Media	Provide Information to Police, Fire, Emergency, Tow Services	Provide Public Service Messages	Provide In-Vehicle Information (As Appropriate)	Provide Signage Information	Provide Route Guidance
1. PROCESS SURVIELLANCE DATA **Perform Validity and Integrity Checks** - Accept Incoming Data - Perform Limit Checking - Check Expected Values and Trends						
Collect ATMS Surveillance Data - Sensor Data Collection - Data Conversion and Processing - Simulate Sensor Devices and Processing						
Generate Derived Data - Compute Time Average - Compute Period Count - Fuse Data Source - Extract Probe and Vehicle Data - Generate Aggregate Counts by Link or Area						
2.MANAGE TRAFFIC OPERATIONS **Assess Current Network Traffic Condition** -Detect Anomaly - Classify Anomaly - Incident Verification **-Incident Detection under Low-Volume Conditions**						
Predict Conditions- Assess Current Strategy - Determine Regional Network Traffic Loads - Medium-Term Prediction of Subnetwork Link Volumes - Specify Effected Subnetwork - Compute MOEs - Short-Term Prediction of Intersection Approach Volumes						
Generate Traffic Management Strategies - Retrieve Alternate Strategies - Adopt Strategies to Predicted Conditions						
Evaluate Strategies - Select Evaluation Models - Prepare Evaluation Models - Run Models - Assess Results of Model Runs						
Implement Management Strategies						
Incident Management - Process Incident Reports/Verification - Classify Incident Severity - Dispatch Emergency Services - Generate Routing Request - Maintain Incident Log - Estimate Incident Duration and Capacity Impact						
3. MANAGE ATMS **Monitor Databases** Maintain **Maintenance Log** **Provide Equipment Status** **Maintain Configuration and Inventory Control** **Schedule** Main**tenance and Repair Activities** **Manage Databases**						
4. DISSEMINATE INFORMATION **Process Request for** Information **Schedule Event for Data Outputs**	**M**	**D**	**D**	**M**	**S**	**M**

LEGEND: D Direct Performer M Manual Controller S Supervisory Controller E Executive Controller

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2.4 ATMS Functional Interface and Generic Requirements

The following discussion presents the requirements for ATMS. The following functions represent basic requirements as derived from the ATMS objectives, as well as requirements imposed upon ATMS by external entities. These requirements will be described by first presenting a summary of the required capability. Following this description will be a list of Level 0 and Level 1 requirements necessary for providing the capability.

We provide a mechanism for maintaining requirements traceability through the following numbering scheme. First, there is a 4 character identifier to designate the source of the requirement. After the identifier is a numeric designator used to signify the level of the requirement. Table 2-2 provides a mapping between identifiers and requirements sources.

During the requirements analysis process, it became apparent that the boundary between different elements of the system is not well defined. Because of the ambiguity of the boundary, there are cases where the direct allocation of functionality to ATMS required an assumption. As a result, some requirements that could conceivably be ATMS requirements are assumed to be performed by a different entity. For example, route selection is a requirement that could be satisfied by several different IVHS entities. For this report, we assume that with the exception of emergency vehicles, route selection will be performed by ATIS, CVO, and APTS. ATMS supports route selection by providing the data input required for making intelligent routing selections. In the interest of completeness, requirements assumed to be fulfilled by non-ATMS entities are included in this analysis. In these cases, the requirement is stated, marked as reserved, and italicized.

Table 2-2. Requirements Identifier Mapping

Identifier	Requirements Source
ATMS	Derived from ATMS Objectives
ATIS	Advanced Traveler Information Systems
APTS	Advanced Public Transit Systems
CVO	Commercial Vehicle Operations
AVCS	Advanced Vehicle Control Systems
NWS	Weather
NADB	National Databases
IVHS	Intelligent Vehicle Highway Systems
EMER	Emergency Response
TRAN	Transportation Departments
LAW	Law Enforcement

2.4.1 ATMS Derived Requirements

ATMS collects data from various sensor types, probe vehicles, and other sources (e.g., toll collection data) to identify traffic infrastructure conditions.

ATMS 1. ATMS shall collect surveillance data from sensors that include: point detectors, video, and voice sources.

ATMS 1.1 ATMS shall ingest data from point detectors, video, and voice data.

ATMS 1.2 ATMS shall validate received data. This capability includes range and limit checking.

ATMS 1.3 ATMS shall check data integrity. This capability includes verifying that received data is consistent with the transmitted data.

ATMS 1.4 ATMS shah fuse received data into a common format.

ATMS 1.5 ATMS shall support both long- and short-term data archives.

Based upon data received from various type of infrastructure and environmental sensors, probe vehicles, and other sources, ATMS shall identify and categorize traffic and infrastructure (roadways and other elements of the environment in which vehicles are traveling) conditions. This includes the capability to determine when conditions are normal/abnormal based upon day and time. In the event conditions are abnormal, ATMS shah determine the nature of the abnormality.

ATMS 2. ATMS shall identify and categorize traffic network and infrastructure conditions.

ATMS 2.1 ATMS shall determine derived traffic performance parameters (Level 1 data; e.g., abnormal link speed; abnormal queue-length).

ATMS 2.2 ATMS shall identify and classify traffic conditions, such as recurrent congestion, non-recurrent congestion, communications failures, equipment failures, and incidents (Level 2 data) .

Based upon conditions of the traffic network and supporting infrastructure, ATMS shall develop and implement traffic control techniques that are both adaptive and predictive. Adaptive techniques allow for adjusting traffic control methods dynamically in real-time in response to changing traffic patterns and demands as they occur. Predictive techniques allow for adjusting control methods in response to anticipated traffic patterns and demands. Traffic control methods are primarily traffic signal timing strategies, but also include CMS; variable access restrictions; and variable lane use and turn movement restrictions. Other control techniques include dissemination of traveler information providing route selection and route guidance instructions designed to optimize performance of the overall traffic network.

ATMS 3. ATMS shall perform adaptive and predictive strategy traffic control.

ATMS 3.1 ATMS shall develop traffic flow predictions using current conditions, historical data and O-D data.

ATMS 3.2 ATMS shall assess effectiveness of system in responding to the predicted flow conditions.

ATMS 3.3 ATMS shall generate alternative control strategies based on actual and predicted traffic network conditions.

ATMS 3.4 ATMS shall evaluate alternative control strategies.

ATMS 3.5 ATMS shall implement selected traffic control strategies.

ATMS 3.6 ATMS shall disseminate traffic control information.

Through monitoring of traffic and the traffic infrastructure ATMS will be capable of detecting incidents and responding with an effective approach to manage the resolution of the incident in the shortest time, with the least impact to traffic throughput. Awareness for the safety of incident victims and others on the affected roadways is also considered in the incident response. An incident is defined as any non-normal occurrence affecting or having the potential to affect the traffic network's performance. Thus, an incident could involve vehicular traffic directly, such as a collision between vehicles on the roadway, or indirectly as an occurrence in the traffic infrastructure, such as ***a*** fallen rock on the roadway. Incident Management will analyze the conditions caused by the incident and employ appropriate traffic control strategies to resolve the incident and restore the network to normal conditions.

ATMS 4. ATMS shall perform incident detection and management.

ATMS 4.1 ATMS shall detect incidents. Most incidents are defined as unanticipated events resulting in a reduction of capacity or an increase in congestion. ATMS shall detect incidents occurring in low volume conditions, which is not readily detectable from traffic flow rates.

ATMS 4.2 ATMS shall classify incidents in terms of traffic network impact, incident seriousness, and human safety.

ATMS 4.3 ATMS shah determine the initial emergency response plan.

ATMS 4.4 ATMS shah contact and coordinate emergency response.

ATMS 4.5 ATMS shall predict incident durations.

ATMS 4.6 ATMS shah predict the impact of the incident on traffic conditions.

ATMS 4.7 ATMS shah determine strategies for responsive traffic control.

ATMS 4.8 ATMS shall evaluate strategies.

ATMS 4.9 ATMS shall implement strategies.

ATMS 4.10 Receive and process incident status reports and update response plans.

ATMS 4.11 Provide route selection for emergency vehicles.

ATMS 4.12 Track emergency vehicles en route for coordinated signal preemption.

ATMS will manage demand upon the roadways in order to optimize the performance of the overall traffic network system. Demand management strategies include the ability to employ traffic control techniques based upon monitored conditions of traffic and of the traffic infrastructure with the specific objective of influencing driver behavior to adjust demand.

ATMS 5. ATMS shall perform demand management.

ATMS 5.1 ATMS shall determine the need to influence demand.

ATMS 5.2 ATMS shall develop an integrated traffic control strategy comprising a demand management component consisting of:

a. Route selection.

b. Integrated control strategies implemented with signals, CMS, ramp meters, HOV enforcement, vehicle restriction, etc.

ATMS 5.3 ATMS shall implement control strategies.

ATMS 5.4 ATMS shall disseminate traveler information (historical data, demand information) to External Systems.

ATMS will maintain static data on the capacity and location of parking facilities and dynamic data on the usage and availability of parking resources as monitored in real-time. A more advanced version will predict traffic resource availability based upon traffic and the traffic infrastructure monitoring. ATMS will disseminate these data through ATIS and APTS elements, as well as through Traffic Advisories in order to optimize the availability of parking resources to satisfy both individual travelers and transit operators. Individual travelers will use parking information to complete a trip as efficiently as possible, minimizing time wasted on roadways after driving to full facilities. Transit operators will use this capability to achieve efficient modal transitions (i.e., park the car and board the subway). Parking facility information is also important to event management .

ATMS 6. ATMS shall manage the dissemination of parking information.

ATMS 6.1 ATMS shall monitor parking usage data

ATMS 6.2 ATMS shall capture parking facility goals from trip planning data.

ATMS 6.3 ATMS shall predict parking availability.

ATMS 6.4 ATMS shall disseminate parking availability data to External Systems.

ATMS will coordinate with the planners and implementors of infrastructure construction and maintenance activities to minimize the impact of these activities on traffic flow. ATMS techniques will include scheduling construction activities at times when impact to traffic is minimized and traffic control techniques appropriate to construction activities.

ATMS 7. ATMS shall manage the impact of construction activities upon the traffic network.

ATMS 7.1 ATMS shall receive construction plans,

ATMS 7.2 ATMS shall evaluate the impact to traffic conditions.

ATMS 7.3 ATMS shall coordinate with construction planners to revise plans and project schedules as indicated by traffic evaluation.

ATMS 7.4 ATMS shall develop temporary revisions to traffic control procedures and strategies as needed.

ATMS 7.5 ATMS shall implement traffic management strategies.

ATMS will coordinate with the planners and implementors of planned special events that are expected to have a significant effect upon traffic in order to minimize the impact of these activities on traffic flow. ATMS techniques include the scheduling of events at times when impact to traffic is reduced (when this is possible), and traffic control techniques appropriate to the event and the anticipated effect upon traffic.

ATMS 8. ATMS shall manage the impact of planned events (conventions, parades, etc.) upon the traffic network.

ATMS 8.1 ATMS shall receive event plans.

ATMS 8.2 Evaluate the impact to traffic conditions.

ATMS 8.3 ATMS shall coordinate with event planners to revise plans and event schedules (as feasible) as indicated by traffic evaluation.

ATMS 8.4 ATMS shall develop temporary revisions to traffic control procedures and strategies as needed.

ATMS 8.5 ATMS shall implement traffic management strategies.

ATIS, ARTS, CVO, and AVCS require the exchange of basic information in order to accomplish an integrated system approach for IVHS. The information components exchanged are primarily static and dynamic traffic data and traffic infrastructure information.

ATMS 9. ATMS shall perform information management and dissemination to support the integrated operation of all IVHS segments.

ATMS 9.1 ATMS shall disseminate the following data to ATIS, ARTS, CVO, and AVCS elements and to non-regional ATMSs:

a. Real-time Level 1 traffic information (i.e., traffic abnormalities identified).

b. Real-time Level 2 traffic information (i.e., traffic abnormalities categorized and quantified).

c. Static and dynamic network data (e.g., geometries, roadway environmental conditions, etc.).

d. Historical Level 1 and 2 traffic information.

ATMS 9.2 ATMS shall respond to ad hoc requests for traffic network status data and impending planned special events and construction activities.

ATMS requires self-sustaining functions that include the ability to monitor its own internal systems and interfaces, identifying when subsystem components require regular maintenance as well as identifying and suggesting solutions for system malfunctions. This capability will also monitor the actions of ATMS operators, automatically providing operator aid when needed. These system management capabilities will contribute to the objective of an inexpensive system to operate and maintain.

ATMS 10. ATMS shall provide a self-sustaining capability, automatically monitoring the performance of ATMS.

ATMS 10.1 ATMS shall monitor status data.

ATMS 10.2 ATMS shall identify system faults.

ATMS 10.3 ATMS shall determine remedies.

ATMS 10.4 ATMS shall fix system faults.

ATMS 10.5 ATMS shall perform preventative maintenance.

ATMS 10.6 ATMS shall monitor operator inputs.

ATMS 10.7 ATMS shall support operator performance enhancements.

ATMS 10.8 ATMS shall respond to equipment malfunction notices.

ATMS 10.9 ATMS shall respond to roadway malfunction notices.

ATMS requires the capability to communicate with both IVHS and non-IVHS entities for the purpose of wide-area traffic control.

ATMS 11. ATMS shall provide capabilities to support information exchange between inter-regional ATMSs.

ATMS 11.1 ATMS shall disseminate traffic management information to inter-regional ATMSs as indicated by agreed upon Memorandum of Understanding (MOU).

ATMS 11.2 ATMS shall receive traffic management information from inter-regional ATMS.

ATMS 11.3 ATMS shall adjust traffic management strategies as appropriate.

2.4.2 Requirements Originating From Other IVHS Elements

The following list provides IVHS External Systems requirements.

IVHS 1. ATMS shall provide historical information related to the roadway system to vehicles and other devices.

IVHS 1.1 ATMS shall develop historical traffic-related data.

IVHS 1.2 ATMS historical data will consist of link times, geometries, road restrictions, volumes, control strategies, incidents, etc., by time of day.

IVHS 2. ATMS shall provide to IVHS entities dynamic, real-time information describing the current status of the roadway system. Real-time information includes, traffic-related data (link times, volumes, incidents, etc.), travel advisory messages, and parking availability.

IVHS 3. ATMS shall contribute to the route selection process. ATMS shall compute suggested routes between aggregate O-D pairs, which it will transmit to IVHS entities. With the the exception of HAZMAT carriers and emergency vehicles, routing of individual vehicles is not performed.

IVHS 3.1 ATMS shall have the capability to receive O-D data from vehicles or aggregated O-D data from other IVHS components.

IVHS 3.2 ATMS shall aggregate O-D pairs and develop suggested routes between O-D pairs.

IVHS 3.3 ATMS shall optimize routes with respect to the requirements of the traffic network.

IVHS 3.4 ATMS shall disseminate real-time suggested route data to IVHS components.

While each of the above requirements is imposed by ATIS, ARTS, CVO, and AVCS, the degree of importance of the requirement to the individual IVHS elements varies. Table 2-3 summarizes the relevance of the requirement to each of the IVHS entities. The following sections describe the use of each of these requirements from the perspective of ATIS, APTS, CVO, and AVCS.

Table 2-3. IVHS External Systems Requirements Matrix

Requirement	ATIS	ARTS	CVO	AVCS
IVHS 1	√	√	√	√
IVHS 2	√	√	√	√
IVHS 3	√		√	

2.4.2.1 ATIS

ATIS requires static data including roadway information such as highway geometries, restrictions due to long-term construction projects, toll locations, incidents, and historical demand levels at network locations by time of day. ATIS elements, either in-vehicle, hand-held devices for travelers, kiosks, or other fixed elements will process received static data against dynamic data to perform traveler services such as Traveler Advisory, Traveler Service Information, Trip Planning, Route Selection, Route Guidance, and In-Vehicle Signing.

ATIS also requires dynamic data. Dynamic data is an ongoing and timely record of the traffic network's current status. It includes such information as control strategies and signal settings in effect, link travel times, demand levels, incidents, events, travel advisory messages (e.g., "Accident Ahead, use alternate routes - Rt. XX"), parking availability, environmental conditions, and restrictions in effect, such as construction projects. ATIS elements, either in-vehicle, hand-held devices for travelers, kiosks, or other fixed elements will process received dynamic data and compare against static data to perform traveler services such as Traveler Advisory, Traveler Service Information, Trip Planning, Route Selection, Route Guidance, and In-Vehicle Signing.

Route selection, assumed to be performed by ATIS elements, is assisted by ATMS. Route selection consists of calculating a best route of travel based upon a trip already selected by the traveler in the form of an origin and destination at a particular time. Route selection can be performed to satisfy a number of objectives, a primary one being to provide a trip with the features preferred by the traveler (e.g., quickest, avoid toll roads, avoid freeways, avoid surface streets, scenic routes, etc.). One advantage to having ATMS play a role in routing, is the ability to influence demand to optimize the performance of the roadway network at the system level. This is done so that congestion is minimized and throughput is maximized for the roadway system as a whole. If routing was done entirely by ATIS entities (i.e., distributed routing where each vehicle computes its own route) and ATMS had no input, it would not be possible to influence demand (since each vehicle is performing their own routing independently) and better utilize the capacity of the roadways. Further, ATMS could not substantially alter/refine control strategies (at least not as well as it could if it had some control over routing), since there would be less statistical control over each vehicle.

2.4.2.2 APTS

APTS requires static data. APTS elements, including transit operations centers and in-vehicle devices will process received static data against dynamic data to perform traveler services such as Bus/Train/Van Planning, Scheduling, and Arrival Prediction; Trip Planning; Route Selection; Route Guidance; and In-Vehicle Signing.

APTS requires dynamic data. APTS elements, including transit operations centers and in-vehicle devices will process received dynamic data and compare against static data (refer to APTS 1) to perform traveler services such as Bus/Train/Van Planning, Scheduling, and Arrival Prediction; Trip Planning; Route Selection; Route Guidance; and In-Vehicle Signing (refer to ATMS 9).

2.4.2.3 CVO

CVO elements, including fleet operations centers and in-vehicle devices will process received static data against dynamic data to perform traveler services such as Fleet Planning and Scheduling, Trip Planning, Route Selection, Route Guidance, and In-Vehicle Signing. It is entirely possible that CVO elements may choose to ignore routes suggested by ATMS and independently develop routes to meet their specific objectives.

2.4.2.4 AVCS

The information generally required by AVCS is local in nature and real-time. For these reasons, it is assumed that the principle infrastructure information, communications, and control capabilities for AVCS will be principally provided through dynamic, interactive interactions by vehicle-to-vehicle, between vehicles and roadside sensors, and through roadside/vehicle communications devices such as beacons. ATMS information services for some data categories, in particular highway geometries and construction status, would be required, as these are data types indicating roadway conditions that could affect the nature in which vehicles interact with the roadway and roadside components in order to carry out enhanced or autonomous vehicle control. It is assumed that a dynamic, interactive interface between ATMS and AVCS will not be required for the purpose of providing these types of information.

2.4.3 Requirements Originating From Non-IVHS External Elements

The following list provides the requirements that originate from Non-IVHS External Elements. The theme that unifies these elements is that they all provide services to ATMS. Because the functionality of each of these elements is unique they are discussed individually.

2.4.3.1 Weather

Weather predictions are an important input required for managing traffic. ATMS will require the capability to receive weather forecast data for anticipating traffic conditions, incident detection, and incident management. This data will be stored for long- and short-term trend analysis.

NWS 1. ATMS will receive and process weather forecast data from commercial and public weather forecast service organizations.

NWS 1.1 ATMS shall receive weather forecast data from public and private services.

NWS 1.2 ATMS shall validate forecast data to ensure it is transmitted from legitimate sources.

NWS 1.3 ATMS shall check data integrity to ensure that the data content is of good quality.

NWS 1.4 ATMS shall archive all received forecast data.

ATMS will pre-process data to extract the appropriate parameters to use as input for managing the traffic network.

NWS 2 ATMS will pre-process weather forecast data.

NWS 2.1 ATMS shall identify and extract parameters of interest.

NWS 2.2 ATMS shall assign the forecast to a network area of interest.

In addition to receiving regular weather service broadcasts, ATMS will require the capability to initiate specific forecast data (e.g., near-term “micro forecasts”) to support activities such as incident management, where occurrences arc unplanned.

Nws 3. ATMS shall generate ad hoc weather forecast requests.

2.4.3.2 Environment

ATMS will require the capability to receive environmental status data such as air quality levels, from public and private organizations.

ENV 1. ATMS will receive and process air quality data from public and private environmental monitoring service organizations.

ENV 1.1 ATMS shall receive environmental status data from Non-IVHS External systems.

ENV 1.2 ATMS shall validate forecast data to ensure it is transmitted from legitimate sources.

ENV 1.3 ATMS shall check data integrity to ensure that the data content is of good quality.

ENV 1.4 ATMS shall archive all received environmental data.

ATMS will pre-process data to extract appropriate parameters to use as input for managing the traffic network.

ENV 2. ATMS will pre-process environmental data.

ENV 2.1 ATMS shall identify and extract parameters of interest.

ENV 2.2 ATMS shall assign environmental data to a network area of interest.

Air quality conditions are fundamentally processes that develop over longer time periods than weather data. It is assumed that a capability to receive air quality status andforecasts is sufficient to ATMS needs and that an ability to initiate special requests is not required.

ENV 3. ***ATMS shall initiate the tranmittal of air quality data (Reserved).***

2.4.3.3 National Databases

It is assumed that large databases containing data from a national perspective will be required by ATMS. One such database could conceivably maintain information about vehicles transporting HAZMAT.

HAZMAT planning data includes description of planned trips, routes, desired schedules, and the hazardous material's nature. ATMS will retrieve these data from the national database and use this information to coordinate routes and provide advance notice to emergency services and other affected organizations.

NADB 1 ATMS will receive HAZMAT manifest data from a national database.

NADB 1.1 ATMS shall detect HAZMAT carriers without cargo identification from surveillance data.

NADB 1.2 ATMS shall send information queries to the national database.

NADB 1.3 ATMS shall receive and validate data, and check data integrity.

ATMS will use this data to manage traffic and the roadway as HAZMAT carriers travel through the traffic network

NADB 2. ATMS will have the capability to receive real-time location information regarding vehicles carrying hazardous materials.

NADB 2.1 ATMS shall receive location data.

NADB 2.2 ATMS shall validate location data.

NADB 2.3 ATMS shall perform mute selection for HAZMAT carriers.

As ATMS monitors and manages HAZMAT traffic, it will send new information obtained to the national database as updates.

NADB 3 ATMS shall send update data to the national database.

2.4.4 Requirements Originating From Emergency Response Systems

This category includes assets used for responding to traffic network problems. There are two distinct classes contained within this category emergency vehicles, such as, police, ambulance, fire, and tow trucks, and road maintenance elements. The requirements associated with each of these classes is discussed in the following sections.

Emergency operations elements, either in-vehicle or operations centers will process received static data and compare against dynamic data to perform services such as Traveler Advisory, Route Selection, Route Guidance, and In-Vehicle Signing.

EMER 1. ATMS shall provide historical information related to the roadway system to vehicles and other devices.

EMER 1.1 ATMS shall develop historical traffic-related data.

EMER 1.2 ATMS historical data will consist of link times, geometries, road restrictions, volumes, control strategies, incidents, etc., by time of day.

As with other components within the system, emergency vehicles require dynamic data. Emergency operations elements, either in-vehicle or operations centers will process received static data and compare it against dynamic data to perform services such as Traveler Advisory, Route Selection, Route Guidance, and In-Vehicle Signing.

EMER 2. ATMS shall provide to IVHS entities dynamic, real-time information regarding the current status of the roadway system. Real-time information includes, traffic-related data (link times, volumes, incidents, etc.), travel advisory messages, etc.

This function, currently performed by emergency operations elements, should be performed by ATMS. Route selection entails calculating a best route of travel based on a trip already selected by the traveler in the form of an O-D at a particular time. Route selection can be performed to provide the quickest, safest route for the emergency vehicle to the desired location (fire, crime, accident). The rationale for providing route selection for emergency vehicles is that ATMS is in the best position to assess the traffic network's current state. Because of this, ATMS is in the position to select the optimum route for these vehicles. In addition, it is likely that signal preemption will be used by emergency vehicles. ATMS is best suited for accommodating this requirement since it can control signals and coordinate the routes of various responding vehicles.

EMER 3. ATMS shall perform emergency vehicle route selection and updates for individual emergency vehicles.

EMER 3.1 ATMS shall disseminate route selection results to IVHS and non-IVHS elements.

EMER 3.2 ATMS shall optimize the routes based on the current state of the traffic network to facilitate a safe and speedy arrival of emergency vehicles to the incident scene.

Keeping other entities informed about the current status of incidents is an important component of incident management. This function, which could be performed by emergency operations elements in some jurisdictions, could also be performed by ATMS. ATMS would determine when to send a Travel Advisory by continuously comparing real-time traffic, roadway, and environmental conditions against pre-determined categories and guidelines. During an emergency ATMS would send frequent and urgent advisories to emergency vehicles in progress to the incident scene.

EMER 4. ATMS shall derive and transmit Travel Advisory Messages to emergency operations elements.

In responding to an incident, an emergency vehicle requires current information regarding the resolution status of incidents in progress, whether it is the incident to which the vehicle is responding or another incident that potentially will be encountered en route.

EMER 5. ATMS shall transmit incident detection and incident management data to emergency operations elements.

Signal preemption is an important tool for promoting rapid response to emergency situations. This capability provides an advanced version of remote signal preemption, where ATMS manages signals along the route of an emergency vehicle based upon decision processing against these data types: real-time dynamic traffic status; the vehicles origin/destination goal; route selection; and real-time tracking of the vehicle. An advantage of this approach is that signals can be coordinated between different responding vehicles, for example, two fire companies converging on the same intersection. Note, signal preemption can be performed by the vehicle on the roadway, directly transmitting signal control as the emergency vehicle approaches intersections.

EMER 6. ATMS shall perform signal preemption for emergency vehicles.

Incident management requires that ATMS should be the initial agent for coordinating incident responses. It is possible that once the response team arrives at the incident scene, that coordination will become the responsibility for some other agency (e.g., the police)

Based upon real-time tracking of the emergency vehicle's position, ATMS would analyze dynamic traffic conditions and communicate with the vehicle, providing interactive guidance.

EMER 7. ATMS shall perform emergency vehicle coordination.

EMER 7.1 ATMS shall perform emergency vehicle dispatch.

EMER 7.2 ATMS shall perform emergency vehicle tracking.

2.4.4.2 Road Maintenance

Road maintenance elements require static data to maintain roadways. Maintenance vehicle operators, through either in-vehicle or operations centers will process received static data against dynamic data to evaluate roadway conditions, and to plan and carry out maintenance activities. Maintenance operators will also use the information to perform services such as Traveler Advisory, Route Selection, Route Guidance, and In-Vehicle Signing, to support operators as they plan and carry out trips to maintenance sites.

MAIN 1. ATMS shah provide historical information related to the roadway system to vehicles and other devices.

MAIN 1.1 ATMS shah develop historical traffic related data.

MAIN 1.2 ATMS historical data will consist of link times, geometries, road restrictions, volumes, control strategies, incidents, etc., by time of day.

Maintenance vehicle operators, through either in-vehicle or operations centers will process received dynamic data against static data to evaluate roadway condition and to plan and carry out maintenance activities. Maintenance operators will also use the information to perform services such as Traveler Advisory, Route Selection, Route Guidance, and In-Vehicle Signing, to support operators as they plan and carry out trips to maintenance sites.

MAIN 2. ATMS shall provide to IVHS entities dynamic real-time information regarding the current status of the roadway system. Real-time information includes, traffic-related data (link times, volumes, incidents, etc.), travel advisory messages, etc.

MAIN 3. ATMS shall provide dispatch notices to maintenance crews for instances where repairs are automatically detected. Additionally, ATMS provides suggestions for preventative action.

2.4.5 Requirements Originating From Organization Users

There are two classes of organizational users. The first class is composed of local transportation departments. This class is responsible for providing ATMS with the budgets and policies that govern the operation of the system. The second class, law enforcement, receives input from ATMS that is used for planning purposes.

2.4.5.1 Local Jurisdiction Transportation Departments

Local transportation departments have the basic responsibility for developing transportation management policy. ATMS will accept this information and evaluate it against the current capabilities and make appropriate modifications to system capabilities, processes, or interfaces in order to comply with the policy. ATMS will prepare and send a response to the transportation department upon completion, indicating the nature of the response to the policy directive.

TRAN 1. ATMS shall receive traffic management policy and budget information, and evaluate and modify transportation management in response.

TRAN 1.1 ATMS shall evaluate policy information against current practice and procedures.

TRAN 1.2 ATMS shall modify and implement procedures as required.

TRAN 1.3 ATMS shall develop budget estimates to meet traffic management policies and objectives.

TRAN 1.4 ATMS shall modify and implement procedures to satisfy approved budgets.

Event planners will negotiate traffic management plans with the transportation department, who will send the information to atms. ATMS will maintain pre-planned event management strategies, procedures, and capabilities and will recall these from the database to apply appropriately. In rare cases, events will be planned for which there are no sufficient pre-planned strategies. ATMS will devise and deploy new strategies. ATMS will prepare and send a response to the transportation department upon indicating the nature of the response to the event.

TRAN 2. ATMS shall receive special event planning information, evaluate, develop, and implement appropriate transportation management capabilities and procedures.

TRAN 2.1 ATMS shall evaluate event plans.

TRAN 2.2 ATMS shall develop traffic management plans.

TRAN 2.3 ATMS shall develop new traffic management capabilities or procedures, if required.

TRAN 2.4 ATMS shall implement traffic management monitor and control strategies for events.

2.4.5.2 Law Enforcement

LAW 1. ATMS will provide law enforcement entities with violation statistics, as special requests or if required, but will not function to actively enforce the law (e.g., speed limits, HOV) for a general system. Statistics might include compliance to HOV and speed restrictions, but will not be for individual vehicles (though this might be obtainable via CCTV).

3.0 SYSTEM DESCRIPTION

This section describes the subsystems comprising ATMS. Logically, ATMS is composed of the following four major subsystems:

a. Process Surveillance Data (PSD).

b. Manage Traffic Operations (MTO).

c. Manage ATMS (MA).

d. Disseminate Information (DI).

The PSD subsystem is responsible for ingesting, validating, and formatting traffic network surveillance data. MTO is responsible for monitoring and controlling the traffic network. Similarly, MA performs like-processing for ATMS internal systems. Finally, DI is responsible for transmitting data to External Users. These four subsystems and their interrelationships are illustrated in Figure 3- 1.

An in-depth discussion of the functionality of each of these subsystems is contained in the following paragraphs. In this discussion, each subsystem is described in terms of the ***components*** that makeup the subsystem. Next, a description of the ***elements*** that the component contains is provided. For each component and element a functional description will be provided. The functional description combined with the data flow inputs from other components, elements, and data stores provides an accurate explanation for the processing taking place.

In performing this analysis functional decomposition techniques, based on the Yourdon/DeMarco and Gane/Sarson methodologies, and a computer-aided software engineering environment was used. In the following data flow diagrams the Gane/Sarson notation is used Figure 3-2 summarizes the notation used in the data flow diagrams.

3.1 Process Surveillance Data

The primary function of the PSD subsystem is to receive and prepare surveillance data for use by the MTO and the MA subsystems. To accomplish this function, this subsystem contains four major components. These four components as shown in Figure 3-3, are:

a. Perform Validity and Integrity Checks on Incoming Data.

b. Collect ATMS Surveillance Data.

c. Generate Derived Data

d. Process Surveillance (PS) Database Access.

The Perform Validity and Integrity Checks component is responsible for aggregating all surveillance data coming into ATMS, and for performing validity checks on the data to determine whether it is within acceptable ranges. Any data not meeting the criteria is not loaded into the ATMS database. Under these conditions, a failure detection message is sent

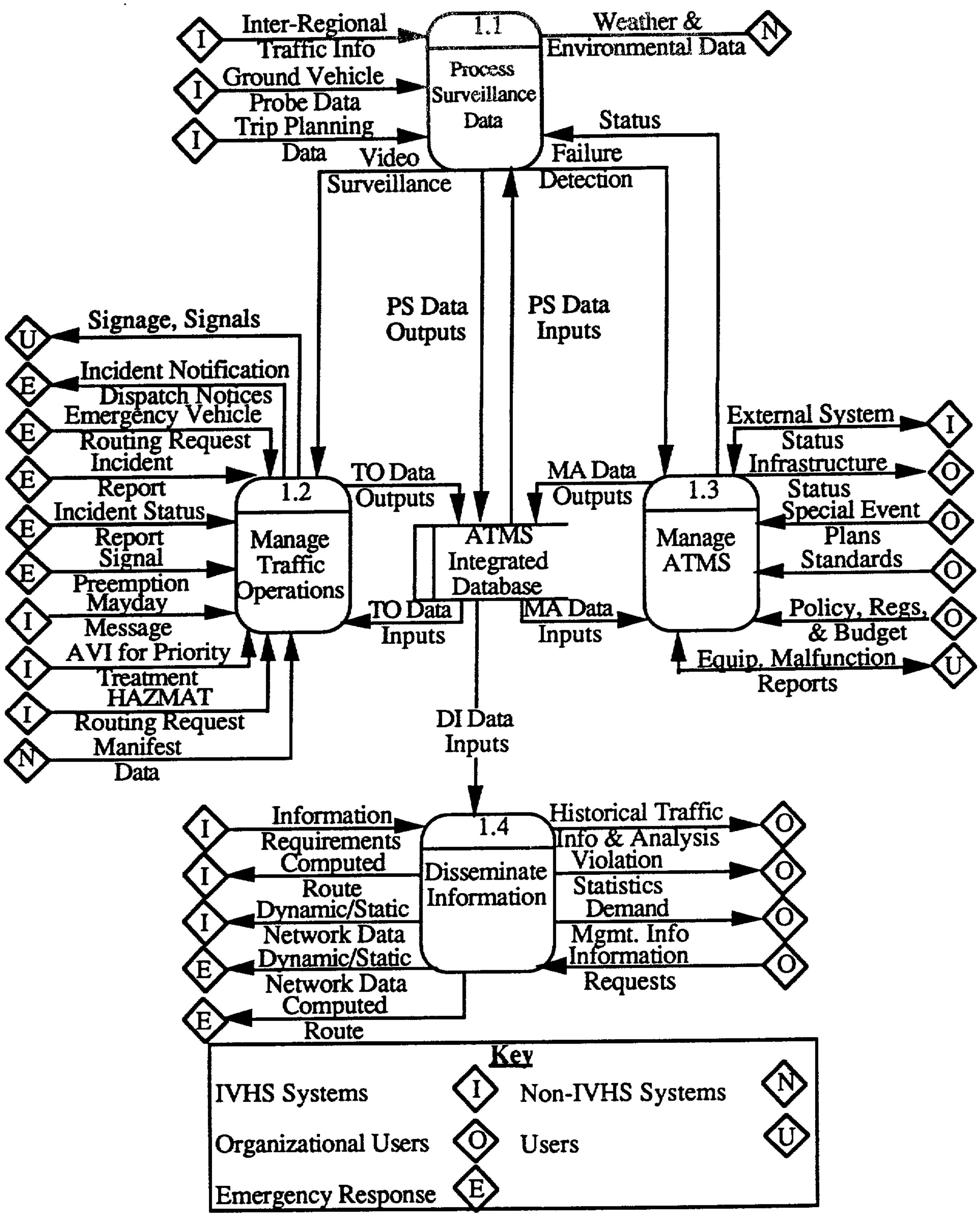
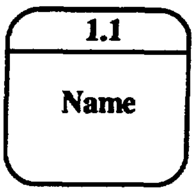


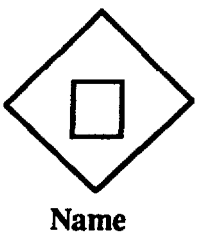
Figure 3-1. ATMS Subsystems

Square boxes are external entities to the system. They are normally found on the context diagram. These are entities that transmit and receive information.

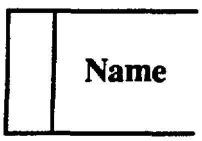
The arrow depicts a dataflow. Dataflows on the context diagram are normally composite dataflows. That is, they consist of sets logically grouped data. On lower level diagrams, composite dataflows are split into individual pieces. Dataflows and their composition are defined in a data dictionary.



Square or rectangular boxes with numbers represent functionality. In the context of this report the highest level is a subsystem, at the intermediate level components, and at the lowest level elements. These boxes are functional areas of the system, they are not necessarily software processes. The number contained with the box maintains the tracking of parents to children.



Diamonds represent external entities on diagrams other than the context diagram. In this context, external entities includes those entities external to the system and those entities that are external to the subject subsystem.



Rectangular boxes without right hand borders indicate data stores for the system. These data stores may include databases, flat files, and computer memory.

Figure 3-2. Design Notation for ATMS Support Systems

to the MA function to verify the failure and initiate maintenance actions. Failed sensors are tagged so that anomalous data does not enter the system.

Along with an internal interface for receiving sensor surveillance data, this component also receives surveillance data from both IVHS and non-IVHS External Systems. This components performs the following processing:

a. Accept Incoming Data - this element ingests both traffic network and equipment status data and formats it for system use. This element is responsible for data communications handling. This includes data address checking, data sequence checks, error checks and calculations (e.g., Cyclic Redundancy Check), and removal of communications protocol overhead. Essentially, this element is responsible for verifying that errors were not introduced into the data as a result

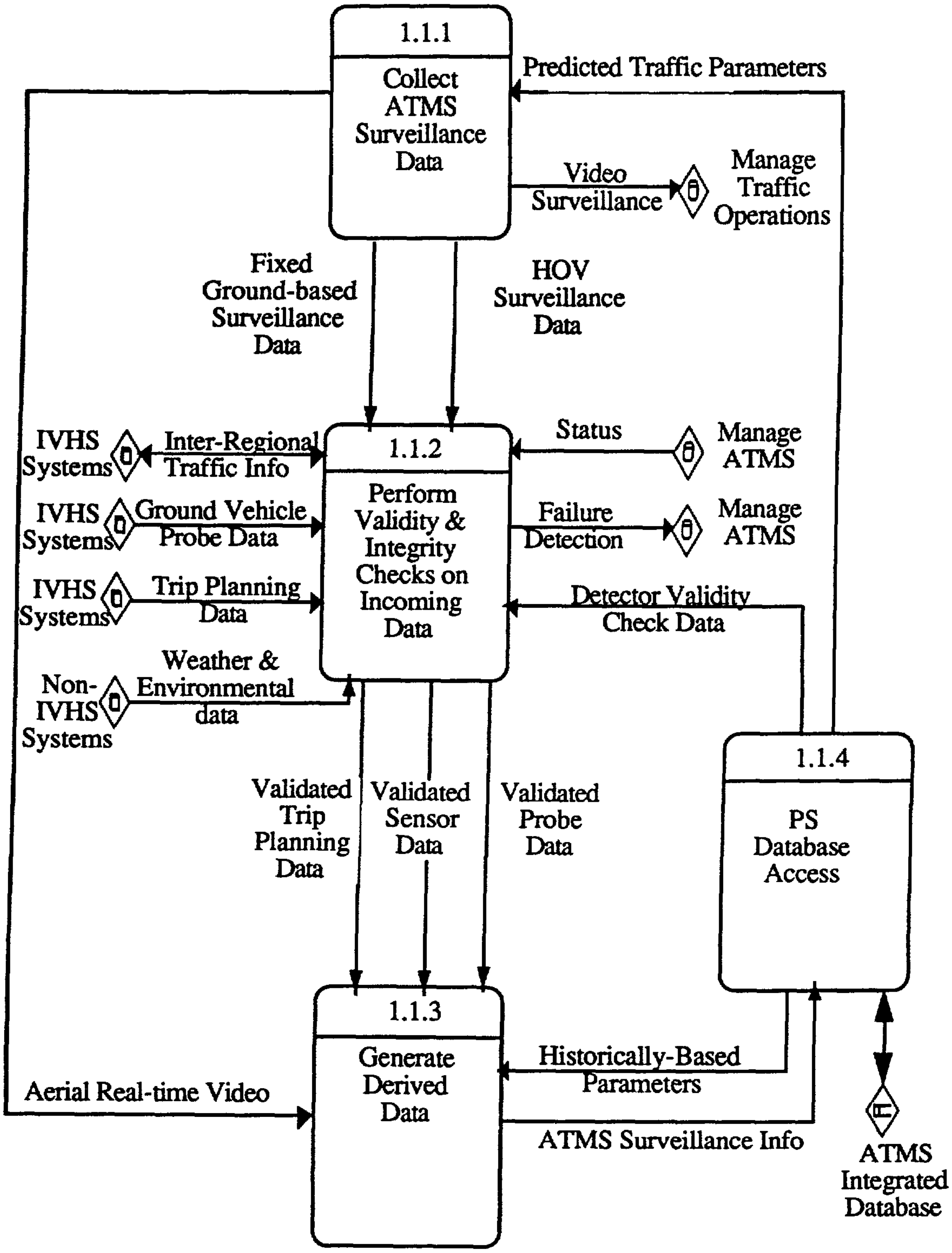


Figure 3-3. Process Surveillance Data

of the communications process. If errors are detected, this entity ensures that error-prone data is ignored.

b. Perform Limit Checking - this element performs the first validity checks on incoming data. The first check is a high/low limit check. A high/low limit check verifies the validity of the data by checking the received data against known operational limits. The second check is a range check. A range check looks at the magnitude of change of the current sample from the preceding sample. Often, a large change is an indication of an error in the sensor. In the event that either of these checks fail, the data is flagged for further diagnostic processing.

c. Perform Check Against Expected Values and Trends - this element performs a "reasonableness" check of the data. This check compares the received data value with the anticipated data value. Expected values may be derived from predictive simulation and recent, short-term trend analysis. In addition, historical data may be supplied by the database. As with the limit check element, data values are flagged for further processing if they fail this test.

These elements are illustrated in Figure 3-4.

The Collect ATMS Surveillance component is responsible for collecting and transmitting surveillance data gathered from organic sensors directly under the control of ATMS. These sensors include: loop detectors, video cameras, IR sensors, environmental sensors, and real-time aerial video surveillance. In addition to collecting traffic network status data, this component also collects sensor health and status data. As shown in Figure 3-5, the following three elements comprise this component:

a. Sensor Data Collection - this element captures and maintains the surveillance data from sensors in the network. For example, a loop detector may be sampled once every second. This element is responsible for collecting and maintaining the data locally.

b. Data Conversion and Processing - this element is responsible for any data conversion and processing performed in the field. This processing includes data reduction, pre-processing, analysis, and communications processing. An example of data reduction and pre-processing might be to take the 1 second loop detector counts and calculate an average occupancy for the preceding 1 minute interval. Preprocessing and analysis might include examining video data in the field and applying data compression algorithms to the raw video data. Finally, this element is responsible for encoding the collected surveillance data into an appropriate communications protocol for transmission.

c. Simulate Sensor Devices and Processing - this element is capable of simulating the outputs of field sensors. This function uses predicted traffic parameters as input and connverts them to sensor data. This element is also capable of indirectly receiving updates to various control strategies, so that changes are reflected in the simulated data.

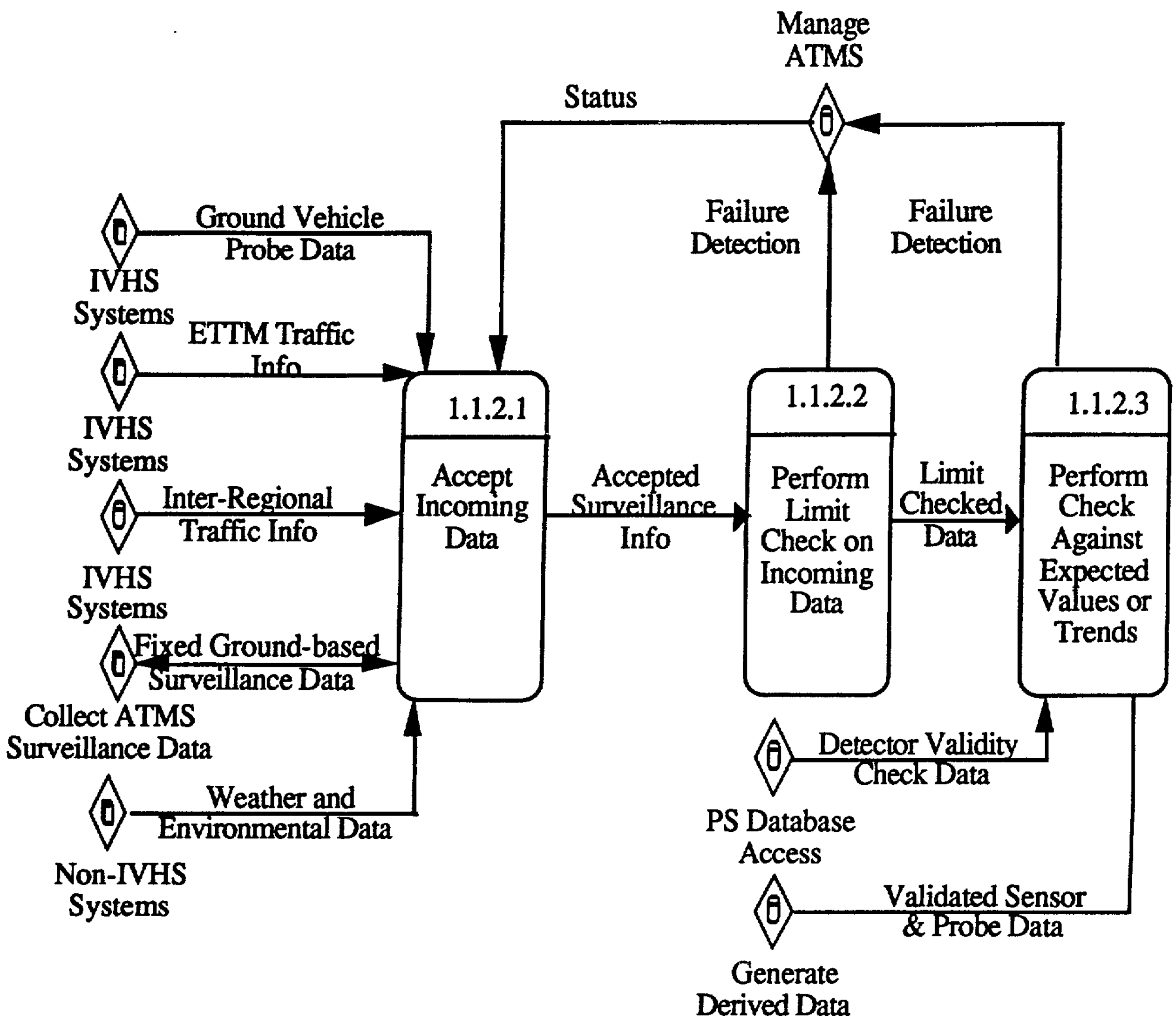


Figure 3-4. Perform Validity & Integrity Checks on Incoming Data

The Generate Derived Data component is the first element that begins transforming raw surveillance data into information not directly available from field surveillance. This component takes raw surveillance data, fuses the data from various sources, and transforms that data into higher level data such as link travel times, average queue lengths, and occupancies. Three basic types of derived values are generated: temporal aggregation, spatial aggregation, and unmeasured parameters. In the context of ATMS an unmeasured parameter is one where a point of information is derived from several different sources.

This component provides the fundamental information points that ATMS requires to function. This includes an overall view of the surveillance information that is useful in identifying potential traffic problems. This component is composed of the following elements:

a. Compute Sensor Period Counts - this element calculates vehicle counts for point detectors. It also generates these averages on an area-wide basis.

b. Compute Sensor, Link, and Area Time-Based Averages - this element is responsible for calculating link travel times and speeds from point detectors. These averages are not only on a per sensor'basis, but also include area-wide calculations.

c. Generate Aggregate Counts by Link or Area - this element combines count data and generates or extrapolates this data to a link or an area.

d. Fuse Link and Area Data Sources - this element is responsible for transforming the various surveillance inputs into a common data format for use by other ATMS applications.

e. Average Probe Link Traffic and Environmental Data - this element develops average link times and environmental information based on input from probe vehicles. Probes include vehicles of all types - passenger, emergency, and public transit vehicles. This element allows for the possibility that environmental monitoring is accomplished by vehicles and transmitted as part of the probe data.

f. Extract Link Traffic and Environmental Data from Probe Data - this element performs the initial processing on surveillance data transmitted from probe vehicles.

g. Extract Link Traffic Data from Video Feed - this element is responsible for calculating link travel times on the basis of video input.

Figure 3-6 illustrates the relationships between these elements.

The PS Database Access component is responsible for managing the input of received data into the system-wide database. It is responsible for maintaining real-time data buffers and data management.

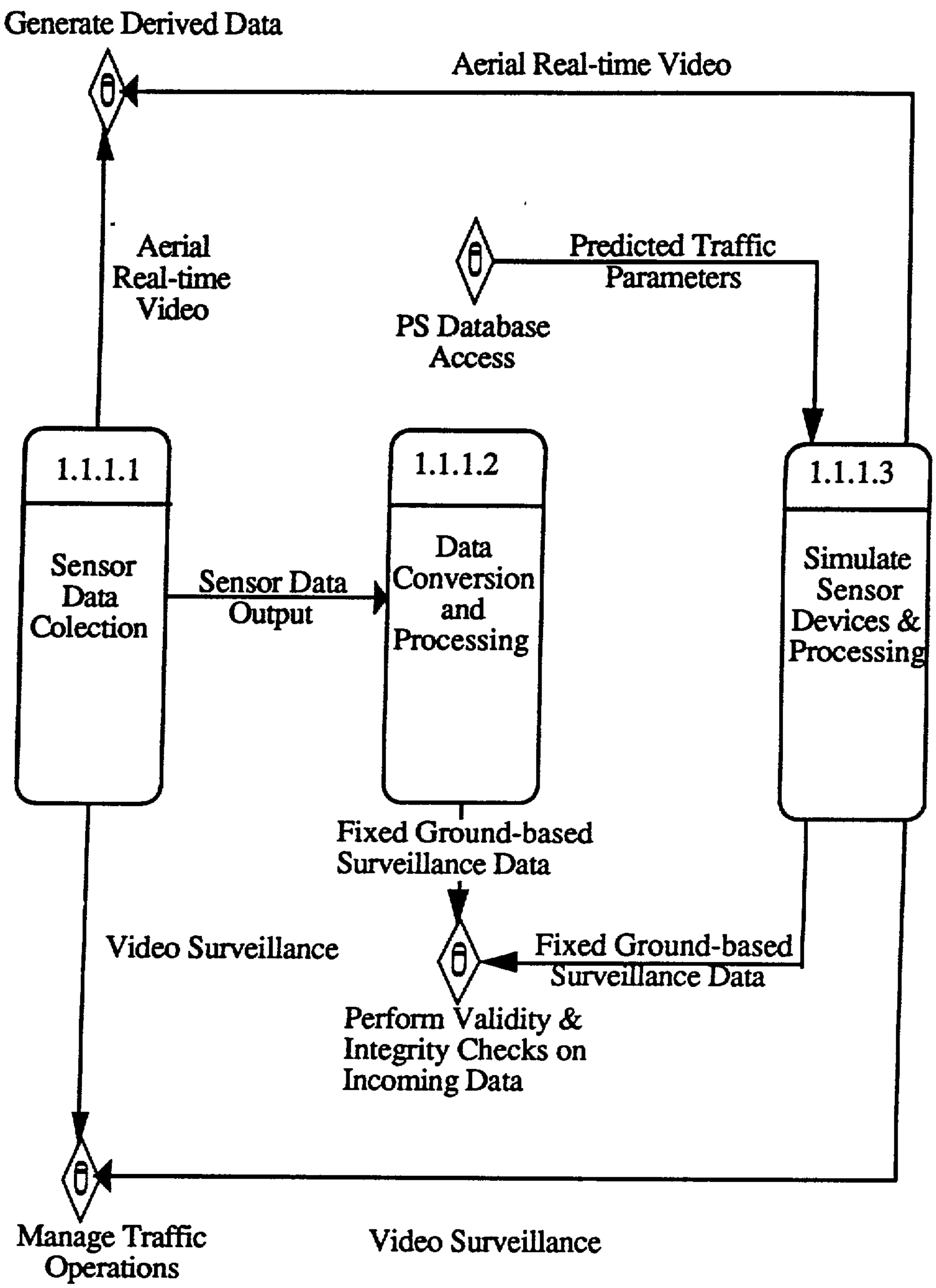


Figure 3-5. Collect ATMS Surveillance Data

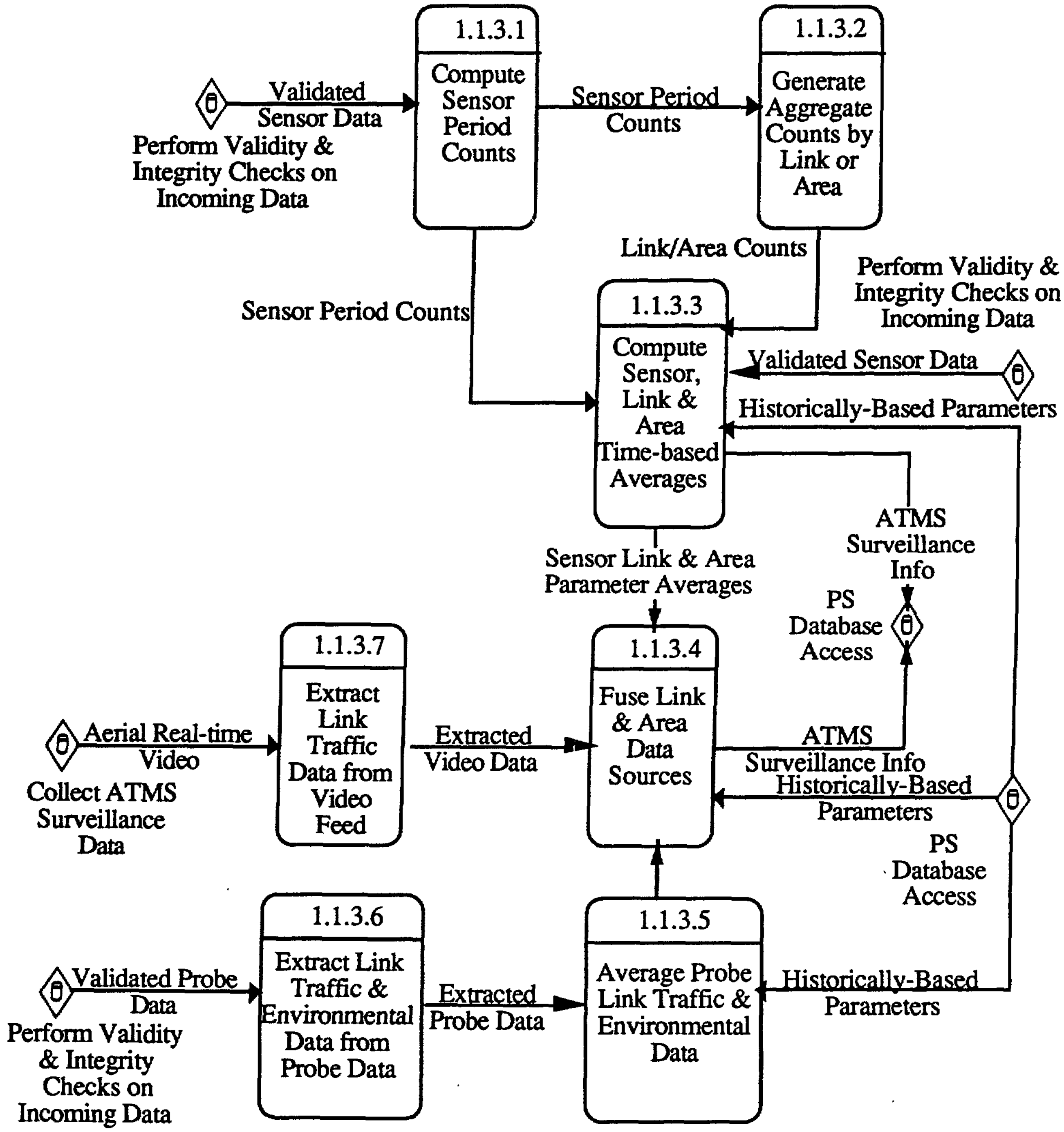


Figure 3-6. Generate Derived Data

3.2 Manage Traffic Operations

The role of the MTO function in the system is to control the traffic network's operation. At a high level, the function this subsystem provides is: assessments of the traffic network's current condition; developing control strategies for maintaining a high level of service; and implementing appropriate strategies. As shown in Figure 3-7, the MTO subsystem consists of the following components:

a. Assess Current Network Traffic Condition - this component is responsible for determining the difference between actual and expected traffic network conditions. It is also responsible for assessing if detected differences adversely impact traffic network operations.

b. Predict Traffic Conditions and Assess Effectiveness of Current Strategy - this component is the hub for the proactive control of the traffic network. It is responsible for predicting the future state of the network given current conditions and trends. It is important to note that the time horizon for this component is 5 to 10 minutes into the future.

c. Generate Integrated Traffic Management and/or Control Strategies - this component develops alternative strategies for improving the state of the traffic network. These strategies are developed on the basis of historically proven strategies adapted to current conditions. Integrated solutions for freeways and surface streets are sought to meet the objectives of different jurisdictions in the ATMS region.

d. Evaluate Strategies - this component is responsible for assessing the merit of traffic management strategies. It accomplishes this task by assessing the results of a strategy through the use of assorted evaluation models.

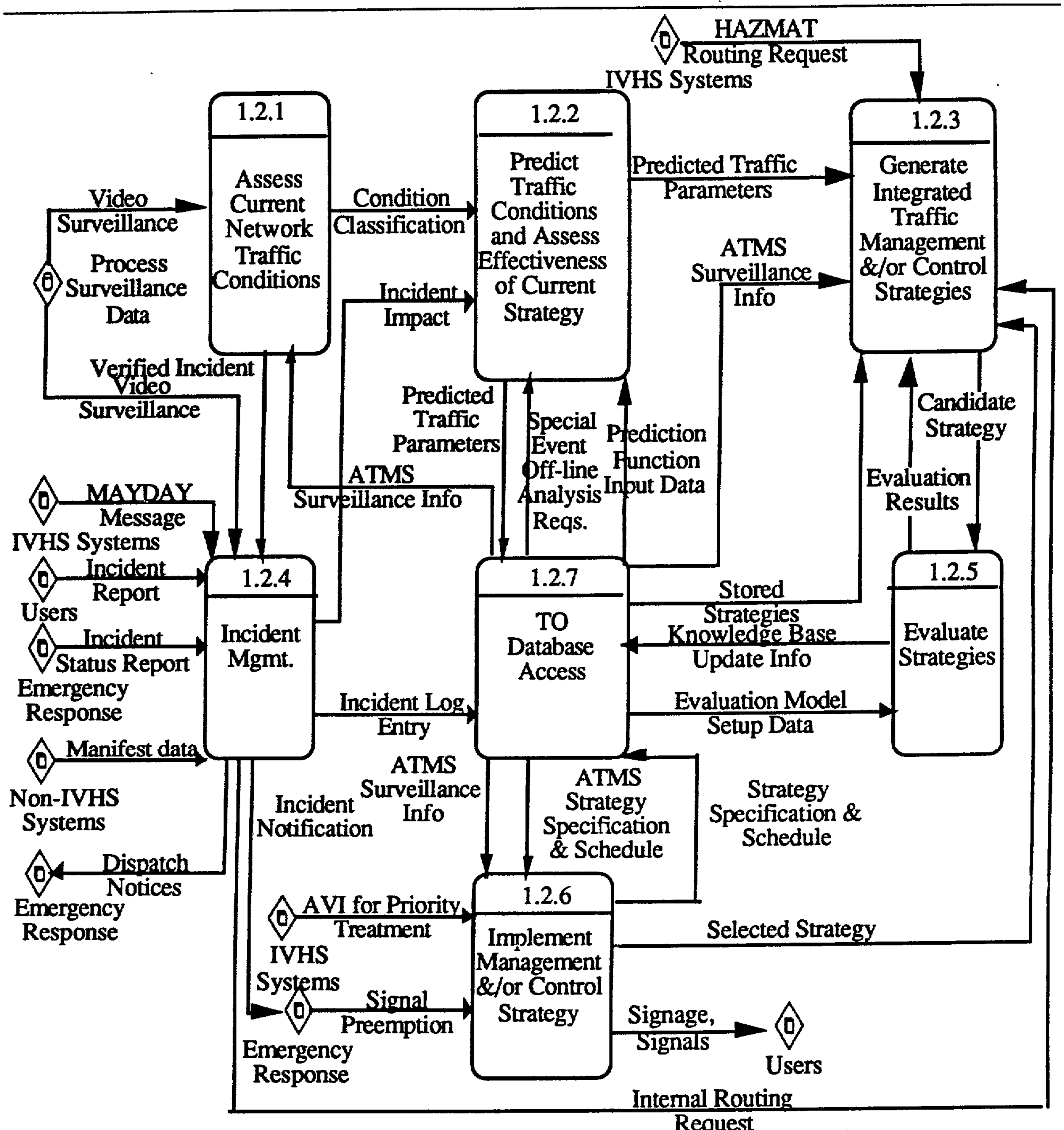
e. Incident Management and/or Control Strategy - this component provides the incident management capabilities of ATMS. When a disturbance in the traffic network is detected, this component verifies the incident, classifies the incident in terms of severity, dispatches and manages the initial response for emergency vehicles, and maintains estimates of the incident's duration.

f. Implement Management Strategy - this component transforms the selected control strategy into the individual commands required for control devices.

g. Traffic Operations (TO) Database Access - this component provides the database operations of retrieve, add, modify, and delete.

The Assess Current Network Traffic Condition component provides an expected versus actual state comparison used for evaluating the traffic network's performance. This component is composed of the following elements:

a. Detect Anomaly - this function detects flow anomalies resulting from either incidents or unplanned/unexpected capacity reducing (e.g., construction) or demand increasing (e.g., unplanned event) situations. Detection is accomplished through the use of an evolutionary, expected traffic network state model. This model is continually refined and expanded by adding anticipated changes (e.g., modifications in the control policy and expected events) and historical input.



Functions shown on this diagram are intended to include both area-wide strategy development as well as those strategies associated with localized control.

Figure 3-7. Manage Traffic Operations

b. Classify Anomaly and/or Traffic Conditions - this element assesses the differences detected by the expected/actual state comparison. In the event that the difference is evaluated as having a negative impact on the traffic network, it is flagged as a potential incident.

c. Incident Verification - in the event that an adverse difference is found in the expected and actual states, or a sensor believes there may be a potential incident, this element is responsible for verifying the incident's existence. Importantly, both this and the Incident Detection element handle incidents detected by sensors under ATMS control. It should also be noted that these activities occur in parallel to ATMS fault detection, isolation, and recovery activities.

d. Incident Detection under Low Volume Conditions - under low volume conditions, incidents cannot be detected by focusing on anomalies in the traffic stream. This function detects incidents through video output processing.

Figure 3-8 illustrates the relationships between these elements.

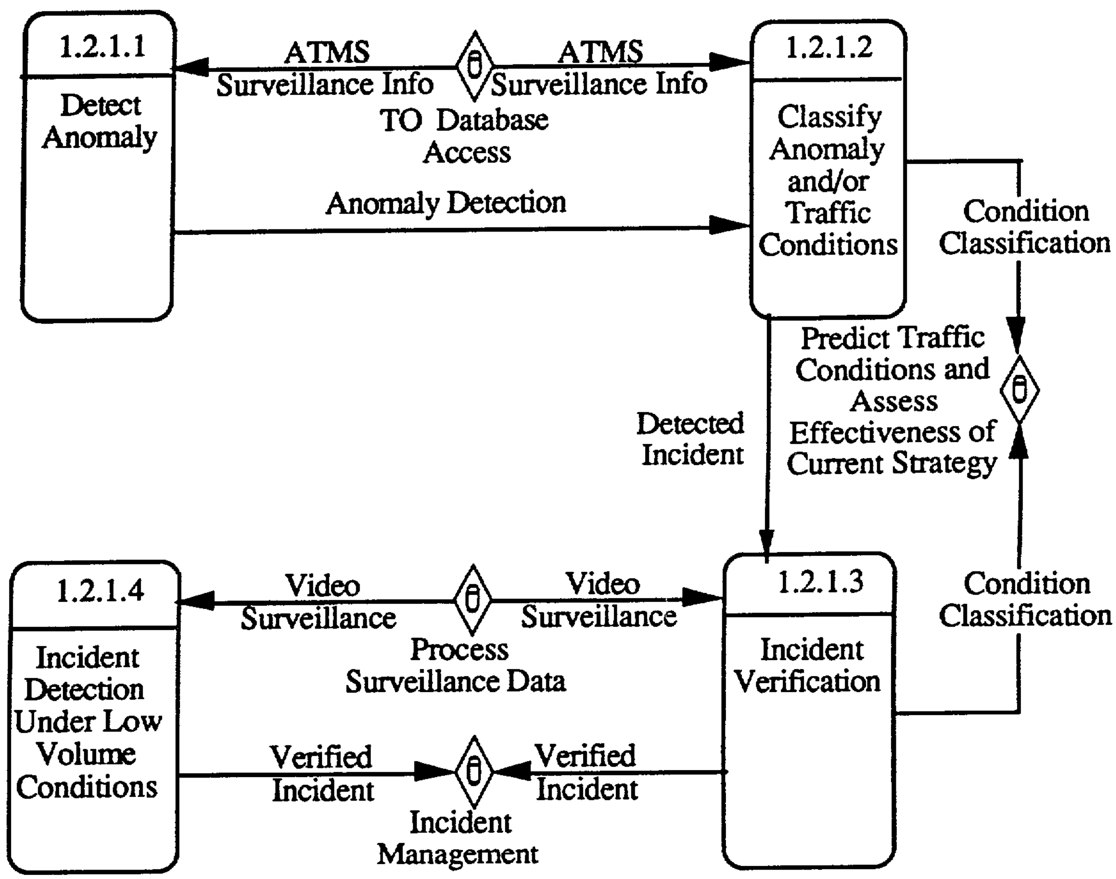


Figure 3-8. Assess Current Network Traffic Conditions

The Predict Traffic Conditions and Assess Effectiveness of Current Strategy component provides the mechanisms for proactively controlling the traffic network. This component is composed of the following elements:

a. Specify Effected Subnetwork - this element defines the area of interest for the forecast of expected traffic conditions. This area of interest could be the entire network, or subnetworks - specified either by the user or automatically by the system.

b. Determine Regional Network Traffic Loads - This function determines regional network traffic loads and essentially solves the traffic assignment problem. To the extent that incidents on the network have region-wide impacts, they are shown as input. The function is performed on-line (as a dynamic traffic assignment), but can also be performed off-line to support requirements analysis (e.g., developing flow predictions for special events planning).

c. Short-Term Predictions of Intersection Approach Volumes - this element develops short-term forecasts of anticipated link volumes by assuming that the current control strategy remains in effect and accounts for known future events. This is primarily prediction based on upstream link flows and is used for intersection control. The element will probably involve simulation and employ dynamic traffic assignment.

d. Medium-Term prediction of Subnetwork Link Volumes - this element receives the traffic assignment results and computes more detailed link traffic flow predictions using information on the current (i.e., employed) control strategy. Whereas the higher level predictions may use more general link impedance measures, this function attempts to specifically incorporate elements of the control system in determining the prediction. The prediction horizon is 5 to 10 minutes and involves prediction over integrated sections (i.e., surface street and freeways). The necessary parameters for the models are automatically retrieved from the database.

   This element receives as input the determined impact of the incident in terms of capacity reduction and duration, which is used in the prediction algorithm.

e. Compute MOEs Based on Current/Nominal Strategy - this element assesses the current control strategy by developing MOEs for the subnetwork.

These elements are shown in Figure 3-9.

The Generate Traffic Management Strategies component develops new control strategies. As shown in Figure 3- 10, this component is composed of the following elements:

a. Retrieve Alternate Strategies from Knowledge-Base - this element develops queries to retrieve strategies successfully used in the past. It performs this function by using manifestations of current conditions as the foundation for queries. For example, given a set of predicted traffic conditions, this function retrieves one or more candidate control or management strategies (i.e., integrated strategies) from a knowledge-base of historical cases. A CASE-based engine could be used for this purpose.

b. Adapt Retrieved Strategies to predicted Conditions - this element adapts retrieved strategy (with some level of human interaction) to the present situation leading to the generation of one or more candidate solutions for the present and predicted conditions. Each candidate strategy is evaluated (refer to 1.2.5 in Figure 3-6). The results are used in the adaptation process.

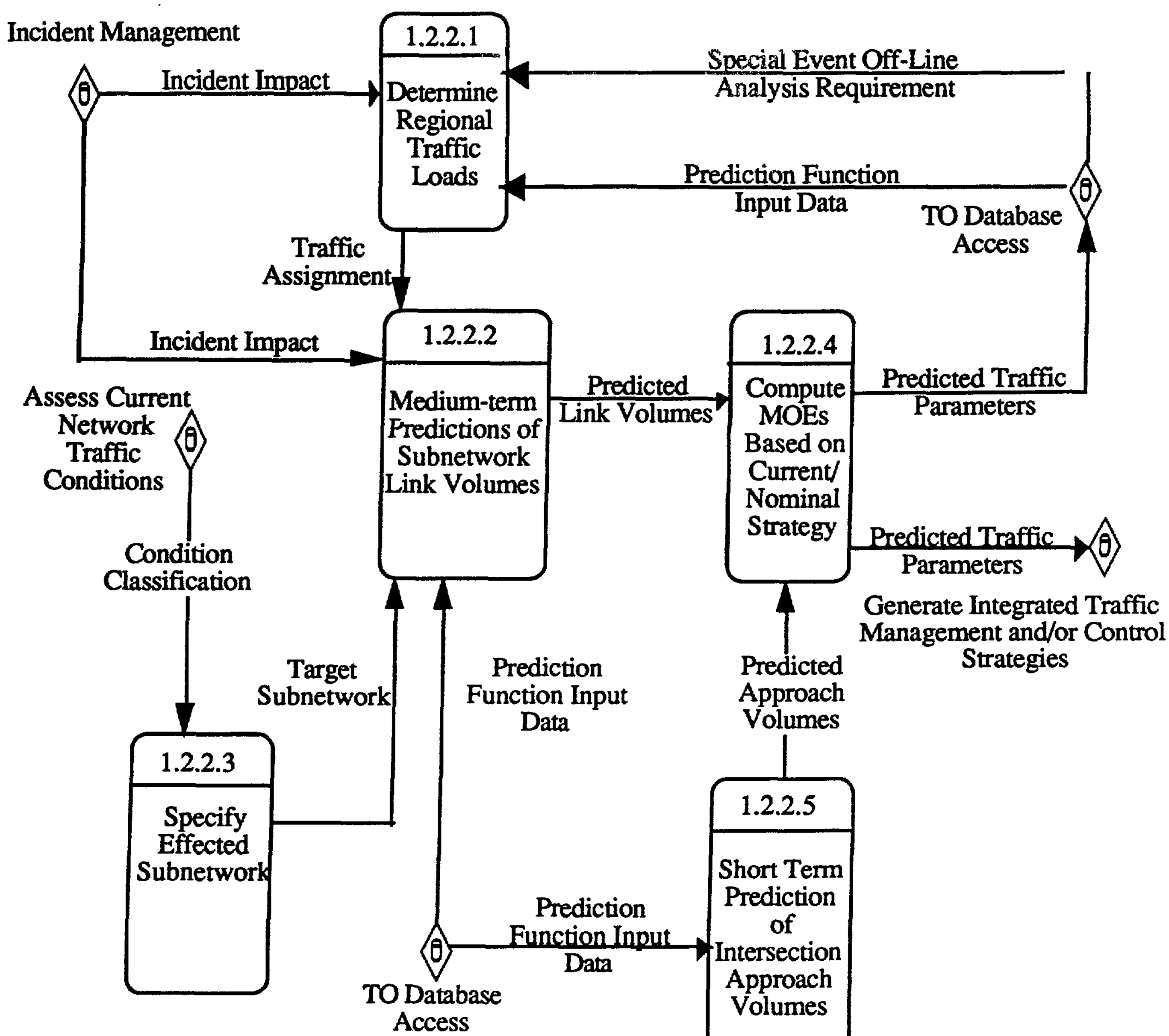


Figure 3-9. Predict Traffic Conditions and Assess Effectiveness of Current Strategy

The Evaluate Strategies component is responsible for selecting one of the generated strategies for implementation. The elements needed for this function are:

a. Select Evaluation Model - this element selects evaluation models appropriate for current traffic conditions.

b. Prepare Evaluation Models - this element is responsible for the pre-processing required to run the evaluation models. This element includes loading simulation parameters from the database.

c. Run Evaluation Models - this element executes and stores the results of the simulation.

d. Assess Results of Model Run - this element quantifies the results from each evaluation model executed and selects the appropriate control strategy.

These elements are shown in Figure 3-11.

The Implement Management Strategy component is responsible for executing the selected control strategy. As shown in Figure 3-12, this component consists of the following elements:

a. Determine ATMS Strategy Specification - given a particular strategy selection (e.g., a signal timing plan, route diversion), this function generates the command sequence for implementing the new plan. This function is normally a component of the traffic control system. In the context of integrated control however, this function assumes a broader role. For example, if a route diversion strategy is

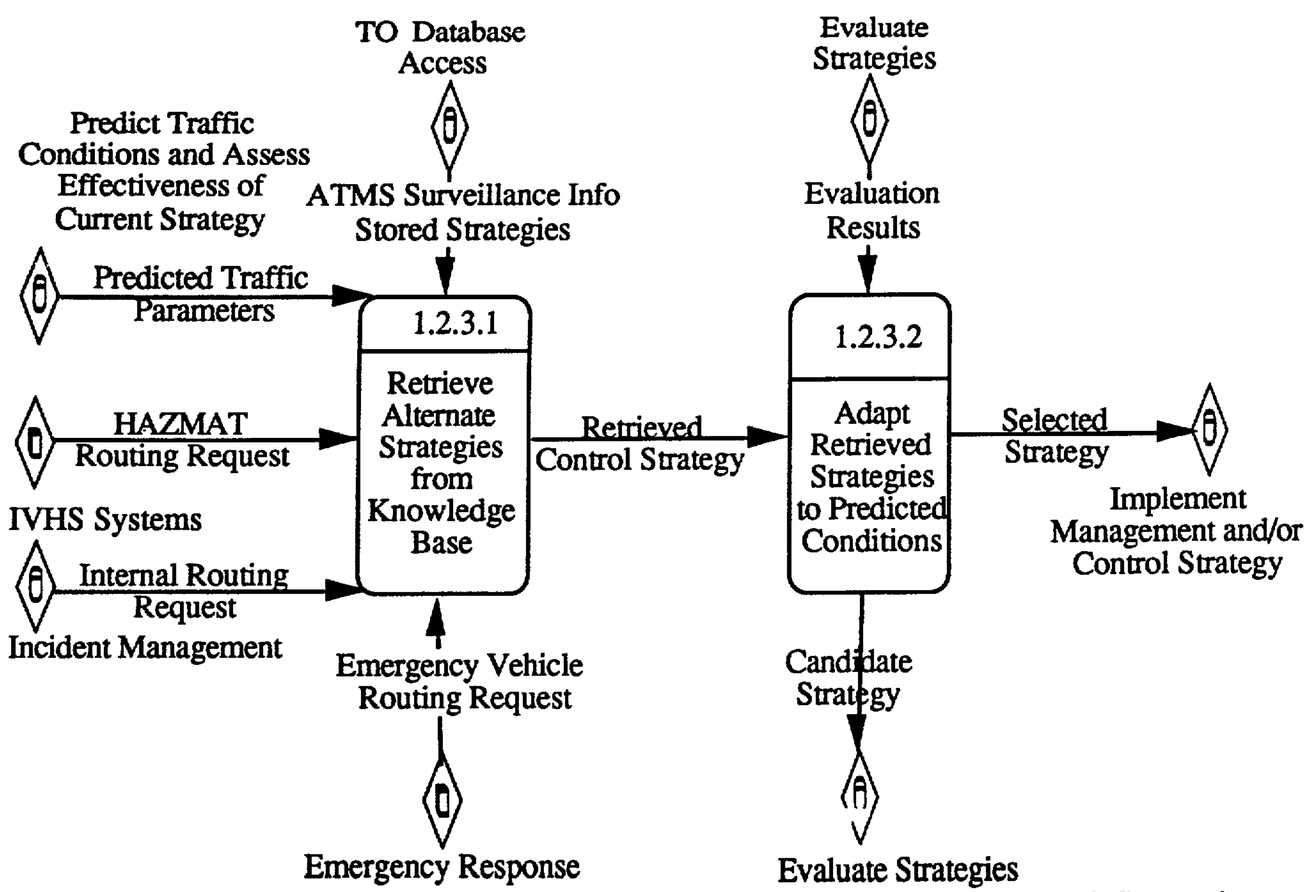


Figure 3-10. Generate Integrated Traffic Management and/or Control Strategies

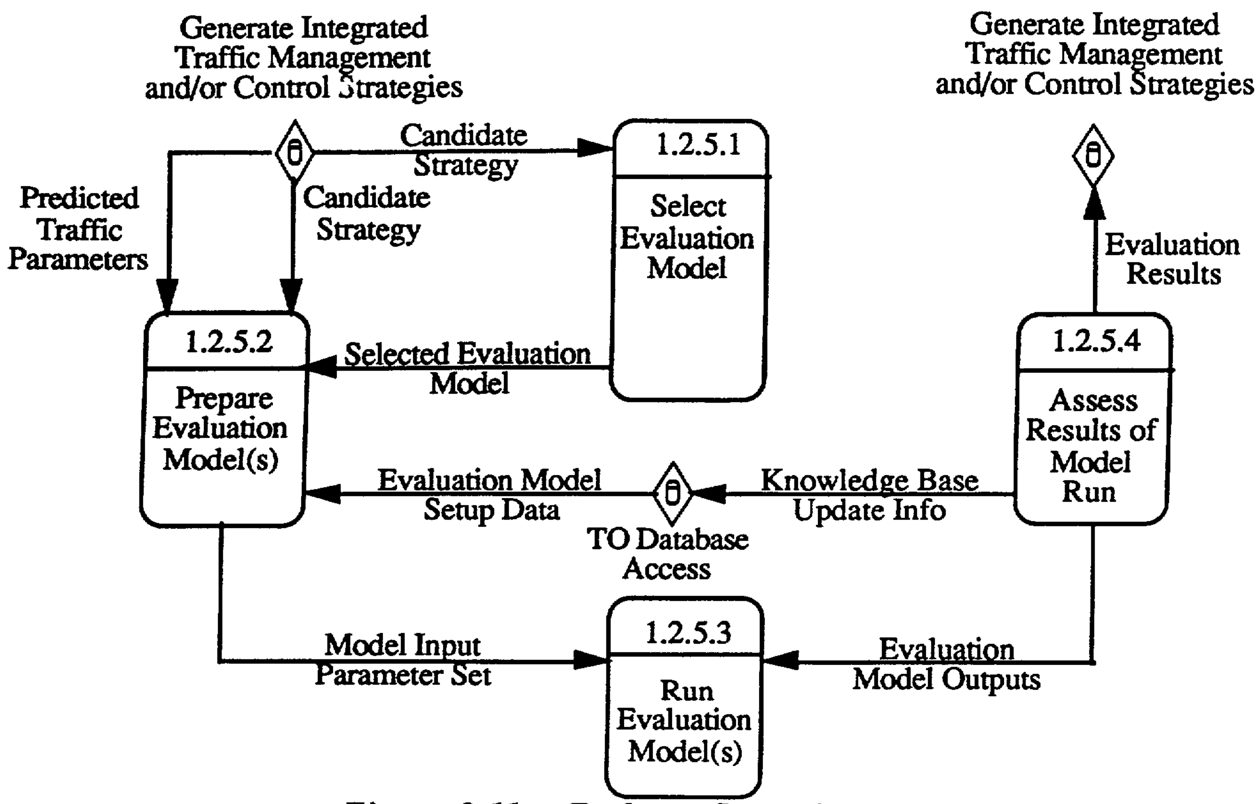


Figure 3-11. Evaluate Strategies

selected, several command sequences must be sent to the various physical components - a new timing plan may be necessary on the surface street network, a CMS ust be updated to direct the diversion, and a freeway on-ramp may be closed or slowed.

This function also supports the specification of strategies developed off-line for future use (e.g., a timing plan for a special event).

b. Determine Strategy Specification for External Systems - this element converts the component of the selected management strategy that will be executed by External Systems to a specification in accordance with agreed upon formats. Included in this function are such items as route selection through an ATIS interface.

c. Schedule On-Line Information Dissemination Activities - this element is responsible for scheduling information to ATMS External Systems.

d. Process Control System Commands - this element transforms the individual control system commands into bit patterns required by local controllers. This element represents the physical control system. It primarily includes controllers, signals, signs, and gates. This function is activated by the scheduler to execute a command sequence for a previously determined strategy (e.g., special event).

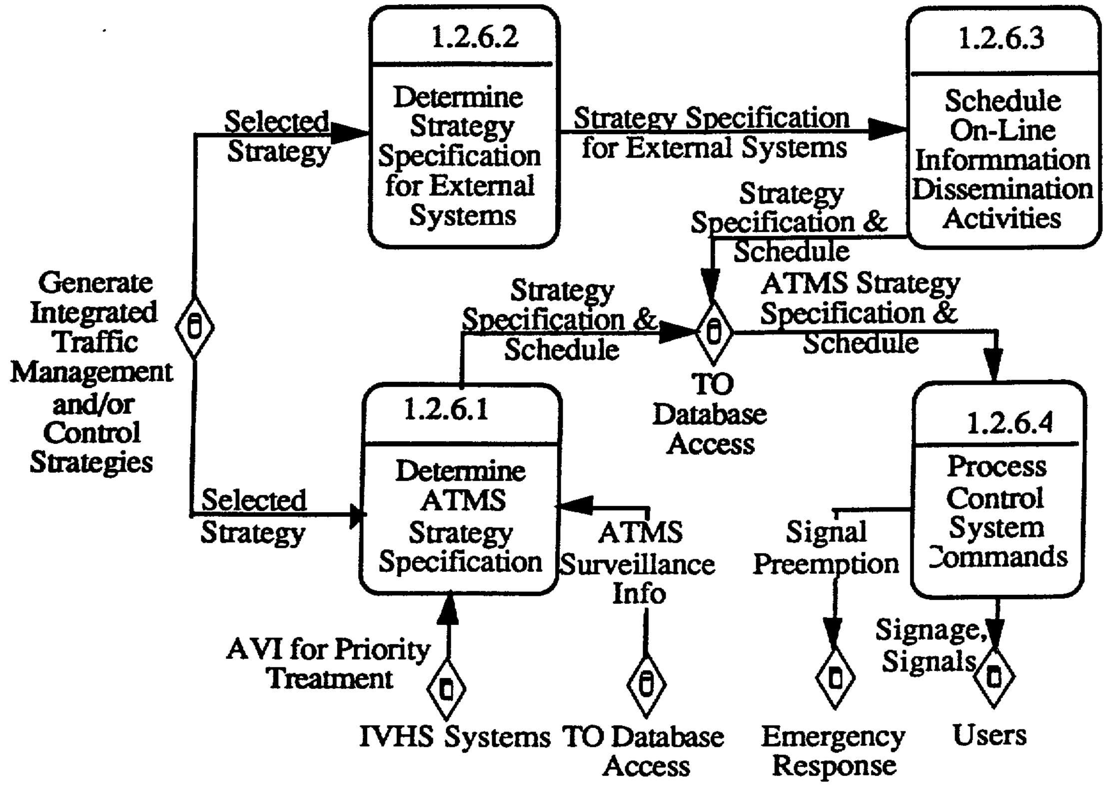


Figure 3-12. Implement Management Strategy

The Incident Management component supports the coordination of incident responses. It is concerned with the activities required for resolving incidents and returning the traffic network to its nominal state. It should be recognized that this component is not responsible for managing congestion resulting from the incident. Traffic management is handled by the previously described MTO components. The Incident Management component is composed of the following elements:

a. Process Incident Reports and Verify Incident - this element is responsible for receiving and verifying incidents detected by non-ATMS controlled surveillance assets. An example of these assets would include motorist telephone calls.

b. Classify Incident and Severity - this element determines incident severity and develops a plan used for the initial response to the incident.

c. Dispatch Emergency Services - this element alerts and dispatches required emergency vehicles to the incident scene.

d. Generate Routing Request for Incident Response Units - on the basis of the assets dispatched to the incident, this element provides routing requests for each dispatched unit.

e. Maintain an Incident Log - this element maintains an historical record of ATMS's response to an incident for post-event evaluation.

f. Estimate Incident Duration and Capacity Impact - using incident status reports transmitted from the field, historical records, and the current state of the traffic network, this element generates estimates of incident duration and impact to the traffic network.

Figure 3-13 illustrates the relationships between these elements.

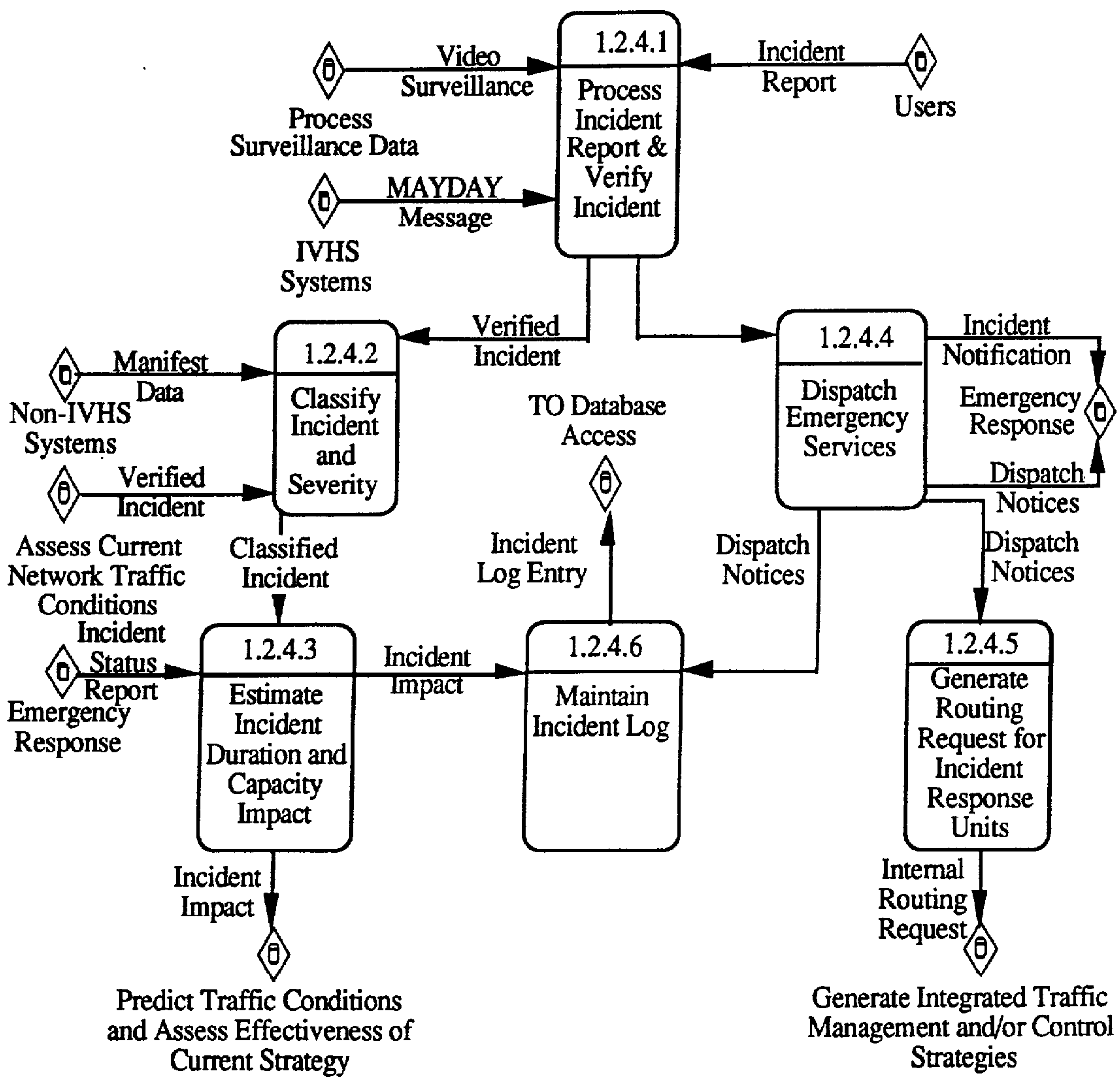


Figure 3-13. Incident Management

3.3 Manage ATMS

The Manage ATMS subsystem is responsible for monitoring and controlling ATMS assets. These assets include: hardware, software database; personnel resources; policy and procedures; budgets and plans; and roadway infrastructure need to operate the system. As shown in Figure 3-14, this subsystem is composed of the following components:

a. Manage Personnel Resources - this component includes all the functionality required for managing ATMS human resources. Included in this component are training, personnel scheduling, and administrative tracking.

b. Manage Hardware, Software, and Databases - this component is responsible for monitoring and assessing ATMS assets. This component manages the computers, software, and databases resident in ATMS. It is also responsible for managing assets located in field, such as sensors, communications gear, signals, and controllers.

c. Manage Roadway Infrastructure - this component is responsible for monitoring the state of the roads that make up the traffic network. In the event a repair is required, ATMS also dispatches the appropriate maintenance assets.

d. Manage Policies and Procedures - this component is responsible for supporting the generation of operational tactics based on the policies and procedures supplied by external organizations. It also supports the generation and evaluation of new policies.

e. Manage Budget and Plans - this component provides the financial support for ATMS.

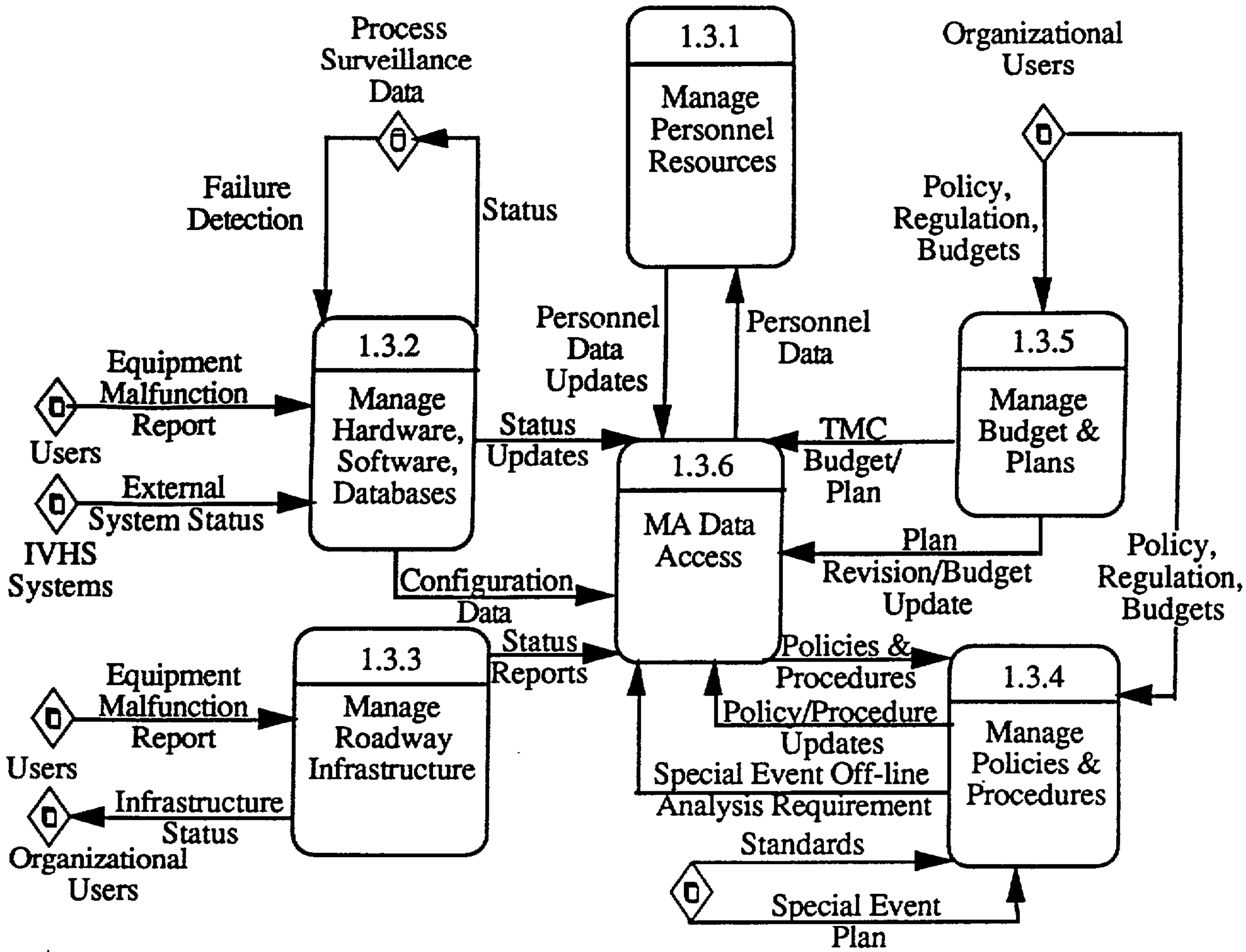
f. MA Database Access - this component provides the database operations of retrieval, modify, add, and delete for this subsystem.

With the exception of Manage Hardware, Software, and Databases these components are highly sensitive to individual jurisdiction requirements. For this reason, Manage Hardware, Software, Databases is the only component covered in more depth in this report.

The purpose of the Manage Hardware, Software, and Databases component is to assess system performance, maintain the system, and identify and implement system enhancements. It is important to note that all of these activities require both real-time and off-line support. It is anticipated that automation to assist in self-monitoring and diagnosis will be required in some cases. This component is composed of the following elements:

a. Monitor and Diagnose Surveillance and Control Equipment - this element is responsible for assessing the performance of the surveillance and control systems. In addition to real-time monitoring of these assets, this element is also responsible for long- and short-term trend analysis. In the event of a failure, this element isolates the fault and develops recommendations for returning the device to service.

b. Monitor and Diagnose Communication System - this element is responsible for managing the communication system for External Systems. Similar to the preceding elements, this function provides real-time and off-line support for



.c8.Figure 3-14. Manage ATMS

evaluating the communication system's performance. Activities supported by this element include configuring the networks, fault detection and isolation, mean time to failure calculations, and network security management.

c. Monitor and Diagnose TMC Hardware and Network - this element is responsible managing the hardware and network assets physically located within the TMC. Determining mean time to failure and repair are performed in this element.

d. Monitor Software Performance - this element manages the software running in ATMS. It is responsible for detecting and categorizing software faults.

e. Monitor Databases - this element assesses ATMS database elements.

f. Log Failure and Schedule Maintenance and Repair Activities - this element maintains a record of all ATMS failures. This includes regular maintenance and repair type activities. In addition, it works cooperatively with the Perform Maintenance and Repair Activities element to schedule maintenance and repair.

g. Send Equipment Status - this element is responsible for keeping the system informed about failures and expected time of return to normal operation.

h. Configuration and Inventory Management - this element is responsible for ATMS configuration control. It keeps and maintains a record of current hardware, equipment status, and current versions of software.

i. Perform Maintenance and Repair Activities - this element has both real-time and off-line aspects. Real-time activities of this element include: repair activities for hardware and software (encompassing activity repair planning and scheduling). This includes the development of plans for temporary repairs (e.g., “work-arounds” or patches) and longer term permanent repairs. The off-line aspect of this element is maintenance in the systems engineering sense. This includes activities such as developing and testing improvements to the current system, and determining the mean time for repair of various assets.

j. Manage Databases - this element provides the functionality typically found in a Database Management System (DBMS). This includes maintaining the integrity of the database, defining user access rights, database backups, and database maintenance.

k. Access Database - this element is responsible for querying the database and providing necessary data to the Monitor Database(s), Manage Database(s), Send Equipment Status, and Perform Maintenance and Repair Activities elements.

The elements comprising the Manage Hardware, Software, and Databases component are illustrated in Figure 3-15.

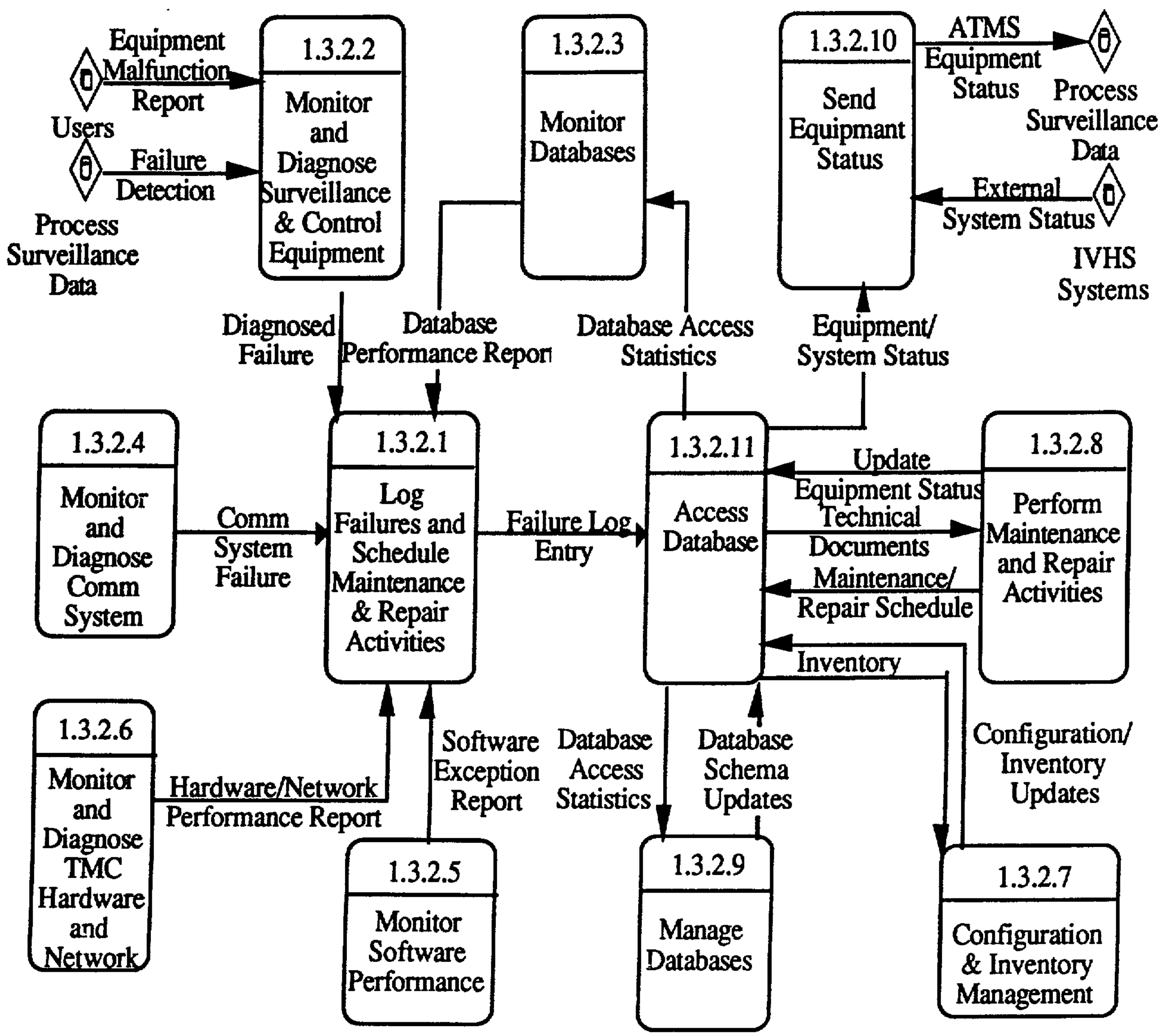


Figure 3-15. Manage Hardware, Software, Databases

3.4 Disseminate Information

The Disseminate Information subsystem ensures that data requirements for external entities are met. It is responsible for accepting requests, scheduling the processing required to respond to the request, and scheduling and transmitting the response. This subsystem is composed of the following components:

a. Schedule Regular Output Dissemination - this function includes an event scheduler for ATMS output dissemination to External Systems on a fixed schedule. Events can be prioritized with the highest priority corresponding to real-time requirements (e.g. traffic information dissemination to ATIS). If a request requires off-line analysis, it is forward to the MTO function which includes both on-line and off-line modeling capabilities.

b. Process ***Ad Hoc*** Requests for Information - this component is responsible for receiving information requests. There are two types of requests entering the system. The first type is a “standing order”. An example of this type of request would be to routinely transmit traffic network status to ATIS every minute. The second type of request is ad hoc. An example of an ad hoc request would be a request by the county council to assess the impact of adding an additional HOV lane.

c. Process Scheduled Data for Dissemination to External Systems - this component is responsible for assessing the processing requirements to respond to the request and scheduling the appropriate resources for the processing. In addition, this element schedules the transmission of the response to the requester.

d. Interface to External Systems - this component is responsible for transmitting the response to the requester.

e. DI Database Access - this function manages the retrieval and update of information used by the DI subsystem.

Figure 3-15 illustrates the relationships between each of these elements.

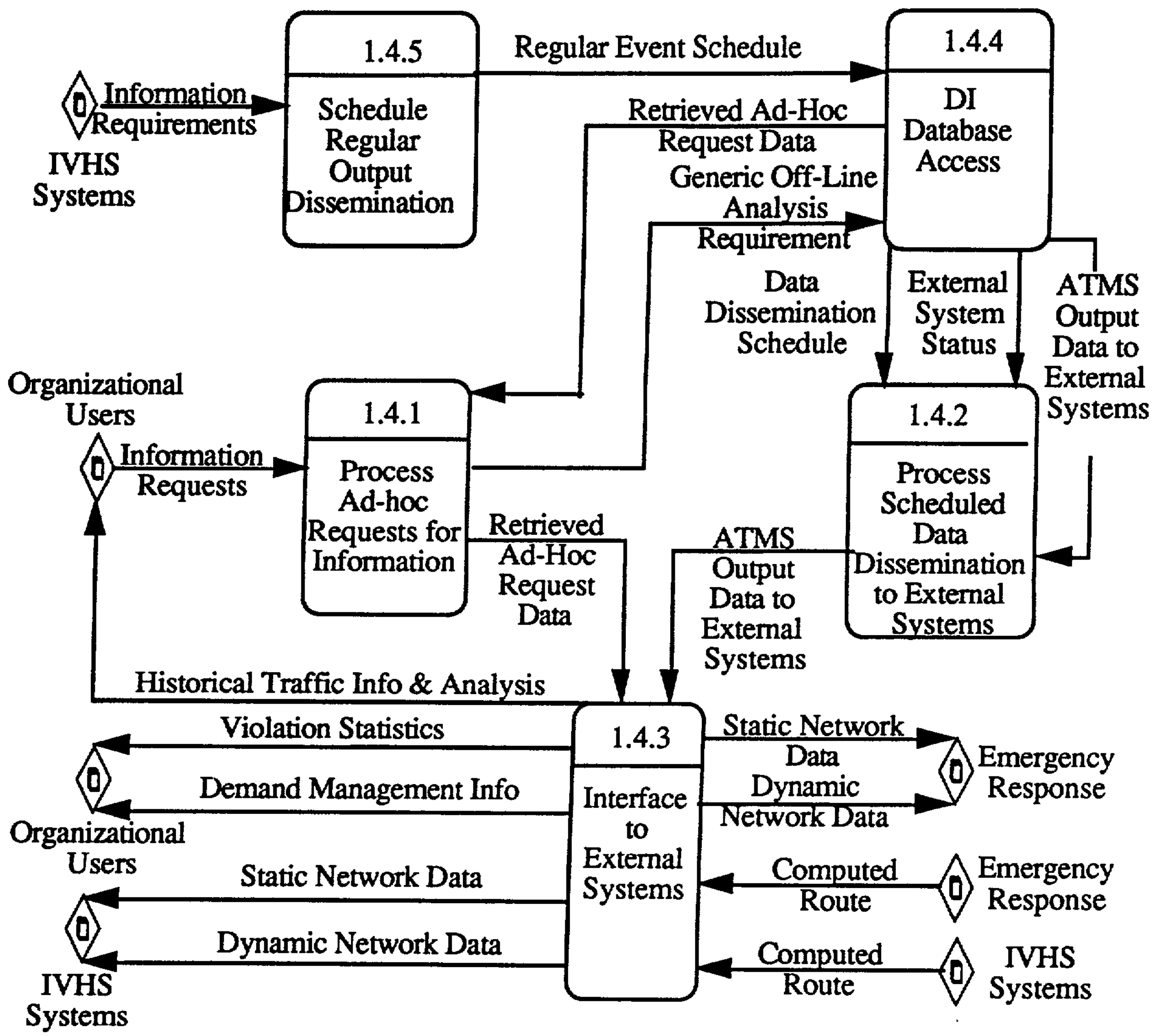


Figure 3-15. Disseminate Information

4.0 OPERATIONAL SCENARIOS

This section presents several scenarios demonstrating ATMS operations. These scenarios are a tool for demonstrating the role of each subsystem in the ATMS architecture. The format for presenting the scenarios will be to first set the context by presenting the underlying conditions setting the stage for the scenario. Next, environmental changes causing system action will be presented. The narrative will then describe the role of each subsystem by describing the source and content of input, processing performed on the input, output resulting from the processing, and resulting changes in the environment. This analysis will demonstrate our vision of ATMS operations.

For the purpose of this demonstration, four scenarios are presented. The first demonstrates system behavior during nominal operations. Using the normal operations scenario as a baseline, differences in the operation of the system are highlighted in the remaining scenarios. The second scenario details the role each component plays while detecting and managing a major incident. The third scenario demonstrates system actions when used in an off-line planning mode. The section concludes with a scenario where the operations staff use system-provided tools to evaluate a proposed enhancement to the system.

4.1 Normal Operations Scenario

This scenario depicts routine system operations. The basic conditions for this scenario are:

a. It is a normal Wednesday rush hour.

b. There is the normal recurrent congestion. There are normal problems such as motorists breakdowns and failed control units.

c. There are no out-of-the-ordinary conditions, such as a major incident or abnormal weather conditions.

d. The traffic network being controlled is a wide-area network composed of both the surface streets and freeways of a large urban area. There are, however, two TMCs, one for the surface street network, while the other controls the freeway network.

e. The surveillance network is a suite of loop detectors, video cameras, and probe vehicles. The video cameras being used are on fixed platforms located throughout the network. The traffic network is divided into quadrants patrolled by video camera-equipped helicopters. All cameras provide pan, tilt, and zoom capabilities that can be commanded remotely by the TMC. There are a significant number of probe vehicles located in the network. These probes include police and public works vehicles, supplemented by several thousand privately owned vehicles.

In this scenario, the system is operating in a highly autonomous mode. The Process Surveillance subsystem is collecting surveillance data and populating the ATMS Integrated Database. The MTO subsystem is proactively controlling the traffic network through control strategies based on forecasts generated once per minute for the next five minutes. The MA subsystem is monitoring all ATMS components and all assets are performing nominally. The DI subsystem is broadcasting traffic network status data once every minute. An in-depth examination of each subsystem is contained in the following paragraphs.

4.1.1 Process Surveillance Data

Loop detector and video data is being gathered by the Collect ATMS Surveillance component of the PSD subsystem. In this case, the loop detectors are being polled on a once per second basis. The loop detector data is being transmitted to the appropriate TMC at 1 second intervals. The video data from both the fixed and airborne cameras is being locally compressed. In this locality, the control units and fixed video cameras are networked through a fiber-optic backbone, video data from the airborne assets are transmitted directly to the TMC through a radio link. This data is received by the Perform Validity and Integrity Checks component. Additionally, this component is receiving data from the probe vehicles. For each data element received, the communications protocol overhead data is fiit removed. This removal process ensures that no errors were introduced into the data during the transmission process. Additionally, integrity checks are performed to ensure that the data from the sensor is valid; if anomalous data is found, failures are logged.

There is special processing for the loop detector, video, and probe data. For the loop detector data, a high/low limit check is first performed. This check consists of verifying that the received data is within a predefined range of legitimate data values. Next, the loop data is examined to determine if there has been a large change in the data value from the preceding sample. Special processing of the video data involves decompressing the received data. After the data is decompressed, the quality of the image is assessed. In the case of probe data, the data packet is examined to ensure that the packet was transmitted from a legitimate probe. Finally, for all classes of incoming data a comparison of expected versus actual value for each data point is performed. At this time all data appears nominal.

Once the initial assessment of the incoming data determines that the received data is of good quality, derived data values are developed. In the case of the loop detectors, individual count data is computed for one minute intervals. This value is then used to compute the count for each link in the network. Simultaneously, video data is examined to extract the number of vehicles in each image. Then, these counts are aggregated and averaged in a manner similar to the loop detector data. The data packets from the probe are also processed to extract the link identifier, speed, and time. These data points are then compared with data from other probes and duplicate data values are removed. After this process the link speeds are averaged. After the loop, video, and probe averages are determined they are then time synchronized and compared for consistency. Data fusion algorithms are then used to generate a consistent set of values for each link in the network. These values are then loaded into the database. In the event of inconsistencies in the data, or data errors, a message is transmitted to the MA subsystem to begin diagnostic routines.

4.1.2 Manage Traffic Operations

The MTO subsystem now retrieves the data from the ATMS Integrated Database. In the normal case (i.e., no incidents), this subsystem first verifies that the predicted state of the traffic network for the time period of interest is consistent with observed conditions. In this scenario, a comparison is done by recalculating the Measures of Effectiveness (MOE) using actual observed data and comparing the numbers with predicted MOEs. In the event of a discrepancy, the discrepancy is analyzed to determine if there is a potential incident or if there was an error in generating the state prediction. At present, there are no discrepancies.

Once it has been determined that current and predicted conditions match, a new prediction is generated for 5 minutes from the current time. In the implementation for this scenario, this prediction is made by computing a weighted average that includes historical time slices taken from five previous Wednesdays at the same time, and traffic growth patterns for the previous 20 minutes. After these predicted counts have been generated, a set of MOEs are developed assuming that the control strategy in effect is maintained.

After predicted traffic parameters are calculated, a query request for potential control strategies is issued to the Control Strategy Knowledge-Base segment of the ATMS database. For the purposes of this scenario, this query is formed using the expected traffic parameters, time, day of week, and current weather conditions. In response to this query six alternative strategies are returned. These six strategies are examined to determine if one is equivalent to the current strategy. If the current strategy is not a member of the returned set, it is added to the set. Since none of the returned strategies exactly match the input characteristics, they are all modified accordingly.

This set of control strategies is then evaluated to select a strategy for implementation. In this scenario, this evaluation is done through the use of simulation tools capable of running in hyper real-time. These models are populated with data such as expected traffic parameters and roadway configurations. Once the results of these simulations are determined, a sensitivity analysis is performed on the input data. The results of all of these runs are then scored and the highest ranking alternative is selected for implementation.

Two distinct activities are involved in implementing the selected strategy. One is to apprise external entities of the change in the current strategy, the other is to develop the tactical operations needed to effect the strategy. Both functions are the responsibility of the Implement Management Strategy component.

The actual dissemination of the selected strategy is the responsibility of the DI subsystem. The Implement Management Strategy component of the MTO subsystem provides support by determining the content of the message to be transmitted. In addition to determining content, the Implement Strategy component is responsible for assigning a time for the implementation and scheduling the release of an advisory message. The Implement Management Strategy is also responsible for translating the selected strategy into the bit patterns required for field control devices.

4.1.3 Manage ATMS

The role of the MA subsystem is to monitor and control ATMS. These functions are performed in both real-time and off-line modes. During real-time, MA monitors and controls the hardware, software, and databases required for ATMS operation. In addition, ATMS is also responsible for monitoring the physical status of the roadways contained within the traffic network. Off-line activities involve managing and training the people operating ATMS, developing operations policies and procedures, developing requirements for and maintaining capital and operating budgets, and maintaining ATMS databases. The remainder of this section will focus on real-time activities during normal operations. The activities that occur during failure conditions are discussed in the Incident Management Scenario, Section 4.2.

One key real-time activity is monitoring the performance of the surveillance equipment. This is done in two ways by the Manage Hardware, Software, and Databases component. First, the analysis of the data content done by the Process Surveillance Data subsystem is amplified by broadening the time reference for the analysis. Second, this subsystem also examines the equipment status data for correct operation. This analysis also includes a short-term trend analysis of the status data to detect gradual degradations in the performance of network sensors. In addition, this subsystem verifies that commands issued to the control system execute as expected.

In addition to monitoring the performance of the surveillance and control network, the MA subsystem also monitors the communications systems used by ATMS. The Monitor and Diagnose Communication System element analyzes communications systems used for communicating with entities located physically outside the TMC. These systems include the surveillance and control network, logically within ATMS, and the interfaces to external entities. This element monitors communications errors and their frequency.

Monitoring and diagnosing communications systems within the TMC is the responsibility of the Monitor and Diagnose TMC Hardware and Network. This element is responsible for the TMC's Local Area Network (LAN) and computers. In the context of this scenario, the status messages are transmitted among the TMC computers every 30 seconds. These are known as "keep alive" messages. This element also assesses the performance and the availability of ATMS resources. For example, this element is responsible for determining that ample disk space exists to support current operations. In the event that there is insufficient space, this element executes archive procedures.

During operations, the performance of ATMS software and databases is monitored. In this scenario, software monitoring is accomplished through an automated procedure that polls each of the processors for active processes. This list is then compared with the record maintained by the Configuration and Inventory Management element. In the event of a failure, the fault is logged and an attempt to automatically restart the missing process is attempted. Assuming this fails, all processes running on the computer where the failed process is located are shifted to a redundant processor. At this point, the processor is placed in an off-line mode and diagnostic procedures are executed. Database monitoring consists of verifying that all read and write operations complete nominally.

A record describing the current configuration of the system is maintained by the Configuration and Inventory Management element. This record is the basis for monitoring and diagnostic activities.

4.1.4 Disseminate Information

Another major aspect of this normal operations scenario is carried out by the DI subsystem of ATMS. It provides the interface between ATMS and its users. It disseminates traffic 'and other information to the external systems for their use. For example, the state of the traffic network is transmitted on a periodic basis. IVHS External Systems will retrieve the disseminated traffic network data and then further process it in order to do the trip planning and route selection. Historical traffic data are retrieved by the organizational users for their use and so forth.

4.2 Incident Management Scenario

The incident management scenario depicts the operation of the system during a major road network incident. With the exception of the incident, the same assumptions used for the normal operations scenario arc used. For the purpose of this scenario, it is also assumed that ATMS is responsible for managing the incident until the police arrive on the scene. At this time, ATMS becomes a coordinating agent responsible for assisting the police in resolving the incident and managing traffic.

4.2.1 Incident Detection

In this scenario, the system is operating as described in the normal operations scenario. The PSD subsystem collects data through physical sensor devices, and performs data conversion and processing. The PSD subsystem performs data validity checks and stores the data in the ATMS Integrated Database where data is retrievable by other system component:. The first indication that the TMC receives is a heart beat from the freeway loop detectors indicating their on-line presence. Next, the data from the detector is ingested and validated. At this point in time the nature of the problem is ambiguous, it is possible that them is an incident or the sensor has failed. Because of the ambiguity of the data, the data is flagged as ambiguous and incident verification and sensor diagnostic routines are begun.

The Incident Verification element of the Assess Current Traffic Conditions component is responsible for assessing the probability that an incident has occurred. In this case, a video camera is used for incident verification. The system automatically trains the camera on the suspect loop detectors location. The incoming video is fed to an image processing algorithm that is capable of analyzing the video. This analysis results in a determination that vehicles are stopped in the lane. Subsequently, an alarm is generated to alert the operator to the problem. The operator is then able to view the scene on the operations console and assess the extent of the incident.

While the preceding activity was occurring, the MA subsystem was assessing the health of the sensor. In this case, the diagnostic routine consisted of examining the output of upstream, downstream, and adjacent loop detectors. All indications are that the output of the sensor is correct.

Once the existence of the incident is verified, the operator uses the video to determine that:

a. There is a major freeway accident in the predominant direction of flow.

b. All but one lane is closed in the predominant direction of flow because of an overturned tanker truck.

4.2.2 Incident Management

Based on the previous observations, the operator immediately broadcasts a “flash” alert to all members of the ATMS network. This includes all IVHS entities and emergency services. This message is composed automatically as a result of the video incident verification routine. Through a database query, the text for the message was retrieved and updated with the location of the loop detector. The operator scans the message and authorizes its transmission. The DI subsystem is responsible for transmitting all messages to appropriate parties.

The police and fire departments respond electronically with a message apprising ATMS of the units initially responding to the incident and their current locations. ATMS takes this information and develops a route for these units. These routes are initially developed using historical information describing the anticipated behavior of the traffic network. The routes are digitally transmitted directly to the responding units through a dedicated a radio link. The freeway TMC next alerts the surface street TMC of the problem. The surface street TMC begins tracking the responding units and preempts signals in favor of the emergency vehicles. This continues until the vehicles enter the freeway.

While emergency vehicles are en route to the accident scene, the freeway TMC operator zooms the video camera onto the overturned truck and is able to view the U.S. DOT number identifying the truck The operator then formulates a query to the national database asking for the vehicle's cargo manifest. In response, the operator is apprised that the tanker's cargo is gasoline. This information is relayed to the police and fire departments, who respond with additional support. In addition, a HAZMAT removal team is informed of the incident and dispatched with the location, a route, and the probable dangerous material involved. Based on an analysis of the scene, the operator dispatches the nearest heavy-duty tow truck.

At this time, the first policeman arrives on the scene and informs the TMC operator that there are also two other damaged vehicles that were obscured from the camera view. The TMC operator then dispatches additional tow trucks. The officer then reports that due to the seriousness of the accident, this portion of the freeway will be blocked for several hours and that they arc closing the freeway in both directions for an indeterminate period. The operator takes this input and broadcasts a message alerting the network that the freeway will be closed in both directions between the appropriate entrances and exits. This input is also provided to the MTO subsystem. During the remainder of the incident, the TMC is in constant communication and is receiving continuous updates regarding incident status. These messages are then passed to other interested parties. In addition, the TMC assists in dispatching and routing additional emergency response units as required.

4.2.3 Traffic Management

In addition to managing the initial response to the incident, ATMS is responsible for managing the traffic network. This involves two separate problems: managing the traffic surrounding the accident scene; and managing the rest of the traffic network. With the exception of the subnetwork immediately surrounding traffic network, operations continue as normal. The incident subnetwork is monitored and controlled as a separate unit. The boundary of this subnetwork changes with the incident's characteristics. Since this particular jurisdiction has an organization controlling the freeways and other organization controlling the surface streets, an integrated control strategy is required. Throughout the incident, the freeway TMC is receiving status updates concerning the resolution of the incident. This information is shared with the surface street TMC. Both TMCs use this information as input to traffic prediction algorithms. For example, when the surface street TMC is informed of the freeway closure, its control scheme is modified appropriately.

The MTO generates traffic management strategies for the incident. The Generate Traffic Management component devises countermeasures (detour routes) and related feasibility measures (e.g., estimated travel times, etc.). Based on this, it determines the most feasible countermeasures and command strategies (signal timing schemes, CMS updates, lane control signs, etc.) for the selected alternative. It then expands the strategy into the individual directives needed for commanding the control system Once the command file is generated, it is transmitted to the control devices (e.g., signage, signals). The selected strategies are then fed into the ATMS Integrated Database for retrieval by other ATMS components.

Throughout the incident, ATMS is monitoring the traffic network. Based on these observations and historical information, ATMS develops predictions for secondary incidents. This information is then used to strategically pre-position emergency response assets.

During the incident, the DI subsystem retrieves the incident information and duration from the ATMS Integrated Database. Affected users, such as the IVHS External Systems, retrieve incident information and adjust trip planning and route selection accordingly.

4.3 Off-Line Planning Scenario

The off-line planning scenario depicts modes of operation, where ATMS can plan for and evaluate various strategies. In these scenarios, realistic and dependable data are very important. A major portion of the necessary data will be obtained from the ATMS Integrated Databases that contain the historic traffic volume information, growth trends, signal control parameters, and other useful information. Other data is obtained from simulations, models, and direct entry. Together, the data are used for engineering/planning studies that may include:

a. Enhancing the regular signal timing schemes (e.g., using programs such as TRANSYT, PASSER, MAXBAND, etc.).

b. Developing strategies for special events (e.g., games, parades, etc.).

c. Evaluating scenarios for alternative Traffic Control Plans (TCP) for road construction/reconstruction projects.

d. Conducting other engineering studies that need information from the TMC, such as safety studies, planning studies (traffic impact for developments), checking warrants for traffic control devices, etc.

While each of the preceding scenarios will have some similarities in nature, let us consider an off-line planning scenario for an upcoming football game. Under this scenario, the system is operational and summary data are available from the ATMS Integrated Database through the user interface for an off-line exercise. The basic conditions for this scenario are:

a. A data dictionary is available. The PSD subsystem of ATMS formats the data in accordance with the data dictionary. The data are retrievable for both on-line and off-line planning use.

b. The off-line applications are governed by the same dictionary or have the capability of pre-processing the data available from the ATMS Integrated Database. The off-line programs' data requirements must be met within the overall design of the ATMS Integrated Database'

The Organizational User entity (local DOT) asks the MA subsystem of ATMS to develop control strategies for an upcoming football game.

The operator (inside the MA subsystem) accesses the ATMS Integrated Database through the user interface without interrupting ATMS operations and retrieves all necessary information such as traffic volume, signal information, lane geometries, etc., for the road network. The information retrieved is historic traffic volume data for a similar football game; also retrieved are related control strategies.

The traffic engineer (inside the MA subsystem) feeds the retrieved data into software applications to test the scenario with different control parameters, including the control strategies used during a previous football game, The scenario covers the total time period that traffic will be affected, including before, during, and after the game. Through this off-line exercise, they determine refined control strategies for an optimum solution. The solution strategies include modal splits, signal control parameters, principal routes to be used by motorists going to/exiting from the game, and CMS advisory messages (for traffic going to/ exiting the game as well as passing motorists). They also estimate the probable number of incidents based on the contributing factors such as traffic volume, type of crowd, etc.

The relevant potential strategies generated by the off-line exercise are then fed into the knowledge-base of the MTO subsystem and ATMS Integrated Database for use during the football game. The Emergency Response Services entity is informed about the expected number incidents, so that adequate resources are made available for incident management on the day of the game. The transit authority (or APTS) is provided with the estimate of modal splits, so that adequate public transit capacity is provided on the day of the game.

In this scenario, the sensor network collects surveillance data and transmits it to the TMC.

The PSD subsystem collects, validates, and transforms data into correct formats. It then stores the data in the ATMS Integrated Database (where the MTO subsystem reads the data in the Normal Operations Scenario).

The ATMS Integrated Database receives the real-time dynamic network data from the PSD subsystem. As previously discussed, this data is used in real-time to manage the traffic network. Later, this data will be archived and stored as historic data for further analysis, and for use in future similar events. The ATMS Integrated Database also maintains incident information retrieved from the MTO subsystem, as well predefmed data such as roadway geometric and signal control parameters.

4.4 Control Center Evaluation Scenario

The Control Center Evaluation Scenario depicts an off-line analysis mode where ATMS performance characteristics are measured and evaluated. The basic conditions for this scenario are:

a. ATMS is deployed and operational.

b. IVHS sensor technologies have evolved, providing more reliable surveillance information at higher frequencies. The use of these technologies for ATMS surveillance will affect TMC operations.

c. The TMC operations staff needs to assess the impact these sensors will have on ATMS.

In this scenario the system is operating in an off-line analysis mode. The system is configured to run simulations of traffic incidents, where a traffic incident could be an accident, inclement weather, or a special event. During simulations, both the system's and traffic network's performance will be evaluated. The TMC operations staff has full control of the simulation, and can stop and restart the simulation at any time.

The simulator provides the TMC operations staff with the flexibility to either run the simulator using historical data from a previous incident, or model the traffic network plus the proposed IVHS sensors. This scenario will discuss a case in which the simulator uses a historical incident and models the data that would have been generated from IVHS sensors. The simulator accepts control directives from the MTO subsystem, and adjusts the simulation accordingly (e.g., signage, signals). This allows the simulation to continue past the point of incident identification through incident management. This is necessary for evaluating all of ATMS' support systems. The simulation's objectives are:

a. To monitor ATMS' support systems performance characteristics and isolate areas of degraded performance related to hardware and software limitations. The increase in data from the IVHS sensors may cause degraded performance in one or more ATMS components. This degraded performance will undoubtedly nullify any possible gains from the IVHS sensors. As ATMS evolves, the system will have to be resized to meet the demands of the users.

b. To monitor the traffic network's performance characteristics and measure relative system response times (both with and without additional sensors installed). This provides the measure of effectiveness of the ATMS traffic network. The installation of the IVHS sensors may be very costly. The TMC Manager will want to test the system's performance prior to the installation. There may be cases where there is little or no performance enhancement.

c. Compare MTO's incident management strategies selected (both with and without additional sensors installed). ATMS selects management strategies based on available information. Presumably, the additional sensors will provide ATMS with more information, enabling ATMS to select a more appropriate strategy.

d. To generate statistics needed to assess the measure of effectiveness of the traffic network with additional IVHS sensors.

Once the simulation begins, the system will operate in an automatic mode. The system will run through a simulated incident management scenario and log all system activities to the ATMS Integrated Database. The TMC operations staff can suspend the simulation, change operational parameters, and restart the simulation. The Off-line Analysis and Trend System provides quick-look graphical displays that can be used in real-time to monitor the systems performance. When simulations are complete, the operations staff will conduct the performance analysis using the Off-line Analysis and Trend System and the data stored in the ATMS Integrated Database.

The MA subsystem has facilities to probe (monitor) the system's performance characteristics during real-time system operation. The data generated by MA's Monitor and Diagnose TMC Hardware and Network element and Monitor Software Performance element is logged in the ATMS Integrated Database. The Monitor Software Performance element monitors performance characteristics including: interprocess message traffic quantity, memory usage, memory paging, CPU usage, disk input/output, and idle states for each process. The calculations are performed at an operator-specified time interval, and are stored in the ATMS Integrated Database. The Monitor and Diagnose TMC Hardware and Network element monitors hardware performance and detects failure modes. A failure mode prompts the operator to switch to the redundant component. The MA subsystem monitors ATMS continuously and generates an alarm if a component is operating outside specifications.

The PSD subsystem typically performs the following functions: Collect Surveillance Data; Perform Validity and Integrity Checks, Generate Derived Data; and Load Integrated Database. During a simulation, the Collect ATMS Surveillance Data component is substituted with the data being generated by the simulator. The Perform Validity and Integrity Check component accepts data from the simulator, and performs data quality, limit, and reasonableness checks. The Generate Derived Data component transforms raw sensor data into higher level data needed by ATMS. This component calculates link travel times, speeds, queue lengths, and occupancies. The PS Database Access component stores the derived data in the ATMS Integrated Database. The MA subsystem monitors the PSD subsystem's performance and writes performance data to the ATMS Integrated Database. The Off-line Analysis and Trend System provides the report and plot generation facilities needed for evaluating data stored in the ATMS Integrated Database.

The MTO subsystem assesses current network traffic conditions, MOE of the current strategy, generates traffic management strategies, evaluates strategies, decides which strategies to implement, and implements the selected strategy. The relative time from incident identification to selection of incident management strategy demonstrates performance enhancements gained by additional sensors. The MTO subsystem stores all results in the ATMS Integrated Database. The MA subsystem monitors the MTO subsystem's performance and writes performance data to the ATMS Integrated Database. Appropriate directives are generated and forwarded to the simulator for implementation. The simulator responds by simulating traffic re-routing and changed signal timing. This allows the TMC operations staff to measure the effectiveness of the implemented strategy.

ATMS generates more information than an individual can process. Therefore, ATMS must provide the means to process large amounts of data, correlate the data to sequences of events, and present the data in the form of plots, statistics, and reports for the traffic engineer. The Off-line Analysis and Trend System provides the analytical, statistical, and reporting functions the traffic engineer needs to evaluate traffic network performance. ATMS performance is dependent on both the traffic network's and TMCs (hardware and software) performance.

The Off-line Analysis component assesses the traffic networks performance using the data stored ***in the ATMS Integrated Database.*** The traffic network's performance is evaluated using performance characteristics that may include queue lengths, queue delay times, intersection stop delays, arterial running speed, and volume per capacity ratios. The system performs minimum, mean, maximum, and standard deviation calculations for these parameters. The comparison of actual versus modeled data provides a means for measuring the effectiveness of additional IVHS sensors. Another measure of effectiveness is integrating these parameters over the incident duration time. This method can be used to characterize the effectiveness of incident management strategies. For example, given a specific incident, the objective of an incident management strategy is to minimize the delays encountered by individual motorists. One MOE for incident management strategies is the total queue time delay per link. One can calculate the total queue time delay be integrating the queue delay time per link over the incident duration time. The strategy yielding the minimal total queue delay time is the most effective. The overall traffic network performance is graded by summarizing the performance characteristics, and performing a weighted calculation of these characteristics. The results are reported to the ATMS Integrated Database. This information validates the operational enhancement gained by additional sensors.

The other major consideration is the performance of TMC hardware and software. The increase in data from additional sensors will eventually overload hardware capabilities, thereby nullifying any performance gains the additional sensors would provide. In an evolving ATMS environment, hardware and software may require upgrades in order to meet user needs. The goal of these simulations is to predict necessary upgrades and allow the TMC operations staff to coordinate these upgrades with the installation of IVHS sensors. System performance is a critical parameter to monitor in a real-time system, because events are time critical The technology and tools needed for evaluating hardware and software performance are available today. Most operating systems provide tools to monitor system resources including CPU, memory, and disk usage. If the sustained usage of these resources is greater than approximately 90%, the system will require a hardware upgrade.

Control Center evaluation capabilities provide the TMC with an analysis tool to aid in system tuning, system resizing, operator training, and system cost per benefit analysis. The simulation’s results can also be stored in MTO's knowledge-base, and aid ATMS in resolving future traffic incidents.

5.0 SUPPORT SYSTEMS

This section identifies ATMS support systems. By the definition specified in the Statement of Work (SOW), a support system is "a process designed specifically to assist in the efficient and effective operation of ATMS control centers". For the purpose of this document, a more refined version of this definition as well as a rationale for defining support systems was required to better understand the scope of this task. A support system as identified in this section, is basically a critical, subsystem decomposition of the ATMS at the third level or lower. These subsystems are function-oriented and logical by defmition, since they were derived from the analysis performed in Section 3. It is important to recognize that a large number of support systems that will be identified using this definition. The number, however, could change based upon the physical subsystem definition (i.e., software, hardware, and people) that will be performed in Task C (Functional Requirements and Specifications) and Task D (Design for ATMS Support Systems). For example, the physical architecture definition may result in the aggregation of two or more individual "logical support systems" into one "physical support system", or alternatively, further decomposition of a single logical support system into two or more physical support systems.

To further understand the definition of support systems and the rationale for their development, it is necessary to better understand the distinction between ***essential*** and ***critical*** subsystems. Essential subsystems are elements that at a minimum, are required for the daily operations and management of ATMS. These subsystems, in most cases, include functionalities that are available and used in the current state-of-the-practice. These elements are the building blocks of an ATMS control center that will be used as a foundation from which further subsystems will be developed. An example of an essential subsystem would be a simulation package used for developing signal timing plans. Critical subsystems, on the other hand, identify areas of functionality that do not exist today, yet for which state-of-the-art technology is now, or will soon be available. Examples of critical subsystems include real-time adaptive control, "hyper" real-time simulation, and wide area control. A critical subsystem could be a essential subsystem that includes a functional area that is not part of existing subsystems (e.g., automated image analysis of CCTV image data as part of a data ingest subsystem); or it could possibly be an instance of an essential subsystem harnessed in a different manner to leverage additional functionality (e.g., the use of simulations to predict secondary congestion from a primary incident). In general however, a critical subsystem addresses an entirely new or evolving technology that could be applied to today's traffic operations and management.

Again, for the purpose of this document the support systems that will be identified encompass a critical, subsystem decomposition at the third level or lower.

5.1 Identification of Critical Areas

Utilizing the definition of critical as previously described, and an understanding of the state-of-the-practice in TMCs, the following is a list of identified critical areas, where a critical area is derived from the associated functional area' of a critical subsystem. it is important to note that Critical Areas are not support systems themselves. Support systems will be developed that map to a critical area (s).

5.1.1 Data and Information Management (DIM)

This is a broad critical area that addresses techniques and technologies to more effectively manage the data and information that comes into, goes out of, and is processed within ATMS. An anticipated ATMS evolution in a mature IVHS world, suggests there will be an increase in the quantity of data, type of data, and complexity of data ingested, processed, managed, and disseminated by internal subsystems. This increase in quantity, type, and complexity of data requires modem data manipulation and management techniques and technologies. Included in this domain are methods for performing data fusion, data dissemination, data inference, and data conversions (e.g., analog to digital, and other conversions for video and voice data). Relational, cooperative, and intelligent databases, along with tools for performing intelligent queries play significant roles in this domain. The ability to quickly recall data for analysis of traffic situations and reporting to external entities is vital to ATMS's existence. Requisite for effective communications with external entities, are capabilities that address the needs of this critical area.

5.1.2 Incident Management (IM)

This critical area addresses methods to satisfy the goal "ATMS will support rapid response to incidents and collaborative action on the part of various organizations to provide integrated responses", identified in Section 1. Functional areas included in this domain are systems for incident detection, verification, and control. Detection of incidents, arguably the most critical role in Incident Management (IM), involves the use of systems and strategies for monitoring real-time surveillance data for anomalous conditions. Different technologies will apply based on the type of data (e.g., voice, image, data) being monitored. In fact, a separate physical support system is likely to evolve for automated voice detection of incidents. This is largely due to the fact, uncovered in the ATMS State-of-the-Practice task, that most incident detection originates from cellular 911 telephones. Verification of incidents involves automated methods for confirming the authenticity of an incident by distinguishing actual incidents from error-prone sensor data, faulty sensors, etc. After incident verification has been performed, classification type and severity can be assessed. Finally, incident control involves automated and non-automated tools and technologies to assist in incident resolution by continuous interaction with external entities (i.e., emergency response entities, law enforcement, towing agencies). A significant form of interaction with emergency vehicles involves preemptive signaling, and possibly route guidance or selection to facilitate a rapid arrival at the accident scene.

5.1.3 Control Strategies (CS)

An important area for proactive control of the traffic network, this critical area addresses advanced demand management tactics, signaling, and control strategies. To accomplish this function, ATMS must not only sense and understand roadway demand, but also develop and deploy effective strategies to better manage the traffic network. These strategies consist of congestion pricing, signaling patterns, ramp metering, route selection, travel advisories, and modal recommendations. Techniques for adaptively, predictively, and dynamically managing traffic will be employed, with particular emphasis on integrating surface streets (local area) with freeways (wide area). Methods for disseminating travel advisories and modal recommendations by highway advisory radio and CMS are addressed. The use of these effective and integrated control strategies is key to the efficient management of the ATMS traffic network.

5.1.4 Traffic Modeling Techniques (TMT)

The use of simulations and traffic network models is important in the effective management of ATMS. These tools are used for testing resources (hardware, software, people), training, planning, validating the expected effectiveness of a potential control strategy, incident prediction and propagation, etc. Sophisticated models of the traffic network, including simulation of sensor data, weather data, parking utilization, probe-data, CCTV data, and other significant areas need to be addressed. Models will need to be of high fidelity to accurately test and train ATMS resources. In addition, the models developed need to possess intelligence. That is, they must have the capability to update their behavior based on their current state. Their current state should be changeable by manual interaction with the model, or electronically by commands transmitted to update the model. This critical area covers techniques and technologies for simulation and modeling, as well as strategies for managing inventories of simulations and models.

5.1.5 Image Ingestion and Analysis (IIA)

Expected increases in the use of video data in next generation ATMSs and the need for improved techniques for data cataloguing and analysis of raw imagery, justify the existence of Image Ingestion and Analysis (IIA) as a separate critical area. IIA includes techniques and technologies to more effectively ingest and process image data. Particularly relevant are technologies to extract traffic related information (volumes, speeds, vehicle identification, traffic status, traffic incidents) from image data using advanced image extraction and classification technologies.

5.1.6 Scheduling Systems (SS)

As traffic control centers mature by increasing in functionality and complexity, there will be a greater need for automated scheduling systems. Significant examples include the scheduling of maintenance and repair activities, and the scheduling of information to be disseminated to signals, signage, users, etc. Both automatic and manual scheduling tools are envisioned. Automatic scheduling could be used for scheduling preventative maintenance repairs, automated sensor failure detection, or for emergency snow removal crews. Instances of manual scheduling are: special event planning, construction planning, and ad hoc roadway repair. In the latter case, scheduling inputs are manual. However, automated scheduling facilitates will be used. Scheduling systems facilitate maximum resource usage and automation to efficiently manage constraints.

5.1.7 Off-Line Analysis and Trend Systems (OATS)

This area addresses systems to be used in off-line modes to draw inferences from traffic related data. For instance, changes in traffic patterns, volumes, incident location, incident frequencies, etc. These systems perform data conelation, analytical modeling, statistical modeling, and short- and long-term trending. The use of trend plots, statistics, and reports provides the user with a "quick-look" and "in-depth" view of the traffic network performance. Off-line analysis is also used to monitor the performance of the hardware and software of ATMS internal resources. Thus, these systems have important roles in determining the level of effectiveness for strategies employed in the traffic network, and for determining system degradation over time.

5.1.8 Information Dissemination (ID)

This area addresses state-of-the-art systems to better communicate information to all ATMS users. ATMS users include Organizational and Individual Users, IVHS External Systems, and Emergency Response Systems. The effective and efficient communication of information to users is a significant mechanism to better regulate traffic demand and to proactively managing the traffic network. Several support systems will be mapped to this critical area

5.2 Identification and Description of Support Systems

The following is a list of support systems consistent with the preceding definitions. For each support system a general description will be given identifying system functionality and mapping to the analysis performed in Section 3, requirements performed in Section 2, and critical areas identified in this section. It is assumed that the mapping of a support system to an analysis process will provide further insight into the high-level input/output and functional requirements of each support system, although each support system will require further analysis to gain a full understanding of the functional and performance requirements. Further, more detailed analysis of the support systems identified here, will be performed in Task C - Functional Requirements and Specifications for support systems.

Note: Some of the support systems (or parts of them) we identify are already being developed under contract (i.e., Real-Time Adaptive Control, Dynamic Assignment). They are identified in this document for two purposes: to provide an analytical mapping to the ATMS system architecture; and to possibly identify pieces of additional functionality that may be required for a total, more integrated solution. The analytical mapping is particularly helpful in understanding where various support systems fit into the scheme of things, from a system's engineering point of view.

5.2.1 Real-Time Adaptive Control (RTAC)

This automated support system uses the current state of the traffic network to regulate signaling patterns of surface streets. The signal controllers rely on sensors indicating current traffic conditions. This data is used to dynamically adapt to new traffic conditions. This is achieved by using algorithms that can derive demand from sensor data at intersections and subsequently adjust the signaling pattern for near-optimum traffic flow. These systems can be used in conjunction with other Real-Time Adaptive Controls (RTAC) to cooperatively manage a network of signals for a given region.

5.2.2 Wide Area Traffic Control Kernel (WATCK)

This automated support system will integrate local area traffic control with wide area traffic control to facilitate the regulation of traffic demand. For example, this support system could provide an integrated approach for traffic control between local areas (e.g., various intersections controlled by RTAC inside a city) and wide areas (e.g., various freeways, and arterials) by integrating RTAC-like systems with other wide-area control techniques, such as signage updates, ramp metering, dynamic lane allocation, etc. As identified in Task A - The ATMS State-of-the-Practice, none of the systems studied integrated local traffic management activities with wide-area traffic management activities. For example, none of the TMCs visited integrated ramp metering and surface street signal control schemes. An important functional area of this support subsystem is information dissemination. Wide-area control could be used as a powerful control technique to regulate traffic demand when congestion exists within a particular local area, due to recurrent or non-recurrent congestion (although, this type of support system is obviously more valuable when a non-recurrent incident, such as an accident has occurred). A major obstacle this support system will try to overcome, is how to use automation to effectively and efficiently disseminate traffic control information to wide-area traveling vehicles in order to influence their current route to a specific, congested local area, while not achieving information overload of any involved system [e.g., humans viewing CMS or humans listening to Highway Advisory Radio (HAR) to determine if their current route needs to be altered]. This is an important obstacle to overcome, because the amount of data disseminated from many local areas to a particular wide area increases non-proportionally with the number of congested local areas. This support system is not intended to complement ATIS technology, but rather it is a short-term mechanism to regulate traffic demand using state-of-the-practice technologies.

5.2.3 Inter- Jurisdictional Traffic Management Supervisor (ITMS)

This support system will provide a mechanism for integrating traffic management/control between adjoining jurisdictions. There are several examples where, within the same region, different jurisdictions have conflicts-of-interest; and moreover, have greater authority in their respective jurisdiction. For example, a Municipal DOT might insist that in all cases (including cases involving incidents) freight vehicles not delivering to the metro-area, not utilize their surface streets and arterials. The State DOT, however, might have a conflicting goal of keeping freight moving at all times. In these types of cases this support system will manage the objectives of the respective organizations (which could involve more than two entities) and attempt to derive solutions to satisfy their objectives. This support system will identify potential inter-jurisdictional conflicts based on the current or recommended control scheme. The system will recommend solutions based on a knowledge of all involved parties' jurisdictional goals, objectives, policies, and procedures, and this system would obviously need to be tightly coupled with the WATCK.

5.2.4 Image Analysis Classification Executive (IACE)

This support system will receive image traffic data from CCTV sources and derive traffic state data from the images received over time. Derived or extracted data might include, link times, queue lengths, volumes, or incident detection. A possible approach for image classification (i.e., for incident classification), proven with raw satellite image data in the NASA domain, combines conventional image processing technology with recent advances in neural network technology to provide improved classification capabilities. Aside from image classification for incident detection, state-of-the-art technology is also available for deriving traffic status data, such as volumes and speeds. A necessary feature of this support system will be to provide libraries of feature extraction and classification programs to support this data processing.

5.2.5 Incident Management Kernel (IMK)

This support system will manage incidents after their detection. An incident is any type of non-recurrent congestion as a result of an accident, visibility, weather conditions, construction etc. This system will ingest incident detection data, classify the incident, determine incident severity and duration, and log the incident. Then, using historical knowledge, Standard Operating Procedures (SOP), and intelligent reasoning methodologies, dispatch appropriate emergency services and generate routes for emergency vehicles to provide a coordinated response to resolve the incident efficiently, while preserving personal safety. Additional support might consist of scheduling roadway repairs and notifying external agencies, such as the EPA and towing organizations. This support system is tightly coupled with the Intelligent Reasoning for Incident Detection and Evaluation (IRIDE) System.

5.2.6 Incident Prediction and Congestion Propagation (IPCP)

This functional area proactively attempts to determine when and where incidents will occur, to take measures to decrease the likelihood of their occurrence, and heighten emergency readiness. This support system employs simulations, models, trip planning data (i.e., from ATIS entities), and historical data to produce congestion and accident predictions. Taking incident prediction a step further, secondary congestion and accidents that are likely due to propagation can be determined.

A support system in this area would probably be tightly coupled to Incident Management and Modeling Systems to derive maximum benefit from the system.

5.2.7 Demand Management System (DMS)

This support system manages the selection, evaluation, and deployment of demand management strategies. These strategies consist of signaling patterns, ramp metering, route selection, travel advisories, and modal recommendations. Also included is demand management information in the form of historical data from which pricing strategies (i.e., parking pricing, toll pricing, congestion pricing, road pricing, impact fees, parking tax, etc.), regulatory strategies, shared-ride strategies, employer strategies, ideas for new technology, and zone-based strategies may be derived (refer to Section 2.2.1). This support system is critical to ATMS success. The public must be confident that the recommendations provided are actually solutions to problems and not new problems themselves. For this support system to function effectively it must interact with the Real-Time Adaptive Control, Wide Area Traffic Control Kernel, Inter-modal Transportation Planning System, Dynamic Assignment System, Congestion Pricing Tool, and Flexible ATMS Simulation System.

5.2.8 Inter-modal Transportation Planning System (ITPS)

This system works in conjunction with IVHS entities to provide an inter-modal transportation planning capability, during incident situations only (ATIS will support transportation planning under normal operating circumstances). This support system, therefore, might be used by (or encompassed by) the Demand Management System or the Incident Management Kernel. This system functions as a tool for disseminating information to users via CMS and HAR to inform them of alternate routes and transportation modes during incident situations. Information on the various modes available, location of parking facilities, predicted availability of parking, etc., will be provided.

5.2.9 Dynamic Assignment System (DAS)

Assuming a mature IVHS world, centralized routing, and assuming we know the origin and destination of each vehicle, this support system will interact with other IVHS entities and dynamically assign vehicles to routes to better utilize the effective capacity of the traffic infrastructure and avoid congestion. This system requires sophisticated routing algorithms to effectively and efficiently manage the traffic network in deriving optimum control strategies.

5.2.10 Congestion Pricing Tool (CPT)

This support system employs the current state-of-the-traffic network, historical data, time of day, and policy data to develop effective congestion pricing information to External Systems. Possible external systems include ETTM entities and parking garages. The implementation of this support system is crucial for effective regulation of traffic demand, but is very much dependent on the development of supporting systems (i.e., ETTM technology).

5.2.11 ATMS System Management (ASM)

This support system is an integral part of ATMS. Functions of this system include: managing personnel resources (e.g., training); managing hardware, software, and databases (including monitoring trend data) of the ATMS; managing the roadway infrastructure; managing policies and procedures; and managing budgets and plans. Various other support systems are tightly coupled with this support system, such as the Database Management, Request-Oriented Scheduling Engine for Maintenance and Repair Activities, Trend Analysis, and Database Management.

5.2.12 Trend Analysis and Statistic System (TASS)

This support system will use conventional and state-of-the-art trending technologies for analyzing and processing historical traffic data, correlating the data to a sequence of events, and using the data to evaluate past traffic performance and predict future traffic patterns of a traffic network. Trend analysis for predicting future traffic patterns is typically separated into two categories, short- and long-term. Short-term trends are usually developed over a few months and are used to predict traffic patterns for the next week. Long-term trends arc developed over a period greater than 6 months and take into account seasonal fluctuations. Long-term trends are used to plan road construction, predict future traffic network problem areas, and special event planning. This support system will accommodate both long- and short-term trending, supported with trend plots, statistics, and reports to be provided to the user of the system. This support system will be tightly coupled to the Database Management support system.

An additional functional area of this support system might include similar technologies to evaluate the hardware and software resources used within the ATMS. In an evolving ATMS, this supporting functionality is useful for identifying system degradation over time.

5.2.13 Data Derivation Management (DDM)

This support system is responsible for generating data derivative products from the various types of data incoming to ATMS. This support system handles Level 0 through Level 2 processing of incoming data. Level 0 processing involves the receipt of raw data, such as vehicle counts, etc. Derived data at this level consists of correlating the raw data to sensors and locations. Level 1 processing involves checking the data for conformance to nominal ranges and the generation of time-based averages. Data derivatives at this level include: tagged sensor data that is out of limits; identifying possible congested links; hazardous road conditions; etc. Also, sensor, link, and area time-based averages are derived. Level 2 processing involves correlating and combining Level 0 through 1 data products and deriving new data that ultimately categorizes traffic conditions (i.e., icy bridge at Rt. 1 and **Rt.** 175, recurrent congestion on northbound I-95 and Rt. 50, accident locations, etc.). This system will provide support for deriving these various levels of data, and for communicating this data to other tightly coupled support systems.

5.2.14 Data Ingestion, Conversion and Fusion Supervisor (DICFS)

This support system is responsible for ingesting the various types of ATMS incoming data (from wide-area, local-area, probe, weather, environment, etc.), converting them to appropriate formats for processing, and fusing them together in real-time, so that they can be used in meaningful ways by other support systems. For instance, the data ingested from various sensors needs to be de-packetized (headers stripped, decompressed, error checked, limit and integrity checked, etc.), and combined with other types of incoming data to maintain integrity and preserve temporal relationships. The latter part of this processing, data fusion, is the process of extracting, translating, combining (removing redundancies), formatting, and synthesizing data from more than one input stream. This process requires a detailed understanding of the structure and contents of each input stream, as well as the volatility (dynamics) and relationships between them. This support system will provide a mechanism for both maintaining the most current data, and the storage of old data (historical) to an archive database. The processing taking place in this system is crucial to the success of many other support systems. For example, the Incident Management Kernel and the Intelligent Reasoning for Incident Detection and Evaluation support systems are heavily dependent on the quality, integrity, and accessibility of the data produced by this system. Additional areas that relate hnctionally to this support system include: routing/dissemination; database management; and data query, report, and display.

5.2.15 Database Management System (DBMS)

This support system uses state-of-the-art database (relational DBMS and object DBMSs) and knowledge management practices to manage all ATMS data types. A current and operational history of all data and data products used or generated by ATMS will be maintained. This includes: policies; procedures; standards; special events; construction **events;** digitized maps; historical data; real-time sensor data; derived, probe data; static and dynamic network data; control strategies, expert knowledge; and other types of data that are either input/output data or data manipulated internal to the system. Inherent to this system is support for Standard Query Languages (i.e., SQL compliance), transaction management with concurrency control, distribution of database elements, intelligent query capabilities that provide rapid search and retrieval when there are complex relationships (table joins) among data elements, retrieval reporting at multiple levels of abstraction, browsing, archiving, backup/recovery and automated mechanisms such as event notifiers (triggers) with alerts and on-line backups for maintenance support

5.2.16 Intelligent Reasoning for Incident Detection and Evaluation (IRIDE)

This support system is envisioned as a suite of artificial intelligence technologies that assist in the detection, verification, and evaluation of traffic incidents due to non-recurrent traffic congestion. The suite will consist of model-, case-, and rule-based reasoning systems. The use of model-based expert system technology has been proven in other domains, and could easily be applied to IM. The basis for this methodology is the use of sophisticated, high-fidelity simulators to generate expected behaviors for a correctly behaving system. Algorithms are then used for detecting and isolating anomalies. Incident detection is performed by comparing the actual incoming data with simulated or expected data. Differences are reported to an internal system blackboard. From there, intelligent reasoning can be performed to isolate the source of fault; this is based on causal information that is built into the model. Case- and rule-based Expert Systems would generally be applied for less complex incident detection and isolation, where there is a preconceived idea of what is going to happen. A probable area for their implementation would be the identification of recurrent congestion or recurrent accident locations. In this case, rules can be assembled to monitor the network for known conditions. It is apparent that the successful application of these technologies is necessary for effective IM. It is envisioned that this support system will be tightly coupled with, if not part of, the Incident Management Kernel.

This support system will function to detect, verify, and evaluate incidents for both freeways and surface streets. An additional function of this support system will be to detect incidents under low-volume traffic conditions, when accidents are not be readily detectable from flow rates (this could be coupled with the Image Analysis and Classification Executive).

5.2.17 Link Volume Prediction, Assessment, and Adaptation System (PAAS)

This support system is responsible for the prediction of link volumes, the assessment of current link volumes with predicted link volumes, and possibly the adoption of new control strategies to improve link volumes. The prediction of link volumes involves the use of historical data, simulated or modeled data, time of day, and weather inputs. The development of new, or the use of existing simulators will be required. The assessment of link volumes involves the use of established MOEs and other evaluation techniques. If MOEs are unsatisfactory, and if new strategies are deemed necessary, this system will retrieve alternate strategies from a knowledge-base, evaluate the strategies, select the appropriate strategy, and implement the strategy. This system will work in conjunction with the Model Management Kernel, the Flexible ATMS Simulation Tool, the Generic Signage and Signal Commanding System, possibly the Real-Time Adaptive Control, and various simulations and models that are available.

5.2.18 Model Management Kernel (MMK)

This support system will assist in evaluating a selected control strategy prior to its implementation. As identified in the ATMS State-of-the-Practice, a previous document, significant support for the on-line use of models and simulators does not currently exist. This support system will attempt to try to solve some of the current hindrances in using models for on-line purposes. Specifically, the Model Management Kernel (MMK) will integrate the available models and allow them to be readily accessible for operations. Support for a common graphical user-interface integrates the models and facilitates operator interaction will be provided. The method for evaluating a control strategy in most cases will be: to select an evaluation model that is well suited for the scenario; implement the new control strategy using the selected model; and assess the results of the new strategy. To accomplish this the MMK support system manages libraries of models that will need to be readily accessible for evaluation of control strategies. Techniques for maintaining characteristics and features of the models are required for fast accessibility.

5.2.19 Generic Signage and Signal Commanding System (GSSCS)

This support system manages control information for various signage and signaling elements. The basic idea of this system is to provide a framework for implementing various control strategies by supporting a standard commanding language that facilitates transmission and verification of commands to signage and signals. For example, this commanding system would allow a user to communicate with a CMS from a remote site (TMC). The user would have support for entering directives that are specific to commanding a particular device and general directives to configure the commanding system. For example, directives that are specific to a CMS device would be different from directives to a traffic signal or a ramp meter; however, directives to configure the commanding system would be the same regardless of the destination device. For instance, this commanding system might support a form of command verification that at the user's discretion could be enabled or disabled. Command verification, in this context, could have many levels: verification that the device is in the proper state prior to transmission of a command (pre-requisite); verification that the command actually was transmitted out of the TMC (loop back); verification that the destination device received the command (receipt verification); and verification that the command actually is working as planned (result verification, i.e., traffic conditions are improving -- CMS said "Accident ahead - exit now!" and drivers have taken action). This system might be used as part of WATCK or other support systems that integrate surface street with freeways or integrate control strategies across jurisdictions.

5.2.20 Request-Oriented Scheduling Engine (ROSE) for Maintenance and Repair Activities

This support system will handle the automatic scheduling of maintenance and repair activities resulting from manually or automatically detected maintenance problems. It is anticipated that a system of this type will be necessary, since ATMS is the focal point for incident reports (i.e., in this case an incident is a traffic infrastructure problem). Examples include, preventative maintenance (e.g., road resurfacing), emergency maintenance and services (e.g., pothole fixes, snow plowing and road salting, repairs to sensors, controllers, effecters, etc.), and planned construction (e.g., road widening, new road, etc.). This system will include high-level and detailed level scheduling support for manual and automatic scheduling, including conflict resolution, resource management, temporal constraint management, and graphical timeline representations of scheduled activities, resource allocation and availability, and timegraph data. Inherent to this system is the specification for a standard request notation that allows various entities to electronically request a maintenance or repair activity.

5.2.2 1 Information Scheduling and Dissemination to External Entities (ISDEE)

This support system is responsible for the dissemination of information to external entities. These entities consist of IVHS external systems, Emergency Response, Organizational Users, and Individual Users. The use of an automated scheduler is envisioned for the scheduling of information to be distributed to these users in a routine, efficient and timely manner. A scheduling system of this type is necessary, in the defined ATMS context (see the decomposition of analysis bubble 1.4 - Disseminate Information), based solely upon the number and types of interactions with external entities (i.e., IVHS External Systems, Organizational Users, and Emergency Response Systems). Aside from the routinely output data such as, dynamic network data and static network data, there are other types of fixed-time output data that need to be scheduled to external systems. For instance, the results of information requests in the form of historical reports (e.g., a historical report of queue-lengths for a given intersection), statistics, or simulation study findings need to be scheduled for dissemination to users.

5.2.22 Flexible ATMS Simulation Tool (FAST)

This support system generates simulated data streams for all of the various ATMS inputs. This includes data from internal (surveillance equipment) and external (Organization Users, Individual Users, On-Line External Databases, Emergency Response, and both Non-IVHS and IVHS) sources. Simulated data will encompass synchronous and asynchronous data. Simulated data from internal sources will include loop detectors, CCTV, visibility detectors, AVI, road temperature sensors, etc. Simulated data from external sources will include weather, parking utilization, mayday, signal preemption, trip planning, routing request, information requests, special event, policy, malfunction and incident report data (see Figure 2-2). The system will provide mechanisms to control the behavior of the simulation, such as variable simulation speed control, and support for ingestion of control information (i.e., commands) which will allow the simulation to change behavior according to the current control strategy. In addition, the capability to manually introduce changes in the data generated will be facilitated. It is likely that this support system will decompose into several physical support systems, each simulating a separate data input.

From the ATMS perspective, this support system has applicability to a number of areas. Among others are operator training, long term-trending, diagnosis and testing, and control strategy evaluation (see the MMK support system 5.2.18).

5.2.23 Command Management System (CMS)

This support system is responsible for disseminating code or data to processors in the field, analogous to a Command Management System in the NASA satellite domain where emphemeris tables or flight software are uploaded to the spacecraft in the form of command loads. In the traffic domain, this system will manage the network of controllers that have in-the-field processors. Software and data that allows these processors to function can be modified and tested in-house and then electronically transmitted to the field for implementation without the intervention of a field crew.

5.2.24 Operator Training and Support System (OTSS)

This support system provides automated training for the operation of ATMS. Training sessions will be provide in off-line modes to teach students how to effectively operate ATMS. Additional support will be provided by this support system to monitor operator performance and to provide real-time assistance when necessary in on-line modes. The specific functionality of this system is expected to evolve as the role of the operator is further defined in Task C and D and in cooperation with the GTRI Human Factors for ATMS.

5.2.25 Route Generation and Selection Assistant (RGSA)

This support system is responsible for ingesting the real-time traffic information and for generating and selecting appropriate routes to better manage the traffic network. This system will support route generation and selection for Emergency Response entities and possibly for ATIS, and CVO entities. Since ATMS has direct control over the manipulation of the traffic network via signals and other controlling elements, it is reasonable to expect that the role of ATMS in providing routes to emergency and commercial vehicles will increase. In addition, ATMS has the data readily accessible to generate routes for ATIS. The role of route generation and selection in the ATIS context, would be to generate (select) mutes for aggregated O-D data, not to generate (select) routes for individual vehicles (consistent with the assumptions identified in Section 1).

5.3 Support Systems Traceability Matrix

The following matrix correlates support systems to requirements derived in Section 2 and analysis elements derived in Section 3. There is not necessarily a 1 to 1 mapping between a support system and an analysis element. For example, a particular support system might map to as many as 6 analysis elements. Further functional analysis and decomposition of support systems and ATMS subsystems, however, are solutions to this phenomenon. Most of these relationships will be resolved when these logical support systems are further defined and mapped to physical entities (i.e., hardware, software, people) in Tasks C and D.

SUPPORT SYSTEM (#)	CRITICAL AREA (#)	REQUIREMENT	ANALYSIS MAP
RTAC (5.2.1)	cs (5.1.3)	ATMS 3, ATMS 5	1.2.1, 1.2.2, 1.2.3, 1.2.5, 1.2.6, 1.2.7
WATCK (5.2.2)	CS (5.1.3)	ATMS 3, ATMS 5	1.2.3
ATMS (5.2.3)	cs (5.1.3)	ATMS 1, ATMS 3, ATMS 4, ATMS 5	1.2.3
IACE (5.2.4)	IIA (5.1.5)	ATMS 1, ATMS 2, ATMS 4	1.2.1
MMK (5.2.5)	IM (5.1.2). ID (5.1.8)	ATMS 2, ATMS 3, ATMS 4, NWS 1, NWS 2. ENV 1, ENV 2, EMER 3. EMER 4, EMER 5, EMER 6. EMER 7	1.2.3. 1.2.4, 1.2.6

SUPPORT SYSTEM (#)	CRITICAL AREA (#)	REQUIREMENT	ANALYSIS MAP
DMS (5.2.7)	ID (5.1.8). cs (5.1.3), DIM (5.1.1)	ATMS 5, ATMS 7, ATMS 8	1.2.2, 1.2.3, 1.2.4
ITPS (5.2.8)	ID (5.1.8)	ATMS 5, ATMS 6	1.4.1, 1.4.2
DAS (5.2.9)	cs (5.1.3)	ATMS 3, ATMS 5	1.2.3
CPT (5.2.10)	cs (5.1.3)	ATMS 5	1.4.3
ASM (5.2.11)	OATS (5.1.7)	ATMS 7, ATMS 8, ATMS 9, ATMS 10, ATMS 11, ATIS 1, APTS 1, CVO 1, AVCS 1. TRAN 1, TRAN2	1.3.1-1.3.6
TASS (5.2.12)	TMT (5.1.4)	ATMS 7, ATMS 9, ATMS 10, ATIS 1, APTS 1, CVO 1, AVCS 1	1.2.5. 1.3.2
DDM (5.2.13)	DIM (5.1.1)	ATMS 2, ATIS 1, APTs 1, CVO 1, AVCS 1	1.1.3
DICFS (5.2.14)	DIM (5.1.1)	ATMS 1, ATMS 6, NWS 1, NWS 2. ENV 1, ENV 2, NADB 1, NADB 2	1.1.1, 1.1.2, 1.1.3.4

SUPPORT SYSTEM (#)	CRITICAL AREA (#)	REQUIREMENT	ANALYSIS MAP
IRIDE (5.2.16)	IM (5.1.2)	ATMS 2, ATMS 4	1.2.1
PAAS (5.2.17)	TMT (5.1.4)	ATMS 3, ATMS 4, NWS1	1.2.2
MMK (5.2.18)	TMT (5.1.4)	ATMS 2, ATMS 3, ATMS 4, ATMS 6	1.2.5
GSSCS (5.2.19)	ID (5.1.8)	ATMS 3, ATMS 5, EMER 4, EMER 5, EMER 6	1.2.6
ROSE (5.2.20)	SS (5.1.6)	ATMS 10	1.3.2
ISDEE (5.2.2 1)	SS (5.1.6)	ATMS 3, ATMS 9, ATMS 10, ATMS 11, ATIS 1, ATIS 2, ATIS 6, ATIS 7, APTS 1. APTS 5, cvo 1, cvo 2, AVCS 1, AVCS 2, NADB 3, EMER 1, EMER 2, EMER 3, EMER 4, EMER 5, MAIN 1, MAIN2	1.4.3

SUPPORT SYSTEM (#)	CRITICAL AREA (#)	REQUIREMENT	ANALYSIS MAP
CMS (5.2.23)	cs (5.1.3)	ATMS 3, ATMS 5	1.2.6
OTSS (5.2.24)	TMT (5.1.4)	ATMS 10	1.3.2
RGSA (5.2.25)	CS (5.1.3), ID (5.1.8)	ATMS 5, ATIS 3, APTS 3, cvo 3, NADB 2.3, EMER 3	1.2.3

5.4 Allocations of Functions to Support Systems

The following matrix correlates requirements from Section 2 to analysis elements derived in Section 3 and to possible support systems derived in this section. Note that a requirement has a 1 to many mapping to analysis elements and support systems. That is, most requirements are fulfilled in more than one place.

REQUIREMENT	CRITICAL AREA (#)	ANALYSIS MAP	SUPPORT SYSTEM (#)
ATMS 1	CS (5.1.3)	1.2.3	ITMS (5.2.3)
	IIA (5.1.5)	1.2.1	IACE (5.2.4)
	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (5.2.14)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	OATS (5.1.7), TMT (5.1.4)	1.1.1, 1.1.2, 1.2.5	FAST (5.2.22)
ATMS 2	IIA (5.1.5)	1.2.1	IACE (5.2.4)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	DIM (5.1.1)	1.1.4	DDM (5.2.13)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
	IM (5.1.2)	1.2.1	IRIDE (5.2.16)
	TMT (5.1.4)	1.2.5	MMK (5.2.18)
ATMS 3	cs (5.1.3)	1.2.3	ITMS (5.2.3)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
	TMT (5.1.4)	1.2.5	\ MMK (5.2.18)
	cs (5.1.3)	1.2.2, 1.2.3	RTAC (5.2.1)
	cs (5.1.3)	1.2.3	WATCK (5.2.2)
	IM (5.1.2)	1.2.4	IFCP (5.2.6)

REQUIREMENT	CRITICALAREA (#)	ANALYSIS MAP	SUPPORT SYSTEM (#)
	TMT (5.1.4)	1.2.2	PAAS (5.2.17)
	ID (5.1.8)	1.2.6	GSSCS (5.2.19)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	cs (5.1.3)	1.2.6	CMS (5.2.23)
ATMS 4	cs (5.1.3)	1.2.3	ITMS (5.2.3)
	IIA (5.1.5)	1.2.1	IACE (5.2.4)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
	IM (5.1.2)	1.2.1	IRIDE (5.2.16)
	TMT (5.1.4)	1.2.5	MMK (5.2.18)
	IM (5.1.2)	1.2.4	IPCP (5.2.6)
	TMT (5.1.4)	1.2.2	PAAS (5.2.17)
	ID (5.1.8)	1.2.6	IMK (5.2.5)
ATMS 5	cs (5.1.3)	1.2.3	ITMS (5.2.3)
	c s (5.1.3)	1.2.2, 1.2.3	RTAC (5.2.1)
	ID (5.1.8)	1.2.2- 1.2.4	DMS (5.2.7)
	cs (5.1.3)	1.2.3	WATCK (5.2.2)
	cs (5.1.3)	1.2.3	DAS (5.2.9)
	ID (5.1.8)	1.2.6	GSSCS (5.2.19)
	c s (5.1.3)	1.2.6	CMS (5.2.23)
	CS (5.1.3)	**1.2.6**	**CMS (5.2.23)**
	ID (5.1.8)	**1.4.1, 1.4.2**	**ITPS (5.2.8)**
	CS (5.1.3)	**1.4.3**	**CPT (5.2.10)**
	CS (5.1.3)	**1.4.1**	**RGSA (5.2.25)**
ATMS 6	**DIM (5.1.1)**	**1.1.1**	**DICFS (5.2.14)**
	TMT (5.1.4)	**1.2.5**	**MMK (5.2.18)**
	ID (5.1.8)	**1.4.1**	**ITPS (5.2.8)**
	OATS (5.1.7)	**1.1.1, 1.1.2, 1.2.5**	**FAST (5.2.22)**
	DIM (5.1.6)	**1.2.2**	**DMS (5.2.7)**
ATMS 7	**IM (5.1.2)**	**1.2.4**	**IPCP (5.2.6)**
	CS (5.1.3)	**1.2.6**	**CMS (5.2.23)**
	OATS (5.1.7)	**1.3.1-1.3.6**	**ASM (5.2.11)**
	TMT (5.1.4)	**1.2.5**	**FAST (5.2.22)**
	TMT (5.1.4)	**1.2.5**	**TASS (5.2.12)**
	ID (5.1.8)	1.2.2-1.5.4	DMS (5.2.7)
[redacted]	OATS (5.1.7). TMT (5.1.4)	1.1.1, 1.1.2, 1.2.5	FAST (5.2.22)

REQUIREMENT	CRITICAL AREA (#)	ANALYSIS MAP	SUPPORT SYSTEM (#)
	CS (5.1.3)	1.2.6	CMS (5.2.23)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	FAST (5.2.22)
	ID (5.1.8)	1.2.2-1.2.4	DMS (5.2.7)
	OATS (5.1.7), TMT (5.1.4)	1.1.1, 1.1.2, 1.2.5	FAST (5.2.22)
ATMS 9	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.1, 1.4.2	ISDEE (5.2.21)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	TASS (5.2.12)
ATMS 10	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	TASS (5.2.12)
	SS (5.1.6)	1.3.2	ROSE (5.2.20)
	TMT (5.1.4)	1.3.2	OTSS (5.2.24)
ATMS 11	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (5.2.14)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	OATS (5.1.7), TMT (5.1.4)	1.1.1, 1.1.2, 1.2.5	FAST (5.2.22)
APTS 1	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	TASS (5.2.12)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
APTS 2	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
APTS 3	CS (5.1.3)	1.4.1	RGSA (5.2.25)
ATIS 1	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	TASS (5.2.12)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
ATIS 2	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
ATIS 3	CS (5.1.3)	1.4.1	RGSA (5.2.25)
AVCS 1	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)

REQUIREMENT	CRITICAL AREA (#)	ANALYSIS MAP	SUPPORT SYSTEM (#)
	TMT (5.1.4)	1.2.5	TASS (5.2.12)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
AVCS 2	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
CVO 1	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	TASS (5.2.12)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
cvo2	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
cvo3	CS (5.1.3)	1.4.1	RGSA (5.2.25)
EMER 1	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
EMER 2	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
EMER 3	IM (5.1.2)	1.2.3, 1.2.4	IMK (5.2.5)
	ID (5.1.8)	1.4.1	RGSA (5.2.25)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
	cs (5.1.3)	1.4.1	RGSA (5.2.25)
EMER 4	IM (5.1.2)	1.2.4	IMK (5.2.5)
	ID (5.1.8)	1.2.6	GSSCS (5.2.19)
	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
EMER 5	IM (5.12)	1.2.4	IMK (5.2.5)
	lD(5.1.8)	1.2.6	GSSCS (5.2.19)
	ss (5.1.6)	1.4.2	ISDEE (5.2.21)
EMER6	IM (5.1.2)	1.2.4	IMK (52.5)
	ID (5.1.8)	1.2.6	GSSCS (5.2.19)
EMER 7	IM (5.1.2)	1.2.4	IMK (5.2.5)
ENV1	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (52.14)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
ENV2	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (5.2.14)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
MAIN1	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	ss (5.1.6)	1.4.2	ISDEE (5.221)
MAIN 2	SS (5.1.6)	1.4.2	ISDEE (5.221)
NADB 1	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (5.2.14)
	IM (5.1.2)	1.2.4	IMK (5.2.5)

REQUIREMENT	CRITICAL AREA (#)	ANALYSIS MAP	SUPPORT SYSTEM (#)
NADB 2.3	CS (5.1.3)	1.2.3, 1.4.1	RGSA (5.2.25)
NADB 3	SS (5.1.6)	1.4.2	ISDEE (5.2.21)
NWS 1	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (5.2.14)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
	TMT (5.1.4)	1.2.2	PAAS (5.2.17)
	OATS (5.1.7)	1.1.1, 1.1.2, 1.2.5	FAST (5.2.22)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
NWS 2	DIM (5.1.1)	1.1.1, 1.1.2	DICFS (5.2.14)
	DIM (5.1.1)	1.3.2	DBMS (5.2.15)
	DIM (5.1.1)	1.1.3	DDM (5.2.13)
	DIM (5.1.1)	1.2.2	DMS (5.2.7)
	IM (5.1.2)	1.2.4	IMK (5.2.5)
TRAN 1	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
TRAN 2	OATS (5.1.7)	1.3.1-1.3.6	ASM (5.2.11)
	TMT (5.1.4)	1.2.5	FAST (5.2.22)

5.5 State-of-the-Practice Analysis and Deployment Considerations

A variety of traffic management systems are in existence today. One design objective of this support system development was to preserve the existing infrastructures. In order to achieve this goal, a comprehensive review of existing infrastructures was necessary. Task A of this study included the survey of the state-of-the-practice of TMC operations at home and abroad. It served two purposes. First, it provided in-depth knowledge and vision for a mature ATMS. Second, it provided knowledge of existing infrastructure, so that design of the support systems will be geared towards maximizing the objective of preserving existing infrastructure.

5.5.1 Analysis of State-of-the-Practice

The analysis and survey of existing TMCs revealed the capabilities of today's TMCs as well as their deficiencies. Also, a review of current research works indicates future products. The following paragraphs provide a brief description of the state-of-the-art for ATMS' limdamental constituents.

Currently, loop detectors are universally used as sensor device for detecting vehicles, generating classifications and determining speeds. The detectors are able to feed the collected data to TMCs automatically. Even with state-of -the-practice detectors, a full-blown ATMS can flourish if the detectors are installed comprehensively. ATMS needs to perform data management that can generate all necessary statistics and inferences in a timely manner. Research is underway on video image detection systems using video cameras. The research product is expected to bring in the portability with the detection system. It will also bring in the flexibility in changing the loop sizes as needed.

For traffic control, Urban Traffic Control Systems (UTCS) is widely used. It is a time of day type control. No adaptive traffic control strategies has been effectively used to date. A lack of integration between freeway ramp metering and network control exists. The lane use control signals have not been adaptively utilized. Currently, research is being conducted on adaptive traffic controls for road networks as well as isolated intersections.

For incident management, algorithms exist for automated incident detection using loop detector data. However, our review of TMCs indicated that the algorithms need to be enhanced. Application of artificial intelligence to this specific area is a topic of ongoing research efforts. Hence, a solution to this area can be achieved within a reasonable time period. In addition, there is a major deficiency in the management and coordination efforts for incident management. Automation for coordinating with different agencies is needed within the ATMS environment,

Another important constituent of ATMS is human factors. Advanced TMCs already have computerized graphic displays, however, in a mature IVHS environment, increases in data complexity, quantity, and type are expected. These increases translate into greater responsibilities for machines and humans. The interaction between humans and machines and the requirements they place one another needs to be further refined. We believe that technology is available and research is being conducted in the area of human factors to develop more sophisticated and effective interfaces between man and machine (i.e., graphical user-interfaces, data abstraction displays, etc.).

Another deficiency of today's TMCs is lack of integrated databases as well as on-line modeling tools. For traffic management, one needs to retrieve data from various sources that are available in different formats, including on-line queries and hard copies. This makes it possible to gather necessary data for making an on-line simulation run for decision making. Even the planning activities are cumbersome due to the lack of data integration. In our view, a mature ATMS will have an integrated database management system that will contain all necessary information related directly to traffic control, such as the traffic information, roadway network data, roadway geometries, traffic control parameters, historical data, and real-time data. In addition, ATMS support systems should be linked to other peripheral databases such as an accident database, pavement management system database (for pavement condition information), and various other external databases (e.g., HAZMAT) for quick access and retrieval.

5.5.2 Deployment Considerations

The state-of-the-practice analysis indicates that many constituents of a future, mature ATMS exist today in some form. Some constituents can be utilized in the present form or with minor upgrades (e.g., loop detectors), some constituents need major upgrades (e.g., automating incident management, adaptive traffic control), while some components require a completely new development effort (automated image analysis using specialized artificial intelligence techniques). The deployment of ATMS within an existing infrastructure will continue using most of the existing resources. However, it will need upgrades of some existing resources (e.g., replacement of UTCS with adaptive traffic control algorithms) and filling in the existing vacuums (integration of databases, inputs of data).

The deployment of ATMS will necessarily be evolutionary in nature. The traffic management systems available in this country vary from a simple conventional traffic control system using pre-timed controller, to an advanced system that already implements advanced traffic control techniques in an integrated fashion.

ATMS must support the partial deployment of the system. The deployment of ATMS is dependent upon the deployment of its customer IVHS components, such as ATIS, ARTS, CVO etc. and user needs. Deployment will be gradual depending on customers' increasing demands (e.g., functions needed by ATIS, APTS, etc.) and upon the state of the system already in place.

Of the many ATMS functions, it is anticipated that one of the early deployments will include adaptive traffic signal control strategies, because the necessary peripherals such as surveillance devices (detectors) and control devices (signals and signs) already exist in some form. The peripherals may need upgrades and expansions for a mature adaptive traffic control system. Other implementations such as interactions with other IVHS elements will occur later. Again, among the IVHS elements, we anticipate that the implementation of ATIS will precede other implementations, and AVCS/AHS implementation will possibly occur at a later stage. The implementations are heavily dependent on the research works being conducted or to be conducted in future.

Another important issue is the source of funding needed for ATMS resources such as TMC hardware, surveillance and control devices, as well as the evolving IVHS technologies. The source of funding for the deployment of ATMS is undoubtedly government sources. Funding is not expected to require any funding from the private users (an adaptive signal control strategy can be envisioned within this picture). The implementation of the IVHS elements, however, will heavily depend on the user participation and associated cost sharing (e.g., such as purchasing ATIS equipment on their automobiles).

5.5.3 Deployment in Phases

In the previous subsection, we discussed that all the possible capabilities of an ATMS will not be deployed at a single time, because some will be implemented earlier than others. In this subsection, we attempt to provide a list of ATMS functions in order of their expected deployment, referring to the ATMS Context Level Diagram (see Figure 2-2). Although this sequence is merely the result of anticipation and very subjective, it will prove helpful in prioritizing the development of ATMS functions. We recognize that within each function, there will be different levels of functionality based on levels of resources used.

Level 0. Interaction with Organizational Users: This is not envisioned as real-time automated activity (although, it is that parts of it will be - automated monthly reports, intelligent queries from remote organizations via dial-in, etc.). There already exists a distinct form of interaction of ATMS with these elements.

Level 1. Adaptive traffic signal control: This function is within the scope of ATMS itself, and as such it is not shown in Figure 2-2.

Level 2. Incident management and interaction with Emergency Response elements.

Level 3. Interacting with IVHS elements: This can again be arranged in the following sequential manner:

a. Interaction with ATIS: The success of, and experience from the TravTek project has brought in the promise for an early implementation of ATIS.

b. Interaction with CVO, APTS: Many requirements of CVO and APTS are similar to ATIS. A successful implementation of ATIS will prompt their implementation also.

c. Interaction with AVCS/AHS: A significant amount of research needs to be conducted in this area.

NOTE

Interactions with external Databases and non-IVHS external systems are not included. These will depend on the gradual development of the databases and communication systems. Fully automated systems of this type will evolve with time. However, weather and environmental data can easily be used in a TMC environment.

5.5.4 Test Case: Houston Architecture

In this subsection, we chose a test case to see how we can deploy an ATMS. The selected site for deployment is the city of Houston, where an existing infrastructure is already in place. TxDOT is currently constructing distributed Traffic Management facilities for the following freeway locations:

a. **IH 45** North Freeway.

b. **IH 45** Gulf Freeway.

c. IH 10 West Freeway.

d. US 290 Northwest Freeway.

Each facility has a satellite computer station that receives data from the field and issues control commands to the field devices. TxDOT plans to build more facilities like this. Let us consider that we plan to deploy our envisioned ATMS within these facilities.

Each facility possesses the following resources:

a. Electronic vehicle detection and monitoring of freeways and arterials.

b. CCTV video surveillance.

c. Traffic control devices such as freeway ramp metering controllers and intersection signal controllers.

d. Motorists information system such as CMS and lane use control signals.

e. Fiber optic communications.

f. Unmanned satellite computer stations for data collection, analysis and dissemination to field devices.

This is a unique case of traffic management system where a hierarchical ATMS architecture needs to be used. Our envisioned ATMS will be at the top-level controlling all of these distributed facilities. The deployment of ATMS will include the following:

a. A central control facility - a central facility will receive data from each individual satellite station and provide a supervisory control on each. This facility is planned to be developed by TxDOT anyway. A portion of the ATMS will be utilized at this time. ATMS will receive and analyze data, and provide traffic control strategies on a wide area basis, within the capability of the existing software applications. In addition, the database will be maintained in accordance with the ATMS data dictionary. It will involve significant amount of data entry or automated translation routines. This will provide the first phase of the deployment of the ATMS.

b. Now that the central ATMS has the data available for all individual regions, the adaptive traffic control will be implemented by replacing the existing software applications. Implementation will need to be implemented on a wide area, integrating freeway and network traffic. The ATMS now requires a sophisticated, user friendly computer map display [Geographic Information System (GIS)] of all real-time and historic information. The display will also include the CCTV video image on the display screen.

c. A gradual growth will be accommodated within ATMS to become mature enough to perform all necessary functions. The ATMS integrated database will be expanded to include other data and be linked to other related databases (e.g., such as accident database system). The incident management component of ATMS will be activated after automating the management coordination efforts. With the advancement of IVHS technologies, ATMS will start disseminating the information from its database to IVHS elements (e.g., ATIS, APTS, CVO, AHS/AVCS). This will require addition of necessary hardware and software support within ATMS.

d. The traffic simulation models will be linked up to ATMS for both on-line and off-line use..

Manual input of data to the database systems will be very intensive during the initial deployment phase. However, a significant portion of the existing databases can be used, by converting the data into a usable format. Translation utilities and data entry will be necessary (to populate the ATMS integrated database) while ATMS evolves to a mature state. All new additions of resources (e.g., new detectors) will need to be entered to the system. The manual data entry process will reach a regular maintenance level when ATMS becomes mature.

6.0 FUTURE DIRECTION

Now that the system operations concept has been developed and the generic system requirements are identified, the next step will be the design of the support systems. The next step in the process will be a thorough functional analysis. This analysis will result in the functional requirements for the support systems. Specifically, these requirements will define performance, fault-tolerance, communications, facility, and human-machine interface requirements. These requirements will be used for developing functional specifications for the support systems. This set of functional specifications describe feasible solutions for meeting the functional requirements, Once the set of possible solutions is identified, an a trade-off analysis will be done to examine each solution. On the basis of this analysis the final support system specifications will be selected. These analysis will be documented in the final working paper for Task C.