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Traffic Management Centers - The State-of-the-Practice

Task A Final Working Paper for Design of Support Systems for Advanced Traffic Management Systems

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1 Introduction

The Design of Support Systems for Advanced Traffic Management Systems Project is a five-year program to define, design, and field test prototype systems to support the multitude of functions within Traffic Management Centers (TMC). Mature TMCs of the future will become components of Advanced Traffic Management Systems (ATMS), with functional responsibility for the collection and dissemination of traffic information, as well as the monitoring, management, and control of traffic on a local and regional basis. The volume and frequency of the information to be processed will overwhelm the ability of TMC operators unless automated support tools are available to aid in the real-time interpretation, analysis, and synthesis of the data.

The Design of Support Systems for ATMS Project is comprised of the following primary tasks:

a. Review the of state-of-the-practice as it relates to TMC operations.

b. Develop concept of operations for a TMC 10 years hence.

c. Design prototype software support systems.

d. Develop and bench test systems.

e. Field test and document operations in three test sites

The first task (review the state-of-the-practice) is intended to provide a baseline of current TMC capabilities, as well as identify applications in other domains such as Air Traffic Control and Satellite Control, which may be potentially applicable. This baseline, in conjunction with the end-state TMC defined by the concept of operations, will determine a realistic design goal for implementation within the time frame of this project.

1.1 Scope

This document provides a review of the applications of various technologies presently available within traffic management centers in the United States and abroad. Since the Federal Highway Administration (FHWA) is currently sponsoring several studies in areas such as adaptive traffic control and dynamic traffic assignment, both functions within an advanced TMC, the focus of the state-of-the-practice review for this project and this report is on automated systems for information processing and decision support. Of particular interest has been the integration of individual systems and the treatment of man/machine interface issues.

The review of existing system capabilities is comprised of a literature review and site visits. Results from the site visits are reported in detail in this report. A summary of unique features applicable to an advanced TMC is also contained within this report.

1.2 Methods and Sources

The review of the state-of-the-practice has been carried out through a combination of a literature review, telephone interviews, and individual site inspections.

The literature review covered professional journals, conference proceedings and research and development reports. Intelligent Vehicle Highway Systems (IVHS) America documents were found useful in defining the overall direction of the IVHS Program and the role of ATMS. A complete listing of referenced material is included in the bibliography.

The site visits were performed to gather detailed data from selected sites. The sites were selected on the basis of their network type and complexity, and the presence of one or more of the following elements:

a. Support systems for incident detection and management.

b. Integrated freeway and surface street management.

c. Unique support system capabilities, including graphical user interfaces, data fusion, expert system and other artificial intelligence algorithms.

d. Automated interfaces to other IVHS components such as, Advanced Traveller Information Systems (ATIS), Advanced Public Transportation Systems (APTS) and Commercial Vehicle Operations (CVO).

The purpose of the site visits was two-fold: first, to identify current technology applications and the level of capabilities they provide, and second, to identify future TMC requirements through a better understanding of the benefits and the limitations of current technologies. Based on the above criteria, control centers in metropolitan Los Angeles, Orlando, and Minneapolis as well as the Federal Aviation Administration's (FAA) National Command Center and the National Oceanographic and Atmospheric Agency's (NOAA) Satellite Operations Control Center were selected for site visits. Telephone interviews were conducted with site personnel at other sites meeting the criteria but not visited. A discussion of the rationale for these selections is presented in Appendix A.

1.3 Document Organization

The remainder of this report is presented in four sections. Section 2 presents an overview of TMC functions in a mature ATMS environment, reflecting a preliminary set of generic support areas. This section is intended to provide the overall framework that guided our information gathering efforts during the site visits and the literature survey. Section 3 provides the summary of our findings as they relate to each of the key support areas defined in Section 2. Section 4 presents the detailed information for each of the visited sites, as well as information collected on other TMCs, either from the literature or through telephone interviews. Finally, our findings are summarized in Section 5.

2 ATMS and TMC Overview

"ATMS is the foundation upon which all other IVHS technologies rely."[1] ATMS will employ innovative technologies and integrate existing and new traffic management and control systems to be responsive to dynamic traffic conditions. The primary characteristics of ATMS are as follows:

a. Collection of real-time traffic data and area-wide surveillance and detection.

b. Integrated management of various functions including demand management, toll collection, signal control, and ramp metering.

c. Rapid response to incidents and collaborative action on the part of various transportation management organizations to provide integrated responses.

d. Proactive traffic management strategies including route guidance and pre-trip planning.

e. Interfaces to other IVHS components, such as ATIS, ARTS, CVO, and Advanced Vehicle Control Systems (AVCS).

f. Interfaces to non-IVHS components, such as police, fire, and municipal organization.

g. A unified database structure in support of integration, operating efficiency, and interface to other systems.

This vision of ATMS will be achieved over a 20-year time frame through the application of advanced technologies in several key areas. Some of these technologies are as follows:

a. Traffic Surveillance.

b. Traffic Control.

c. Traffic Models.

d. Human Factors.

e. Integration of Systems.

Additionally, operational support and maintenance of systems are areas that must not be overlooked as they are critical factors for successful deployment.

At the core of ATMS are the TMCs where many of the technologies will be implemented and where most, if not all, of the information will be collected and processed. Activities that will likely occur in a TMC include the following:

a. Receiving and processing surveillance inputs.

b. Executing traffic models.

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[1] Strategic Plan for IVHS in the United States, prepared by IVHS America, Report No. IVHS-AMER-92-3, May 20, 1992.

c. Planning and monitoring of traffic control strategies.

d. Disseminating travel information.

Issues that must be addressed to provide these capabilities include the following:

a. Human factors considerations, such as situational awareness.

b. The integration of internal systems.

c. Interfaces to external systems have to be provided.

The remainder of this section summarizes the key features of the support elements. In Section 3, these required support elements will be contrasted with those found in use in today's TMC.

2.1 ATMS Surveillance Systems

Traffic surveillance is the quintessential element of ATMS. Traffic information can be collected using any one or combination of the following:[2]

a. Inductive loop detectors (sensors).

b. Video Detection and Closed-Circuit Television (CCTV).

c. Infrared sensors.

d. Direct observation (police, public works, etc.).

e. Vehicle Probes.

f. Aerial surveillance.

g. Motorist reports through call boxes and cellular phones.

In general, the information is captured by the sensors, processed locally, and aggregated for transmission to the TMC. For example, loop detectors at signalized intersections are polled by a local controller at 1/240 second intervals, but the information to the TMC is communicated at 1-second intervals. Similarly, the direct output from a CCTV camera is processed to produce a count of vehicles or a measure of speed prior to submission to the TMC.

Communication with the TMC may employ a variety of technologies, including the following:

a. Radio.

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[2] Various surveillance technologies are potentially applicable in IVHS. These span the spectrum and include radar, microwave, infrared, and the visual range. In this report we concern ourselves only with those technologies that directly support ATMS surveillance. For example, weigh-in-motion sensors are considered within the scope of CVO rather than ATMS.

b. Microwave.

c. Cable.

d. Fiber Optics.

e. Telephone.

Interfaces to a variety of surveillance equipment must be made available because a single technology is not likely to meet all requirements. Specific requirements will depend on the IVHS architecture currently under development through FHWA sponsorship.[3]

The monitoring function processes incoming data and detects malfunctions in the operation of traffic and surveillance networks. A direct interface from the monitoring function to administrative support software will prove to be most useful by automatically generating failed equipment reports and equipment repair work orders for the maintenance department.

2.2 ATMS Control Systems

One of the fundamental properties of an ATMS is the capability for controlling the traffic network. Control in an ATMS signal may be centralized, distributed, or hierarchical. In a centralized control environment, a central facility collects traffic status data and makes traffic control decisions. In a distributed environment, control is performed locally, generally at the intersection level. A hierarchical control configuration is a hybrid between central and distributed control. In this architecture, control is generally performed locally; control decisions are monitored by a central facility that may override local control to achieve optimize traffic flow on a sub-region basis.

Regardless of the specific architecture, the vision is for integrated, proactive control rather than reactive control. A wide range of options are available, including real-time traffic adaptive signal control, adaptive freeway control including ramp metering, transit and emergency vehicle preferential treatment, and lane usage control. Other strategies involving route diversion are treated within the context of the ATIS interface.

In all of the above options, the control mechanisms are directly managed by the TMC. For most control system configurations, the control software will reside within the TMC as one of the support systems. In the case of distributed control, the TMC functions as a supervisory node with control override capabilities. In the future, the design of TMCs will need to be sufficiently robust to accommodate variations in the architecture.

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[3] Under some architecture alternatives individual vehicles may communicate directly with the TMC; in other cases vehicles communicate with local processors which may in turn communicate with the TMC via fiber-optic lines. The chosen architecture will determine the requirements.

2.3 Detection and Management of Non-Recurrent Congestion

One of the primary goals of IVHS is to reduce congestion. According to IVHS America estimates, congestion can be reduced as much as 20 percent by 2011 in cities adopting IVHS technologies. Since a significant portion of traffic congestion is due to traffic accidents and other incidents, a primary functional requirement of ATMS is the detection and management of incidents. Because of the importance of this function, it is generally treated separately, although it involves elements of surveillance, monitoring, control, and decision support.

The TMC is the focal point for incident management within IVHS and ATMS. Once an incident is detected and verified (e.g., using video input) various traffic models are available in the TMC workbench for developing a response strategy.[4] The strategy may involve an integrated response by several organizations, as in the case of an accident involving hazardous materials. Control options may include sending advisory messages to changeable message signs, or route diversion alternatives via an interface to ATIS, or via radio broadcast. In the latter case, an interface to the TMC with responsibility for the adjacent arterials or street network is required. It is anticipated that as artificial intelligence technology matures, some of these support tools may be automated.

Certain information processing capabilities are required for the TMC to provide the services described above. These include: integrated data management, real-time traffic simulation model execution, image processing for area-wide surveillance and incident detection, and man/machine interfaces providing transparent access to needed information.[5] TMCs covering large regions will need the capability of simultaneously managing multiple incidents. Providing this capability will require multi-user computing environments.

2.4 TMC Decision Support Capabilities

All the traffic models and simulations used in the TMC reside within the Decision Support element. It is useful to distinguish between operational and planning models. The latter are exercised offline to generate potential strategies that are saved in libraries for future use. While it is desirable that the execution speed of these offline programs be as fast as possible, performance is not the key requirement. A critical feature of these programs is that they must meet their data requirements within the overall design of the TMC databases. Specifically, surveillance information should be automatically archived in the proper format for use by these models.

Online models are used for developing response strategies. They must execute faster than real-time so that their results can affect decision-making processes occurring in real time.

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[4] The concept of an operator workbench in the TMC is to provide the operator with integrated access to all decision support tools through a graphical user interface.

[5] The operator should be able to access all data in the database through the activation of icons without having to resort to database syntax.

To aid in this process the predefmed route diversion strategies may be employed while an incident specific-strategy is developed.

In designing these decision models, particular attention must be paid to human factors considerations. These tools should effectively maximize the operator's ability to understand the situation and to respond effectively in a timely fashion.

2.5 ATMS Integrated Data Management

Unified database structures are an essential component of ATMS. Integrated database structures will facilitate interface requirements between internal and external TMC entities. The ATMS requirement for multi-agency integrated response will be difficult to meet without fully integrated databases.

The capability for "fusing" data from a variety of sources also resides within the TMC data management function. This element may involve rule-based systems for validating the reliability of the incoming data and generating a fused result (e.g., a weighted sum of the individual values).[6]

All data management functions normally associated with databases, such as database backup and recovery, are handled within this support system

2.6 TMC Interfaces to IVHS Systems

ATMS is the core of IVHS. As such, it will be the integrating agent for both IVHS and non-IVHS systems. Within the TMC, interfaces are required to all other IVHS systems including ATIS, APTS, and CVO and AVCS. Of these, the strongest coupling is between ATMS and ATIS. This coupling is created by the requirement for supporting route guidance and route diversion. Depending on the option recommended by the IVHS Architecture Study, the data loading and processing requirements imposed on the TMC can be quite significant. Centralized route guidance, for example, will require high performance processors and efficient algorithms to be resident in the TMC. The communications load will vary depending on whether vehicles communicate directly with the TMC or through roadside processors. In either event, standard protocols and data structures will be required for an integrated system.

Interfaces with the APTS and CVO components impose similar but less stringent requirements. Again, the requirements will be determined by the end-state of the IVHS architecture. In one scenario, the TMC would serve as an information resource on traffic conditions and that information could be relayed to other systems. Alternately, the information could be directly accessed from TMC databases on demand. If the option of using transit and commercial vehicles as probes is selected, these vehicles will require methods for communicating with the TMC.

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[6] A rule-based system refers to an expert system paradigm in which the knowledge base comprises a set of IF-THEN-ELSE rules. These rules are derived as a result of a knowledge acquisition process involving an expert.

Through the TMC to AVCS, interface vehicles will obtain information necessary for automated vehicle control. Examples of this type of information include roadway weather conditions for use in vehicle safety systems, and roadway geometries and configurations. Standard interfaces will be defined to achieve fully automated vehicle and highway systems.

2.7 TMC Administrative Support Capabilities

Various administrative functions are handled by TMC personnel. Foremost among these is the maintenance of equipment, both located within and outside the TMC. Prompt repair of failed surveillance and control equipment is essential for effective operation of the system. Direct interfaces with monitoring elements will facilitate the issuance of work orders and track maintenance needs, and will contribute to the overall effectiveness of the TMC in meeting its ATMS objectives. Other functions in this category include those associated with personnel and financial management.

Interfaces to non-IVHS external systems are handled within the TMC through automated and non-automated procedures. These may include automated alerts to other agencies, procedures for hazardous material spill coordination, and others.

3 TMC State-of-the-Practice

In the previous section, an overview of TMC functions found in a mature ATMS system was presented. Using Section 2 as background, this section summarizes the findings of the state-of-the-practice task. These findings are based on a literature survey, telephone interviews, and site visits by the Project team to a number of sites in the United States. In the first portion of this section, observations made during the site visits are summarized and contrasted with the vision described in Section 2. Included in the presentation is a description and evaluation of capabilities currently in place, as well as those capabilities that are planned as part of an ATMS upgrade. This section concludes by presenting a summary of significant observations found through the literature review.

3.1 Surveillance

Based on our research and the site visits, loop detection is the predominant surveillance technology in use today. This is a result of the fact that existing signal control systems such as the Urban Traffic Control System (UTCS), Split Cycle Offset Optimization Technique (SCOOT), and Sydney Coordinated Adaptive Control System (SCAT) are based on loop detection,

By contrast, freeway surveillance, in many cases, employs both loop detectors and CCTV cameras. The standard design places detector banks at 1/2-mile intervals on each freeway lane. These detectors provide speed and density measures of the traffic flow which are relayed to the control center, and are processed by incident detection algorithms. Each detector bank is controlled by a local processor, which communicates with the control center.

There are many installations of CCTV for freeway surveillance. A typical installation places cameras on 50-foot poles at one to three mile intervals. Cameras have zoom, pan, and tilt capabilities with a zoom range of two miles. Video outputs from the cameras are transmitted to the control center where they are viewed on video monitors and are used for incident detection and verification.

In several locations, surveillance programs have been set up through the cooperation of various local agencies and radio stations, whereby surveillance reports on accidents and congestion are relayed to the TMC.

Various operational tests are currently underway to test emerging surveillance technologies. The GuideStar program in Minnesota is evaluating AutoScope^{TM}, a video sensor that is trained on a fixed point of the freeway that uses an image processing algorithm to determine speed and occupancy at that point. When used in this way, the video sensor essentially operates as a loop detector in terms of its outputs. AutoScope's^{TM} advantage over loop detectors is that the camera can be repositioned to another point on the freeway within its line of sight. AutoScope^{TM} is limited in application by the fact that it has been designed to emulate a point detector. As a consequence, it does not take full advantage of image processing for area-wide detection.

Other on-going research efforts focus on testing and evaluating a variety of IVHS sensor technologies. The use of these technologies for ATMS surveillance will impact TMC operations in two ways. First, having increased surveillance coverage and more reliable surveillance information will increase the effectiveness of the control strategies. Second, depending on the overall architecture, higher data loading requirements may impose additional demands on the data handling systems within the TMC. These additional requirements will be accommodated.

The use of vehicles as probes is being investigated as part of several ATIS operational tests. In all cases, link travel times experienced by vehicles are transmitted to the TMC where they are integrated with other data. The data fusion algorithm used by the TravTek Project in Orlando, FL, uses rule-based expert system technology for determining the validity of the various incoming data sources, and determines the “fused“ result. Link travel times transmitted by vehicles are thus integrated with historical, as well as other travel time data sources to compute the expected travel times. These values are transmitted to vehicles for in-vehicle routing computations.

Other IVHS technologies for Automatic Vehicle Identification (AVI) and Automatic Vehicle Location (AVL) which are being used in Electronic Toll Collection and other commercial vehicle applications, are also potentially applicable to ATMS by providing vehicle probe traffic data.

3.2 Control

Most network traffic control systems in the United States are based on UTCS or its derivatives. Some implementations use only Time of Day (TOD) control, others use the Traffic Responsive (TRSP) and Critical Intersection Control (CIC) options.7 SCOOT and SCAT have not been able to penetrate the US market although two applications are in progress.[8] We found in our site visits that TMC managers have not been convinced of the potential benefits of the more advanced systems. There is an impression that these systems require constant attention, which translates to higher manpower requirements, and a higher level of instrumentation.

Ramp metering is a freeway control strategy that seems to have been accepted in many locations. In general, ramp metering signals are connected to the control center via a local controller. At the control center, ramp metering rates are adjusted either manually or automatically in response to freeway traffic conditions as determined by the surveillance data. Minnesota appears to have one of the most comprehensive ramp metering programs on its freeway system. Metering rates are adjusted in response to upstream traffic conditions. Additionally, many ramps are monitored by video cameras, where output is viewed in the control center to determine ramp overflow situations and to verify signal operation.

The site visits did not uncover integrated ramp metering and surface street signal control schemes. Both the INFORM project in Long Island and the Gardiner-Lake Shore Corridor project in Toronto have plans for integrated control, but the current systems do not support automated control.

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[7] TOD uses predetermined signal timing plans which are selected for implementation based on time of day; TRSP selects a timing plan on the basis of current traffic conditions; CIC permits the adjustment of individual intersection signal setting parameters.

[8] Oakland County, Michigan is evaluating SCAT; Oxnard, California is operating SCOOT.

The literature search has revealed that in areas where signal preemption capabilities are available, the control is strictly between the vehicle and the local signal. The TMC's role in signal preemption for emergency vehicles has not been defined.

Lane usage controls are relatively common on bridges, tunnels, and some arterials and HOV facilities, but do not appear to be used on a larger scale, primarily due to geometric restrictions. Most applications are time-of-day based with the particular control strategy determined offline. As reported in the literature, lane usage controls have been used effectively in Amsterdam.

In several of the sites visited, procedures are established for handling the traffic during special events. In all cases, offline models are used to generate signal timing plans corresponding to a set of event scenarios. The UTCS software manages the storage and execution of these plans. In Anaheim, for example, operators observe the traffic conditions during the event and adjust the signal settings in real time using the UTCS CIC capabilities. In all cases where special event planning take place, the affected agencies meet on a regular basis to plan their response to future events.

3.3 Incident Management

As mentioned previously, most freeway surveillance is based on loop detectors whose outputs are processed by incident detection algorithms. These algorithms essentially compare the traffic flow parameters at successive detector locations to arrive at a "detect incident" condition. In most applications, the algorithm requires several cycles of the detect condition as a procedure for verification. In locations using CCTV, video outputs are used to verify possible incidents once the operator has been informed of the incident. Many of the operators interviewed during the site visits and by telephone expressed some doubt about the reliability of current detection algorithms, particularly in high-density conditions.

Only a fraction of today's freeway incidents are detected using automated detection systems. The remainder are called in to the TMC by passing motorists, radio station traffic advisory aircraft, and highway patrol. At the TMC, the operator must evaluate the reliability of information that may be confusing, contradictory, and incomplete. Unless the freeway is instrumented, few options exist, and the operator must decide whether to dispatch an emergency or repair vehicle. In a mature IVHS, equipped vehicles could transmit automatically or manually activated traffic incident reports to the TMC.

The management of incidents in today's environment is manually intensive with minimal automation support. In all cases, we found that the management of incidents is heavily shaded by the operator's experience and judgement. In many locations, the operator's judgement is augmented by predefmed procedures. This is particularly true for incidents requiring the coordinated action of external agencies.

The current use of IVHS technologies for incident management is limited to the following:

a. Advisory messages on CMS.

b. Broadcast messages on Highway Advisory Radio (HAR) or local radio and TV stations.

c. Prepositioning of repair/tow vehicles.

Integrated management of incidents involving multiple jurisdictions is not widely practiced. Some cities (e.g., Los Angeles, CA) have developed memoranda of understandings or operating procedures specifying the scope and specific actions of each jurisdiction under various incident scenarios. In Los Angeles, the UTCS Traffic Responsive (TRSP) mode of control automatically downloads the proper timing plan from the library of plans. Through the Los Angeles Smart Corridor project, this method of automatic control will be expanded to surrounding municipalities. In Orlando, FL, a set of special timing plans for the street system adjoining the freeway have been computed offline, and are used in situations where traffic is diverted off the main line. In case of an incident on the freeway, the Orlando TMC is contacted by the freeway control center, and a joint decision is made regarding diversion. The appropriate timing plan is then downloaded to the local controllers from the TMC. These types of activities are currently minimally supported and require considerable manual interface.

3.4 Decision Support Capabilities

For purposes of this discussion, decision support capabilities are categorized as follows:

a. Displays and User Interfaces.

b. Online Models and Simulations.

c. Offline Models and Simulations.

This grouping reflects the view that display formats and user interface options (e.g., graphical versus character based) are key elements in supporting the operator's ability for analyzing and synthesizing data.

3.4.1 Displays and User Interfaces

Map displays in TMCs are of two types: fixed displays and computer-driven displays. Fixed map displays are inflexible and cannot accommodate any changes without considerable investment in time and money. Most TMCs are upgrading their capabilities to computer-based map displays that can be projected on large screen monitors. These monitors can then be used for other applications in the TMC. For example, the map display in the Minneapolis TMC is normally used to show the network geometry along with the level of service on each freeway segment.[9] It can also be configured to display the outputs of any computer, as well as the video monitors in the TMC. This dual use application appears to have been adopted by many of the TMCs that were visited.

With respect to the configuration of video monitors within the TMC, all sites visited (with the exception of Minneapolis) prefer to use a limited number of monitors to which any

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[9] The level of service provided by a freeway segment is related to the traffic volume and density. The level of service measure ranges from A to F with A representing free flow conditions (speed > 55 mph) and F denoting forced flow (speed < 10 mph)

camera output can be directed by operator selection. This configuration conserves space and appears to be less likely to lead to operator information overload.[10]

The user interfaces primarily reflect the variety of application software found in the TMCs. Since standard interfaces are not established for most traffic engineering applications, there is an assortment of user interfaces and user interface styles. For example, many UTCS implementations have character-based displays; Farradyne's MIST^{TM} uses IBM's Presentation Manager; and customized map-based interfaces are used by JHK's Series 2000. There is no clear operator consensus for the various graphical interfaces available on the market. Integrated interfaces were found neither during the site visits nor in the literature review. The most sophisticated applications included map based Geographic Information System (GIS) displays in a "windowing" environment, such as the one in Montgomery County, MD.

It is interesting to note that in several cases, operators expressed a preference for a character-based display. The most-cited reason for this preference is a higher density of information content in the displays.

Nevertheless, many managers are looking to upgrade the quality of user interfaces through the use of graphics. The commercial availability of many graphical user interfaces and map-display packages will certainly improve this aspect of TMC operation. To take full advantage of these capabilities, many of the existing traffic engineering models and simulations have to be upgraded accordingly.

3.4.2 Online Models and Simulations

No significant support in this area has been reported in the literature or found in the TMCs visited. Most of the managers interviewed expressed the requirement for Decision Support System (DSS) capabilities. DSS applications that were suggested include the following:

a. Expert systems to aid in incident detection and management. Many managers expressed a desire to capture the experience and knowledge of senior TMC operators and managers in a "lessons-learned database". In addition to improving existing incident detection and management techniques, such systems would serve as an invaluable aid to junior operators.

b. Access to traffic simulations models. Existing traffic simulations models are not used online for three reasons: most models are extremely data-input intensive; the data structures in the models do not correspond to the structures in the TMC databases; some of the network models cannot be executed and analyzed within the time frame available for decision making.

c. Evaluation models to support route diversion as a component of incident management. Currently there are no methods for the real-time evaluation of route diversion strategies.

The overall scarcity of online models results from the fact that existing models have been developed for offline use and are difficult to integrate within an online environment. In addition to this fact, most TMCs are not in a position to fund such integration efforts. Some traffic control system vendors have begun to embed decision support capabilities in their

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[10] FHWA is funding a Human Factors in ATMS Study which will address issues such as these.

system packages. Unfortunately, these functions are not separately available because most of the products are closed-loop systems.[11]

There are examples where the large metropolitan organizations are undertaking projects in this area. As part of the Smart Corridor project in Los Angeles, expert systems for incident management are being evaluated, but currently there do not appear to be any operational examples.

3.4.3 Offline Models and Simulations

Unlike online models, many offline models have been developed by the FHWA, Universities, various State DOTs, and foreign transportation organizations. The use of many of these models, however, appears to be limited in normal TMC operations. The reasons cited most often are lack of personnel resources and "user friendliness." Many of the large simulation and signal optimization packages require significant data inputs and are cumbersome to operate. The large organizations that have full-time traffic engineers use models such as Traffic Network Study Tool (TRANSYT) to develop timing plans. Other organizations use signal timing packages such as Progression Analysis and System Evaluation Routine (PASSER), Maximal Bandwidth (MAXBAND), and Signal Optimization Arterial Package (SOAP) to compute coordination plans for major arterials and timing plans individual intersections. In general, the lack of integrated access to the planning data, makes the use of many of these models difficult.

Facilitating the use of existing models through data integration and user friendly interfaces will alleviate some of the support requirements in this area. As mentioned, there are additional requirements for developing evaluation models for route diversion. The complexity of the online requirement depends on whether centralized route diversion is required in the context of the overall IVHS architecture.

3.5 Data Management

The requirement for and lack of integrated databases and effective data management within TMCs has been alluded to in the discussion of several support areas. All of the sites visited were clearly deficient in data management capabilities. Current operations and software applications depend on the capabilities of the control system software and the individual software packages for performing data management functions. As a consequence, such basic automated functions as backup, recovery, ad hoc data access, database monitoring, and integrity checking are not available in the TMC. Even more importantly, the fact that individual software packages and the control system use different data structures precludes effective data sharing, resulting in redundant data storage.

The lack of a data dictionary standard for TMCs creates a situation where Commercial-Off-The-Shelf (COTS) software packages and tools are not easily integrated into existing TMC-computing environments. This limits available options for buying new tools to upgrade

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[11] Closed loop systems do not provide external interfaces and are thus extremely difficult to integrate with other systems.

centers. The lack of modularity is recognized by FHWA as a stumbling block in ATMS evolution.

Supporting both the online DSS and offline planning capabilities within the TMC will require integrated databases accessible by all of the application software, including the control system. Future TMC scenarios require that incoming surveillance data is automatically processed and stored in appropriate planning format for on demand access by both online and offline applications. The various data processing activities to achieve this should be transparent to the operator. By providing this essential capability, TMCs will be able to communicate with each other more easily. The lack of capable and effective data management support systems also increases the complexity of communication with external systems, both IVHS and otherwise.

3.6 Interfaces

In existing TMCs, interfaces to non-IVHS external systems generally are not automated and are based on telephonic communications and manual data transfers (e.g., reports, data tapes). This is a manifestation of the overall lack of data and software integration within TMCs and the lack of network connectivity between TMCs and other agencies.

Some facilities are making efforts to facilitate external interfaces. In Montgomery County, MD, for example, plans exist for coordinating the selection and implementation of a GIS user interface countywide, so that other agencies such as the police department, would be using the same map displays. In Orlando, a TravTek terminal was installed in Metro Traffic Control through which traffic information can be passed directly to the TMC.[12] In the Caltrans center, police computer aided dispatch terminals located in the TMC receive messages from the police about traffic problems. Examples of this information are equipment malfunctions, accidents, or suggested timing changes during special events.

Because of the strong coupling between ATIS and ATMS, interfaces to IVHS systems are predominantly ATIS interfaces. In the TravTek demonstration project, all 100 test vehicles communicate with the TMC every second to pass and receive traffic information. The TMC to vehicle data consists of link travel times adjustment factors. In the vehicles, this information is used by route guidance computers for calculating the optimal routes to the driver's selected destination and to update trip time computations. The vehicle transmits its travel time to the TMC for the last link traversed. That data is accumulated in the TMC for all vehicles and fused with other information to recompute expected link travel times for the network. Other ATIS projects, such as the one in Oakland County, Michigan, operate on the same principles. The Oakland County system uses roadside communication beacons that communicate with the vehicle. The TMC, in turn, passes network traffic information and receives vehicle travel time data from the beacons. The same type of configuration is found in various implementations in Europe and Japan.

Other ATIS demonstration projects which do not involve in-vehicle systems include the use of information kiosks (e.g., Anaheim, CA). In most sites, we found a strong desire to move to a multimodal approach to traffic management, including the management of huses, rail and individual travellers. In this approach, the TMC would provide information for

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[12] Metro Traffic Control in Orlando is a company which collects and disseminates traffic information through radio and TV.

determining the most appropriate mode for specific planned trips. The TMC would provide this information through a number of media, including cable television, public radio, transmission to in-home personal computers (PCs), and kiosks in hotels, banks, and other public places. The Anaheim TMC is engaged in a demonstration project to transmit traffic information to kiosks in selected locations. Currently, however, these kiosks provide data primarily on freeway congestion, and do not provide sufficient information that would help a traveller make a mode choice. Plans are also being developed to connect the TMC to the mass transit system of Orange County, CA.

Interfaces to APTS are extremely limited in the United States. As mentioned above, Anaheim is planning an interface to the Orange County, CA bus system. ln Denver, CO, Tucson, AZ, and other cities, plans are underway to develop a comprehensive APTS which include interfaces to the TMCs, but no operational systems have been identified as a result of the literature review.

Similarly, CVO and AVCS systems to date have been disjoint research efforts. The focus of the research has been on applying technology rather than on integrating these systems with ATMS and TMCs.

3.7 TMC Computing Environments

Open computing systems environments are generally recognized as critical success factors in the information system lifecycle. Open systems promote upgrade flexibility capabilities and over the life cycle, result in cost-effective configurations. In evolving to an open systems information architecture, it must be recognized that most new information systems developments are not stand-alone, but must be installed within an existing information systems infrastructure In many cases, the existing infrastructure contains a significant amount of proprietary software and hardware, and the investment in these systems is too large to abandon in the desire to move to an open environment. As a result, any realistic migration plan to an open systems environment must also contain provisions for retaining significant portions of installed base of software and hardware.

The sites visited are generally not operating in open computing environments. The typical configuration uses a mini-computer (e.g., Concurrent, Perkin-Elmer, Modcomp) to operate the control system software, and a networked group of PCs to provide all other TMC functions. Sites which operate the MIST^{TM} use an OS/2 configuration.[13] SCAT runs on Digital VAX architecture machines under VMS, Digital's proprietary operating system.

The dominance of PCs in the TMC primarily reflects the fact that historically, PCs were much less expensive than workstations. Additionally, much of the traffic engineering engineering software was originally written under Microsoft's Disk Operating System (DOS) machines, possibly for similar reasons. The prevalence of personal computers has created a ***de facto*** "standard" operating system in TMCs, namely DOS. Some installations of OS/2 exist to serve MIST^{TM} Many of the managers interviewed did express an interest in moving towards UNIX environments and have included UNIX-based systems in their upgrade plans.

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[13] Operating System 2 is an IBM operating system for Personal and Mini-computers.

Interviews of TMC managers uncovered mixed feelings about the various non-DOS and window-based operating systems. Some operators believe in the indispensability of windowing environments for man-machine interfaces and the effective use of the computer. These operators are proponents of Presentation Manger for OS/2, OSF/Motif for Unix, and Microsoft Windows for PCs. In Minneapolis. they expressed an interest in OS/2 because of its multitasking features. At the other extreme are operators, who are satisfied with current systems, and believe that current capabilities are sufficient.

Over the last several years the price/performance ratio gap between personal computers and UNIX-based workstations has steadily declined. Because of this fact, hardware considerations are no longer the driving force in configuration selections. The primary motivator for selecting a PC-based architecture is the cost of COTS software for workstations. As more COTS software becomes available at affordable prices, the proliferation of non-DOS machines will significantly increase in the future.

As mentioned previously, the UTCS software performs its own data management functions that are limited in scope. No commercially available database management systems are currently installed in any of the visited TMCs, nor have any been reported in the available literature.[14] Coincidentally, no distributed data applications nor distributed processing applications have been identified.

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[14] MIST™ comes bundled with an SQL interface to a commercial DBMS.

4 Detailed TMC Information

There are many traffic control centers in the United States, some have been in operation for decades. They all have distinctive features reflecting such factors as age, local customs and problems, and technology availability. The following examples represent the range of traffic control center technology as it is practiced in the United States.

Paragraph 4.1 presents detailed observations gleaned from inspection visits. Those sites that have been researched but were not visited are presented in paragraph 4.2.

4.1 Visited Sites

The sites visited are found in Los Angeles, CA, Orlando, FL, and Minneapolis, MN. Since multiple TMC's were visited in two of the regions, a total of six TMC's were visited: Anaheim TMC; Los Angeles ATSAC; Caltrans District 7 freeway control center; Orlando/TravTek TMC; Florida DOT's Orlando Freeway Management Center; and Minneapolis' TMC.

In addition to these non-local visits, we visited control centers found in the Washington, D.C. area: Maryland's Montgomery County TMC, the Federal Aviation Administration's National Command Center, and the National Oceanic and Atmospheric Agency's spacecraft control centers.

4.1.1 Anaheim TMC Overview

Anaheim, CA's traffic control center is designed to manage the surface street traffic network. Because there are a large number of tourist attractions located in Anaheim, special event handling is highly important. Anaheim has had a TMC in operation since 1988; the new upgraded control center has been in operation since August 1992. The new facility was designed to meet the following goals:

a. Provide the ability to monitor the traffic network at a rate of l/second.

b. Provide an easy upgrade path as new technologies and requirements evolve.

c. Reduce the number of m-the-field law enforcement personnel required to manage traffic during special events by systematically managing the traffic network.

d. Promote the integrated control of the surface streets and freeways by providing an electronic interface with Caltrans for exchanging traffic management information.

The surveillance support system for the Anaheim TMC is sized to accommodate a maximum capacity of 400 intersections equipped with 1600 loop detectors. The signaling system is controlled by the National Electrical Manufacturers Association (NEMA) and 170 controllers. Anaheim is running UTCS in the Time-of-Day mode (TOD), with operator override for special events. There are nine video cameras at eight locations throughout the city for incident verification. The cameras support pan, tilt, and zoom operations by remote control from the TMC. Communication with the field equipment is through twisted pair cable with some phone company-supplied drops. Much of the cabling is done through a cooperative agreement with the local cable TV company. This solution provides the advantage of saving in installation costs. A disadvantage of this arrangement is that it provides a traffic network that is greater than that required by the traffic control network. CATV requires a large network with many nodes, this adds a lot of unnecessary cable mileage to the traffic network. One problem the TMC has is that due to the excess size of the communications network, a large amount of time is spent resolving communications problems. These problems have led to plans for upgrading the communications network to a fiber-optic backbone.

The control center is in operation from 7 a.m. to 6 p.m. on weekdays and for special events. The staff consists of two full-time traffic technicians and four part-time technicians. Student interns from the University of California, Irvine make up the part-time staff. The part-time staff is evenly split between civil engineering and computer science students. There is no formal training program; all training occurs on the job.

The hub of the TMC's computing power is a Concurrent computer. Raw sensor data enters through a Peripheral Processor Unit (PPU). The Concurrent transforms the data for display on PC workstations. This equipment is housed in a shared facility with other City Hall computers. Maintenance of the hardware is done by an outside contractor.

The Anaheim TMC console accommodates three operators. Contained within the console are two engineering workstations and a police workstation. Each workstation is composed of three PCs. The engineering workstations are equipped to monitor the traffic network, control central computer functions, and provide real-time graphics of the network. The police workstation provides functionality for a police computer-aided dispatch system and police radio. Each of the workstations is situated so that the operators can view the large screen projection system displaying input from fielded CCTV systems.

This system is modelled after the Los Angeles system and provides the same features. The most impressive function that the system provides is the graphical display of traffic network status data. The graphic display system is developed using a JHK and Associates package known as Softgraph. The top-level display is a map of the traffic network showing the current phase of the traffic signals. There is a capability to “zoom” the display down to the intersection level.

Related to the graphic display is a video support system. There is a large-screen monitor surrounded by eight smaller monitors. The input to these monitors is switchable, each monitor is capable of displaying the graphics map or the CCTV video feed.

Anaheim is also just beginning to experiment with integrated surface street and freeway management. An electronic link has been established with Caltrans to support the electronic exchange of information. At the present time this information is the exchange of the graphic map data.

There is also a support system in place to develop plans for managing special events. There is an event scheduler (the TMC representative) who operates as the liaison with other agencies, from within and outside the city government, to coordinate traffic engineering and event operations. At weekly meetings, the scheduler gathers information needed for planning and managing traffic requirements for upcoming events. This information includes attendance estimates, arrival rates, occupancy rates, departure rates, and pedestrian rates. Based on this information, a plan for managing the traffic is established. During the event , Variable Message Signs (VMS) are used to route traffic and advise the public about the traffic network's status. In the future, Anaheim plans to incorporate highway advisory radio to augment the the VMS. Another important aspect of this support system is that past performance of previous events is analyzed and critiqued.

In addition to the use of VMS as a traveller information system: Anaheim is developing a Motorist Information System (MIS). There are four main components to this system: information kiosks, highway advisory radio, highway advisory telephone, and a local CATV feed. The information kiosks will be strategically placed in public locations to allow walk-up access. Currently, there are two kiosks in place. At the kiosks, the user selects an area of interest, and the state of the traffic network is displayed in the form of color-coded map. These same maps will also be displayed through the CATV feed. The highway advisory telephone system will play recorded messages describing current traffic conditions. These messages will be updated at a periodic rate to maintain currency.

In addition to the communications problems mentioned above, there are two other shortcomings to the center perceived by the center's staff. The first problem is the inability to receive commercial radio and television inside the control center. Many of the special events that Anaheim manages are sporting events; a commercial radio and television feed would provide the operations staff a cue for when the exit traffic will start. The second problem in the control center is with the operation of a significant events display. The purpose of this display is to provide a cue to the operations staff whenever a significant event is detected by the system. However, the display inadequately filters the events. For example, there is an entry every time there is communications spike, resulting in the generation of a lot of messages. However, the operators ignore the cue when there is only one occurrence, since communications spikes are significant only when the frequency of occurrence on a particular link rises.

In the TMC, the operators primarily monitor and investigate equipment malfunctions and actively manage traffic during special events. The systems supporting the operator in these tasks are a mixture of automated and manual disjoint procedures. For example, during the visit the following operation was observed:

a. The TMC operator was hailed over the two-way radio by a field technician.

b. The field technician was attempting to bring an intersection's controller online.

c. The operator interfaced with the UTCS package to determine the current timing plan.

d. At another terminal, the operator ran a communication and test package, testing the communications, the controller function, and determined the current timing plan for the intersection.

e. The operator compared the actual and desired timing plans.

f. As the two plans differed, the operator manually copied the timing parameters from the database system to the communication system.

Anaheim is working towards the concept of an Advanced Transportation Management Center. The key to this concept is that such a center manages the movement of people in a multi-modal fashion, through automobiles, mass transit, and pedestrian means. By Anaheim's definition, such a system provides the methods for collecting, analyzing, and distributing transportation information to the travelling public. The public can select from one of several modes of transportation if given adequate information. As a first step towards realizing this concept, there is a study in progress to design a cooperative system with the Orange County Transit Authority (OCTA). This system is intended to set up a two-way electronic interface with OCTA. The OCTA's buses will be probes transmitting traffic data to the TMC. The TMC will transmit data back to OCTA to be used for planning and route diversion purposes. This system will serve as the backbone for an ATIS. Anaheim is also considering the implementation of other ATIS systems. One is a direct connection to the local CATV through the public access channel to broadcast maps of the traffic network and state in a slide show format. They are also considering setting up a PC bulletin board-like system to allow dial-in access.

Anaheim is also considering advanced signal control methods. They are looking for a grant to evaluate a SCOOT implementation. They are also considering a SCATS implementation. Because SCATS requires a specialized controller, there is a concern that cost of replacing the existing controllers may make a SCATS solution infeasible.

4.1.2 LOS ANGELES, CALIFORNIA

The Los Angeles Automated Traffic Surveillance and Control (ATSAC) system manages the surface street traffic using UTCS in traffic responsive mode, running on Concurrent processors. The system is designed to provide four basic functions: surveillance, real-time traffic adaptive control, performance monitoring, and traffic network evaluation.

In the ATSAC system, surveillance is primarily done through loop detectors. At the present time there are 1566 signalized intersections under control of the ATSAC system. The standard approach for signalizing an intersection is through loop detectors connected to 170 controllers. As Los Angeles gamed experience with ATSAC, they realized that relying upon loop detectors exclusively for surveillance is inadequate. The major shortcoming that they observed was the operator's inability to classify the nature of traffic problems based on count and occupancy data that loops provide. Because of this they have integrated the use of CCTV into the surveillance network. These cameras are used for detecting, verifying, and managing incidents.

ATSAC uses the enhanced version of UTCS (1.5 generation) for traffic control purposes. In the ATSAC, four modes of control are used: time-ofday, critical intersection, traffic responsive, and manual override. For the time-of-day mode, signal timing plans are developed offline using the TRANSYT-7F model and traffic data acquired through manual traffic counts. This was the method used in the initial version of ATSAC. Los Angeles has moved away from this method because of its operational labor requirements. Their experience was that the tuning plans that were developed required extensive real-time modifications by the operations people. Los Angeles believes that there are day-to-day fluctuations in traffic conditions that cannot be captured in models. ATSAC eventually moved toward the use of the critical intersection control. In this mode, a traffic demand equation is updated each cycle, and green time is prorated based on relative volume. Approximately 25 percent of the intersections under ATSAC control use this method. ATSAC also uses the traffic responsive control feature provided by UTCS enhanced. In this mode, the timing plan is selected automatically by matching surveillance data with the data used to create the timing plans. The final method of control that ATSAC uses is manual override. This method is employed when the other control methods are inadequate for the current traffic conditions (e.g., a special event, holiday shopping). An example of manual override are the “flush” and “royal flush” plans that are used in the event of grid-lock. These manual override mechanisms are special timing plans that are used to clear congestion in the central business district. Both "flush" and "royal flush" use a long cycle time (100 seconds) with the split favoring one direction of travel (60% for "flush" and 75% for "royal flush"). The plan is implemented for a few minutes (5 cycles), until it is reported cleared via visual information (e.g., field personnel, CCTV, police, etc.). No offsets are used in either plan. That is, all lights are synched to the same clock and begin the green phase at the same time.

In ATSAC, two separate types of analysis are performed: performance monitoring and evaluation. In ATSAC, the term "performance monitoring" means the ability to assess the operation of the infrastructure's assets (e.g., communications, detectors, controllers). This monitoring is done through the graphical display. Status data is color coded for immediate identification by the operations staff. All signal timing parameters are available for display and can be printed out in report form.

Evaluation in the ATSAC context is the ability to asses the performance of the traffic network. In ATSAC traffic performance data is temporarily stored in a buffer with a capacity to store 7 days of data. This buffer is essentially a circular buffer: every seventh day, the data from 7 days ago is overwritten. If there is a noteworthy event, the data relevant to that event is written to a file and copied to tape. Lotus l-2-3 macros are then used for retrieving data from the file into the spreadsheet program for analysis.

The system architecture is hierarchical in nature, made from three different processors. For front-end data , collection activities are devices known as Peripheral Processing Units (PPU). Each PPU is configured with 16 Motorola 68000 boards responsible for processing control commands, surveillance data, and equipment status data. Each board can accommodate up to 32 intersections with 128 detectors. PPUs are connected to the signal controllers through a fiber optic communications link. The PPUs are connected to several Concurrent processors that are designated as "area computers." Each area computer processes data from 400 intersections and 1600 detectors on a once-per-second basis. These area computers are connected to a supervisory computer via an ethernet LAN. Connected through a serial port to the supervisory computer are IBM PC workstations used for human interface purposes.

Los Angeles has collected several statistics through a quantitative study of the effectiveness of the ATSAC system. The following performance measures were reduced by the indicated amount:

a. Travel time has been reduced by 18 percent.

b. Intersection delays have been reduced by 44 percent.

c. Stops reduced by 41 percent.

d. Air emissions reduced by 35 percent.

The overall benefit/cost ratio for the system is 23: 1.

The major source of innovation to the ATSAC system is through the Smart Corridor Project. The objective of the Smart Corridor is the demonstration of improvements in corridor performance using advanced technologies. Specific goals include improving incident management, improving driver information, and coordinating several government agencies.

The major tasks of the project include the following:

a. Linking the control centers of the various agencies electronically.

b. Constructing a communications/control network.

c. Creating a centralized database.

d. Developing an operations plan.

e. Developing an expert system.

f. Developing a driver information system. Examples of technologies being considered include low-power radio, highway advisory telephone, personal computer bulletin boards, and CATV.

g. Demonstrating and evaluating Pathfinder.

h. Evaluating the Smart Corridor system performance.

JHK & Associates is responsible for implementing the Smart Corridor project. Many technologies applicable to ATMS are being implemented in the Smart Corridor project. For example, the centralized database will be an "open" architecture that can be accessed through standard Structured Query Language (SQL). The planned expert system includes procedures designed to aid operators in selecting the best response to a wide variety of situations including accidents, equipment malfunctions, and recurrent and non-recurrent congestion. Discussions with representatives from JHK indicate that, as of December 1992, the system is planned to be operational in July 1993.

4.1.3 Caltrans District 7

Caltrans District 7 claims its Traffic Operations Center (TOC) is the oldest TOC in operation in the United States. The TOC consists of a large room with several workstations for operators from several different agencies and departments, including the California Highway Patrol (CHP), Traffic Engineering, and the Highway Dispatchers. The center is normally staffed with one CHP officer, four Traffic Engineers, and two Operators. The center is in operation 24-hours-per-day, 7-days-per-week.

The purpose of the center is to manage the freeways in metropolitan Los Angeles. To accomplish this purpose, loop detectors are used to measure the flow of traffic on the freeways. The center also receives video data from 18 CCTV cameras. This data is used to verify the loop data and incidents. The TOC also uses the CCTV cameras to validate that the correct massage was posted the changeable message signs. Control of the system is performed through ramp metering and the CMS. Ramp metering is done through atime-of-day algorithm. Other sources of data feeding the control center include Computer-tided Dispatch (CAD), call boxes, the media, 9 11, cellular phones, and the CHP.

The dominant feature of the TOC operations room is a large static wall map showing the freeways in the area. Red, yellow, and green LED's on the map display the status of the traffic network. Interestingly, the "readability" of the large display is preferred by the operations personnel over computer-generated graphics. They state a preference for being able to see the "big picture" - the whole network at a glance.

The hub of the TOC's computer processing power are Dual Modcomp Classic CPUs for the traffic data. The Modcomps run the Semi-Automated Traffic Management System (SATMS) software for traffic management. An HP-1000 mini-computer is used for controlling the CMS system. In addition, there are several PC-based systems for supplementary analysis purposes. Communications among the processors are through direct serial interfaces, using each system's proprietary protocol.

The TOC is due for a major upgrade to be completed in 1995. Major design drivers for the new system are:

a. More CPU processing power to support graphics and analysis.

b. A modular, open system. All processors must run under a non-proprietary operating system.

c. Additional redundancy, to include an Uninterruptable Power Supply (UPS), and the ability to failover to redundant systems in less then 30 minutes.

d. Networking with other agencies.

e. Support for multi-modal transportation management by providing more driver information systems.

f. Support for inter-regional control (e.g., desire the ability to close down smaller centers during off-peak hours).

g. A data archive and distribution system capable of storing 300 MB of data per day for 3 years.

h. Analysis tools for trend analysis, algorithm calibration, and incident detection.

i. Support for wide area ramp-metering.

4.1.4 Orlando TMC

The traffic management center controls approximately 350 intersections under 1.5GC UTCS operating primarily under TOD mode. The UTCS system uses Perk&Elmer mini computers under a standard configuration. The system can be expanded to 750 intersections. The TMC has access to the video output of the 18 cameras on the 11 mile interstate being monitored by the State Highway Patrol.

The system is operated on a 24-hour-per-day basis. The TMC is staffed by five operators, one signal system engineer, and two field technicians. Each shift is manned by one operator.

Communication with the controllers occurs every second; if communication is not achieved over a three-second interval, the controller is considered "failed", and maintenance is dispatched.

The surveillance system in Orlando makes use of a Traffic Information Network (TIN) consisting of a network of citizens who provide traffic flow information from locations such as convenience stores. The Metro Traffic Control also provides information to the TMC via a TravTek terminal. MTC has “spotters”: people who are paid to drive certain routes. Orlando reports that 90 percent of its detectors are functional at any one time. This number appears to be above average, and may reflect the weather in Orlando.

A fixed map display of the street network can display queues, speed, and occupancy. One of the major benefits of the display is its value as a public relations tool. One of the problems with the fixed map display is its inflexibility, changes in street names or configuration result in a large maintenance task. The operations staff expressed a preference for a projection TV display.

The operations staff in Orlando expressed the belief that the time-of-day implementation is adequate for their needs. In Orlando, the traffic patterns are reasonably stable and can be handled by time-of-day. The staff did express an opinion that more surveillance is needed, both freeway and surface streets, but they implied that the surveillance requirements of SCOOT are excessive. There was also a stated desire to have tools supporting the planning for special events, incident management, and seasonal fluctuations. The operations staff pointed out that seasonal fluctuations in Orlando are significant. For example, there is the “Canadian Vacation Season” and college vacation periods.

The Orlando TMC is extremely sensitive to having the public call with complaints about changes to the timing. They report that the public does notice changes in timing and does not hesitate to voice complaints. The staff in the TMC also expressed an opinion that traffic responsive control schemes will require more staff. In fact, they just hired an additional person with responsibility for signalization. This person will be validating the current plans and will develop new ones. Additionally, they have to manually collect count data; the surveillance system does not provide sufficient coverage for this purpose.

For special events, Orlando prefers the implementation of specialized timing plans developed offline for this purpose. It was interesting to note that different events at the same location generate different traffic patterns based on the demographics of the attending population. For example, it is not sufficient to know only that there is an event going on; the type of event must also be known. In conjunction with managing special events traffic, there is a desire to use CMS for directing travellers to off-the-freeway parking facilities.

Orlando plans to upgrade their traffic control system, primarily to reduce the maintenance costs associated with the Perkin-Elmer minis. The main driver for the upgrade plans is not based on a desire for an upgrade in control capabilities, but a desire to have a system based upon industry standards. The upgrade will probably be to an PC OS/2 environment, based on the favorable impression that the TravTek system has made.

Another interesting feature of the Orlando TMC is that it is set up to be a redundant facility to the State-owned Freeway Management Center (FMC). In the event of a failure, the TMC is capable of controlling the the FMC’s traffic network assets.

The Orlando TMC also houses the TravTek system. TravTek is run by 3 computers - one 80386 to process all communications to the 100 vehicles, one 80435 for data processing and one 80486 to drive the map user interface. Communications with all 100 vehicles occurs at l-second intervals. This includes both TMC-to-vehicle and vehicle-to-TMC communications. The link travel time data from the vehicles is fused with the traffic data from surveillance detectors and is communicated back to vehicles in the form of link travel time adjustment factors. In TravTek, a comparison of actual link traversal times with historic link times is done to calculate traffic network performance.

The TravTek user interface is map-based on which one can display the locations of all the vehicles. One can also display the location of incidents as input by vehicle operators. The TravTek computers operate under OS/2 with the graphics being done under Presentation Manager. There is no electronic interface between TravTek and the TMC. For example, the operator at the TMC manually inputs capacity restrictions such as lane closures and automatically recomputes link travel-time adjustments.

Operations staff were queried about their experience serving as a test site for TravTek. They indicated that they did not experience many integration problems with TravTek installation. Neither space nor cabling was cited as a problem.

4.1.5 Florida Freeway Management Center

The Freeway Management Center (FMC) controls 11 miles of I-4 and includes 24 vehicle detector locations, 18 cameras, and 4 CMSs. Each detector station is composed of 12 detectors (two per lane for six lanes). Stations are half a mile apart; each detector station is controlled by a 170 controller with polling done every l/240 second. The center is staffed by a civilian traffic engineer, with day-today operations performed by Florida Highway Patrol officers.

The FMC computer is a VAX Micro running FORTRAN. They use a “modified California” incident detection algorithm. The user interface is character based with a main menu including the following key items:

a. Incident detection.

b. CMS.

c. Equipment status/summary.

d. Traffic data

e. Event and incident log.

f. TravTek.

g. Operational parameters.

Cameras have zoom (2 mile), tilt, and pan capabilities. Cameras are mounted on 40-foot poles located in the median or the shoulder. Communications are fiber optic for the cameras, and twisted pair for the loop detectors and the CMS. They experience surge problems on the communications lines and have had lightening problems with the cameras.

Their planned incident management strategy involves route diversion. There are in-place predetermined candidate routes and they are now working on timing plans. The freeway configuration around Orlando is such that they can divert around certain freeway sections using local roads. Central to these diversion plans are negotiated agreements between the FMC and Orlando TMC. In order to preclude the FMC from overflowing the capacity of the local roads, they would need access to non-freeway data. The route diversion decision would have to be coordinated among the controlling parties based on common data. As part of their strategy, detected incidents will be reported to the Metro Traffic for broadcasting.

One problem that the FMC noted is associated with detecting incidents under heavy volume conditions. In fact, the FMC is participating in a project with the University of Central Florida to develop alternate algorithms.

An interesting point was made regarding the usefulness of a weather data feed. Experience indicates that over some sections of the I-4 freeway, bad weather almost always leads to accidents. Prediction of the onset of bad weather over these sections can be used to place emergency vehicles in strategic positions, reducing the response time. It would, of course, be even better if one could somehow affect the drivers via CMS in order to reduce speeds, etc.

As part of a Phase II project (approximately $3 million), the FMC is looking to add another 24 miles of freeway surveillance to the system, and to upgrade the software. They want to move to a more user friendly and graphics-based software (such as TravTek). Because the center is staffed with police officers, turnover is high. With the turnaround in their staff and the overall experience level of the operators, there is a need for flexible report writing support capabilities, online help, and computer-based training.

Phase II will bring up to the state-of-the-art with respect to incident detection and route diversion Future possibilities include the following options:

a. Additional CMS to provide messages which convey information such as:

HEAVY CONGESTION NEXT 2 MILES

TRAFFIC CLEARS UP AT LEE ROAD

EXPECT 30 MIN DELAY

b. Automating the sign message generation process.

c. Using historical data on incident management to develop training simulations.

d. Evaluating the relocation of the FMC. It was not clear whether the FMC should be collocated with the TMC because of potential jurisdiction considerations.

e. Investigating conversion to fiber-optic cable. They have been experiencing surge problems with the twisted pair wires for loop detectors and CMS.

4.1.6 Minneapolis TMC

Minneapolis has been in freeway traffic management since the early 1970's. In 1970, they had the first permanent installation of ramp meters on I-35E. The TMC was initially planned in 1971, and the entire system has been growing in stages to include major segments of I-35, I-94, I-694 and others. The system is strictly a freeway traffic management system. Communication with the Minneapolis traffic management system (700 intersections) is planned using fiber optics.

Minneapolis' experience with ramp metering has been very successful; freeway throughput has been increased significantly. For example, on I-35W there has been a 35 percent increase in peak-hour speed, and a 38 percent reduction in accident rate. To encourage High Occupancy Vehicle (HOV) usage, HOV bypass ramps are used. In Minneapolis, 60 percent of congestion is related to non-recurring incidents. This includes any localized event which reduces capacity. To manage these incidents effectively, Minneapolis focuses upon rapid detection.

The surveillance system consists of loop detectors at half-mile intervals on each freeway lane, and TV cameras at one-mile intervals mounted on 50-foot poles. Currently there are 108 cameras installed. In some cases, the cameras are mounted high-rise buildings located within the commercial business district.

Control is accomplished via ramp metering and CMS. The 300 ramp signals are controlled via 170 controllers. A Honeywell/Bull minicomputer manages the ramp metering centrally, with updates every 30 seconds. The operator can override the system-generated timings for ramp meters. Upgrade plans for the system are based around a PC-LAN architecture, potentially OS/2. The primary appeal of OS/2 is its multi-tasking features. This option is favored over a workstation/UNIX architecture because it's multi-tasking operating system will require minimal effort in translating the communication protocols from their environment.

Minnesota's incident management support system centers around the use of video for detection, with the police providing incident detection support. One of the functions of the operator is to detect and/or respond to vehicle breakdowns, and to dispatch the Highway Helper. In order to do that, the operator constantly scans the monitors. Once an incident is detected, the operator may dispatch an emergency response team, alter ramp metering rates, or dispatch a portable CMS.

Minneapolis has instituted an emergency response program known as Highway Helper. These Highway Helpers are heavy duty pick-up trucks that are equipped for assisting stalled vehicles and the State Patrol. Currently, there are six Highway Helper vehicles patrolling the most congested freeway stretches during peak traffic periods.

As part of its incident management strategy, Minnesota also makes use of CMS. There are currently thirty-six permanent CMSs in place. These are six-sided rotating drum type signs. In addition to these fixed signs, Minnesota also makes use of trailer-mounted, portable CMS. These signs are used when the effects of an incident are likely to last for several hours. Portable CMS have proven their utility when they are positioned within half an hour of the incident. These signs are used to warn motorists of traffic problems ahead and to suggest alternative routing.

Ramp metering plays a role in incident management and daily operations. Metering rates are updated every 30 seconds by the Honeywell minicomputer, based on current traffic conditions. A manual override feature is available to aid in managing incidents. Once an incident is detected and verified, the operator has the option for setting the ramp meters upstream at a more restrictive rate, and meters downstream of the incident are turned off or set at a faster rate.

As part of this strategy, there is a dedicated line linking the TMC to the Minneapolis surface street traffic control center. For coordination purposes, this line handles voice and video. This capability allows the Minnesota traffic center to view signalized diamond interchanges during a major incident. Using this information, signal timings are modified to accommodate the diversion caused by the incident.

To mitigate the effects of minor accidents, Minnesota has instituted the concept of accident investigation sites. Under this program, sites are strategically placed off the freeway to allow the investigation of minor accidents. The intent is to provide a place where motorists can exchange information in a safe area while reducing the impact to capacity and the effect of "gawkers." Using a series of trailblazing signs, motorists are directed off the freeway to the accident investigation site. At these sites, there is a direct telephone link to the State Patrol. Public acceptance of this program has been low because of misperceptions relating to liability and insurance claims. There are increased public education efforts in an attempt to address these misperceptions.

Within the control center there is an operator station in front of two walls of video monitors (108 monitors in all). They also have a large screen BARCO on which they can display traffic data on a map background. From the control center they can control the CMS. Included within the FMC is a radio broadcast capability using a public broadcast cable channel. The operators have found the character-based user interface inadequate.

As part of the GuideStar program they are field-testing AutoScope^{TM}. The data retrieved by AutoScope^{TM} is not being currently used for traffic management. The cost of AutoScope^{TM} is prohibitive at present but the latest version can control up to four cameras. Also, the new version can process the data locally. Their evaluation of AutoScope^{TM} to date is mixed. It appears to do as well as loop detection under ideal conditions but the quality of results is unclear if the camera is not positioned perfectly.

4.1.7 Montgomery County TMC

The Montgomery County, MD TMC is a surface street management facility. The center is in operation from 6:00 a.m. to 9:00 p.m., Monday through Friday. There is one console position manned by one of four traffic management technicians. Recruiting qualified personnel is always a problem. Montgomery County recently advertised for engineering technicians with a traffic signals background and were unable to get qualified candidates. As a response, they created two new positions Traffic Management Technician I and II. These positions do not necessarily require degreed engineers; instead, five years of demonstrated experience in traffic signal background is adequate.

Monitoring and incident detection capabilities are provided by loop detectors, aerial observation, fire, police, and DOT vehicles. The TMC is currently monitoring 750 sensors and managing 600 signals. Detectors are downstream of intersections.

Montgomery County uses video for incident verification. In contrast to Minneapolis, the output of only one camera can be viewed at one time. An operator in the TMC selects which video camera will be displayed on the large screen monitor. There is also a capability to automatically bring a camera's output on to the monitor. Aerial detection involves an observer in an airplane forwarding voice descriptions to the TMC.

The existing computer equipment in the TMC are Data General mini-computers and PCs. The sensor network is sampled at a l-per-second rate, and tallied by the TMC computers once per minute.

Montgomery County is an affiliate member of the State of Maryland's Chesapeake Advisories Routing Traffic (CHART) program. CHART is intended to become a state-wide traffic management system that will demonstrate a network of traffic management facilities. Other future plans include upgrading the TMC to a UNIX workstation network architecture with an integrated data-base; using aerial video surveillance; and using a Geographic Information System (GIS) to support incident management.

4.1.8 Amsterdam, The Netherlands

This center controls the highways surrounding Amsterdam. The city is ringed by a system of highways (32 km in length) that includes two tunnels; the center is responsible for keeping traffic moving on these roads and in particular in the tunnels. The Center is not responsible for surface street traffic control within Amsterdam.

The basic operation of the center is as follows: induction loops in the roadway are connected to a computer system that is programmed to detect slowdowns in traffic. Once a slowdown is detected, overhead signs on the highway are automatically triggered to display a reduced speed limit of 50 - 70 km (down from the normal 100 km). The selected speed is dependent on the degree of slowdown. In addition, an alarm is sounded in the TMC, and if the slowdown is within the tunnels or their approaches, video cameras are turned on to view the situation. When an incident such as an accident occurs, the center personnel direct the traffic around the incident by controlling overhead traffic lights.

The center also monitors the height of vehicles on the tunnel approaches. When the roadside infra-red sensors detect an overheight vehicle, the traffic lights ahead of the vehicle automatically turn red. A road-blocking boom is then lowered to ensure that the vehicle does not attempt to enter the tunnel. Video cameras are turned on in the center. By the use of a roadside communication system, the truck is diverted to a side road and off the highway.

The TMC also controls a high-occupancy lane, refered to as a tidal flow on a portion of the highway. Overhead signs and barriers are used to designate traffic flow. The position of the barriers can be shifted under direct control from the TMC. The barriers are slightly lifted on a cushion of air (similar to a hydroplane) and shifted into position, all controlled from the center.

One of the highway entrances has a ramp metering system, The system permits vehicles to enter the highway, individually, on a fixed schedule. This system helps avoid congestion and has eased the traffic flow into the tunnel.

There are three systems that compose the TMC: a Monitor and Control System that controls the ring road (highways) and two Tunnel Control Systems, one for each of the tunnels. Each system has a dedicated control console. The Monitor and Control System is housed on a P800 Phillips machine and a Sun SPARCstation front end. The Phillips machine is of the same era as a PDP-11 (a late 1970's architecture); there are plans to upgrade the Phillips to an IBM RS6000.

The tunnel systems consist of SATT controllers (from Sweden) running on Digital Equipment platforms. The system controls all tunnel systems including traffic lights, backup generators, air pumps, rain water pumps, fire pumps, and ventilation. It is referred to as the Programmable Logic Control (PLC).

A large screen display can be used to view any of the computer screens. From the tunnel consoles, a bank containing 18 video monitors for displaying video from the cameras in the tunnel and their approaches can be viewed. Each camera can be manipulated from the tunnel consoles.

The center is staffed by three controllers. Operations consists primarily of monitoring and handling alarms. Peak hours are from 7 AM to 9:15 AM and from 4 PM to 6 PM. When slow traffic is detected an alarm is set off attracting the controller's attention and triggering the camera covering the effected loop.

The operator then shuts off the alarm, and the appropriate video camera is adjusted to view the scene. In the event of an accident, the operator calls a tow truck, police, or an ambulance as needed. The level of required on-scene assistance is determined from observing the video. When required, overhead lights on the highway are turned to red to stop traffic. After the accident scene is cleared, the overhead traffic lights are changed back to green.

The decisions made by the operator are characterized as being of three types, as follows:

a. To close a particular lane of traffic.

b. To close an entire direction. This operations must be coordinated with the police as major traffic jams ensue.

c. To re-route traffic. This occurs if one of the tunnels is blocked. Highway signs re-route the traffic through the second tunnel.

When asked about problems, the operators focused on mechanical failures. There are 300 road signs and failures that can occur. Failures also occur with the loop detectors. The operations staff did not, however, report on any operational problems. They referred to a major accident several months back when a cargo plane crashed into an apartment building, requiring all neighboring highways to be closed. In comparison to this incident, all other problems are considered minor.

4.1.9 FAA National Command Center

The primary objective of the National Command Center is to manage capacity through flow control. Unlike the regional control centers (which exercise in-route control, and local air traffic control centers managing airport landings), their view is systemwide. The control exercised by the NCC is through the Ground Delay Program, which is essentially a modification to the scheduled take-offs used to control the flow (landings per hour) into capacity constrained airports. The Ground Delay Program is disseminated to the airlines by the NCC.

The control center is composed of a set of regional air traffic control stations and a weather station. All of the control stations have identical hardware and software capabilities. The purpose of the stations is to monitor the flow on a regional basis, and to execute control as necessary on the basis of capacity problems.

At the control center, all air traffic data (this only includes flights filing flight plans) is accessible. A large screen display is available for traffic locations of all flights airborne, including various information about that flight (e.g., flight number, type of plane). All of this data is obtained from the regional control centers and routed through the main computer located in Atlantic City, NJ.

Voice communications support is available at each of the air traffic control stations. At every station, there are 26 different voice links that are used for communicating with the regional centers and airport towers. Using these communication links, the weather feed, and the Ground Delay Program, the controllers make decisions for managing the air traffic.

The primary capacity-reducing event is the weather. Within the NCC, they have a weather station staffed by National Weather Service personnel. The function of the station is to predict weather conditions based on multi-source data input including a full complement of NWS data. The weather workstation integrates the various data sources and allows a variety of display formats. The meteorologists use experience and knowledge of the importance of specific weather conditions at specific airports to develop recommendations to the controllers. Based on these recommendations, a delay program may be put into effect.

The FAA has an ongoing effort to develop the High Altitude Route System (HARS) which will integrate the air traffic status displays with weather data from the weather station and computes optimal routes based on parameters such as fuel consumption. The underlying algorithm is based on dynamic programming to determine route segments between "beacons." HARS has some interesting options for re-centering map displays, setting up map color schemes, and default screen settings and options. The system is being developed on an HP workstation using OSF/Motif windows. This system is a true model-based DSS which, in the context of ATMS, would be similar to a route diversion model.

4.1.10 NOAA Satellite Operations Control Centers

The purpose the Satellite Operations Control Center (SOCC) is to manage space-borne assets. The two different spacecraft controlled from this facility are the Geostationary Operational Environmental Satellite (GOES) and the Television and Infra-red Orbiting Satellite (TIROS). These satellites observe the Earth and provide important data used for predicting the weather.

Each control center is designed to receive multiple input streams from different spacecraft simultaneously. The basic architecture of the control centers is a MicroVax front-end communications processor, a Vax 8530 as an application processor, and a series of VaxStation 2000 processors. There is no single point of failure in the system, for example, there are redundant communications processors, each linked to a dual ethernet rail. The front end processors are responsible for receiving the input data stream, removing the communications overhead, and transmitting this data to the applications processor.

The applications processor receives the input data stream, and processes that data into a common format for use by the various applications. These applications include high-/low-Emit checking, display, monitoring, data management, and spacecraft command execution verification. The applications processor also maintains a configuration table for the purpose of monitoring the performance of the ground system. There are spare applications processors that are generally used for offline purposes, such as mission planning and scheduling, training simulations, and long-term trend analysis. These offline processors are configured into the network for use in the event of failure of the online applications processor.

The VaxStations serve as operator workstations. In the SOCC, there are three different types of operators, schedulers, analysts, and controllers. Any workstation can be configured for use in support of these functions through individual login procedures for the functional position.

The schedulers workstations provides the tools for mission planning and scheduling. Operation of the NOAA spacecraft is essentially a time-of-day operation, each day a schedule is generated that contains the detailed spacecraft and ground system commands for achieving the desired activities. The schedule is in the form of two automated procedures, one is transmitted to the spacecraft for execution by the onboard processor, the other is downloaded to the applications processor. A schedule is generated by integrating the day's desired payload activities with the spacecraft operational constraints, engineering requirements, and orbital position. An analyst's workstation provides tools designed for performing real-time and short-term trend analysis. There is support for statistical analysis, with video and hardcopy graphic output. A controller's workstation has all of the same capabilities as the analyst, and has the additional capability for issuing spacecraft and ground system configuration commands.

The SOCC is relevant to ATMS is because it demonstrates that it is possible to design a generic command and control system capable of accommodating different modes of operation. For example, one of the big differences between the GOES and TIROS family of spacecraft is the difference in the orbital characteristics of the satellites. The GOES spacecraft are geostationary satellites, meaning that the satellite is stationary with respect to a point on the ground. Because of this attribute, the satellite is in constant communication with the ground. On the other hand, the TIROS satellites are Low Earth Orbiting (LEO),. requiring that the satellite can only be communicated with when it is in view of the ground tracking station. These contact periods are 10 - 15 minutes in duration and occur once every 98 minutes. These differences in communications capability lead to different operations procedures. It is standard NOAA practice for operations personnel to operate either satellite. Because the designs of these two control centers are so similar, this operations practice is easily accommodated.

The training program for NOAA operations personnel incorporates classroom and on-the-job training. The training program is divided into' two tracks: one track is dedicated to operation of the ground system; the other is devoted to the spacecraft. The purpose of the ground system track is to familiarize operations with the correct procedures for configuring and operating the radio equipment, ground computers, and ground-based communications network. For the ground system track, there are 200 hours of formal classroom training. The spacecraft track focuses on the design and safe operation of the spacecraft. This program consists of a l-day overview lecture and a 40-hour course. This classroom training is supplemented through periodic l-day refresher courses. All classroom training is typically provided by the appropriate vendor. The ground system course is provided by the prime contractor; the spacecraft course is provided by the spacecraft manufacturer.

Integrating the two tracks is done through a 4-week, on-the-job training program. In this program, a newly hired spacecraft controller works on a console with an experienced operator. During each week of the program, the new controller works with a different experienced operator. At the end of the on-the-job training period, the new controller must successfully complete a certification test. In addition, to these techniques, extensive online help is available to assist operators during real-time operations.

4.2 Site Data Obtained through Reference Works

The following paragraphs contain control center descriptions obtained through reference documents. These descriptions provide a listing of the salient features of each of the control centers. Readers desiring a more in-depth treatment are referred to the bibliography.

4.2.1 Chicago, Illinois

The Chicago, IL system is a freeway traffic surveillance and control system that has been in operation for over 30 years. The freeway surveillance and control system is composed of over 130 miles of roadway, instrumented with 2,000 detectors, 95 ramp controls, and 13 changeable message signs. The Traffic Systems Center (TSC) houses the surveillance computer and a staff of 14. This staff is augmented with 16 cooperative engineering students technicians with skills in the traffic engineering, electrical engineering, and computer science disciplines. The system is a centralized architecture with one computer performing monitoring.

In the Chicago system, there are three programs supporting incident management. The first is the Emergency Traffic Patrol (ETP). The purpose of the ETP is to provide continuous mobile surveillance and to offer motorist assistance at freeway incidents. The ETP is a fleet of 35 trucks outfitted with relocation tow rigs and other equipment for emergency situations. Chicago has also instituted a motorist assistance program. This program has established a special free cellular telephone line (*999) for reporting traffic incidents. Chicago has also implemented a real-time Highway Advisory Radio (HAR) system. In this system, there are 11 low-power, roadside AM radio transmitters. An interesting feature of the system is the real-time automatic update mode: in this mode, output from the surveillance sensors is used for producing digitized voice broadcasts at each transmitter site.

Chicago is also beginning to field test a new IVHS project, entitled the Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE). ADVANCE is being implemented in the northwest Chicago suburbs, near the heavily congested vicinity of O'Hare Airport. The test areas covers 300 square miles, and involves three counties and 40 municipalities. There are more than 750,000 people living in the test area.

ADVANCE is much like Orlando's TravTek project, with the difference that the focus is on providing driving information for drivers who are familiar with the area. ADVANCE is field testing a dynamic route guidance system, designed to provide drivers with up-to-the-minute traffic information. The ADVANCE project is a 5-year initiative; it is expected that at the end of Phase 1 (mid-1993), there will be 20 vehicles deployed with the ADVANCE equipment. When ADVANCE is fully deployed it will involve up to 5,000 commercial and private vehicles.

In the ADVANCE system, each vehicle is equipped with a video screen, a data communications radio, and a global positioning satellite (GPS) receiver. Drivers select a destination from a displayed area map or by entering an address on the video screen. The ADVANCE system also provides a “yellow pages” service, where drivers can view a list of services and other points of interest. During the trip, the vehicle’s position is calculated using data from the GPS receiver and a map of the area.

ADVANCE vehicles are in constant contact with the Traffic Information Center (TIC). As the vehicle progresses through its trip, it collects traffic information and transmits that information to the TIC. The TIC then fuses that data with data from the loop detectors, police reports, and the cellular data to generate travel times. There are plans to eventually augment this process with information from predictive traffic models. The output from this process is then transmitted to the vehicles in the form of updated route guidance instructions.

4.2.2 Oakland County, Michigan

Oakland County&II is currently field testing a large-scale deployment of an integrated ATMS and ATIS, in a program known as Faster and Safer Travel Through Routing and Advanced Control (FAST-TRW). The objective of FAST-TRW is to demonstrate that mobility can be improved, energy consumption can be reduced, air quality can be improved, and traffic accidents can be reduced. The most unique facet of the FAST-TRAC approach is the integration of video detection with adaptive control and beacon technologies. FAST-TRAC is a 5-year program that was started in 1991; currently, SCATS has been installed in 28 intersections, and AutoScope^{TM} has been installed in 23 intersections. Immediate plans for the system are to expand the number of intersections with SCATS and AutoScope^{TM} to 95, deploy 30 Ali-Scout beacons, and equip 60 vehicles with Ali-Scout.

In the current system, 28 intersections are using SCATS. Of these 28 intersections, 23 are exclusively using AutoScope^{TM} for vehicle detection; the remaining 5 intersections are using loop detectors. The SCATS approach is a distributed control approach. The local SCATS controller is responsible for managing vehicle counts from the AutoScope^{TM}, traffic parameters, and statistics. On the basis of this data, the SCATS controllers execute timing plans defined by the regional controller. This allows synchronization and coordination among local controllers in a region. In addition, the regional computer has a user interface supporting monitoring and management of the SCATS controllers. The regional computer also provides input capabilities for command and control activities.

In later phases of the program, these capabilities will be integrated with the Ah-Scout route guidance assistance system. Ah-Scout systems provide full-duplex communications with the TMC and the vehicle through the use of beacons. The computer receives location and traffic data when the vehicle passes through an intersection equipped with a beacon. This beacon provides full-duplex data communications by means of infrared equipment. The in-vehicle computer then computes the best route and provides directions to the driver.

4.2.3 Long Island, New York

Long Island’s INFORmation for Motorists (INFORM) is using a computerized traffic management and information system for corridor control. INFORM collects data from sensors that is processed and communicated to motorists using variable message signs and commercial radio. INFORM is also researching route diversion techniques through the use of traffic signal techniques, ramp metering, and a parallel corridor. In INFORM, there are two major parallel freeways, the Long Island Expressway and the Northern State Parkway/Grand Central Parkway coupled with parallel and crossing arterial streets.

A traffic control center, housing 3 mini-computers, is responsible for monitoring, control, and incident management in the INFORM system. The traffic monitoring system consists of loop detectors augmented by roadside citizens band (CB) radio monitoring units. Control for the freeway portion of the system is done by ramp metering and VMS. In the surface street network, control is through 170 controllers.

Surveillance in INFORM is primarily performed by loop detectors. On the freeways, loop detectors are generally placed at half-mile intervals and at ramps. Using this data, incident detection is done by one of the mini-computers using a modified California incident-detection algorithm. Surveillance on the arterials is also done using loop detectors. CB radios, police scanners, and CCTV are used for incident verification.

INFORM uses VMS, ramp metering, and UTCS for control purposes. The VMS are used to provide travel information to motorists. The types of information displayed on the signs include the following:

a. Delays due to recurring congestion.

b. Delays due to incidents.

c. Absence of delays (e.g., average speed ahead greater than 30 miles per hour).

d. Adverse weather conditions.

e. Future construction activities.

f. Implementation of new devices.

g. Catastrophic events impacting capacity.

Automated and manual methods are used for creating sign messages. There are four modes of operation in the automated method: intervention, semi-automatic, use, and automatic. In the intervention mode, the operator receives an audio and visual cue that the system has detected a need for a sign. The operator then has the ability to accept, reject, or modify the message to be displayed. In the semi-automatic mode, messages describing the problem and its location are automatically transmitted to the appropriate sign. No diversion statements are included in the message. The “use” mode includes the same capabilities as the semi-automatic mode, with the addition that the operator is prompted with route diversion alternatives. Finally, in the automatic mode, all sign messages are sent and updated automatically without operator intervention. The manual mode provides the operator with a method for developing and transmitting specialized messages.

Ramp metering is used for controlling the traffic flow on the freeways. The capability exists to operate the ramp meters in either manual, time of day, or traffic responsive modes. In manual mode, individual or a selected group of ramp meters operate at a specific rate. In the time of day mode, the operator specifies the turn on/off time and the metering rate for each individual ramp meter. In this mode, queue length detectors are used for automatically turning on or off the ramp meter in the event the queue grows past the ramps storage capability. In the traffic responsive mode, the ramp metering rate is set on the basis of the freeway and ramp's traffic condition. For managing the freeways flow, the traffic responsive algorithm examines both the upstream and downstream detectors to calculate the metering rate. In the event that the queue length on the ramp exceeds the ramp's capability to hold vehicles, the metering rate is increased.

Control for the arterials is performed using UTCS-extended software and 170 controllers. The intersections are primarily controlled using TOD timing plans. If communications with the TMC fail, the controllers run local timing plans. When the arterials are used as part of a route diversion strategy, the operator can download a diversion timing plan.

4.2.4 Fairfax County, Virginia

The key feature of the Northern Virginia facility is the use of video for incident verification. The traffic network is composed of 30 miles of freeway instrumented with loop detectors and video cameras. Control of the network is through ramp metering and changeable message signs. Northern Virginia is also testing a video-imaging detection system (AutoScope^{TM}).

4.2.5 Seattle, Washington

The most important feature of Seattle's TMC is its cooperation with the Freeway and Arterial Management Effort (FAME) projects. FAME has two primary focus points, congestion management and lVHS systems. The goal of the FAME effort is to investigate and implement advanced strategies for arterial control based on real-time changes in traffic conditions. FAME researchers are also working on short-term traffic prediction algorithms. The Seattle system monitors traffic flow through sensors and video cameras. In addition, Seattle has formulated extensive incident management strategies, including response team and accident investigation methodologies with the State Patrol.

The Seattle TMC has a new centralized system based on a Vax 6000 mini-computer with PCs, running windows for operator workstations. In the Seattle system, loop detectors are used as the primary surveillance method. The central computer runs an incident detection algorithm, and CCTV is used for incident verification. One of the workstations in the TMC displays police-computer-aided dispatch information. In addition, the state patrol has one of the operator workstations and five video monitors that are used for the purpose of monitoring traffic conditions and incidents.

In Seattle, several innovative techniques for managing incidents have been developed. The main objective of Seattle's incident management program are as follows:

a. Respond to incidents in a timely manner.

b. Provide traffic control for the safe passage of motorists and protection of emergency personnel.

c. In conjunction with the state patrol, oversee the quick cleanup and clearance of the incident site.

Seattle has created an incident response engineer position dedicated to organizing and operating the incident response program. Day-to-day duties of the incident response engineer include pre-event planning and coordination with the state patrol and other agencies, coordination of the incident response team volunteers, equipment procurement, and documenting incidents for future evaluation. During an incident, the engineer is the point of contact for all agencies responding to the incident. The incident response engineer works in conjunction with the state patrol at the incident site for directing traffic and cleanup. In addition, this engineer provides traffic information to the TMC.

The TMC transmits this information through VMS, highway advisory radio, and the news media. CCTV is used for incident verification. Another interesting feature of the TMC is its direct interface to local news media. The capability exists for a direct feed of the CCTV and displays in the TMC to local radio and television stations.

At the incident site, Washington State DOT (WSDOT) personnel assist the incident response engineer. These people are typically WSDOT highway maintenance workers who are nearest the incident. When they are not responding to incidents, they perform normal maintenance duties. During evenings and weekends, maintenance people are on-call. While on-call, the volunteers are paid standby wages and take an incident response vehicle home. The responding personnel charge their time at an incident scene to a special WSDOT account funded by reimbursements from those the state patrol has deemed as responsible for causing an incident.

The incident response trucks are 4-wheel drive, extended-cab pickups . The trucks carry communications equipment, including cellular telephones and three different radio frequencies. In addition, there is a short-range portable radio, known as the On-Scene Communications and Response (OSCAR) system, for communicating with other responding agencies at the incident scene. The trucks also carry other equipment for handling an incident, including the following:

a. Traffic control equipment that includes an arrow board, a push-bumper, signs, and channelizing devices.

b. Each truck has a fusee dispenser that allows the engineer approaching an incident to set up flare lines without leaving the truck.

c. A 4-million candlepower light system to illuminate nighttime incidents.

d. A diesel pumping system and 55-gallon storage drum to handle leaking diesel tanks.

e. Booms, pads, and drums of sand to handle a 100-gallon spill.

f. A backpack blower to clean debris from the road.

g. A 35-mm camera for documenting incident scenes.

4.2.6 Melbourne, Australia

The Road Traffic Authority of Victoria is implementing the Signal Coordination of Regional Areas of Melbourne (SCRAM) system to coordinate all traffic signals and to introduce high priority schemes for public transportation at signal intersections. SCRAM uses the Sydney Adaptive Control System (SCATS), which is used throughout Australia, New Zealand, and China. SCATS as used by SCRAM consists of microprocessor based signal controllers interconnected by a telephone network. The essential characteristics of the SCRAM system are:

a. Isolated intersection control where the controller passes information to centralized control, but responds only to local detector input.

b. Flexlink control whereby the local controllers continue to communicate information to the central controller, but the local control is determined by predefined data held in online memory and synchronized to local software clock.

c. Dynamic control where groups of controllers operate in a fully traffic-adaptive mode.

Currently, 820 signal sites on 350 km of arterial roads are operating under the SCRAM system. Future plans for the system include increasing the number of regional controllers from 12 to 16, and increasing the number of controlled signals to 2000.

4.2.7 Toronto, Canada

There are two major programs in Toronto: the use of the Split Cycle Offset Optimization Technique (SCOOT) algorithm for adaptive control, and the Gardiner-Lake Shore corridor project. The Toronto SCOOT demonstration project encompasses 75 intersections within three distinct operational control areas. One control area includes 42 intersections within a grid network of the central business district. Another control area includes 20 intersections along a major suburban arterial The third control area includes 20 intersections along Lake Shore Boulevard.

The Gardiner-Lake Shore corridor project consists of an urban freeway and a parallel signalized artery. These two routes form a major access route into downtown Toronto. The idea behind this project is that in addition to traditional techniques such as loop detectors, CCTV, HAR, changeable message signs, and ramp metering, it is important to integrate other concurrently operating traffic management systems that are related functionally and geographically. As the major commuter route into Toronto, the Gardiner-Lake Shore corridor accommodates peak volumes of 8,800 vehicles per hour, with an average daily traffic count in excess of 200,000 vehicles.

4.2.9 London, England

The London system is a surface street control center using the SCOOT technology for adaptive signal control. Monitoring in the system is done by a central computer. The monitoring process is aided through the use of CCTV and police reports. The control centers have color monitors with color-coded graphical maps for displaying congestion data. In addition, there are monitors for the CCTV.

4.2.10 Berlin, Germany

The Berlin system has an interface to a route guidance and information system, LISB (also known as ALI-SCOUT). The LISB system requires the driver to input a destination into an in-vehicle computer. The computer receives location and traffic data when the vehicle passes through an intersection equipped with a beacon. This beacon provides duplex data communications by means of infrared equipment. The in-vehicle computer then computes the best route and provides audio directions to the driver. The LISB test involved outfitting 240 traffic signals with beacons and 700 computer equipped cars.

4.2.11 Torino, Italy

The freeway control system in Torino contains several unique features. The Italian system (UTOPIA) is a real-time distributed control system. Data concentration and preprocessing are performed at the local units and transmitted back to the central computer. The central computer is responsible for further data processing, storage management, man / machine interface, and operator support functions. The central computer drives an expert system used for traffic network diagnosis. The system consists of a database of information, a set of final goal states, rules frequencing actions, an interactive user interface, and an inference engine. Roadside equipment includes variable message signs, and also air quality analyzers.

4.2.12 Tokyo, Japan

Japanese IVHS activities are primarily dedicated towards driver information systems. The premiere programs are the Road / Automobile Communication System (RACS) and Advanced Mobile Traffic Information and Communication System (AMTICS). Both systems assume that vehicles are equipped with a digital road map data base. RACS is composed of roadside communications beacons, in-vehicle units, and a system center. Two-way communication is through microwave transmission. The in-vehicle unit performs navigation, information processing, and individual communication. The on-board navigation system uses autonomous dead reckoning with nap-matching techniques and displays results on a CRT terminal. The roadside beacons are used for transmitting vehicle identification, automatic position monitoring of particular vehicles, collection of detailed traffic data, and other information.

AMTICS is much like RACS differing in the communications mode. AMTICS uses a mobile communication link called the Teleterminal System. The Teleterminal System is a cellular type, two-way digital packet, multi-channel communications system. Traffic congestion information is transmitted to the AMTICS vehicle from the traffic control center using the downlink portion of the Teletermmal System.

4.2.13 Missile Warning System

The Air Force's Missile Warning System located in Colorado Springs, CO is responsible for detecting and reacting to missile attacks. The Air Force monitors and operates a suite of spaceborne and airborne sensors in order to detect missile launches. When an incident is detected, the Air Force must categorize and develop the appropriate response.

This system is of interest to the ATMS study from a number of perspectives. First, the system uses sophisticated incident detection and management schemes. Second, training and simulation are also important facets of this system. Finally, the control center will be interesting from a human factors perspective.

4.2.14 Nuclear Power Plant

Yankee Atomic Electric Company operates and trains operators / engineers at several nuclear power plants in the New England area. Of special interest to the ATMS Support Systems project is the existence of full-scale training simulators at each of the sites. These simulators emulate the actual operation of the reactor, the control center, and its decision support systems. Yankee Atomic Electric Company operates plants in Maine, Vermont, New Hampshire and Connecticut. There are control centers and simulators associated with each reactor. The reactors represents several generations of technologies ranging from the Connecticut Yankee Plant, which is one of the oldest systems using analog technology to the Millstone Unit #3, one of the newest plants in the country which uses (almost completely) digital technology . The nuclear power industry represents one of the most mature control center industries. A problem associated with the development and deployment of advanced technologies has been the strict regulations placed on the industry. The systems that are currently in use are subject to rigorous testing standards.

5 Summary of Findings

The purpose of this report is to document the state-of-the-practice in the implementation of IVHS technologies in ATMS and, in particular, in Traffic Management Centers. In order to maintain the correct perspective, a brief summary of potential capabilities within a TMC in a mature ATMS environment is presented in Section 2. Relative to that discussion, Section 3 summarizes the findings from the site visits and the literature survey. Section 4 provides the detailed site visit data. Based on our observations in the site visits and the literature the following generalizations can be made:

a. There is an uniform lack of standards for interfaces and data management, and the recognition that such standards are needed.

b. There is minimal automated support for analysis, particularly online decision support, and integrated management of transportation services.

c. Lack of automated interfaces to non-IVHS systems.

d. General satisfaction with the operational capabilities of UTCS-based systems.

e. The common belief by TMC managers in the effectiveness and success of their operations, and the desire to improve through a selective application of new technologies and products.

f. TMC managers are beginning to appreciate the advantages of an open systems architecture.

In this report, several deficiencies in the state-of-the-practice for traffic management are documented. As cited in the document, inadequacies in effectively managing data, incident management strategies, decision support tools, offline analysis support, and user interfaces severely hamper the ability to effectively manage traffic. Our research uncovered another common theme: that the traffic community has developed an appreciation for the need for standards. Unanimously, all future TMC's and upgrade plans include the need for conventional workstation (or PC) computers running common, non-proprietary operating systems. We have also learned that interfaces to other IVHS components are still in the conceptual stage. There has been significant research into driver information systems and driver support systems, yet there is very little experience with integrating these systems into transportation management systems. The final major finding of our work to date is that the traffic community is not actively pursuing multimodal environments as a strategy for optimizing transportation flow.

Appendix A

A. 1 Site Selection Criteria

Using Section 2 as a frame of reference, the goal of the site selection process was to identify those sites where visits would yield the maximum benefit in identifying the use, experience or planned use of advanced IVHS technologies for ATMS and TMC operations.

In order to help prioritize the potential list of sites, the project team identified the following key areas in which the presence of a significant installation or current activities would be applicable to the project goal of developing a concept of operations for an advanced TMC and a set of prototype support systems. These are as follows:

a. Overall network complexity and size.

b. Freeway monitoring, incident detection, and management.

c. Integrated freeway and surface street management.

d. Decision support systems for traffic management, as well as TMC operations.

e. External interfaces to other IVHS and non-IVHS systems.

Table A. 1 summarizes the information gathered from the literature and some preliminary telephone surveys on most of the known installations. It was extremely difficult to identify sites through preliminary evaluation with any significant DSS capabilities. Yet this is one of the most important factor in the study.

When the site selection strategy was devised, attention was paid to four factors. First, all of the selection criteria must be covered. Second, sites meeting multiple selection criteria are more desirable. The third consideration was that there should be a mixture of freeway and surface street control centers. Finally, in the interest of economy, sites that could be clustered into one visit were preferred.

On the basis of the information shown in the table, the decision was made to visit the Los Angeles, CA, Orlando, FL, and Minneapolis, MN. Los Angeles was selected because it met many of the criteria. Located within the metropolitan Los Angeles area are the ATSAC, Anaheim, and CalTrans TMC's which potentially meet all five criteria as identified above. Orlando met the fourth and fifth, and Minneapolis met the second. In addition, sites local to the Washington, D.C. area could be visited at no cost.

Table A.1 Preliminary Site Characteristics

Site	Network Complexity	Monitoring & Incident Management	Integrated Management	Decision Support Systems	External Interfaces
Los Angeles	3			3	
Anaheim			3	3	
CALTRANS					
Orlando		3		3	3
Minneapolis		3	3	3	
Oakland County		3		3	3
Long Island			3		
Seattle		3	3		
Chicago	3				
Montgomery County				3	
Berlin		3			3
Amsterdam		3		3	
Torino		3		3	
London	3	3			
Toronto	3		3	3	
Melbourne				3	
Tokyo					3
FAA	3	3		3	
NASA		3		3	
Nuclear Power Plant		3		3	
Missile Warning System	3	3		3	

Appendix B Recommendations for Additional Site Visits

B.l Europe

Europe is recognized as a leader in IVHS, with mature programs and applications of IVHS technologies. Because of this, the U.S. is in the unusual position of being able to leapfrog state-of-the-practice by taking advantage of lessons learned in foreign systems. Of particular interest to this study is work in traveller informations system promoting multimodal transportation. In addition to this research, experiences with the application of large scale, real-time adaptive control systems merits investigation. The level of automation inherent to TMCs appears to be much higher than that found in the U.S. Finally, understanding the experiences gained through large IVHS projects such as Program for European Traffic with Highest Efficiency and Unprecedented Safety (PROMETHEUS) and Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE) are important to this study. It is our opinion that a state-of-the-practice survey will be incomplete without the inspection of European programs.

The apparent lack of multi-modal initiative in the United States is the primary driver for visiting Europe. In the Netherlands, there is a formal government policy to promote the use of alternative modes of transportation. Because of this there are active research and test programs designed to accomplish the goals of this policy. An example of such a program is the System of Cellular Radio for Traffic Efficiency and Safety (SOCRATES). SOCRATES, as part of the DRIVE I initiative, is designed to provide the traveller with real-time traffic information. This information includes dynamic route guidance, parking information, hotel and scenic route information, and Mayday signal capabilities. The system is designed to provide aids in decision making on using the car versus public transportation that are available both in the car and through in-home information services. In addition to this work, the Dutch have a reputation for highly automated, fault-tolerant traffic control systems. Inspection of one of these systems provides an added bonus. Another example of the European work in traveller information systems is the Stuttgart Transport Operating Regional Management (STORM) effort. The idea behind this system is to make information such as weather, parking, transit schedules, and traffic data available for dual mode guidance. The operations concept for this system is that regional computers will provide input to the central computer for access. In addition, the use of beacon technology as the basis of traveller information systems differs from approaches being tested in the U.S. Inspection of these programs promises to provide valuable input into this study from two perspectives. First, we need to understand the use of multi-modal transportation policies and applications as a method optimizing transportation flow. Second, it will help us gain a better understanding of the interface requirements of other IVHS components.

Real-time adaptive control, as a component of a traffic management centers, is a crucial next step towards proactive control. Because of this, we should take advantage of the benefits achievable through interviewing people with experience with large SCOOT implementations. The London system provides such an opportunity. One of the perceived drawbacks to a SCOOT implementation is that it requires constant maintenance by a traffic engineer to remain effective. Researching and gaining the practical experience will be extremely valuable to the team.

The level of automation found in many European TMCs is much higher than in domestic TMCs. The automated barriors and the truck height sensors found in the Amsterdam **TMC** are examples of a high level of automation. A more in-depth study of these systems will benefit this study tremendously.

Understanding and designing the interfaces to other IVHS components appropriately is critical to the success of the Support Systems Contract. In Berlin, the LISB system (a version of ALI-SCOUT) presents an opportunity to study a traveller information system. The LISB system is composed of 250 beacons for traffic information and has over 600 participating vehicles. Much can be learned from the approach in the LISB systems to receive and process data from a large population of probe vehicles. The use of beacons as a medium for transmitting traffic information is a different approach than is being used in the U.S. Examination of this approach should be interesting from the perspective of the application of alternative approaches. The Traffic Master in England system is an example of a traveller information system implemented without the benefit of government support. A visit with the Traffic Master people will be beneficial from the perspective of developing industrial partners for IVHS.

It is our opinion that the investment of a European visit is sure to pay dividends throughout the course of this effort. For example, by taking advantage of the lessons learned in Europe and the exposure to their innovative ideas, we can improve the overall quality of this study. Written correspondence and telephone calls will be a poor substitute for on-site discussions in a brainstorming environment,

B .2 Toronto, Canada

A visit to Toronto would prove worthwhile. The most alluring feature of the Toronto system is it's Integrated Traffic Control Center (ITCC). This is a new facility that is designed to control both surface street and freeways in an integrated fashion. The ITCC is composed of three major entities: the Corridor Traffic Management System (CI'MS), the Traffic Signal Control System (TSCS), and the Traffic Situation Room (TSR). The primary responsibility for the CTMS is to monitor and manage the traffic flow along the Gardiner Expressway and the parallel signalized arterial, Lake Shore Boulevard. The TSCS is responsible for operating the traffic signals throughout metropolitan Toronto. The purpose of the TSR is to provide a central repository for traffic information and to transform this data into a format for transmission to external agencies. Staff in the TSR coordinate with the CTMS, TSCS, maintenance, police, and Toronto Mass Transit Commission in managing traffic, planning for special events, and coordinating incident management activities. In addition to the work in integrated traffic management, Toronto has an on-going experiment using SCOOT. These preliminary efforts in regional traffic management are of major interest to our study.

B .3 Nuclear Power Plant

As a second alternative to Europe, consideration should be given to visiting a nuclear power facility. It is our observation that much of the underlying support mechanisms for a traffic control center are in place (e.g., communications). What is missing is the ability for transforming the reams of data that is collected into information for use by the operations staff. The mature, finely honed support systems inherent to a nuclear power plant make it attractive. These systems tend to be extremely rigorous and require a high degree of operator training. Also interesting are the requirements of a nuclear power plant for redundancy and fail-safe operations. Finally, nuclear power plants are notorious from a human factors perspective.

A visit to a nuclear power plant may prove enlightening when their methods are compared to the support systems found in FAA and spacecraft control centers. Like a nuclear power plant, the activities of FAA controllers are governed by finely groomed procedures. For example, there is a specific vocabulary that FAA controllers use to execute their job. Similar to the operation of a nuclear power plant, the operation of a spacecraft is highly procedure orientated. Developing an appreciation of analogous nuclear power plant support systems would be constructive.

Because of the small tolerance for error, fault tolerance and redundancy are important characteristics of nuclear power plants. As in a spacecraft control center, there are system design characteristics, such as the need to develop systems with no single point of failure. Enhancing our understanding of such design considerations and the resulting system architectures will be useful to this study.

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