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Design of an ITS-Level Advanced Traffic Management System

A Human Factors Perspective

Research and Development
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FOREWORD

This report documents a top-down system analysis conducted during the course of an investigation of human factors issues critical to the design of an advanced traffic management system (ATMS). Methodologies employed in conducting this analysis, procedures for implementing such methodologies, and analysis results are presented. System objectives and performance requirements for an ideal ATMS, as well as the functionality for such a system, are defined. (The ideal system represents a hypothetical ATMS, one that is unconstrained by real-world events, existing practices in traffic engineering, or current technologies.) Ultimately, real-world elements were considered, where idealized objectives, performance requirements, and functional definition were revised. These revisions are documented here.

Issues associated with the human operator (assignment of operator roles to each ATMS function, specification of operator performance requirements, and identification of operator tasks) are also addressed. Results of the ATMS function allocation process are presented. Included in this presentation is an introduction to the theoretical framework guiding ATMS function allocation: *operator role theory.* In this report, assessment of the human operator begins at a global level and progresses through increasingly detailed levels. This assessment terminates with the results of a detailed task analysis. Task analysis results supported the preparation of a human factors specification for traffic management center (TMC) configuration items.

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Director
Office of Safety and Traffic Operations
Research and Development

NOTICE

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16. Abstract

This report documents an approach for designing an Advanced Traffic Management System (ATMS) from a human factors perspective. In designing the ATMS from a human factors perspective, a user-centered top-down system analysis was conducted. Methodologies employed in conducting this analysis, procedures for implementing such methodologies, and analysis results are reported.

System objectives and performance requirements for the AIMS, as well as ATMS functionality, are derived. Human operator issues (assignment of operator roles to ATMS functions, specification of operator performance requirements, and identification of operator tasks) are also addressed. Results of the operator task analysis supported the preparation of a human factors specification for the ATMS.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	**ha**
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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List of Abbreviations

ADSS	Administrative Support System
ATCS	Adaptive Traffic Control System
ATMS	Advanced Traffic Management System
AVI	Automatic Vehicle Identification
BIT	Built-In Test
CCTV	Closed Circuit Television
CSS	Communications Support System
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
IDLS	Incident Detection and Location System
IDS	Information Dissemination System
IRAS	Incident Response and Advisory System
ISDN	Integrated Services Digital Network
ITPS	Intermodal Transportation Planning System
ITS	Intelligent Transportation System
IVHS	Intelligent Vehicle-Highway System
MMCS	Motorway Monitoring and Control System
MTS	Maintenance Tracking System
MTSS	Maintainer Training Support System
O-D	Origin-Destination
PTMS	Predictive Traffic Modeling System
SOV	Single Occupancy Vehicle
SSC	Support Systems Contract
TDMS	Traffic Data Management System
TDSA	Top-Down System Analysis
TMC	Traffic Management Center
TMS	Traffic Management System
TMTS	Traffic Management Training System
VMS	Variable Message Sign

EXECUTIVE SUMMARY

HUMAN FACTORS RESEARCH IN ITS: MOTIVATION

Advanced technology for information collection, data processing, decision support, and automation has created major changes in the ways people work and play. By employing new computer-based technologies, we can greatly expand our capabilities. Research has discovered, however, that available advanced technologies are substantially underutilized because (1) they are difficult to learn, (2) they present usability problems, and (3) people are as yet unwilling to trust them. Ultimately, in order for newly developed systems to be used to their full potential, they must be designed to be in harmony with the needs, expectations, capabilities, and limitations of the end user.

The intelligent transportation system (ITS) era is bringing elements of this advanced technology to traffic management. Many traffic management centers (TMC's), for example, are expanding their roles and upgrading their capabilities. Estimations indicate that by the year 2000, over 200 cities will have adopted some elements of ITS technology. ITS technology has emphasized the borrowing of advanced computer, information, and control technologies and wedding them to existing, relatively low-technology traffic management hardware. Increasingly capable and affordable computer technology is driving much of the current ITS development.

Much of ITS technology evolution involves upgrading older technologies of the traffic signal control center or traffic operations center to newer technologies of the ITS-class advanced traffic management system (ATMS). The nascent ATMS collects roadway and traffic information with considerably more detail, accuracy, and speed than earlier systems. The increased quantity and quality of information, along with improved data fusion processes (that enhance operators' abilities to interpret information), provide increased opportunities for the TMC to make appropriate decisions and responses.

New display and communication technologies, within vehicles and as part of the infrastructure, provide increased opportunities for controlling and influencing traffic. In-vehicle displays for navigation instruction are becoming available. In selecting an optimal route between two points, these navigation tools use a combination of onboard geographical data bases and computers, global positioning system (GPS) receivers for rough positioning (within tens of meters), and communication with a dynamic central data base of traffic problems, congestion, and delays. Infrastructure-based displays, including variable message signs (VMS), highway advisory radio (HAR), and information kiosks, provide drivers with warnings of incidents and congestion ahead so that they might select an alternate route or make other changes in their travel plans.

New information and communication technologies allow TMC's to obtain more (and improved) information and subsequently use it to provide more and different services to the motorist and to other public agencies than ever before. Unless the impact of these technologies on human operators is considered and addressed, the expansion of capabilities and responsibilities for the TMC could potentially create excessive workloads for TMC staff. Furthermore, the introduction of new, complex information display and control systems creates an increased likelihood of system-induced human errors. In order to maximize the efficiency of TMC operators and systems and minimize error rates, the TMC must be designed from a human factors perspective.

Program Overview

In order to investigate TMC design from a human factors perspective, Federal Highway Administration (FHWA) is exploring the roles of computers and humans within the context of ITS traffic management systems. A research program entitled "Human Factors in Advanced Traffic Management Systems (ATMS) Design Evolution" is currently in progress. This program consists of three major research thrusts. The first of these three, a user-centered top-down system analysis of the ATMS, has been completed, and the remaining two are underway. A brief description of each research thrust is provided here.

- *User-Centered Top-Down System Analysis.* The results of this particular analysis enabled us to develop a detailed description of an ideal (future) traffic management system. This description was based on (1) interviews with "ITS visionaries" and (2) system analyses performed by researchers knowledgeable in the areas of human factors and state-of-the-art automation. The top-down system analysis also facilitated an investigation (performed independently by a separate group of analysts) of existing transportation system control facilities. This comparable systems investigation generated detailed reviews of the selected facilities, and its purpose was two-fold. First, as a means of ensuring that results obtained from the interviews and system analyses were realistic with respect to available technology, the comparable systems analysis validated or revised results obtained from interviews and system analyses. Second, the comparable systems investigation documented "lessons learned" during design and operation of the set of selected control facilities. Results of the interviews, system analyses, and comparable systems investigation agree that data input, fusion, and output activities are likely to undergo substantial degrees of automation, and computer-based decision aids will become common. In spite of the increase in operator assistance, however, the most challenging traffic data interpretations, decisions, and actions will continue to be the responsibility of human operators.

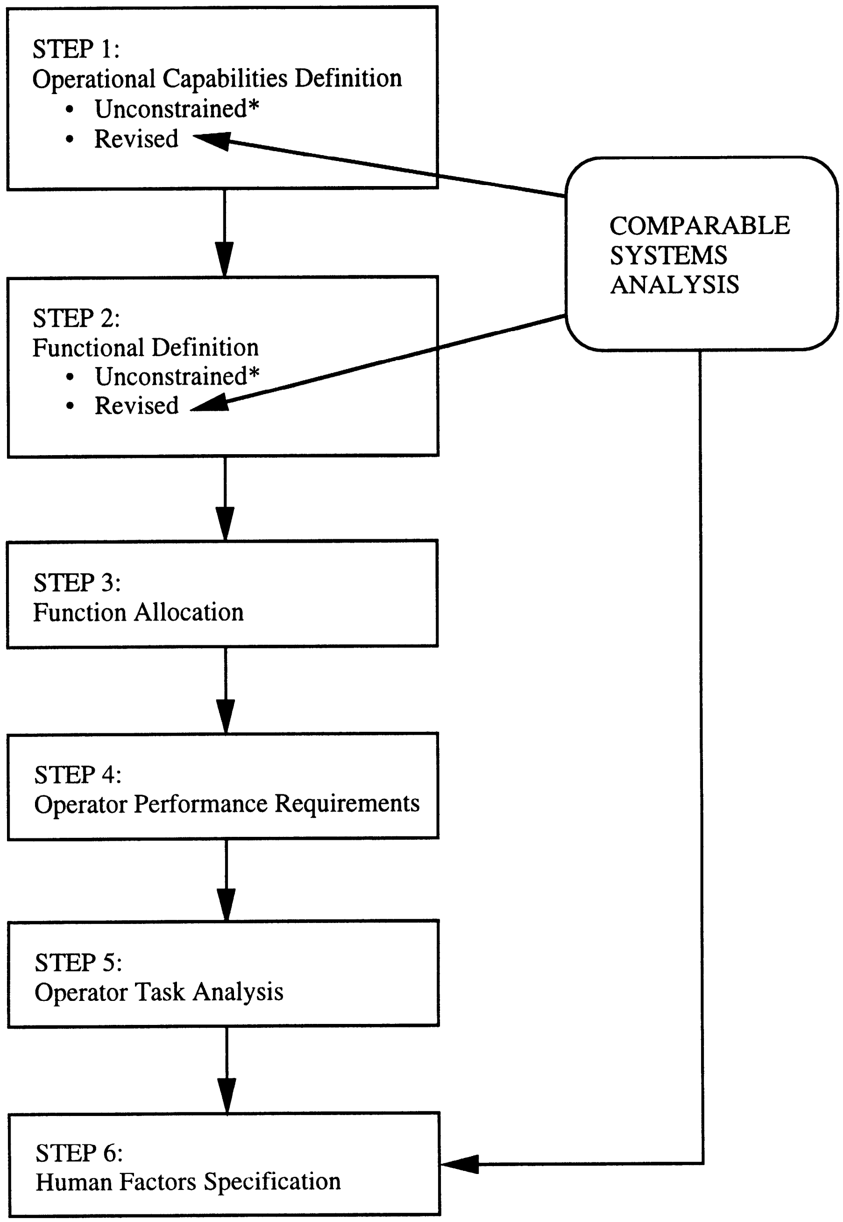
- *Traffic Management Center Simulator Development.* A high fidelity advanced traffic management center simulator is under development. It is currently supporting a program of empirical research in which a range of human factors issues in TMC design are being addressed.

- *Human Factors Handbook Development.* A handbook of human factors guidelines that is intended to support TMC design and operation is under development. Information provided in the handbook is to be based on lessons learned from the top-down system analysis, as well as from empirical research conducted in the TMC simulator.

In what follows, more detailed discussions relevant to each of the three research thrusts are provided. Emphasis is placed on the top-down system analysis, as it is the segment for which final results have been generated.

USER-CENTERED TOP-DOWN SYSTEM ANALYSIS

As stated in the Program Overview, in order to define an ITS-class AIMS, a detailed top-down system analysis was implemented. Our objective in applying this particular analytic approach was to investigate ATMS design from a human factors perspective. Specifically, the purpose of the top-down system analysis was to define human operator roles and tasks within the framework of a next-generation ATMS. Interviews with "ITS visionaries" and a series of system analyses (performed by researchers knowledgeable in the areas of human factors and state-of-the-art automation) were completed. In addition, the top-down analysis procedure facilitated a parallel investigation of comparable systems. In figure 1, the steps required for implementation of the top-down system analysis procedure are outlined. In essence, this figure depicts the flow of project tasks required for completion of the top-down system analysis. Our interviews with "ITS visionaries" were conducted in fulfillment of Step 1 (Operational Capabilities Definition). The series of system analyses yielded a definition of ATMS functionality (Step 2), function allocation results (Step 3), an initial specification of operator performance requirements (Step 4), results from an operator task analysis (Step 5), and a human factors specification (Step 6). An investigation of comparable systems, performed independently of the analyses that yielded unconstrained definitions of operational capabilities (Step 1) and functions (Step 2), was also completed. This independence was established in order to maintain the ITS "visionary" aspects of Steps 1 and 2. Specifically, independence ensured that the initial definitions of operational capabilities and functions remained unconstrained by existing control room configurations and existing traffic engineering practices. As illustrated in figure 1, once unconstrained (ideal) operational capabilities and functional definitions were established, results of the comparable systems analysis were considered



*The unconstrained definition was formulated independently of the comparable systems analysis.

Figure 1. Project task flow for top-down system analysis.

and used to revise the definitions such that they projected realism. Finally, results of the comparable systems analysis also served as inputs to the human factors specification (Step 6). An overview of the outcomes of the top-down systems analysis procedure is offered here in the executive summary.

Step 1: Operational Capabilities Definition

A number of ITS experts were nominated by their peers as "visionaries" and were interviewed in order to obtain a consensus of the objectives and capabilities of an ATMS of the next decade. According to a composite view of these visionaries, the overall mission of the ATMS is to facilitate the safe movement of persons and goods, with minimal delay, throughout the roadway system network. In order to perform this mission, the ATMS must pursue the following five major system objectives.(1)

Objective 1: Maximize the Available Capacity of Area- Wide Roadway Systems

The first objective is to promote the maximum effective traffic volume (vehicles per unit of time) for existing roadways.

Objective 2: Minimize the Impact of Roadway Incidents

Roadway incidents (accidents, stalls, fallen debris, equipment malfunctions), particularly during peak demand times, may have a significant impact on travel times and create a threat to public safety. Reducing the effects of these incidents requires ATMS involvement on two fronts: reducing the likelihood of incidents occurring and minimizing the delays associated with incidents that do occur.

Objective 3: Assist in the Provision of Emergency Services

Interaction with emergency service providers may include incident detection and verification, incident notification, coordination of responses when multiple services are needed, and modification of system parameters to improve speed or accuracy of an emergency response. TMC support for emergency services is not limited to roadway incidents. It may be needed in any situation in which the roadway is used by emergency responders (e.g., clearing highways between a disaster site and hospitals).

Objective 4: Contribute to the Regulation of Demand

This objective requires motivating drivers to reschedule/reroute trips or to take alternative modes of transportation. Regulation of demand may be short or long term, reactive or proactive. It involves cooperative efforts with the media and other transportation agencies.

Objective 5: Create and Maintain Public Confidence in the ATMS

The ATMS must be perceived as providing accurate and useful information to the public. Public confidence in the ATMS must be assessed continuously. Public relations efforts may be conducted in order to reinforce positive public perception of the ATMS.

Step 2: Functional Definition

To further define the five objectives resulting from completion of Step 1, a list of requirements for information collection, processing, storage, retrieval, and output was produced. These requirements were based on discussions (conducted with the group of visionaries) in which ATMS capabilities were projected. A set of 113 ATMS functions necessary to meet these requirements was produced.(2)

Comparable Systems Analysis

As part of the same program, approximately two dozen operational control centers in North America and Europe were visited. (3) A majority of these were centers that monitored, controlled, or influenced automobile traffic on urban streets or major highways. Detailed interviews were conducted with managers, operators, and engineers to document system design, function allocation, operating procedures, and human factors lessons learned. Additional visits to hardware and software vendors provided insight into expected evolution paths for TMC automation and design difficulties vendors sometimes experience in working with the ITS community.

The comparable systems analysis was performed independently of the initial stages of Steps 1 and 2. (In these initial stages, unconstrained definitions of operational capabilities and functionality were formulated.) This independence allowed us to maintain the ITS "visionary" aspects of Steps 1 and 2. Specifically, by imposing the independence requirement, we ensured that the initial definitions of operational capabilities and functionality remained unconstrained by existing control room configurations and existing traffic engineering practices. As indicated in figure 1, once unconstrained definitions of operational capabilities and functionality were established, results of the comparable systems analysis were used to revise the definitions such that they projected realism. As a result of the comparable systems analysis, the following recommendations for revision were adopted.

- Include interfaces between the ATMS and those traffic management systems located in neighboring jurisdictions.
- Include arterial but not local streets in the roadway system served by the ATMS.
- Recognize that a metropolitan rail system includes both light and heavy rail.
- Recognize that traffic signal cycle times will constrain update rates of control algorithms.

Automation Approaches: Three Examples

Partial automation is becoming very common in traffic management systems. Automation of changes in traffic signal and ramp meter timing plans according to time of day or traffic demand is already common; future signal control software will be increasingly capable of automatic reaction. Fusion of sensor data into meaningful displays is well advanced. Automation of VMS control and message content is the next likely TMC function for extensive automation. As would be predicted from our function analysis, automation of other decisions and functions is lagging.

By comparing the philosophy and operation of three relatively new ITS TMC's, large differences in automation philosophy can be recognized. The three systems are equally successful at performing their respective missions, even though they perform them very differently.

The least automated of the three is located in a city in the United States. Its primary function is to control the city's traffic signals in response to predicted and unpredicted traffic flow. A network of approximately 1000 traffic sensors and 20 closed circuit television (CCTV) cameras provides information on traffic flow and incidents. The traffic signal "timing plan" (the time devoted to each green, yellow, and red phase) is automatically controlled by the time of day. The software also allows automated adaptive control according to traffic demand, but this feature is not used. Much of the operator's time is spent manually changing timing plans to optimize flow at individual intersections. The operator also detects and reports incidents, monitors and troubleshoots component status, communicates with drivers via a network of VMS's, and works closely with police in traffic control.

The second example, a system in Canada, monitors and controls traffic on one of the busiest freeways in North America. A network of loop detectors, computers, and VMS signs provides automatic measurement of traffic flow, selection of appropriate VMS messages, and display of congestion warnings to alert drivers and support their rerouting decisions. Congestion levels suggestive of incidents are presented to the operators via a graphical display. Operators using CCTV verify that an incident is present, call up an appropriate data entry page on their computers, and enter the location and precise nature of the incident. Appropriate VMS incident messages are automatically selected according to a complex set of preestablished rules and are then displayed on the VMS network while operators communicate with other agencies to help coordinate any required emergency response.

The third example, implemented on major roadways in The Netherlands, has the highest degree of automation. The Motorway Monitoring and Control System (MMCS) is a "lane control" system that can provide different speed limits or traffic restrictions dynamically for each motorway lane. Stations consisting of loop detectors in each lane, VMS's for each lane, and a networked computer are placed at approximately every 500 m. When traffic is flowing freely, no restrictions are displayed, and speed limits remain at 120 km/h. When slow or stopped traffic is detected in a lane, the station computer communicates with upstream and downstream stations. All sign changes are coordinated and approved by a central computer system. Operators can, but rarely do, override the automated VMS system. The primary operator role is monitoring for MMCS maintenance problems and closing roadway lanes for maintenance (or as requested by other agencies). In order to compose appropriate sign patterns and transmit them to roadway outstations, operators interact with the MMCS through the central computer. Automated support systems validate operator-composed signs. In the MMCS, operators' incident management functions are very limited.

Some Lessons Learned

Automation of traffic signals can create problems when operators enter the loop. In one center, signal timing changes occurred at set times of day. The operator frequently made extensive manual changes only to have them erased, without warning, by an automated change to a new plan. In partially automated systems, the operator must be informed of those actions the automated system is preparing to implement. Furthermore, error traps in the software are required as a means of checking commands that might have catastrophic effects.

Automated detection of roadway incidents is relatively ineffective. Numerous algorithms based on measured variations in traffic flow have been developed by traffic engineers. Use of these algorithms becomes a classic signal detection problem, where high detection rates are associated with even higher false alarm rates. In practice, operators usually chose to ignore graphical incident detection displays that were based on fused sensor data and chose instead to rely on CCTV, even when reliance on CCTV caused excessive visual workload.

In several traffic management systems the ultimate design goal is full automation. While some existing support systems are capable of approaching that goal, research results suggest that the human operator must always have a role in the traffic management system. Several reasons for such human participation are as follows:

- Failures in automation logic due to unforeseen circumstances (e.g., the support system that interpreted maintenance activity in a closed lane as a wrong-way driver and closed the roadway).

- Events that cannot be detected by sensors but that require response (e.g., the airplane crash near a freeway that required road closure to all but emergency vehicles).

- Support system hardware or software malfunctions that require full or partial degradation to manual mode.

One TMC implemented an automation scheme in which a support system would determine the "best" pattern of changeable signs, and the operator would review and consent to each system-recommended change. Sign changes were so frequent (200 per hour) that operator workload was unacceptably high. Once operators recognized that the support system operated at near 100 percent reliability, they modified the automation scheme to give the support system initial response capability. Under this scheme, operators were able to modify a pattern manually if a problem was noticed. Three lessons can be obtained from this example: (1) initial function allocations must be empirically validated, (2) higher than expected support system reliability may allow implementation of higher levels of automation, and (3) partial task automation does not necessarily yield decreased operator workload.

Step 3: Function Allocation

While all 113 of the ATMS functions might possibly be performed manually, all were considered as candidates for full or partial automation. A panel of engineers and human factors specialists familiar with current and anticipated automation technology examined each of the functions and, in a two-step process, selected an appropriate level of automation. [(4)] In the first of the two steps, the panel explored whether the function could (and

Table 1. Description of operator roles.

Operator Role	*Description*	*Example*
Direct Performer	Human performs a function directly with virtually no involvement of machine components. No automation. Only human senses and effectors are used.	Operator composes messages and manually places letters on sign. May use passive tools such as ladder or hand tools.
Manual Controller	The human is solely responsible for closing the control loop. Automated systems may sense or process information but the human is the decision maker.	Operator composes messages and types them on a keyboard. Automated system posts them on the designated sign.
Supervisory Controller	Machine elements may make decisions about what control actions to take based on input from the environment. The human monitors the machine performance and may approve, revise, or reject the machine decision.	Computer selects sign message and displays to operator for approval. Operator may consent, edit message, or deny permission to display any message at all.
Executive Controller	Machine components are solely responsible for performance of a function. The operator enables the system and may turn it off if it becomes unreliable but cannot intervene in the system's in-progress performance.	Operator enables messaging system but may not alter the contents of a message. The operator may disengage the messaging system if it becomes inaccurate or unreliable.

should) be fully automated or whether it could (and should) be performed by the operator (with no computer assistance). In the second step, functions that could not be assigned to fully manual or fully automated status were assigned to one of two partial automation categories. In each of these categories, automation level was defined in terms of the amount of autonomy given to computer systems. The four automation levels, referred to as operator roles, are summarized in table 1.

In a fully automated ATMS, every function would be assigned to the *Executive Controller* role. At this automation level, the operator's primary function is to disable or enable system computers. Based on the automation analysis, however, only 29 of the 113 functions could (and should) be performed solely by an automated system. Many of these potentially automated functions involved sensing of information or transmitting of previously formatted messages. A sample of executive controller functions is provided:

- Detect vehicle locations.
- Detect vehicle speeds.
- Receive Built-In Test (BIT) reports.
- Post route advisories.
- Post speed advisories.

In spite of the emphasis on increased automation, 40 of the 113 functions were allocated solely to the human operator (implying no automated assistance). These *Direct Performer* functions typically involved communication with outside agencies, formulation of output data, or planning. A sample of direct performer functions is provided:

- Receive incident reports (phone).
- Receive special event plans.
- Determine TMC upgrade needs.
- Issue request for onsite traffic control.
- Implement policy and procedures.

The remaining functions required a mixture of human and system effort. Of these functions, 28 were allocated to a human

Table 2. Level of operator involvement with respect to information processing stages.

	Level of Operator Involvement:			
	H	Hm	Mh	M
Processing Stage:				
Input	23	45	02	43
Processing	42	23	10	38
Response Selection	68	00	16	29
output	19	44	00	50

decision-maker who would receive system support *(Manual Controller* functions). These typically included use of CCTV assets or decision-making with assistance from a decision aid. A sample of manual controller functions is provided:

- Monitor incident clearance using CCTV.
- Assess traffic congestion using CCTV.
- Determine need for emergency services.
- Develop contingency plans using decision aids.
- Maintain personnel records.

The remaining 16 mixed functions were allocated to a computer support system that would perform information processing and decision-making; however, because of the criticality and/or complexity of the decision, analysts determined that a human should be the final authority on decision implementation. Thus, the human could approve, revise, or reject an action recommended by the automated system. In some noncritical cases, the automated system could implement the decision and allow the human an opportunity to alter it after implementation. Such functions were assigned a Supervisory *Controller* role, and a sample of these is provided:

- Anticipate near-term traffic conditions.
- Identify traffic control options.
- Select best traffic control option.
- Identify anomalies in traffic flow.
- Determine maintenance needs.

Each of the 113 functions was defined in terms of four information processing stages: input, processing, response selection, and output.[(4)] For each function (and based on functional requirements, human capabilities, and projected machine state-of-the-art), a level of operator involvement was assigned to each of the four information processing stages. Four levels of operator involvement were characterized. Each operator involvement level and its respective notation is defined below:

- H: The human operator is solely responsible for performing the processing stage.
- Hm: The human operator (with machine assistance) performs the processing stage.
- Mh: The machine (with human operator assistance) performs the processing stage.
- M: The machine is solely responsible for performing the processing stage.

Table 2 summarizes the frequency with which each of the four operator involvement levels was assigned to all processing stages. Figure 2 offers a graphical representation of these data -- depicting the distribution of operator involvement levels across each processing stage. Each of 452 processing stages (4 stages for each of 113 functions) was assigned a single operator involvement level.

Not surprisingly, the percentage of information stages (input and output) proposed for full automation (M) was greater than the percentage of response selection stages that was proposed for full automation. Specifically,

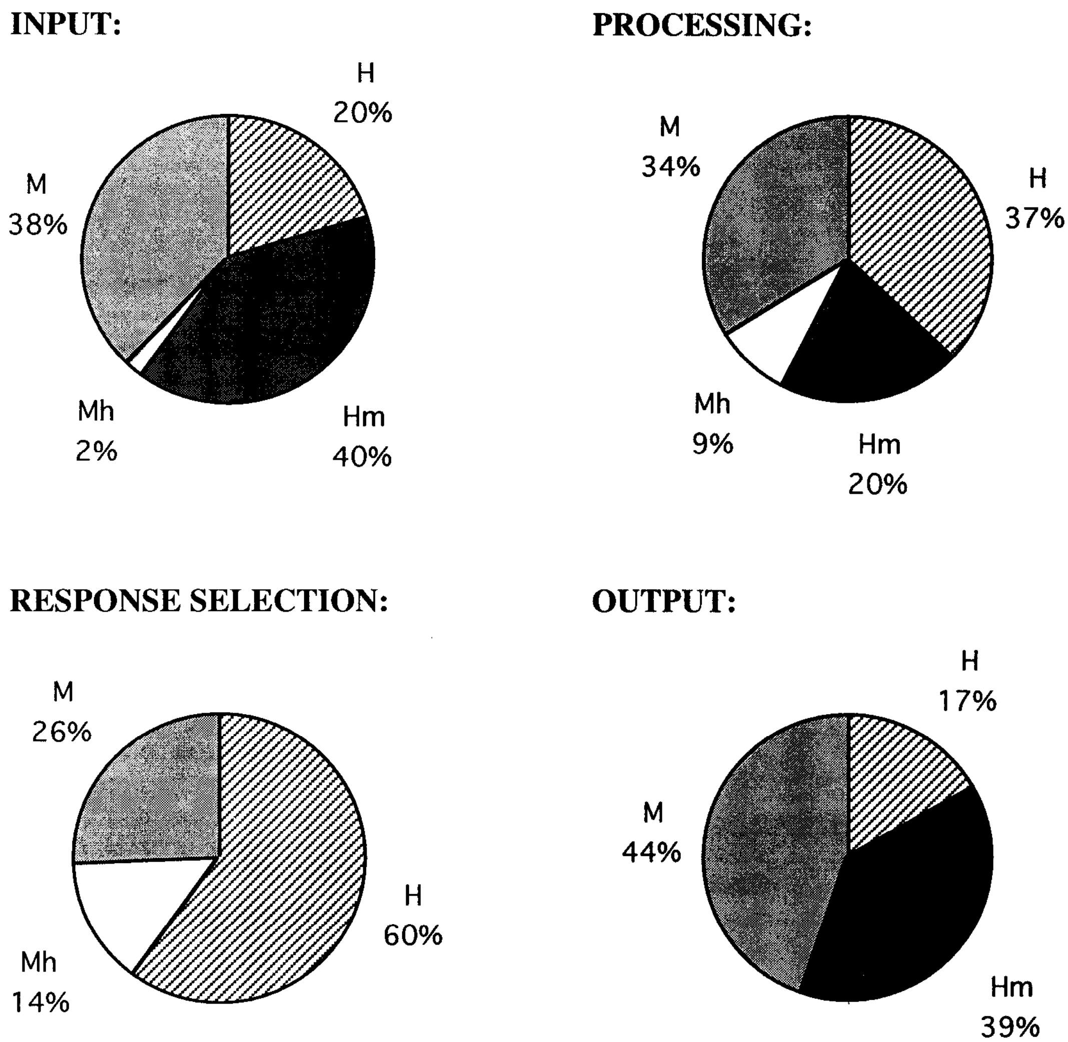


Figure 2. Distribution of operator involvement levels across information processing stages.

38 percent of all input stages and 44 percent of all output stages were proposed for full automation, while only 26 percent of all response selection stages was proposed for full automation. Input and output stages primarily involve electronic transmission of (1) raw data from sensors or (2) processed data between support systems. Human input/output activities typically involve voice or text communication and keyboard data entry.

A smaller, but a significant percentage of data processing stages (34 percent) is performed under full automation. These stages typically include analysis and fusion of raw data, support system computation of various algorithms, and tracking the location and condition of ATMS resources.

Response selection (decision making) is the most critical (and frequently the most complex) processing stage. Sixty percent of all response selection stages were assigned solely to the human operator (H). Fully automated response selection stages typically involved (1) identification and notification of system malfunctions and (2) identification and deletion of corrupted data.

The purpose of these analyses was to define human roles and tasks in an ideal next-generation ATMS. While one objective was to increase the level of automation, the overall goal was to optimize the system effectiveness. After exploring the detailed functional requirements of the ATMS, the panels of experts agreed that most of these functions could not be performed optimally without a human in the loop.

Step 4: Operator Performance Requirements

Operator performance was considered in terms of three types of requirements: information requirements, decision-making requirements, and output (response) requirements. They were considered within the context of four reference scenarios:

- Normal operations during rush hour traffic.
- A major freeway incident during rush hour traffic.
- Special event planning and traffic management during the planned event.
- A major winter storm during rush hour traffic.

These scenarios demonstrated functional capabilities of the ATMS and suggested the range of performance demands placed on system operators.

Information Required

An analysis of each of the four scenarios suggested that, in the course of responding to scenario events, TMC operators typically interact with three types of incoming information:

- Data to be incorporated in TMC analyses.
- Analysis results.
- Information employed in the operators' conduct of real-time traffic management.

Operator Decisions

Information received by TMC operators is subsequently processed, and one of the outcomes of such cognitive processing activities is a set of decisions. In other words, operators' decisions reflect their responses to the large amounts of data they receive. Analysis of the four traffic scenarios revealed that operators make four types of decisions:

- Accept or reject system recommendations.
- Initiate activities.
- Transmit information.
- Assess information.

Operator Responses

Any decision reached by a TMC operator is followed by some form of output. Thus, each output is a manifestation of an operator's cognitive processing activities. Operator outputs are displayed via a range of media. Scenario analyses identified five types of outputs operators typically manage:

- Messages.
- Strategies.
- Simulations.
- Traffic control commands.
- Data.

A subset of operator responses will involve the distribution of traffic information to various users. In order to ensure the appropriateness of such operator responses, we must "know the traffic information users" and understand their information requirements. Our taxonomy classifies traffic information users according to four categories:

- Institutional users.
- Traffic data users.
- Special service providers.
- Public users.

Institutional users include city officials/planners, other agencies (e.g., school districts, public safety organizations), public transportation systems, future special events hosts, and commercial vehicle operations systems. Users of traffic data include TMC personnel, the traffic control system, and information services (e.g., the media and traffic bulletin board services). Special service providers include incident responders, maintenance providers, pre-positioned assets (e.g., snow plows, salt trucks), and emergency (non-incident) responders. Public users are represented by special event traffic, roadway drivers, the general public, public transportation operators, and commercial vehicle operators.

Step 5: Operator Task Analysis

The primary objectives of the operator task analysis are to:

- Identify the operator tasks required for successful execution of each ATMS function.
- Ensure that the operator tasks associated with a given function satisfy the performance requirements imposed by the operator role assigned to that function.
- Provide an organizational framework for operator tasks.
- Identify significant maintenance tasks.
- Describe operator tasks in sufficient detail (and context) to support the preparation of a human factors specification.

The task analysis identified a total of 363 *required* operator tasks and 485 *related* tasks. Required tasks represent a core set of activities the operator must perform in order for successful execution of the associated function. When a given function is executed, an operator performs all of the required tasks associated with that function. Required tasks also represent a high level set of activities. This reference to high level activities has particular meaning when one considers the second category of task type: related tasks. In essence, related tasks support completion of required (high level) tasks. A related task may be unique to a given function, or it may appear as a related task in more than one function. In some instances, related tasks are required tasks of other functions. Note that completion of all related tasks associated with a given function may not be required for successful execution of that function. Function execution may require completion of only a subset of related tasks. Thus, the context in which a function is executed will determine the related tasks that are appropriate for completion of that function.

An assessment of all operator tasks (required and related) enabled us to establish six categories of task type:

- Communications.
- Coordination.
- Decision making.
- Information processing.
- Observation.
- Outcome.

Each required and related task was assigned to one of these six task type categories. Communications tasks represent those activities that require TMC operators to receive and transmit information, where this information arrives from (and is distributed to) internal and external entities. Coordination tasks reflect activities requiring TMC operators to plan, formulate strategies, and cooperate with other individuals or agencies that may be internal or external to the TMC. Decision-making tasks suggest activities that are performed as a result of reasoning strategies or cognitive processing implemented by the TMC operator. They are performed once the operator recognizes that (1) the TMC is awaiting a response and (2) intervention of ongoing systems functions is necessary. Information processing tasks require the operator to analyze incoming information such that some form of reasoning strategy is implemented. Observation tasks involve the TMC operator's ability to oversee (and manage) ATMS events, where such events may be anticipated or unanticipated. Outcome tasks represent end products. Typically (within the context of ATMS activities), end products are analysis results. The operator's performance of outcome tasks ensures that these results are conveyed.

Figure 3 depicts the distributions of required operator. tasks and related operator tasks, respectively.

ATMS functionality encompasses a number of maintenance-related responsibilities. A total of 47 required maintenance tasks and 56 related maintenance tasks were identified. Note that ATMS functionality does not encompass activities directly related to the repair of components in the field. Rather the ATMS focuses on (1) receiving adequate levels of information on current conditions such that data reflecting system degradations and malfunctioning components are available, (2) identifying maintenance needs in a timely manner, (3) issuing maintenance requests to the appropriate set of service providers, and (4) conducting maintenance training.

Step 6: Human Factors Specification

Development of a human factors specification represents the sixth and final step of the top-down system analysis process. In

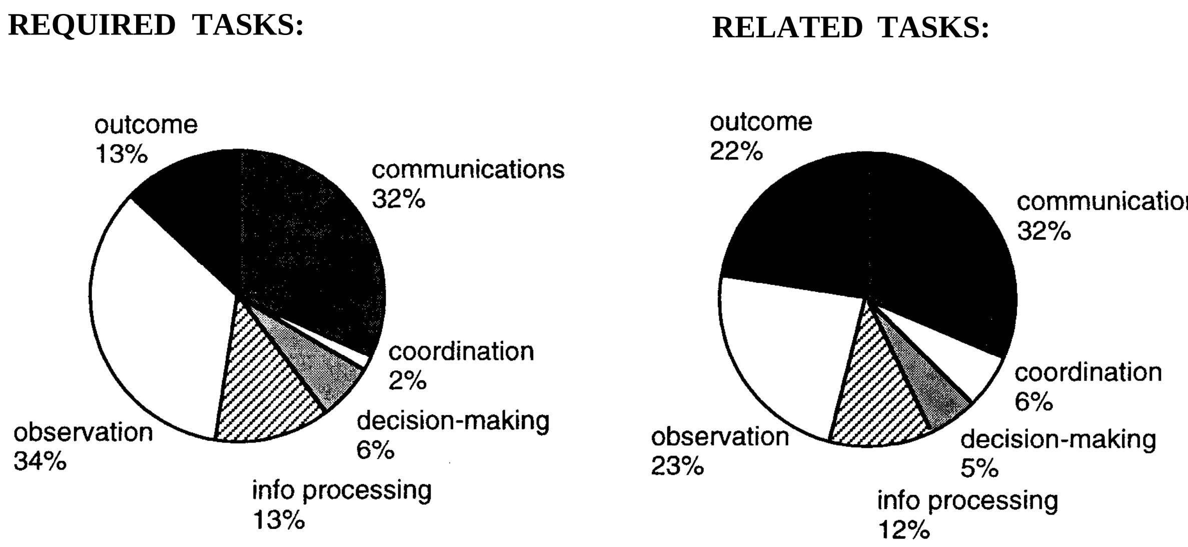


Figure 3. Distributions of required and related operator tasks.

general, any human factors specification is driven by analyses of operator performance requirements and operator tasks (Steps 4 and 5 of the top-down system analysis). Furthermore, results obtained from these analyses of the human operator are driven by the function allocation process (Step 3 of the top-down system analysis).

The human factors specification developed for the ATMS was no exception. That is, results of the function allocation process enabled us to define appropriate operator performance requirements and operator tasks for each ATMS function. [5,6] Specifically, task analysis results suggest that the configuration of human and machine components assigned across the four processing stages of a given function (i.e., the manner in which human and machine components are allocated to a given function) will enable us to predict the general nature of the operator tasks specified for that function. Consider, for example, fully automated (executive controller) functions. In such functions, rather than executing a given activity, an operator only monitors machine-execution of that activity. Consequently, tasks defined for executive controller functions reflect this form of human-ATMS interaction.

In defining ATMS functionality, completing the function allocation process, and then in turn conducting analyses specific to the human operator, we considered the following question. Through what means will ATMS functionality be executed? That is, what machines, apparatus, or devices will facilitate the satisfactory execution of ATMS functions? In addressing the issue of function execution, we defined a set of support systems. Consequently, support systems represent the means by which ATMS functionality is executed. In general, a support system is a tool (hardware and/or software) through which an operator interacts in order to ensure that ATMS functions are satisfactorily executed.

Our initial support systems analysis yielded a set of nine idealized (conceptual) support systems. [1] Capabilities required for the following support systems were defined:

- Adaptive Traffic Control System (ATCS).
- Predictive Traffic Modeling System (PTMS).
- Incident Detection and Location System (IDLS).
- Incident Response and Advisory System (IRAS).
- Information Dissemination System (IDS).
- Intermodal Transportation Planning System (ITPS).

- Traffic Management Training System (TMTS).
- Maintenance Tracking System (MTS).
- Traffic Data Management System (TDMS).

Based on further analyses of operator performance requirements, we identified the need for three additional support systems. Capabilities required for these support systems were defined: [5]

- Communications Support System (CSS).
- Administrative Support System (ADSS).
- Maintainer Training Support System (MTSS).

The resulting 12 support systems (and the capabilities assigned to each system) provide a mechanism by which all 113 ATMS functions can be executed. In other words, these 12 support systems reflect (completely) ATMS functionality. Note that the capabilities analyses documented in references 1 and 5 have focused on *idealized* support systems, where the capabilities of such systems are conceptual in nature. In other words, the capabilities assigned to a given idealized support system serve as a model for those ultimately implemented and incorporated in an operational ATMS. A brief description of each support system is presented in table 3.

In developing the ATMS human factors specification, we first defined the capabilities appropriate for each of the 12 support systems and then established a set of human interface requirements for each system. [7] Each set of interface requirements identified and described the information displayed to operators via the respective support system interface, as well as information to be provided to the system by operators.

Associated with the support systems is a set of hardware configuration items used by operators for voice and text communication, information/data collection, information processing, and data archiving. Some of these configuration items represent stand-alone systems (e.g., electronic mail or fax systems), while other items are incorporated into a given multi-purpose system, where such a system is typically computer-based. By developing the human factors specification such that it focuses on the support systems, we ensure that the specification reflects all functional characteristics of the ATMS, as well as the operator performance requirements and operator tasks defined by ATMS functionality.

TRAFFIC MANAGEMENT CENTER SIMULATOR: HUMAN FACTORS RESEARCH

Many human factors questions can only be answered as a result of conducting empirical research within the context of realistic traffic scenarios and a realistic control room environment. The TMC simulator facilitates the conduct of such research. It is a real-time, interactive, reconfigurable computer network with the flexibility to allow testing of a variety of operator control and display concepts, workstation designs and control room layouts, and operator task assignments. The simulator is capable of emulating the following types of inputs, outputs, and support systems.

Inputs

- Traffic and roadway sensors.
- Cellular phone dialogue.
- Visual CCTV sensors.
- Voice communication systems.
- Probe vehicles.
- Data base services.

Outputs

- Intersection control devices and algorithms.
- Commercial radio/TV.
- Roadway access devices/control algorithms.
- Cable TV traffic channel.
- Variable message signs.
- Traffic bulletin board.
- Highway advisory radio.
- Voice output.

Support Systems

- Incident Detection and Location System.
- Adaptive Traffic Control System.
- Predictive Traffic Modeling System.

Note that other support systems are to be simulated as needed throughout the simulator experimentation program. An overview of the simulator hardware network is provided in figure 4. The computer systems in this configuration (counterclockwise from upper left) include a Video Simulation Server, four Operator Workstations (labeled “Op WS”), five

Table 3. Support system descriptions.

Support System Description

- **Adaptive Traffic Control System (ATCS)**

The ATCS will optimize current traffic flow. It will receive roadway sensor data and use it to control traffic signal timing and ramp metering. A key feature will be its ability to *integrate control across surface streets and freeway traffic.*

- **Predictive Traffic Modeling System (PTMS)**

The PTMS will use current data, historical data, and weather forecasts to predict traffic flow a few minutes into the future (c. 5-30 min). PTMS predictions will allow *preemptive actions* to be taken well before an actual traffic problem arises.

- **Incident Detection and Location System (IDLS)**

The IDLS will detect and verify the presence of incidents on the roadway system and determine the *exact location of an incident.* In some cases the first indications of an incident will be abnormalities in traffic flow in the immediate area. Thus, the IDLS will identify anomalies characteristic of a potential incident. In other cases, especially when traffic volumes are light, the first indications may come from other sources (e.g., calls from cellular phone users).

- **Incident Response and Advisory System (IRAS)**

The IRAS will assist in determining the appropriate response to an incident. IRAS advice will include options for controlling traffic and disseminating information. Responses to an incident may include (1) informing motorists of a slight delay, (2) re-routing some traffic, (3) no action on the part of the ATMS, or in extreme cases (4) closing a major freeway and re-routing all traffic.

- **Information Dissemination System (IDS)**

The IDS will interface with established communications links (to response forces such as police departments, ambulance services, fire departments, and towing services). It will also interface with data services supplied to the mass media, the Traffic Channel, and bulletin board services. The IDS will be capable of posting messages on variable message signs (VMS) and creating voice messages for broadcast via highway advisory radio (HAR).

- **Intermodal Transportation Planning System (ITPS)**

The ITPS will supply the simulation capability to support strategic planning for the ATMS. It will, for example, have the capability to (1) simulate different configurations of roadway systems, (2) support coordinated strategic planning (performed in conjunction with public transportation systems), and (3) support special event planning.

- **Traffic Management Training System (TMTS)**

The TMTS will provide training for TMC operators. It will have the ability to conduct training exercises in routine traffic management, incident management, and special event management. Operators will also use the TMTS to develop and maintain skills needed in infrequently-occurring but critical situations (e.g., extreme weather conditions).

- **Maintenance Tracking System (MTS)**

The MTS will track remedial and preventive maintenance needs and schedules. It will support the issuing of maintenance requests and monitor the status of maintenance activities. It will receive results obtained from diagnostic tests of electronic components.

- **Traffic Data Management System (TDMS)**

The TDMS will serve as the ATMS information hub. It will accept all roadway sensor data and perform validity/integrity checks of such data. The TDMS will archive traffic and incident data. When required, the TDMS will aggregate data and analyze compliance measurement data.

Table 3. Support system descriptions (continued).

Support System Description

- **Communications Support System (CSS)**

The CSS will manage the two-way communications channels (1) within a single TMC and (2) between TMC operators and entities external to the ATMS (including operators in other TMC's, operators in other agencies, the media, and the public at large). The CSS will support voice communications, teleconferencing, electronic mail, data base links, and fax communications.

- **Administrative Support System (ADSS)**

The ADSS will support operators' performance of administrative duties (e.g., fiscal planning and personnel management). To this end, it will include specialized software such as data basetools, graphics and word processing applications, and spreadsheet software; fiscal planning information; and personnel files.

- **Maintainer Training Support System (MTSS)**

The MTSS will provide training for maintenance providers. It will also be used to develop and maintain skills or procedures required for the maintenance of ATMS assets (e.g., signal controllers, roadway sensors, VMS's, probe vehicle instrumentation, ATMS computers/software).

touchscreen-equipped PC's, an Experimenter Workstation (labeled "Exp WS"), a Traffic Model Server, and a Large Display Server. Through connections to a local area network, these computer systems are able to communicate. Also included are a large-screen display with an associated switching device, several video monitors, and a network for audio communications.

The Video Simulation Server is a workstation dedicated to generating simulated traffic surveillance camera views. This server includes a "splitter" that converts the digital simulated video images into analog video signals. The analog video images may be displayed either on standard video monitors or on Operator Workstation monitors via real-time video display cards installed in the workstations.

Video signals from the Video Simulation Server enter a switching device attached to the large display. Other signals entering the switching device include those for the Video Simulation Server's monitor, the Operator Workstation monitors, and the Large Display Server monitor. The switching device may be used to select any 1 of its 10 input signals for viewing on the large display, which is positioned such that it can be viewed by all operators.

The Operator Workstations provide the means for each operator (experimental subject) to monitor and control the simulated ATMS during experiments. The displays on the workstation monitors provide information regarding both traffic conditions and the status of the ATMS infrastructure, and they allow operators to specify actions that control the effectors of the ATMS. Each operator's work area includes a touchscreen-equipped PC for simulation of physical console controls such as pushbuttons and switches.

The Experimenter Workstation provides the means for an experimenter to set up, control, and monitor a traffic scenario during an experiment, as well as to monitor the performance of the subjects.

The Large Display Server provides a means of presenting information on the large-screen display. This server is capable of presenting simulated traffic video, information from an operator workstation, or an independent information display (e.g., an overall situation display) on the large-screen display.

The Traffic Model Server is a workstation dedicated to running the real-time traffic model (AUTOS). Traffic flow data calculated by the model is distributed to the Video Simulation Server, Operator Workstations, Experimenter

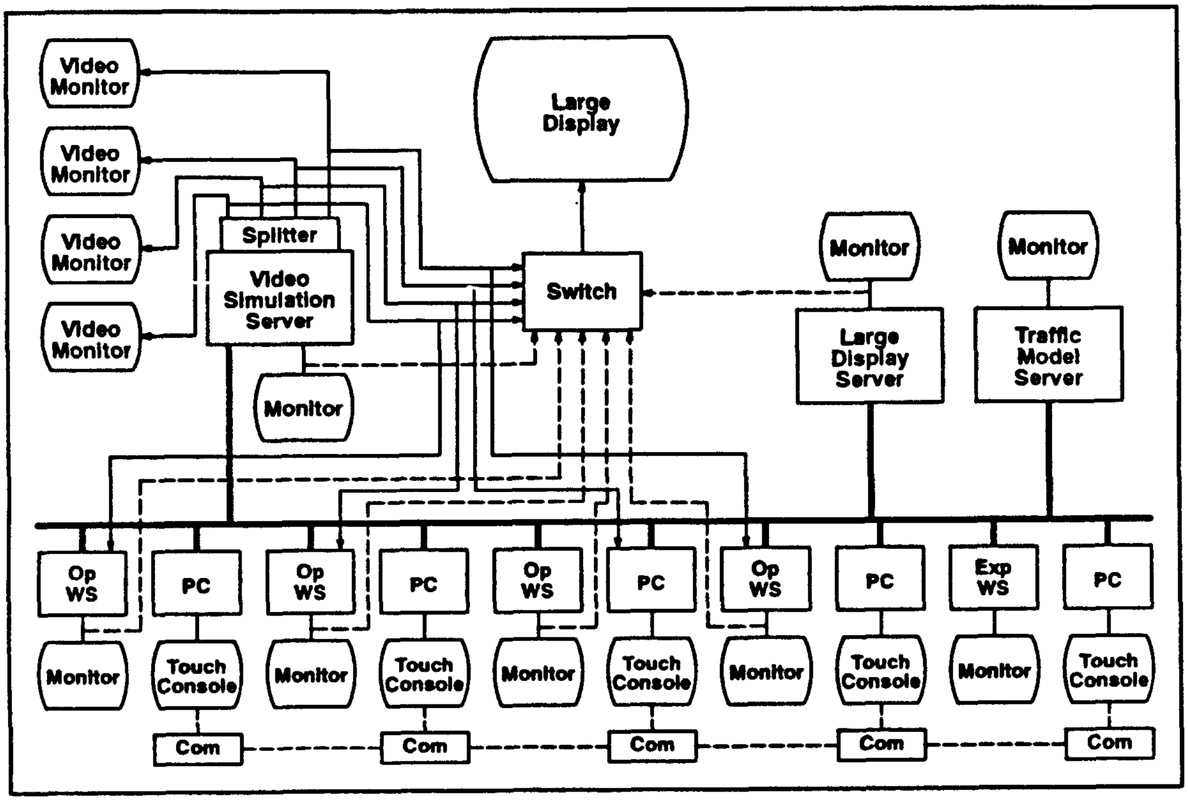


Figure 4. TMC simulator hardware configuration.

Workstation, and Large Display Server via the local area network. Commands executed at the Operator and Experimenter Workstations modify parameters of the traffic model and thereby affect the traffic simulation.

The final simulator component is the audio communications network. This component supports communications between operators and simulated outside agencies such as police, emergency dispatch, and other TMC's. The experimenter and members of the experimenter's staff assume the roles of outside agency personnel. An Integrated Services Digital Network (ISDN) network using a Teleos network hub and PC-based ISDN cards is used for audio communications.

A comprehensive program of human factors research has been designed to help prepare design guidelines for future ITS TMC's. [(8)] Teams of subjects are trained on the use of the TMC Simulator equipment until their performance stabilizes (generally 8 to 12 h). They then perform realistic traffic management functions, reacting to preset roadway conditions that involve combinations of traffic extremes, weather, and/or incidents.

Initial experiments are focusing on human factors issues relevant to the design and control (manual and automated) of existing systems (e.g., CCTV systems, graphics displays). Later experiments will address design issues relevant to team coordination, workload, training, and issues critical to the design and introduction of automation and computer-based support systems. This research will address available automation and support technology for the early ITS (current) period and the mature ITS (post-2000 AD) period. It will also address TMC's that are designed "from scratch" and subsequently implemented as an integrated system, as well as the more common design approach in which upgrades are performed in a piecemeal fashion, as budget increments allow.

HUMAN FACTORS HANDBOOK DEVELOPMENT

The third and final feature of this research program encompasses the development of a human factors design handbook. The handbook is intended to support TMC design and operation. Information provided in the handbook is to be based on lessons learned from the top-down system analysis, as well as from empirical research conducted in the TMC simulator.

Two editions of the handbook will be produced. The first edition will incorporate existing human factors guidelines (that are relevant to the TMC environment), as well as applicable design information documented in the research literature. The second edition handbook will incorporate results obtained from the conduct of TMC simulator experiments.

SOME GENERAL COMMENTS ON TOP-DOWN SYSTEM ANALYSIS AND THE ATMS

The technical report to follow describes the methods and philosophy underlying the user-centered top-down system analysis of an ideal (but realistic) ATMS. Conducting the comparable systems analysis independently of the initial phases of Step 1 (derivation of an unconstrained definition of operational capabilities) and Step 2 (derivation of an unconstrained definition of functionality) enabled us to maintain the ITS "visionary" aspects of these two system analysis components. At the same time, data from the comparable systems analysis affirmed that our resultant operational capabilities definition and functional requirements were realistic.

Note that each ATMS is unique, where objectives, priorities, funding, experience, and problems vary across systems. Such an analysis for a system whose primary responsibility is special event management, for example, will most likely generate results that are different from those generated by a top-down analysis for a system whose primary responsibility is the management of traffic congestion. While the methods and analysis philosophies offered in this report may be applied broadly, analysis results represent one example, rather than a universal solution.

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SECTION 1.
BACKGROUND AND INTRODUCTION

Roadway traffic congestion is a costly world-wide problem. In the United States, costs associated with congestion-caused accidents, loss of resources, lost time, and added pollution have been estimated at $170 billion per year. [1] One partial solution is to bring high technology to traffic management through the widespread use of *smart cars* and *smart highways* of the intelligent vehicle-highway system (IVHS). Estimates indicate that by the year 2000, more than 200 United States cities will have adopted some elements of IVHS technology. Similar technology growth is evident in Europe and on the Pacific Rim. Receiving major emphasis is the IVHS advanced traffic management system (ATMS). The ATMS is designed to coordinate and facilitate the safe movement of individuals and goods, with minimal delay, throughout a roadway network.

The Typical Traffic Management System

Current traffic management systems (TMS) are beginning to integrate IVHS technology with existing traffic sensing and control resources. Emerging ATMS's incorporate a complex network of traffic sensors, information processing and decision aiding systems, and effector systems. Traffic sensors are placed at critical roadway locations and typically consist of two types of components: loop *defectors* and closed circuit television (CCTV) cameras. Loop detectors (wire coils embedded in roadway pavement) detect and signal the passage of ferrous metal in vehicles. Effector systems most frequently include intersection traffic signals, freeway ramp meters, and variable message signs (VMS's) that may warn drivers of traffic problems and suggest alternate routes. Within the TMS, computers (1) fuse data from, perhaps, thousands of loop detectors, (2) display sensor and CCTV information (to support the operators' situation awareness), and (3) in some cases make and carry out decisions.

Traditionally, the TMS's data gathering, decision making, and communication functions have been performed manually. Operator knowledge of traffic situations were incomplete, and the available repertoire of response capabilities was limited. Thus, only a limited range of traffic management services could be provided.

Innovative technologies in data sensing, data fusion, communication, automation, and decision support systems are expanding information flow and promoting a broad range of traffic management options. With the expansion of computer technology, many new and traditional functions can be fully or partially automated. The most apparent results stemming from advanced technologies are an increase in (1) the number of traffic management services that can be provided and (2) the efficiency with which traffic can be controlled.

Given recent advancements in computing and communication technologies, some existing centers have established a design goal of full automation, i.e., a *lights-out* (completely automated) ATMS. Yet many attempts at automating tasks currently performed manually have been clumsy and not entirely successful. Other attempts have automated tasks successfully by reducing their complexities or by distributing parts of given tasks to other agencies. [2] For the near future, full service ATMS's will continue as hybrid automated systems, where most automation will be designed to *support* human operators, rather than *rep/ace* them.

USER-CENTERED DESIGN

A less visible result of recent technology advancements is a substantial change in operator jobs. The broader range of services to be provided by the ATMS requires operators to demonstrate a broader range of expertise and skills. Operators will be expected to interact with complex, partially automated systems with which they have little experience.

Designers and manufacturers of complex, programmable, and automated equipment have found that users are often befuddled by even the simplest of tasks. [3] Effective utilization and performance of a complex system are dependent upon system design and the interface between system hardware and the end user.

To ensure usability of new systems, designers should center the design process on the *human factors* of the ultimate system user (i.e., the needs, expectations, capabilities, and limitations of the end user). In a user-centered design process, emphasis is placed on the user during the initial stages of the process. User requirements are represented in the system specification. Users' needs are identified, analyzed, and reanalyzed. Every aspect of the system, from its overall purpose to the most seemingly trivial aspect of the user interface, is carefully designed to satisfy user needs

The user-centered design process consists of four basic elements: [4]

- Early focus on users.
- Integrated system design.
- Continual user testing.
- Iterative design.

An early focus on users places designers in direct contact with a representative set of users. Such contact can be achieved through interviews, surveys, and users' active participation in the design process. Integrated system design implies that all elements with which the user will have contact (user interface, on-line help, training, and documentation) are designed in parallel. System usability and acceptability are continually evaluated through the use of simulations, mockups, and prototypes that, through testing, are capable of measuring user performance and reactions. An iterative design philosophy ensures that design revisions, as well as repetition of the initial three elements (early focus on users, integrated system design, continual user testing), are implemented.

Design of a complex human-machine system (such as the ATMS) from a user-centered perspective must go far beyond assessment of individual display and control components and arrangement of them in a given workstation. Human factors inputs to the design process should have a significant impact on high-level design philosophy, particularly in establishing the rationale that underlies the allocation of roles to the system's human and machine components.

As a crucial part of TMC configuration trade studies, human operator roles must be defined. Specifically, each system function may be allocated to the human operator, an automated system, or some combination of the two. Function allocation becomes the basis for a detailed specification of expectations for (1) TMC hardware and software capabilities and (2) operator-system interaction activities. A detailed operator task analysis enhances the design, the selection and training of operators, and the development of on-line help facilities and written user documentation.

As TMC structure and architecture are clarified in this process, designers can begin to define the operators' interfaces to (1) configuration items, (2) one another, and (3) outside agencies. Whenever operators are available, their expertise should be used to assist in refining a system design.

Applying the user-centered design process is more convenient during systematic system upgrades than during initial design. During upgrade planning, a cadre of operators who have experience with the roadway network, operating philosophies, and system capabilities/constraints is available. User-centered design was effectively applied in one remodeled European control center. By conducting operator interviews and consulting procedures manuals and job aids, a design consultant performed requirements, function, and task analyses. Based on analysis results, three candidate mockups of the new control room were prepared. Operators selected their favorite and then worked with the designer to refine the design. This process produced a very functional center. [2]

User-Centered Top-Down System Analysis Methods

Top-down system analysis (TDSA) is an iterative process by which the operations of a system under design are described in ever-increasing levels of detail. Each analysis step defines (in greater detail) the results generated by the previous step. When applied to the ATMS environment such an analysis represents a comprehensive depiction of the flow, processing, fusion, and use of information. Technology is not considered until system capability requirements, operator tasks, and human interface requirements have been analyzed. Decisions concerning specific information channels (e.g., telephone versus hardcopy) or allocations of functions to specific machines are reserved for the later stages of analysis.

Each step of the TDSA explores and documents details of the results obtained at the previous analysis level. In turn, results obtained at a given analysis level are subject to elaboration in subsequent steps.

As part of the user-centered development process in this IVHS research program, a detailed TDSA for the ATMS was conducted and documented. Figure 3 defines the progression of steps associated with the TDSA process. A brief overview of each step is provided in the remainder of this section. More detailed discussions of these steps, and the results we obtained upon their implementation, are presented in the subsequent sections of this report.

IMPLEMENTATION OF USER-CENTERED TDSA

Step 1: Operational Capabilities Definition

The first step of the TDSA was to derive a comprehensive statement concerning the ATMS's mission and objectives. Consequently, we determined that the global mission of the ATMS is to coordinate and facilitate the safe movement of individuals and goods, with minimal delay, throughout a roadway system. In order to achieve this mission, the ATMS must pursue the following objectives: (5)

- Maximize the available capacity of area-wide roadway systems.
- Minimize the impact of roadway incidents.
- Assist in the provision of emergency services.
- Contribute to the regulation of demand
- Create and maintain public confidence in the ATMS.

Section 2 of this report defines these objectives in greater detail.

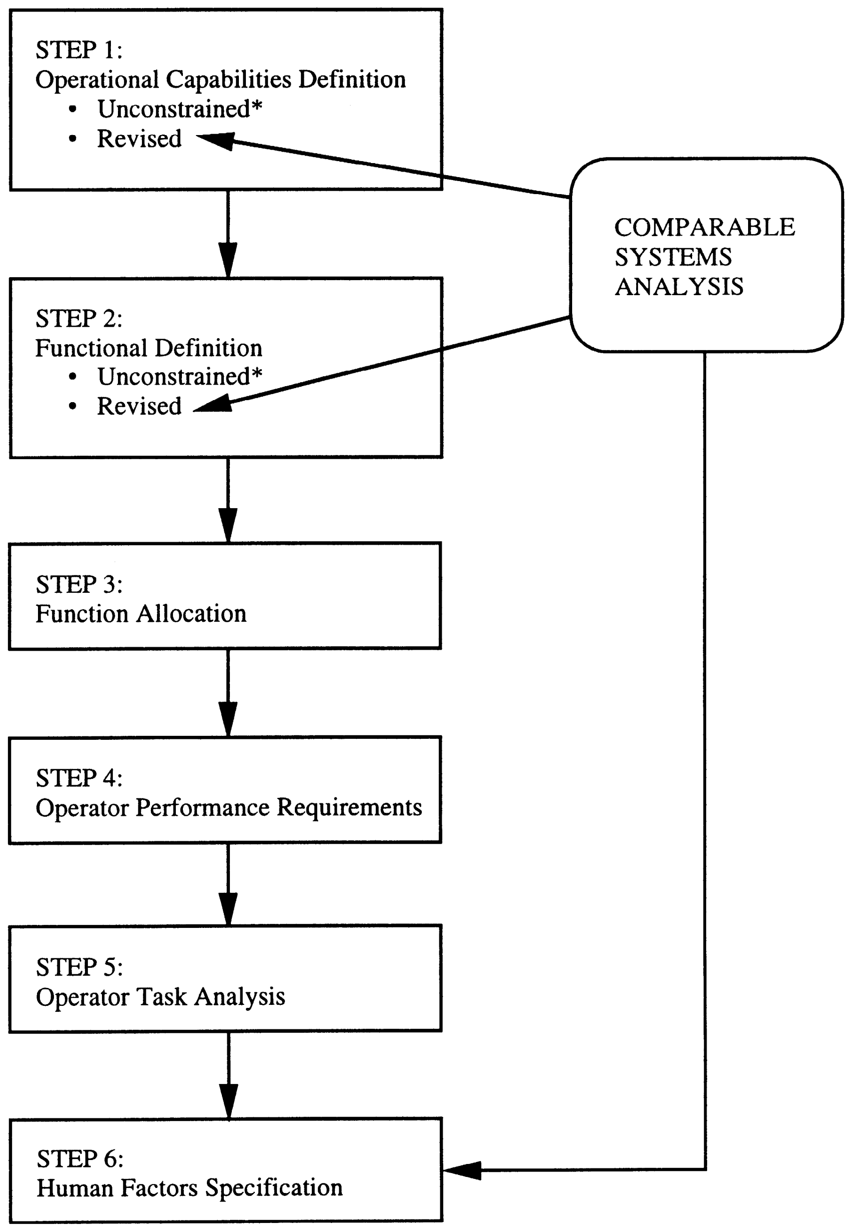
Step 2: Functional Definition

Performance requirements specified by the five system objectives were developed. Functionality associated with these requirements was defined. A detailed function analysis produced 113 ATMS functions. (6) Section 2 of this report documents the functionality derivation process.

While the initial derivation of (ideal) system objectives and functionality represented no real-world constraints, we recognized the importance of a certain degree of realism. Realistic system objectives and functionality, for example, could not incorporate technologies that would be unavailable in the next decade. Consequently, a comparable systems analysis investigated existing and anticipated ATMS's and the lessons learned in the implementation and operation of such systems. Based on the findings of this analysis, our initial, visionary descriptions of the ideal ATMS and its functionality were slightly revised.

Comparable Systems Analysis

The comparable systems analysis was performed independently of the initial stages of Steps 1 and 2. (During these initial stages, unconstrained definitions of operational capabilities and functionality were developed.) This independence allowed us to maintain the IVHS “visionary” aspects of Steps 1 and 2. Specifically, by imposing the independence requirement, we ensured that the initial definitions of operational capabilities and functionality remained unconstrained by existing control room configurations and existing traffic engineering practices. As indicated in figure 3, once unconstrained definitions of operational capabilities and functionality were established, results of the comparable systems analysis were used to revise the definitions such that they projected realism. As a result of the comparable systems analysis, the following recommendations for revision were adopted.



*The unconstrained definition was formulated independently of the comparable systems analysis.

Figure 3. Top-down system analysis procedure.

- Include interfaces between the ATMS and those traffic management systems located in neighboring jurisdictions.

- Remove local streets from the roadway system served by the ATMS.

- Recognize that a metropolitan rail system includes both light and heavy rail.

- Recognize that traffic signal cycle times will constrain update rates of control algorithms.

Revisions to the operational capabilities definition and functional requirements are discussed in greater detail in section 2.

The comparable systems analysis explored existing ATMS technology and near-term enhancements that will be available. Approximately 20 advanced operation control centers in the United States, Canada, and Europe, along with developers and vendors of hardware and software systems for the traffic management market, were visited. (2) While most of the centers represented advanced traffic control and traffic management centers, several represented other types of advanced control centers (i.e., air traffic control, air combat training control, public transit operations management, and fleet operations centers for trucking and air cargo.)

During site visits, control room design and operations were observed. Training and operational documentation was examined. Additionally, structured interviews were conducted with center managers and operators. Special emphasis was placed on obtaining information related to experience gained and lessons learned for the following issues:

- Analysis of a timeline of activity.
- Demographic information.
- Minimum qualifications for TMC managers.
- Minimum qualifications for TMC operators.
- TMC layout (including recent or planned changes).
- TMC configuration items (including recent or planned changes)
- Interjurisdictional coordination.
- Data archiving.
- Human factors of system documentation.
- Human factors of job handbooks and procedures manuals.
- Human factors aspects of control room, layout, and furniture.
- Human factors of operator displays.
- Human factors of operator controls.
- Allocation of manager and operator activities between tasks.
- Sources of input information.
- Applications of automation.
- Human factors aspects of communication systems.
- Maintenance responsibilities.
- TMC staffing.
- Large-screen displays.
- Console video monitors.
- TMC design process (including contractors and methods).
- TMC environmental factors.
- Operators' musculoskeletal complaints.

At each site, still-photographs were taken. Copies of training documentation, procedures, standard forms, and checklists were also obtained, and their roles in operator tasks were documented. Where possible, operators were observed during normal operating conditions. Descriptions of operator tasks, operator inputs and responses, roadway event history, and any significant successful (or awkward) applications of display, control, or automation technologies were recorded. At each site, state-of-the-art and future plans were documented. Human factors lessons learned in the design and operation were recorded.

Step 3: Function Allocation

Early function allocation approaches assigned a given function to either an operator or machine component, according to the component that could best perform the function. This approach is far too simplistic to apply to current complex systems: it does not address those situations in which functions are executed jointly by the two components. New approaches to function allocation define the level of operator involvement. A long-term goal of some traffic management systems is total automation; the goal of others is to remain operator-intensive. Each philosophy has significant design implications for the ATMS.

Operator role theory provides a framework under which human factors engineers can define operator responsibilities and machine performance requirements. [7] In hybrid-automated systems, the operator's role in a given function is considered to represent a point on a continuum that ranges from complete manual performance to complete automation.

While all 113 ATMS functions might possibly be performed manually, all were considered as candidates for full or partial automation. A team of engineers and human factors specialists familiar with current and anticipated automation technology examined each of the functions and, in a two-step process, selected an appropriate level of automation (operator role) for each function. [7] In the first of the two steps, the team explored whether the function could (and should) be fully automated or whether it could (and should) be performed solely by the operator (with no computer assistance). In the second step, functions that could not be assigned to fully manual or fully automated status were assigned to one of two partial automation categories. In each of these categories, operator role was defined in terms of the amount of autonomy given to computer systems.

Each function was defined in terms of four stages of information processing: input, processing, response selection, and output. The analysts assigned each stage to one of four levels of operator involvement (solely operator, primarily operator, primarily machine, solely machine). This assignment was based on the anticipated state of near-term automation technology. The bias was toward assigning the highest practical level of automation.

The assignments of (1) operator roles to ATMS functions and (2) operator involvement levels to information processing stages are described in section 3 of this report.

Step 4: Operator Performance Requirements

Once operator roles were assigned to all functions, specific implications for operator performance were derived. [8] Operators' information requirements, information processing/decision-making requirements, and response requirements were specified. Results of these analyses are presented in section 4.

Step 5: Operator Task Analysis

An operator task analysis was conducted. This analysis was based upon results of the function allocation process (i.e., assigning an operator role (level of automation) to each function and assigning levels of operator involvement to that function's information processing stages), as well as operator performance requirements. [9] A set of operator tasks was defined for each function. Tasks were defined in accordance with the operator role designation. Task analysis results are presented in section 5.

Step 6: Human Factors Specification

The operator task analysis provided a basis for developing a human factors specification for the ATMS and its respective configuration items and functional areas. Many operator tasks, for example, assume a configuration item and this item's links to other functional areas. In developing a human factors specification, we grouped tasks according to a corresponding configuration item (e.g., all tasks requiring telephone communications were grouped together) or a functional area (e.g., all tasks performed with electronic mail system were grouped together). This task reorganization defines the operator activities that must be supported by a given configuration item or functional area. In other words, the reorganization summarizes performance requirements for configuration items (or functional areas) and provides preliminary interface requirements for configuration items and functional areas. [10] Discussion related to development of the human factors specification is presented in section 6.

Decision-making tasks were not assigned to a configuration item, as they reflected human cognitive activities. For some tasks, assignment to a unique configuration item was inappropriate, as multiple configuration items would serve equally well (e.g., data transmission via facsimile versus data transmission via electronic mail). Under these conditions, the task was assigned to all appropriate configuration items. In some cases, analysts assigned tasks to a configuration item according to professional judgment, noting that a certain degree of ambiguity existed. For those tasks not obviously associated with a configuration item or functional area, we suggest additional research to assist in selection of the appropriate item/area.

The performance of many ATMS functions (and their respective operator tasks) will be assisted by automated or hybrid-automated support systems. Such support systems represent the means by which ATMS functionality is executed. Each support system will consist of an operator interface through which the operator can enable or disable the system, monitor system activities, accept or reject system recommendations, modify system output, or actively control the system. For each support system, information displayed to operators via the support system interface, as well as information to be provided to the system by operators, was specified. These requirements are discussed in section 6.

SECTION 2.
OPERATIONAL CAPABILITIES DEFINITION AND FUNCTIONAL DEFINITION

INTRODUCTION

This section begins to document the top-down system analysis used to describe the operations of an advanced traffic management system (ATMS). Specifically, the initial stages of this analysis procedure (determining operational capabilities and deriving ATMS functionality) are described. In establishing operational capabilities, we consider the ATMS mission, its objectives, and its performance requirements. ATMS functionality is defined such that ATMS objectives and performance requirements are satisfied. Additionally, analysis results are presented.

In what follows, the methodology employed in conducting the analysis is described. Initially, the approach focused on an idealized ATMS, that is, a system unconstrained by existing practices, funding uncertainties, political environments, or the performance of advanced technologies. System objectives, performance requirements, and functional definition formulated for the unconstrained environment were ultimately revised to reflect actual and anticipated constraints. (These revisions are incorporated in the functional definition presented later in this section.) Methods for (1) collecting and analyzing relevant data, (2) formulating functionality for the unconstrained environment, and (3) revising this idealized functionality are offered.

Finally, results obtained from implementation of the methodology are presented. We begin with a general mission statement and a set of system objectives. System performance requirements that identify output, input, throughput, and support requirements are subsequently specified. Note that each system objective is achieved only through successful execution of ATMS functionality. In other words, system objectives drive the functional specification. Consequently, the functionality required by each objective is identified, and a complete ATMS functional definition is offered.

METHOD: OPERATIONAL CAPABILITIES DEFINITION AND FUNCTIONAL DEFINITION

A survey of leading traffic management and traffic engineering experts in the United States was conducted. Each expert participated in a structured interview and presented his vision of ideal ATMS performance (projected 5 to 10 years in the future). Edited transcripts of each interview were evaluated by four analysts working independently. Results generated by these analysts were combined into a composite view of ATMS capabilities. System objectives and performance requirements were derived from this composite view.

The analysts then examined selected documents (bibliography) in order to extract projections on IVHS technology maturation for a period of 20 years into the future. These projections enabled the analysts to extend the existing composite view of ATMS capabilities to a view representative of mature IVHS environments.

Participants

Thirteen individuals participated in the personal interview/survey study. These participants, experts in traffic management and traffic engineering, represented private companies, as well as a number of local, State, and Federal agencies. (11) A list of candidate experts was formed. Names appearing on this list were suggested by the Federal Highway Administration (FHWA), Georgia Tech personnel, and supporting contractors for the FHWA and Georgia Tech. The candidate experts were contacted, and personal interviews were arranged with as many of these experts as possible. Eleven personal interviews were conducted. Two individuals, unable to meet for their scheduled interview sessions, provided colleagues to serve as substitutes. Two additional individuals were unable to schedule appointments, and they volunteered to provide written responses to the interview questions.

Participants were approximately evenly divided across local (city) governments, State/Federal government, and private industry. (Four participants represented local governments, and four represented State/Federal government. The remaining five participants represented private industry.) Within local government, State/Federal government, and private industry categories, participants' professional responsibilities were focused either on traffic engineering/ management activities or research and development. All four participants from the local government sector performed traffic engineering or traffic management activities. On the other hand, four of the five participants from the private industry sector were involved in research and development efforts, while only one of these five performed traffic engineering/ management activities. This particular distribution reflects the tendency of traffic engineering personnel within local governments to be directly involved in traffic management and for traffic engineers within private industry to focus on research and development efforts. Participants from the State/Federal government sector were equally divided across the traffic engineering/management and research and development categories.

Survey Procedure

A preliminary statement of survey content was drafted and presented at the program kickoff meeting. Revisions were made according to comments received at this meeting. A draft of the survey was developed, and a pilot test in which one of the survey participants responded to the draft was conducted. Based on feedback obtained as a result of the pilot test, minor procedural revisions were made. A blank survey form is included in appendix A.

Personal interviews were conducted by a two-person team, where one team member posed the questions appearing on the survey form, and the other recorded responses in writing. (No tape recording was made.) Interviews were conducted in participants' offices. A letter of introduction from the FHWA was presented. This letter identified the FHWA as a research sponsor and described the general nature of the program. An introduction to the survey was reviewed with each participant. It discussed relevant background material and the purpose of the interview. (Refer to item one of the blank survey form in appendix A). Any questions posed by the participant were answered.

Shortly after conclusion of the interview, the interviewers reviewed their handwritten notes and prepared an edited transcript of the interview for use in an analysis of content. Editorial changes included the rewording of any responses that might reveal the participant's identity, clarification of pronoun referents, the addition of proper punctuation, and the addition of explanatory material (in instances where the literal transcript did not convey the meaning as understood by the interviewers). All editorial changes (excluding punctuation) were enclosed in square brackets.

For the two individuals who volunteered to complete the survey in writing, the following procedure was employed. Survey content was discussed by telephone, and a copy of the survey form was sent to the respondent. The respondent prepared handwritten responses on the survey form and returned it to the interview team.

Content Analysis Procedure

Four analysts with backgrounds in physics, electrical engineering, math and computer science, and engineering psychology were selected to perform a content analysis of interview transcripts. The analysts were instructed to work independently. Analyses began once the first four interviews had been conducted. A seven-step procedure was followed.

Step I: Initial Reading and Summarization

As a means of controlling for order effects, each analyst read the first four transcripts in a unique order. The analyst read a transcript and prepared a brief written summary. The summary described the major themes and areas of emphasis in the interview and identified those aspects of the interview that seemed prominent or distinctive. This step was repeated for each of the first four interviews.

Step 2: Paired Comparison of Surveys

For the first four surveys, the analysts compared survey pairs. (Six survey pairs were possible, and analysts compared all possible survey pairs.) In the comparisons, the analysts identified areas of agreement, disagreement, and non-overlap. The comparisons were summarized in writing.

'Step 3: Description of Prominent Vision and Variants

Based on the data obtained from the first four interviews, the analysts prepared a preliminary description of the most prominent vision of the ideal ATMS. Subsequently, they constructed four scenarios reflecting this vision, where thescenarios depicted in the survey form served as a basis for development. (Scenarios 1 and 2 of the survey were combined into a single scenario.) In documenting the prominent ATMS vision, analysts constructed four scenarios encompassing a broad range of events for which the ATMS must be responsible. These scenarios depict the following conditions:

- Normal operations during rush hour traffic.
- Major freeway incident during rush hour traffic.
- Super Bowl planning and traffic management.
- Major winter storm during rush hour traffic.

For the purpose of example, the second scenario (major freeway incident during rush hour traffic) is provided in appendix B. The analysts also described variants (i.e., minority opinions appearing in the survey data that deserved consideration).

Step 4: Reading and Processing of Additional Interviews

As additional interviews were conducted, respective transcripts were made available to the analysts (again, in varying ordering schemes). Analysts repeated Step 1 for each interview. Step 2 was also repeated; however, analysts did not conduct all possible paired comparisons. Rather, they selected four previous interviews (offering a broad range of contrasts) and compared newly acquired transcripts against these four.

Step 5: Updating of Scenarios

As analysts read and compared additional interviews, they updated scenario descriptions and significant variants. For the purposes of improving the illustration of ideal ATMS performance objectives, analysts were sanctioned to make fundamental changes to any scenario.

Step 6: Conduct of Joint Working Session

Once all participants were surveyed, analysts and interviewers assembled for a joint working session in which differences of interpretation were discussed. Each analyst also shared suggestions for scenario enhancements. Responses obtained from the two individuals providing written survey responses were distributed. The analysts did not summarize/compare data from these two participants (Steps 1 and 2), but they were free to incorporate any of these participants' ideas in the scenario revisions. (See Step 7.)

Step 7: Derivation of Detailed Timelines

After conclusion of the joint working session, analysts returned to Step 5 and revised the scenarios (1) according to the opinions and suggestions of the other analysts and (2) after considering the ideas of the two experts who provided written responses. For each scenario, the analysts produced a detailed timeline of events. These timelines were defined according to time-based performance goals specified by the experts. These timelines included descriptions of events "in the field" as well as ATMS actions.

Product of the Content Analysis

Analysts' results were combined into an overall ATMS description. System objectives and performance requirements were derived from this overall description. Five scenarios were developed to illustrate the performance capabilities of the ATMS.

Extrapolation to a Mature IVHS Environment

The product of the content analysis reflected experts' assumptions and expectations with respect to human operator roles in a future ATMS (i.e., an ATMS available 5 to 10 years in the future). The 5- to 10-year time frame also produced a fairly conservative view of the availability of IVHS technologies.

In order to extend the vision of ATMS capabilities to a mature IVHS environment, the analysts reviewed relevant sections of selected documents (bibliography). Each analyst provided an assessment of the impact of IVHS-related technology development on ATMS performance requirements and capabilities. ATMS performance requirements were updated to reflect these assessments.

Derivation of Functional Definition

ATMS objectives are the basis of functional requirements. For each objective, corresponding functions are derived from (1) the outputs required to satisfy the objective and (2) the input, throughput, and support functions required to generate those outputs. Output functions control traffic (directly or indirectly). They disseminate information, control electronic devices, and issue requests. Input functions receive information: sensor data, reports from external sources, and information requests. Throughput functions are internal to the ATMS and use available information to properly select outputs. They process and fuse data, make predictions, assess current conditions, and make decisions. Support functions create and maintain the capabilities of other functions. They are responsible for storing and retrieving information, training operators, planning, performing administrative duties, and coordinating with other agencies.

Revisions: Objectives, Performance Requirements, and Functional Definition

The initial formulation of ATMS objectives, performance requirements, and functional definition was intentionally developed without regard for real-world constraints, existing practices in traffic engineering, or specific proposals for the design of an ATMS or its subsystems. Consequently, the system analysis procedure required subsequent consideration of these constraints, practices, and proposals. Upon consideration of such constraints, analysts revised idealized objectives and performance requirements developed initially.

Three sources of information were used to modify the objectives and performance requirements of the ATMS:

- Preliminary findings the comparable systems analysis. [(12)]

- Recommendations from the prime contractor of the Support Systems Contract (SSC). The SSC is a parallel contract in which plans for ATMS support systems are being developed).

- Consideration of current practices in conventional traffic engineering. (Many of these practices will continue well into the IVHS era.) Conventional traffic signals, for example, will continue to be used for intersection control in the near-term and mid-term of IVHS deployment. An ATMS introduced at the inception of IVHS deployment must exert control over conventional and advanced systems.

The specific recommendations adopted during the process of revising ATMS objectives, system performance requirements, and the ATMS functional definitions are presented in the following paragraphs.

Recommendations

Include interfaces between the ATMS and those traffic management systems located in neighboring jurisdictions. Initially, the ATMS was conceived to exercise complete jurisdiction over traffic management for a metropolitan area. Although such jurisdiction may be achieved in some areas, political considerations will cause some ATMS boundaries to correspond to municipal, county, or State lines. In some metropolitan areas, interactions between several ATMS's may be required. In this manner, the management of traffic flow is coordinated, where cooperation among this group of ATMS's is essential. (The sources for this change were the comparable systems analysis and the SSC.)

Include a capability to receive policy and budgetary directives from governing agencies. Initially, the ATMS was described as an independent agency -- independent of funding constraints and free to establish its own policies as needed in fulfilling objectives. A real-world ATMS, however, must operate according to a budget established by a governing agency, and the ATMS must comply with policy directives issued by that agency. (The source for this change was the SSC.)

Remove local streets from the roadway system served by the ATMS. The original description included no specification regarding an exclusion of certain roadway segments from system sensor and control coverage. By default, all segments were covered. In the revised description of the ATMS requirements and capabilities, service is limited to tollways, freeways, major arterials, minor arterials, and collector streets. (The source of this change was consideration of existing practices.)

Include a capability to collect data for electronic toll and tax. Although the ATMS is not a toll or tax-collecting agency, the use of certain roadway segments is subject to the payment of tolls or taxes. In some areas (and as a means of regulating demand), the charge for using certain segments of the roadway system may be based, in part, upon congestion. Automatic Vehicle Identification (AVI) systems would provide a means for collecting tolls such that properly-equipped vehicles would not be required to slow or stop. Given its inherent requirements to monitor the roadway system and minimize congestion, the ATMS presents a reasonable mechanism for collecting the data required to levy electronic tolls and taxes. These data would be passed to the appropriate public authority. (The source for this change was the SSC.)

Recognize that traffic signal cycle times will constrain update rates of control algorithms. The pervasive use of conventional traffic signals to control intersections (control of pedestrian and vehicle traffic) places constraints on the frequency with which control schemes can be updated. (The source of this change was consideration of existing practices.)

Include the functional requirement for administrative support. This recommendation affords a means of incorporating the ATMS's role in conducting administrative functions in a wide range of areas, including financial management, policy development, personnel administration, and data base management.

RESULTS: OPERATIONAL CAPABILITIES DEFINITION

ATMS Mission and Objectives

The overall mission of the ATMS is to facilitate the safe movement of persons and goods, with minimum delay, throughout the metropolitan area. Although its operational capabilities are limited to the roadway system, the ATMS performs its mission in conjunction with other area transportation systems, including the public rail transit system, the commercial railroad system, and the commercial aviation system. In order to perform its mission, the ATMS recognizes and pursues the following system objectives. The rationale for each objective is discussed.

Objective 1: Maximize the Available Capacity of the Area- Wide Roadway System

An increasing inability to significantly expand existing roadway systems requires the ATMS to protect the public investment by obtaining the maximum available capacity from existing roadways. By distributing the traffic load spatially and temporally, the ATMS seeks to minimize congestion and delay and increase available capacity.

Objective 2: Minimize the Impact of Roadway Incidents on Delay and Safety

Roadway incidents (accidents, stalls, fallen debris, equipment malfunctions), particularly during peak demand times, may have a significant impact on travel times and may create a threat to public safety. Reducing delays associated with these incidents requires ATMS involvement on two fronts: reducing the overall likelihood of incident occurrence and minimizing delays associated with incidents that do occur. This objective includes safety considerations for (1) individuals involved in the incident, (2) incident responders, and (3) the general public.

Objective 3: Assist in the Provision of Emergency Services

The presence of emergency service providers on the roadway system may create conditions that lead to minor incidents (e.g., police flasher causing slowing of traffic) or major incidents (e.g., distracted motorist collides with an ambulance). Active ATMS involvement is warranted in order to (1) facilitate the provision of services and (2) protect public safety by maintaining system performance. The assistance provided by the ATMS may include notification of emergency service providers, coordination of responses in cases where multiple services are needed, and priority control of traffic signals to improve the speed of the emergency response. ATMS support for emergency services is not limited to incidents; it also includes situations in which emergency service providers must use the roadway system in order to reach non-incident-related destinations (e.g., a fire in an office building).

Objective 4: Contribute to the Strategic Regulation of Demand

In addition to real-time traffic management (refer to Objectives 1 through 3), the ATMS must act strategically to assist in regulating roadway system demand. The presence of special events or special maintenance activities may create conditions in which the overall demand exceeds available capacity, regardless of the efficiency with which traffic is managed in real time. Long-term growth could lead to chronic over-demand for the roadway system. Thus, the ATMS must act strategically to regulate demand for the roadway system such that traffic volume remains manageable. Pursuit of this objective often involves cooperative efforts with other public agencies, particularly public transportation. Achieving Objective 4 also satisfies larger societal goals: reducing air pollution and conserving fossil fuels.

Objective 5: Create and Maintain Public Confidence in the ATMS

In order to fulfill the first four objectives, the ATMS must be perceived as reliable and competent. To this end the ATMS must ensure that it provides accurate information to the public. Motorists, for example, are less likely to heed advisories recommending an alternate route if they do not trust the ATMS. The ATMS satisfies Objective 5, to a great extent, through its competency in satisfying Objectives 1 through 4; however, it must continually provide the public with general information regarding its operations. Public relations campaigns are conducted, often in conjunction with the public transportation system, in order to reinforce positive perception of the ATMS.

System Performance Requirements

Functional performance requirements imposed by the five system objectives are discussed below. The discussion begins with a specification of the outputs required for achievement of ATMS objectives. Subsequently, the inputs and throughputs required for generation of these outputs are discussed. Finally, support requirements imposed by input, throughput, and output specifications are considered. For each output, input, throughput, and support specification, a set of system capabilities is identified.

Output Requirements

Outputs required of the ATMS include real-time control over traffic management effectors, as well as information dissemination to other agencies and the general public. Specific output requirements are described in what follows.

Influence vehicle motion and speed. The ATMS must provide outputs that influence vehicle motion and speed. These outputs must influence vehicles to proceed safely through intersections, enter limited access roadway segments safely, and maintain safe speeds at all points in the roadway system. This influence must be sufficiently strong to enable the ATMS to achieve Objectives 1 and 2.

The following capabilities are required:

- Coordinated intersection controls.
- Adaptive speed advisories.

Intersection controls must be coordinated for intersections located within 0.8 km (0.5 mi) of one another. Such coordination is required to minimize delay and maximize available capacity. Speed advisories must adapt to current conditions such that available capacity is maximized and the probability of incidents is minimized.

Influence route selection. The ATMS must provide outputs that influence roadway system vehicles to select routes (i.e., pre-trip route selection and en route detours). This influence must be sufficiently strong to enable the ATMS to achieve Objectives 1 and 2. Achieving these objectives may require differential route selection, where vehicles with a common destination are not necessarily influenced to select the same route. Influencing route selection must not undermine public confidence in the ATMS (Objective 5).

The following capabilities are required:

- Spatial spreading of demand.
- Alternate routing.

Route selections made during peak demand times must be influenced such that all segments of the roadway system operate at optimal capacity. This spatial spread of real-time traffic demand is required for the maximization of available capacity. When temporary conditions (incidents or inclement weather) reduce capacity, route selection advisories must influence vehicles to select appropriate alternate routes in such a manner that the impact of incidents on travel times is minimized and available capacity is maximized.

Control vehicle access. Objectives 1, 2, 3, and 4 require the ATMS to provide outputs that control the vehicles' access to certain segments of the roadway system or to the roadway system as a whole. These outputs must be capable of denying access to some or all vehicles (e.g., closing a segment to all vehicles except emergency vehicles) and of controlling the rate at which vehicles gain access to a segment. Vehicle occupancy can be used as a basis for controlling access (e.g., high occupancy vehicle (HOV) lanes) in accordance with the requirements of Objective 4.

The following capabilities are required:

- Segment closures.
- Metered access.
- Class access.
- Coordinated intersection controls and access rate controls.

In order to effectively close a segment of the roadway system (e.g., a frozen bridge), the ATMS must be capable of denying access to all vehicles, and it must be capable of controlling the rate at which vehicles gain access to certain segments of the roadway system. The ATMS must be capable of permitting or denying access to certain roadway segments on the basis of vehicle class (e.g., HOV's, large trucks) Access rate controls must be coordinated with nearby intersection controls.

Request services. Objectives 1, 2, 3, and 5 require the ATMS to provide outputs that result in the timely provision of appropriate services. These outputs must alert available service providers to the type of service required and the location of the service requirement.

The following capabilities are required:

- Communications with service providers.
- Timeliness.

The ATMS must be capable of establishing and maintaining communications with appropriate service providers (emergency service providers and maintenance providers). Allowable time between the determination of a service need and communication of that need to the appropriate provider is dependent upon the urgency of a given situation. Requests for emergency services should be made with minimum delay. Requests for response to non-emergency situations should be made in a time frame commensurate with the time required for the response.

Influence trip decisions. Objective 4 requires the ATMS to be capable of providing outputs that influence trip decisions: determining whether (and when) a trip should be made. The influence of these outputs must be strong enough to enable the ATMS to achieve Objective 4.

The following capabilities are required:

- Information dissemination.
- Overall demand management.
- Selective demand management.

The ATMS must be capable of disseminating trip decision advisories (at the time and place those decisions are made) to individuals who make trip decisions. Thus, for the general traveling public, information must reach individuals in their homes and other places trip decisions are made (e.g., places of business). For commercial vehicle operators, information must be disseminated to dispatch centers, truck stops, and other places trip decisions are made. In order to maintain area-wide roadway demand at manageable levels, the ATMS must be capable of influencing discretionary travel. For example, when weather conditions impact available capacity, the ATMS must be capable of inducing an appropriate reduction in overall demand. When a temporary condition (e.g., a major incident) significantly reduces the available capacity on a sector of the roadway system, the ATMS must be capable of selectively inducing an appropriate reduction in demand for that sector of the roadway.

Influence mode selection. Objective 4 also requires the ATMS to be capable of providing outputs that influence mode selection, including selection of (1) public transportation versus personal transportation and (2) HOV's versus single occupancy vehicles (SOV's). Again, the influence of these outputs must be sufficiently strong to enable the ATMS to achieve Objective 4.

The following capabilities are required:

- Information dissemination.
- Overall demand management.
- Selective demand management.
- Advisory accuracy.

The ATMS must be capable of disseminating mode selection advisories (at the time and place those decisions are made) to individuals who make mode selection decisions. For the general traveling public, information must reach individuals in their homes and other places mode selections are made (e.g., in the vicinity of park-and-ride lots, in airports). In order to maintain area-wide roadway demand at manageable levels, the ATMS must be capable of influencing mode selections. For example, when special events generate unusually high demand for the roadway system, the ATMS must be capable of inducing an appropriate proportion of travelers to select an alternate mode of transportation. These travelers include attendees of the special event, as well as others who must travel in the vicinity of the event during the time it is in progress. When available capacity on a subset of the roadway system is significantly reduced from its normal level, the ATMS must be capable of selectively inducing an appropriate proportion of travelers to select an alternate mode. The ATMS must issue mode selection advisories that accurately depict capacity of alternate modes. For example, if the public transit system is unable to accommodate increased demand, a recommendation encouraging travel via public transit is inappropriate.

Conduct public relations. Objective 5 requires the ATMS to be capable of providing outputs that influence public confidence in the ATMS. This influence must be sufficiently strong to maintain public confidence at levels enabling the ATMS to meet Objectives 1 through 4.

The following capability is required:

- Maintaining sufficient compliance.

The ATMS must establish public confidence such that a sufficient proportion of travelers is willing to comply with speed limit and route/ mode selection advisories.

Table 4 summarizes the output requirements specified for the ATMS. Associated with each output requirement is a set of capabilities. The set of capabilities will ensure that its respective output requirement is satisfied. In other words, these capabilities will facilitate satisfactory output performance.

Input Requirements

The ATMS is unable to generate required outputs without receiving input from a range of sources. In order to manage traffic in response to current traffic conditions, certain inputs have real-time (or approximately real-time) requirements. Specific input requirements are described below.

Sense current traffic conditions. Objective 1 requires the ATMS to sense (1) the location and type of vehicles on the roadway system and (2) the speed at which they are traveling. These inputs are required 24 hours a day, regardless of meteorological conditions.

Table 4. System performance requirements: Output.

Output Requirement	*Associated Capabilities*
Influence vehicle motion and speed.	• Coordinated intersection controls. • Adaptive speed advisories.
Influence route selection.	• Spatial spreading of demand. • Alternate routing.
Control vehicle access.	• Segment closures. • Metered access. • Class access. • Coordinated intersection controls. • Access rate controls.
Request services.	• Communications with service providers. • Timeliness.
Influence trip decisions.	• Information dissemination. • Overall demand management. • Selective demand management.
Influence mode selection.	• Information dissemination. • Overall demand management. • Selective demand management. • Advisory accuracy.
Conduct public relations.	• Maintaining sufficient compliance.

The following capabilities are required:

- Receipt of link statistics.
- Appropriate update rates.
- Vehicle class identification.

For each roadway system link, the ATMS must be capable of sensing current volume and average speed. The required resolution of these measurements is a function of incident probability. That is, measurement resolution must increase with the probability of incident occurrence. On surface streets, the required update rates for traffic condition data is determined by minimum signal cycle times. That is, the timing patterns for intersection controls cannot be changed more frequently than once per cycle. The implication is that during periods of very light volume, minimum cycle time must elapse before another control change can be implemented. The ATMS must be capable of determining class membership for any classification scheme designed to control access. For example, if vehicle occupancy is used to control access, then the ATMS must be capable of determining if a given vehicle is classified as "high occupancy."

Sense current roadway system conditions. Objective 1 requires the ATMS to be capable of sensing current roadway system conditions: degradation of roadway surface conditions, impaired visibility, and malfunctioning components.

The following capabilities are required:

- Monitoring pavement conditions.
- Precipitation detection.
- Monitoring visibility conditions.

Friction coefficients (drag factors) of wet and dry pavement should be monitored with sufficient frequency to ensure that maintenance actions are initiated before degradation of the pavement produces a significant increase in the probability of an accident. The presence of precipitation on roadway surfaces (in amounts sufficient to significantly increase the probability of an accident) should be detected as quickly as possible. The ATMS must be capable of detecting degraded visibility conditions and interpreting degrees of degradation. The degree to which visibility is degraded (on a given roadway segment) should be represented as a percentage *(P)* of that segment's desired operating speed under benign conditions. *P* should be specified in accordance with driver reaction times predicted for the degraded conditions. That is, lower *P* values would be associated with longer reaction times (and higher degrees of degradation). Degraded visibility could arise from meteorological conditions such as fog, low ambient lighting levels (e.g., as exists in tunnels), and glare created by direct sunlight shortly after sunrise and shortly before sunset.

Sense incident location and severity. Objective 2 requires the ATMS to be capable of sensing the presence of incidents.

The following capabilities are required:

- Timely detection.
- Detection of incident type and severity.
- Determination of incident location.
- Estimation of expected duration.
- Sufficient update rates.

The ATMS should detect incidents as quickly as possible under all traffic conditions. During peak demand times, the (potential) negative impact on traffic conditions warrants rapid detection. Information regarding the nature and severity of the incident must be received with sufficient accuracy to permit proper response selection. Incident location must be determined with sufficient accuracy to permit the routing of incident responders via the most direct route. For incidents located at a surface street intersection, the respective intersection can be specified. For incidents located between intersections, the street and block can be specified. On limited access roadways, incident location should be specified with sufficient accuracy to permit identification of the nearest access ramp [or the nearest mile marker if the adjacent ramps are separated by more than 1.61 km (1 mi)]. The duration of the incident's impact on effective capacity must be estimated with sufficient accuracy and timeliness to allow remedial measures to be selected and implemented. These inputs must be updated given any change in incident conditions that will change traffic management tactics.

Track location and destination of emergency service vehicles. Objective 3 requires the ATMS to track emergency vehicle locations and to be aware of their destinations with sufficient accuracy to implement priority control when appropriate.

The following capabilities are required:

- Knowledge of vehicle route.
- Knowledge of vehicle position.
- Sufficient update rates.

The destination of emergency vehicles must be known in sufficient detail such that all segments of planned routes may be anticipated/designated at the time of dispatch (or as soon thereafter as such information can be determined and relayed by the dispatcher). On surface streets, position accuracy of less than one block is required in order for priority control of traffic signals to be implemented and coordinated. Assuming a nominal block length of 200 m (one eighth of a mile), the resolution of vehicle position data should be less than 200 m. These requirements may be somewhat relaxed on freeways. Vehicle route data should be updated as soon as possible whenever a change in intended route is made. Vehicle position data must be updated with sufficient frequency to support priority control of traffic signals. Assuming a city block of 200 m and a vehicle moving at a top speed of 1.6 km per minute (c. 60 mi/h), updates on vehicle position should be received at least every one-eighth of a minute (7.5 s).

Track location and movement of commercial rail traffic. Objective 1 requires the ATMS to track the progression of commercial rail traffic through various intersections of the rail and roadway systems. Blockage of these intersections can be a significant source of delay for roadway traffic.

The following capabilities are required:

- Sufficient lead time.
- Knowledge of expected duration of intersection blockage.

A train's blockage of a crossing should be anticipated by the ATMS with sufficient lead time to adjust traffic signal patterns in the vicinity and to post appropriate advisory messages. The exact lead time will vary according to street layout in the vicinity of each crossing. Expected blockage duration should be known with sufficient accuracy to permit the posting of valid advisories where applicable. At a minimum, advisories should indicate approximate remaining delay time. When appropriate, advisories should indicate an alternate route.

Receive current and forecasted weather conditions. Weather conditions, particularly precipitation, can have a major impact on traffic conditions. The ATMS is required by Objectives 1 and 2 to receive input on any current and predicted weather conditions that may affect (1) roadway availability and (2) incident probability. The accuracy of this input must be sufficient to allow the ATMS to determine appropriate responses.

The following capabilities are required:

- Knowledge of area-wide conditions.
- Knowledge of localized conditions.
- Tracking of current conditions.

Forecasts of weather conditions that will negatively affect travel conditions throughout all or a significant part of the ATMS service area (e.g., a winter storm) should be known in advance such that appropriate advisories may be posted. For severe conditions (those warranting attempts to significantly reduce demand), a minimum of 24 h advance notice is required. This lead time will allow information to be disseminated and contingency plans to be established. Forecasts of those weather conditions that will have a localized impact on travel (e.g., a severe thunderstorm cell) should be known when the forecasts can identify the probable affected area. When inclement weather conditions exist in any part of the ATMS service area, progression of those conditions through the service area should be tracked as closely as possible such that controls and advisories can be appropriately adjusted.

Obtain demand for transportation facilities. Objective 4 requires the ATMS to obtain inputs regarding the demand for metropolitan-area transportation facilities.

The following capabilities are required:

- Receipt of strategic planning inputs.
- Receipt of special event information.
- Input resolution.
- Sufficient lead time.

Plans for any new housing, industrial, and commercial developments that will affect overall demand levels and patterns should be received by the ATMS. Information related to special events (time, location, and expected attendance) should be received by the ATMS for any event expected to generate abnormal demand levels or patterns. Transportation demand inputs must be of sufficient accuracy to allow identification of probable overload, where overload is caused by excessive roadway system demand (chronic or acute). Demand inputs should be received with sufficient lead time to permit problem identification and implementation of demand regulation measures.

Receive indicators of public confidence in ATMS. Objective 5 requires the ATMS to receive inputs indicating the level of public confidence in the ATMS.

The following capabilities are required:

- Receipt of current indicators.
- Receipt of trend indicators.

The ATMS must receive inputs that indicate current levels of public confidence. These indicators identify any lapses in public confidence that negatively affect the ATMS's ability to fulfill its other objectives. The ATMS must receive inputs that indicate trends of increasing/decreasing public confidence. The accuracy and timeliness of this input must be sufficient to permit implementation of preventive measures.

Table 5. System performance requirements: Input.

Input Requirement	*Associated Capabilities*
Sense current traffic conditions.	• Receipt of link statistics. • Appropriate update rates. • Vehicle class identification.
Sense current roadway system conditions.	• Monitoring pavement conditions. • Precipitation detection. • Monitoring visibility conditions.
Sense incident location and severity.	• Timely detection. • Detection of incident type and severity. • Determination of incident location. • Estimation of expected duration. • Sufficient update rates.
Track location and destination of emergency service vehicles.	• Knowledge of vehicle route. • Knowledge of vehicle position. • Sufficient update rates.
Track location and movement of commercial rail traffic.	• Sufficient lead time. • Knowledge of expected duration of intersection blockage.
Receive current and forecasted weather conditions.	• Knowledge of area-wide conditions. • Knowledge of localized conditions. • Tracking of current conditions.
Obtain demand for transportation facilities.	• Receipt of strategic planning inputs. • Receipt of special event information. • Input resolution. • Sufficient lead time.
Receive indicators of public confidence in ATMS.	• Receipt of current indicators. • Receipt of trend indicators.

Table 5 summarizes the input requirements specified for the ATMS. Associated with each requirement is a set of capabilities. The capabilities of each set will ensure that the corresponding input requirement is satisfied.

Throughput Requirements

Inputs received by the ATMS must be processed prior to implementation of actions (outputs). This processing may be predictive, real-time, or historical. Specific throughput requirements are described below.

Predict traffic conditions. Objectives 1, 2, and *4* require the ATMS to predict traffic conditions.

The following capabilities are required:

- Congestion prediction.
- Assessment of incident impact.
- Prediction of demand.

Predictions required by Objective 1 must permit identification of probable congestion (prior to its occurrence) within a time frame sufficient for preventive measures (i.e., those measures resulting in congestion avoidance) to be implemented. Predictions required by Objective 2 must permit accurate assessment of an incident's probable impact on travel times such that remedial measures (i.e., those measures resulting in minimizing incident impact) can be taken. The predictions required by Objective 4 must permit identification of excessive demand with sufficient time to identify and implement demand reduction strategies (i.e., those that reduce demand to acceptable levels).

Identify maintenance and upgrade needs. Objectives 1, 2, and 5 require the ATMS to identify maintenance and upgrade requirements.

The following capabilities are required:

- Identification of roadway surface maintenance needs.
- Identification of electronic component needs.
- Identification of training needs.
- Timely identification of needs.

The ATMS must identify preventive and remedial maintenance needs for roadway surfaces and for the roadway system's electronic components (e.g., sensors, processors, effectors). The ATMS must also be capable of identifying hardware and software upgrade needs. The ATMS must identify training needs (in order to maintain and upgrade the skills of its personnel). All needs must be identified when the deterioration of any part of the roadway system will negatively impact the ATMS's ability to satisfy its objectives.

Select responses. All five objectives require some form of response selection. Response selection involves identification of response options, assessment of those options in terms of feasibility and predicted result, and selection of one or more of those options for implementation.

The following capabilities are required:

- Selection of traffic management tactics.
- Selection of incident management approach.
- Provision of emergency service support.
- Demand regulation.
- Maintenance of public confidence.

Objective 1 requires the selection of those traffic management tactics that will avoid congestion. If congestion cannot be avoided, tactics to dissipate it in a timely manner are required. Implicit requirements are a knowledge of traffic management principles and an ability to estimate the impact of traffic management tactics on current traffic conditions. Objective 2 requires the selection of those incident management tactics that will minimize an incident's impact on travel times such that safety is not compromised. Implicit requirements are a knowledge of incident management principles, an ability to predict an incident's impact on traffic conditions over time, and an ability to match available response resources to the requirements of a specific incident. Objective 3 requires selection of traffic management and incident management tactics necessary to facilitate the provision of emergency services. For example, the ATMS must identify situations in which the provision of priority control of traffic signals is appropriate. Implicit requirements are a knowledge of the types of available emergency services and their respective capabilities. Objective 4 requires selection of those demand regulation strategies (for overall demand reduction) and demand regulation tactics (for special events) that will reduce the demand to acceptable levels. Implicit requirements are a knowledge of the capabilities and limitations of alternate transportation modes and an ability to estimate the impact of demand regulation strategies and tactics on roadway system demand. Objective 5 requires the selection of those strategies that will maintain and improve public confidence in the ATMS. Implicit requirements are a knowledge of public relations principles and an ability to estimate the impact of any ATMS action (tactical or strategic) on public confidence.

Table 6 summarizes the throughput requirements specified for the ATMS. Each requirement is assigned a set of capabilities, where the capabilities of this set facilitate satisfactory throughput performance.

Support Requirements

In addition to the primary functional performance requirements imposed by system

Table 6. System performance requirements: Throughput.

Throughput Requirement	*Associated Capabilities*
Predict traffic conditions.	• Congestion prediction. • Assessment of incident impact. • Prediction of demand.
Identify maintenance and upgrade needs.	• Identifying roadway surface maintenance needs. • Identifying electronic component needs. • Identifying training needs. • Timely identification of needs.
Select responses.	• Selection of traffic management tactics. • Selection of incident management approach. • Provision of emergency service support. • Demand regulation. • Maintaining public confidence.

objectives, a number of ancillary (support) requirements are necessary. Such requirements support the overall mission of the ATMS and are discussed below.

Collect and store traffic data. This requirement is associated with forecasting and strategic planning. Traffic data support planning for those roadway system improvements and major special events (parades, football bowl games, etc.) that disrupt normal traffic flows.

Collect and store incident data. Through this requirement, lessons learned and incident management strategies are documented.

Collect data for electronic toll and tax. Included are data on individual vehicles subject to toll or tax, as well as aggregate data that provide a basis for congestion pricing.

Conduct operator training. Operator training is accomplished through the simulation capability of the ATMS. Training courses include units on major hazardous incident management and emergency weather conditions, as well as normal operations.

Conduct transportation planning. Planning activities include strategic, special event, and contingency planning. These activities may include interaction with other agencies (e.g., police) or other transportation modalities (e.g., rail transit).

Perform administrative support. Administrative support is required in such matters as fiscal planning and budget tracking, maintenance of personnel records, and receiving and implementing policy directives from appropriate agencies.

Table **7** summarizes the support requirements specified for the ATMS. For each requirement, a set of capabilities is identified. These capabilities will ensure that the corresponding support requirement is satisfied.

RESULTS: FUNCTIONAL DEFINITION

ATMS functionality is a product of ATMS objectives, and, in turn, system performance requirements. That is, ATMS functionality represents the means by which ATMS objectives and system performance requirements are satisfied. In what follows, the functions required by each objective are discussed. In these discussions, names of the top-level functions are printed in boldface type when introduced, and subfunctions associated with each top-level function are described. Fulfillment of an objective requires those functions specified for previous objectives, in addition to any new functions specific to the objective under consideration. For example, the functions required by Objective **3** (assist in

Table 7. System performance requirements: Support.

Support Requirement	*Associated Capabilities*
Collect and store traffic data.	• Collection and storage of data to support strategic planning.
Collect and store incident data.	• Collection and storage of lessons learned. • Collection and storage of incident management strategies.
Collect data for electronic toll and tax.	• Collection of individual vehicle data. • Collection of aggregate data (congestion pricing).
Conduct operator training.	• Simulation of major (and hazardous) incident scenarios, emergency weather conditions, and normal operations.
Conduct transportation planning.	• Strategic planning. • Special event planning. • Contingency planning.
Perform administrative support.	• Fiscal planning and budget tracking. • Maintenance of personnel records. • Receiving policy directives. • Implementing policy directives.

the provision of emergency services) include the functions required by Objectives 1 and 2 *and* any new functions specific to the provision of emergency services. For this reason, the discussions of functional requirements for Objectives 2 through 5 focus only on the additional functions and/or subfunctions required by each objective.

Functions Required by Objective 1

Objective 1 is to maximize available roadway system capacity. This objective requires the ATMS to generate outputs that influence traffic. This **Influence Traffic** output function includes the implementation of traffic controls (intersection control, roadway access controls, railroad crossing controls) and the issuing of advisories that influence route selection and vehicle speeds. Planned advisories (posted on typical information outlets) and supplemental advisories to other agencies (e.g., informing police of a posted advisory) may be included. In order to satisfy Objective 1, the ATMS must also maintain and upgrade its assets as needed. Consequently, an **Issue Requests** output function is required. This function includes requests for maintenance (remedial and preventive), upgrades (software, hardware, personnel), and requests for the provision of onsite traffic control.

In order to generate outputs that maximize effective roadway system capacity, the ATMS must monitor conditions on the roadway system. This **Monitor Roadway System** input function includes vehicle detection and the sensing of roadway system conditions. (Surface conditions, the status of electronic components (via built-in-test reports or ad hoc component status reports), and visibility conditions must be sensed). In order to complement its organic sensor capabilities, the ATMS must also **Receive External Information** (external traffic reports). These external traffic reports may include reports of traffic volume, travel times (via probe vehicles or ad hoc communications), roadway conditions, or origin-destination (O-D) data (e.g., from Commercial Vehicle Operators and from “smart cars”). Other external information to be received includes commercial rail traffic reports and weather reports. The presence of trains at railroad crossings dynamically alters available flow paths in the roadway system and must be recognized by the ATMS. Similarly, weather conditions may have a major impact on roadway conditions, and these reports must be received by the ATMS. External information may be received either electronically or through verbal communication with outside agencies or the public.

Exercising its throughput functionality, the ATMS assesses available data in order to determine output requirements. The function **Select Traffic Management Tactics** includes assessing network conditions and (given those conditions) determining optimal control schemes. Assessing network conditions includes calculating current system load and (based on current load) anticipating the very-near-term load. Determining an optimal control scheme involves identifying traffic control options (where one option always available is to continue the current control scheme), predicting traffic conditions in the near term given those options, assessing the predictions, and selecting the best option. Predictions can be based on expected changes in conditions (e.g., as a function of changing weather conditions), as well as current data.

Maximizing effective capacity also requires the maintenance and upgrading of roadway system components. Thus, a second throughput function required by this objective is to **Determine System Welfare Needs.** This function involves a self-assessment of system effectiveness and the determination of maintenance and upgrade requirements. Remedial and preventive maintenance requirements are determined. Upgrade requirements might include upgrades to hardware, software, or personnel. Personnel upgrades might involve new hires or additional training for existing personnel.

Satisfying Objective 1 also requires the specification of support functions. The ATMS must **Maintain Records:** store and retrieve network data to be used in (1) predicting traffic conditions (e.g., as a function of time-of-day or day-of-week) and (2) self-assessment of system effectiveness The ATMS must also **Provide Training** for operators and maintainers and **Develop Traffic Management Plans** (strategic, special event, and contingency plans). Contingency plans include those to be implemented during extreme weather conditions, disasters, or other potential major problems. Finally, the ATMS must **Perform Administrative Duties** in areas such as financial management, policy development, personnel administration, and data base management.

Functions Required by Objective 2

The second objective is to minimize the impact of incidents. Much of the required functionality is obtained from the functions derived in response to Objective 1. (A major component of minimizing incident impact is optimal management of traffic around those incidents.) In order to minimize incident impact, the ATMS must facilitate incident clearance. Thus, the output function Issue Requests is expanded to include subfunctions that issue requests for (1) incident services (e.g., towing, medical, police, fire) and (2) additional information from external agencies. For some incidents the ATMS may **Provide Information** to other agencies (or the public): incident reports and incident management reports. Issuing requests and providing information to the most frequently involved agencies/outlets are typically performed through direct electronic links. For atypical situations, special reports may be provided through personal communication.

Minimizing the impact of incidents requires the TMS to detect the presence of incidents as rapidly as possible. Detection is accomplished in two ways. First, as input, the Receive External Information function is expanded to include subfunctions that receive incident reports from the general public and from public authorities such as the police. A new subfunction that focuses on the receipt of incident response reports is added. Second, the ATMS must review traffic data for anomalies in flow patterns, where such anomalies may indicate the presence of an incident. (Note that anomalies could arise in the absence of an incident.) An **Assess Anomalies** throughput function enables the ATMS to identify anomalies and determine anomaly sources. Determining the need for services (and in some cases identifying the source of an anomaly) requires the ATMS to obtain more information than is typically associated with traffic conditions existing in the vicinity of an incident. If the Monitor Roadway System input function is expanded to include a subfunction that enables the ATMS to observe incident sites, service requirements can be assessed directly. This new subfunction also provides another means for the ATMS to verify incident data and monitor incident clearance procedures.

Facilitating the clearance of an incident requires incident management. Some incidents fall solely within the province of the ATMS; other incidents (e.g., those involving threats to human life or public safety) may require involvement of other agencies. Thus, as throughput the ATMS must **Select ATMS Responses to Incidents:** determine the ATMS's responsibilities relative to other agencies, determine the specific incident service requirements, and determine appropriate ATMS responses.

Support functionality implied by Objective 2 includes an expansion of the Maintain Records function to include the maintenance of incident data records (storing and retrieving data electronically or through hardcopies). An expansion of the Provide Training function to include providing incident management training is required. For incidents involving additional agencies, the appropriate role for the ATMS may require it to **Provide Interagency Coordination:** maintaining interagency communications and coordinating multi-agency incident responses.

Functions Required by Objective 3

Objective 3 requires the ATMS to support the provision of emergency services. In many cases emergency services are provided in response to roadway incidents; therefore, because of Objective 2, most of the functionality required by Objective 3 is already defined. The output functions required to support incident management are sufficient to support provision of emergency service vehicles. Consequently, no additional output functions are added by this objective.

Objective 3 does impose requirements for additional input, throughput, and support functions. As input, the Receive External Information function must be expanded to include subfunctions that receive other types of emergency response reports (i.e., emergency responses unrelated to roadway incidents): interagency response data and supplemental emergency response reports. For example, a major fire in the metropolitan area, while not a roadway incident, may require the ATMS to assist in managing traffic near the site and thus facilitate a speedy response by fire, police, and medical services. A second example is a hazardous materials release that necessitates evacuation of the affected (surrounding) area. The evacuation may create traffic conditions requiring the implementation of special traffic management strategies and the closing of roadway segments as a means of enforcing the evacuation. The throughput function Select Traffic Management Tactics must be expanded to include a subfunction that determines special vehicle support measures. This subfunction includes determining the requirements for ATMS services and tracking special vehicles on the roadway system.

The support function Provide Interagency Coordination must also be expanded to include the coordination of multi-agency responses to other emergencies (i.e., emergencies that are unrelated to roadway incidents).

Functions Required by Objective 4

Objective 4 focuses on the regulation of roadway system demand. Most of the functionality required by Objectives 1 through 3 has considered tactical operations, with some strategic planning as a support function. Accomplishing Objective 4 imposes requirements for more extensive functionality at the strategic level and for some expansion of functionality at the tactical level.

At the tactical level, Objective 4 requires the ATMS to provide outputs that assist in demand regulation. The output function Issue Advisories must be expanded to include subfunctions that issue travel advisories (e.g., advisories intended to influence travelers' trip-making decisions) and mode selection advisories (e.g., advisories enabling travelers to weigh the advantages/disadvantages of travel via public transportation versus carpool versus SOV). Advisories are either planned (posted on typical information outlets) or supplemental (provided to other agencies as needed). At the strategic level, the ATMS must provide information in support of demand regulation efforts. The Provide Information function must be expanded to include subfunctions that provide traffic data (historical or real-time), as well as reports and recommendations, in support of demand regulation efforts.

As input, the ATMS must **Receive Requests for Information:** requests for historical data and simulation studies that will produce reports and recommendations related to demand regulation. The Receive External Information function must be expanded to include a subfunction that receives data from other transportation systems. These systems may be other traffic management centers (TMC's) or alternate transportation modes (e.g., public transportation).

Special events (e.g., major sporting events, conventions, concerts) often generate a high demand for transportation services, and they may create unusual traffic flow patterns. Traffic management planning for special events was included in Objective 1. Objective 4 also requires the ATMS to be involved in multimodal demand regulation efforts for special events. Thus, the Receive External Information function must be expanded to include a subfunction that receives special event reports electronically or through verbal communication. Reports describing the event, reports from other cities in which similar events have been held, and reports from other agencies that document special event management strategies (e.g., provisions for extra police patrols) could be included.

As a throughput requirement, the ATMS must **Conduct Simulations to Support Transportation Planning.** These simulation studies assess multimodal demand and capacity and subsequently determine an optimal demand regulation scheme. They produce reports and recommendations that are transmitted to a requester. Simulation studies may generate predictions that are quite different from those provided by the function Select Traffic Management Tactics. The latter predictions are concerned solely with roadway system traffic and do not consider other transportation modes. Predictions associated with the function Select Traffic Management Tactics are based on current traffic conditions and existing configurations of the roadway system. In contrast, the predictions generated from simulation studies may well involve other transportation modes, and they could also involve different demand pattern assumptions or different roadway system configurations. Such simulation studies, for example, could support planning for the implementation of innovative IVHS technologies (e.g., technologies incorporating specially-instrumented, restricted access lanes on certain roadways.)

Two support functions must be expanded to accommodate the requirements of Objective 4. The Provide Training function must be expanded to include a subfunction that provides special event training. (Routine traffic management training could include lessons that focus on traffic management for special events. However, expanded functionality is required for situations in which specialized training for specific events is of interest; in particular, those instances in which individuals from other agencies participate in training.) The Provide Interagency Coordination function must be expanded to include a subfunction that coordinates multi-agency transportation planning.

Functions Required by Objective 5

Objective 5 is to create and maintain public confidence in the ATMS. The ATMS satisfies Objective 5, to a great extent, through its successful attainment of Objectives 1 through 4; however, Objective 5 does require the ATMS to actively influence public confidence. As output, the Provide Information function must be expanded to include a subfunction that provides public relations information. As input, the function Receive Requests for Information must be expanded to include a subfunction that receives requests for public relations information. Also as input, the Receive External Information function must be expanded to include a subfunction that receives public comments. These comments could arrive from other agencies, businesses, or private citizens.

As a throughput function, the ATMS must **Assess Public Confidence.** Such assessment includes monitoring travelers' compliance with both general and current ATMS advisories, assessing public comments received either directly (written or verbal comments) or via survey data, and planning activities that will enhance public confidence. Such planning activities culminate in the release of public relations information, included as a new subfunction under the Provide Information function. This information could be in the form of media releases, brochures, addresses to civic groups, or tours of ATMS facilities.

SUMMARY

In this section we document results obtained from a top-down user-centered analysis, specifically, results obtained from the initial stages of this analysis. These initial stages include (1) identifying ATMS objectives, (2) specifying system performance requirements, and (3) deriving functionality that corresponds to objectives and performance requirements. The methodology employed in conducting the analysis is described.

The global mission of the ATMS is to facilitate the safe movement of individuals and goods (while minimizing delay) through a designated roadway system. This mission is achieved through attainment of five objectives:

- Maximize available capacity of the designated roadway system.
- Minimize the impact of incidents.
- Assist in the provision of emergency services.
- Contribute to the strategic regulation of demand.
- Create and maintain public confidence in the ATMS.

ATMS operators have a distinct impact on the ATMS's ability to meet system objectives. Each objective is achieved only through successful execution of its corresponding functions and operator tasks. In other words system objectives drive the functional specification. Thus, a thorough definition of functionality is required. Our analysis indicated that ATMS functionality is defined in terms of four function types: input, throughput, output, and support. Input functions receive information from sensors and external sources. Throughput functions process information and make decisions. Output functions disseminate information, control electronic devices, and issue requests. Support functions create and maintain the capabilities of other functions (e.g., store and retrieve information, train operators, and coordinate activities). A total of 113 functions were derived: 32 input functions, 29 throughput functions, 25 output functions, and 27 support functions.

Table 8 provides a breakdown of the top level functionality required by ATMS Objectives 1 through 5 (i.e., the functions indicated via boldface type in the previous discussion). The complete functional definition, specifying all subfunctions and respective top level functions required to satisfy the five ATMS objectives, is documented in appendix C. Appendix C also identifies functional requirements according to ATMS objectives. That is, if a function is required by a given objective, an "x" is included in the column corresponding to that objective.

Table 8. High-level ATMS functionality.

1.0 INPUT
- 1.1 Monitor Roadway System
- 1.2 Receive External Information
- 1.3 Receive Requests for Information

2.0 THROUGHPUT
- 2.1 Select Traffic Management Tactics
- 2.2 Determine System Welfare Needs
- 2.3 Assess Anomalies
- 2.4 Select ATMS Responses to Incidents
- 2.5 Conduct Simulations to Support Transportation Planning
- 2.6 Assess Public Confidence

3.0 OUTPUT
- 3.1 Influence Traffic
- 3.2 Issue Requests
- 3.3 Provide Information

4.0 SUPPORT
- 4.1 Maintain Records
- 4.2 Provide Training
- 4.3 Develop Traffic Management Plans
- 4.4 Perform Administrative Duties
- 4.5 Provide Interagency Coordination

SECTION 3. FUNCTIONAL LOCATION

INTRODUCTION

The functions required to satisfy ATMS objectives have been defined in terms of four function types: input, throughput, output, and support. [6,13] Ultimately, a total of 113 functions were specified. [6,13] Of this total, 32 input functions and 29 throughput functions were specified; 25 functions were designated as output functions, and 27 functions were designated as support functions.

In what follows, the theoretical framework guiding ATMS function allocation, referred to as *operator role theory,* is introduced. Function allocation is the process through which human factors analysts specify how system functions will be executed (i.e., through a human operator, through a machine, or through the joint effort of a human operator and a machine). The fundamentals of operator role theory and the manner in which it is applied to ATMS functions are described. A discussion of results, including an example of the function allocation methodology, follows. Finally, a brief summary statement and implications derived from results of the function allocation process are presented.

OPERATOR ROLES AND FUNCTION ALLOCATION: THEORETICAL FRAMEWORK

Operator role theory provides a framework for guiding ATMS function allocation. Within this framework, a continuum of operator roles is defined such that at one end of the continuum, a function is allocated solely to a human operator, and at the opposite end, a function is allocated solely to a machine. Between the extremes, function performance is shared by human operator and machine components. Note that a *role* refers to the collection of tasks or activities an individual performs within a given context, rather than a just specific task. An operator can have one role in a given function and another role in a second function. Within each role the operator may have several tasks.

Operator role theory was originally developed to describe human activities required for the operation of air defense systems. [14] Subsequently, operator role theory has been generalized to apply to all types of human-machine systems. It can be applied as a prescriptive (as well as descriptive) tool.

In considering ATMS design from a human factors perspective, one of our primary objectives has been to designate the appropriate human operator role for each function. As a consequence of such role designation, the level of automation associated with each function can be established. This section presents the results of our application of operator role theory to ATMS functionality. Here, operator role theory supports the function allocation process, enabling analysts to specify the agent of function execution (i.e., human operator, machine, operator-machine combination) for each ATMS function.

OPERATOR ROLE THEORY

Design of the ATMS from a human factors perspective requires more than an assessment of individual display and control components and their arrangement in a set of workstations. While workstation design is critical, human factors inputs to the design process must affect high-level design philosophy. Specifically, the rationale underlying the allocation of functions among human operators and machines must be driven by human factors considerations. In this manner, system and operator performance is optimized.

Operator role theory was applied in the allocation of ATMS functions. According to this theoretical framework, a continuum of operator roles is defined such that at one extreme of the continuum a function is allocated solely to a human operator and at the opposite extreme a function is allocated solely to a machine. The continuum is divided into four regions, where each region indicates an operator role (and corresponding degree of automation). These regions are Direct Performer (no automation), Manual Controller (operator performs decision-making activities but is assisted by machine elements that play a role in sensing the environment, processing input data, or executing control actions), Supervisory Controller (operator has the ability to override a machine-made decision), and Executive Controller (operator enables or disables a fully-automated function).

Note that three of the four roles are labeled with the term *Controller,* indicating that operator activities are focused on controlling machine components. The fourth role, labeled with the term *Performer,* indicates that direct performance of a function, rather than the control of machine components, is the focus of operator activities.

Fundamentals of Operator Role Theory

Operator roles are defined more precisely by considering the manner in which information is processed within a function. Each function is defined in terms of four stages of information processing: input, processing, response selection, and output. In other words, successful execution of any given function (regardless of function type -- input, throughput, output, support) requires completion of each stage. At the input stage, information is received from an external source by a *sensor.* At the processing stage, received information is manipulated by a *processor.* At the, response selection stage, a *controller* decides what control actions are to be performed. At the output stage, an *actuator* executes control actions. In order to apply operator role theory to the function allocation process, the manner in which humans and machines accomplish each information processing stage must be specified.

In both the Direct Performer and Manual Controller roles, the controller (decision-maker) is human. That is, a human performs response selection. In the Direct Performer role, however, sensors, processors, and actuators are human, while in the Manual Controller role, at least one of these three components is a machine. In both the Supervisory Controller and Executive Controller roles, response selection is performed by a machine (i.e., the controller is a machine). In the Executive Controller role, sensors, processors, and actuators are machine components. Furthermore, except to terminate function execution, the human is unable to influence machine performance. In the Supervisory Controller role, however, the human can intervene during the response selection stage (e.g., override a machine-made decision). Additionally, the human may choose to modify. performance of sensors, processors, or actuators.

For a given operator role, human and machine components associated with the four information processing stages can be configured in a number of ways. These possible configurations are provided in table 9. The following notation is used to represent the level of operator involvement at each information processing stage.

- H: The human is solely responsible for performing the processing stage.
- Hm: The human (with machine assistance) performs the processing stage.
- Mh: The machine (with human assistance) performs the processing stage.
- M: The machine is solely responsible for performing the processing stage.

APPLYING OPERATOR ROLE THEORY TO ATMS FUNCTION ALLOCATION

Here, our procedure for allocating ATMS functions according to operator role theory is described. Additional details associated with this procedure are presented in reference 7. A team of human factors engineers, psychologists, and software engineers analyzed each lowest-level function. Appropriateness of assigning either of the two extreme operator roles (Direct Performer or Executive Controller) to a function was assessed. One of the two roles was considered appropriate if (1) its assignment to the function would satisfy that function's performance requirements and (2) a significant increase in capabilities could not be expected by the assignment of a different operator role to the function. If the team determined that a Direct Performer role would satisfy performance requirements and no significant gains in performance were expected by the assignment of some other role, it was assigned to the function. Similarly, if a function's performance requirements could be

Table 9. Human and machine configurations for operator roles.

	Information Processing Stage:			
Operator Role	INPUT	PROCESSING	RESPONSE SELECTION	OUTPUT
DIRECT PERFORMER	H or Hm	H	H	H
MANUAL CONTROLLER	H, Hm or M	H, Hm, or M	H	H, Hm or M
SUPERVISORY CONTROLLER	Mh or M	Mh or M	Mh	M or Mh
EXECUTIVE CONTROLLER	M	M	M	M

met by an Executive Controller role and no significant gains in performance were expected via some other role, an Executive Controller role was designated for that function.

In considering all remaining functions (those assigned neither Direct Performer nor Executive Controller roles), the analysts assessed the appropriateness of Manual Controller and Supervisory Controller roles. Again, appropriateness was evaluated in terms of the satisfactory achievement of performance requirements and the expectation of realizing significant performance gains through another role assignment. Once the team reached a consensus on operator role designations, further details of function allocation were completed with the four-stage information processing model. For each function, the analysts considered possible human/machine configurations associated with its respective operator role (table 9) and identified the configuration that would best meet performance requirements.

DISCUSSION OF RESULTS

To each of the 113 ATMS functions, an appropriate operator role was assigned. Additionally, a configuration of human and machine components was specified for each function's four information processing stages. The Direct Performer role was assigned to 40 of the 113 functions, while the Manual Controller role was assigned to 28 functions. The Supervisory Controller role was assigned to 16 functions, and the Executive Controller role was assigned to 29 functions. In what follows the general nature of the functions associated with each role are discussed.

Direct Performer Functions

The 40 Direct Performer functions were distributed (according to function type) as follows: 15 input functions, 6 throughput functions, 7 output functions, and 12 support functions. All of the 15 input functions assigned a Direct Performer role represent personal communication activities. These functions allow the ATMS to receive information, reports, comments, and requests from external agencies or individuals. Such communications are facilitated via face-to-face conversation or standard communications devices (e.g., telephone, fax transmission, electronic mail).

Of the six throughput functions assigned a Direct Performer role, three are decision-making functions. For these functions, decisions concerning software, hardware, and personnel upgrades are the focus. The remaining three functions are associated with the formulation of demand regulation recommendations, the assessment of public comments, and the planning of public confidence enhancements.

The seven output (Direct Performer) functions represent personal communication activities. These functions allow the ATMS to disseminate information and requests via personal communication channels.

The 12 support functions assigned a Direct Performer role include 2 clerical functions (storing and retrieving hardcopies of incident reports), 6 administrative functions, and 4 functions requiring coordination between the ATMS and other agencies

Manual Controller Functions

The 28 Manual Controller functions were distributed (according to function type) as follows: 2 input functions, 8 throughput functions, 7 output functions, and 11 support functions. Both of the input (Manual Controller) functions are associated with the observation of incident sites (i.e., verification of incident data and the monitoring of incident clearance). Because human operator control of remote sensors (e.g., surveillance cameras), as well as operator-observation of incident sites, are essential to successful execution of these functions, they are assigned a Manual Controller role.

Three of the eight throughput (Manual Controller) functions are decision-making functions that require ATMS responses to incidents. Two of these eight functions represent the control of transportation planning simulations. The remaining three functions rely upon operator assessment: determining the source of anomalies in traffic patterns, monitoring general compliance with ATMS advisories, and assessing data associated with public confidence surveys. In these three functions, machine capabilities are critical to data processing; however, decision-making is the sole responsibility of the operator.

Seven output functions are assigned a Manual Controller role. All involve the transmission of reports or requests of such volume that personal communication (i.e., a Direct Performer role) is impractical. Consequently, machine capability assists operators in the preparation and distribution of such information.

Eleven support functions are assigned a Manual Controller role. Four are training functions. Training programs may rely (to a large extent) on machine capability, but decisions concerning content and procedure will be the function of human instructors/course coordinators. Three of these support functions focus on planning activities. Again, while planners may rely on computer-based algorithms (to support long-term strategic planning activities or perhaps fiscal planning activities), decision-making responsibilities are assigned to humans. Three additional support functions represent administrative activities. The remaining function facilitates data base management.

Supervisory Controller Functions

The 16 Supervisory Controller functions were distributed (according to function type) as follows: 2 input functions and 14 throughput functions. The two input (Supervisory Controller) functions are associated with the sensing of roadway network conditions (i.e., the sensing of roadway surface conditions and the sensing of visibility conditions). These functions are judged inappropriate for an Executive Controller role for the following reason. Machine-sensing capabilities alone are not expected to surpass (or even equal) the combined capabilities of human operators and machines. Both functions will rely in part on human vision. Relying upon their own visual inspection capabilities and heuristic knowledge, operators serving as supervisory controllers will have the ability to override sensor reports of roadway surface conditions or visibility conditions.

The 14 throughput functions assigned a Supervisory Controller role include a majority of the principal traffic management activities: assessing current load, predicting near-term traffic conditions, assessing traffic control options, and selecting the optimal control option. We envision machine-performance of real-time traffic management activities, where (in special situations) the operator as supervisory controller will selectively intervene in order to override machine-made decisions. The sheer number of traffic control decisions to be made in any reasonably large network precludes a requirement for operator approval of all such decisions. Rather, the operator will intervene when his or her domain knowledge/expertise surpasses that of the machine. Routine maintenance decisions will also be made under supervisory control. The machine will make decisions associated with remedial and preventive maintenance needs, where all decisions are subject to operator override.

No output or support functions are assigned a Supervisory Controller role. For each of these function types, machine capabilities were either sufficiently advanced as to suggest the Executive Controller role, or were so poor as to suggest that little would be gained from incorporating machine-made decisions.

Although only 16 functions are assigned a Supervisory Controller role, many represent the core capabilities in ATMS traffic management. They are Supervisory Controller functions rather than Executive Controller because of the requirement to maintain operator-in-the-loop capabilities.

Executive Controller Functions

The 29 Executive Controller functions were distributed (according to function type) as follows: 13 input functions, 1 throughput function, 11 output functions, and 4 support functions. The 13 input (Executive Controller) functions are associated with the receipt of electronically-formatted data from sensors or other systems. For these functions the technology required for function execution (with no operator involvement) either exists currently or is expected to exist in the IVHS era.

Only one throughput function is assigned an Executive Controller role. This function facilitates the tracking of special vehicles (e.g., emergency vehicles, probe vehicles). Given a requirement to update vehicle position every few seconds, we anticipate no benefit from providing a means for operator intervention.

The 11 output functions assigned an Executive Controller role focus on the electronic transmission of information. In these functions the content and intended destination of such information is selected in predecessor functions, and consequently, the actual transfer of information can be performed under executive control.

The four support functions assigned an Executive Controller role are associated with storage and retrieval of electronic data.

Function Allocation Example

In the example to follow, the function allocation methodology, as applied to a given throughput function, is documented. The function of interest is Function 2.1.1.2: Anticipate Near-Term Traffic Conditions. The phrase *near-term* refers to traffic conditions that will occur 1 to 5 min in the future. Function 2.1.1.2 ensures that such conditions are anticipated. The methodology requires each function to be assigned one of four operator roles (Direct Performer, Manual Controller, Supervisory Controller, Executive Controller). In this case a Supervisory Controller role was considered appropriate. The role assessment conducted for Function 2.1.1.2 follows.

Operator Role Assessment

Assessment of Direct Performer Role: Given the need to evaluate and make predictions from a complex set of traffic conditions, this function requires machine assistance.

Assessment of Executive Controller Role: This function cannot be achieved under executive control. Although prediction of near-term traffic conditions can be automated, these predictions have limited fidelity, and the plausibility of such predictions would require operator assessment. The validity of a prediction depends on the conditions considered and on the soundness of the analysis that forecasts the evolution of those conditions. To expect that a predictive traffic model would account for all relevant current conditions in all circumstances is unreasonable. A random building fire, for example, could affect traffic on many nearby roads, yet many predictive models would fail to allow for such a possibility. Because expecting that all conditions relevant to traffic prediction could be enumerated as a basis for automation is unreasonable, the operator must be permitted to intervene in this function.

Conclusion: Neither the Direct Performer role nor the Executive Controller role is appropriate for this function. Assessment with respect to Manual Controller and Supervisory Controller roles must be conducted.

Assessment of Manual Controller Role: Real-time assessment of a large volume of traffic condition information is required for the execution of this task. Consequently, for the majority of traffic situations, automation is suitable for task completion. Requiring a manual "closing of the loop" under all conditions would place an unnecessary burden on the operator. Therefore, this function is inappropriate for the manual controller role.

Assessment of Supervisory Controller Role: Anticipation of the details of near-term traffic conditions involves the processing of a large volume of data. Clearly, such processing requires substantial automation. For this function, relying on the output of a near-term predictive model is reasonable, but under some circumstances, an operator might be required to override or adjust near-term predictions. The need for such adjustments would be indicated either when an operator recognizes the occurrence of conditions not handled by the predictive model, or when the output of the predictive model is questionable (or possibly erroneous). Therefore, this function is appropriate for a Supervisory Controller role designation.

Role Designation: The Supervisory Controller role is recommended for Function 2.1.1.2.

Subsequently, each function is defined in terms of four stages of information processing: input, processing, response selection, output. Finally, the level of operator involvement required for each information processing stage (H, Hm, Mh, or M) is assigned.

Configuration of Human and Machine Components

Function 2.1.1.2: Anticipate Near-Term Traffic Conditions

Operator Role: Supervisory Controller

Input: (M) Current load assessments and roadway system status, external reports (e.g., incident, weather, incident response, emergency response) are provided via software.

Processing: (Mh) Input data are provided to a near-term traffic model. From these data, the following road segment-specific information is predicted: traffic volume, density, speed.

Response Selection: (Mh) In some instances, the operator may have access to more relevant/accurate input data or may have better predictive capabilities than the software. Under these circumstances, the operator may choose to modify input information and override predictions (or, at a minimum, identify inaccurate/imprecise predictions).

Output: (M) Predictions derived by this function are sent via software to Function 2.1.2 (Develop Optimal Control Scheme) and Function 2.1.2 (Determine Special Vehicle Support Measures).

Note that an operator's ability to intervene at the response selection stage (in order to modify input information and thus override machine-generated predictions or to identify inaccurate/imprecise predictions) suggests this function's appropriateness for a supervisory controller role. Input and output stages (i.e., the receipt of input data and the transmission of near-term predictions) are automated, where the level of operator involvement associated with each stage is M. Processing and response-selection activities are dominated by machine involvement (Mh); however, the potential for operator involvement (e.g., operator-adjustments of input data, an operator override capability) exists. Note that the configuration of human and machine components specified for this particular function (M, Mh, Mh, M) is one of the possible configurations specified for the Supervisory Controller role in table 9.

Appendix D summarizes results of the function allocation process. Included with each ATMS function is its role designation (Direct Performer, Manual Controller, Supervisory Controller, or Executive Controller) and the level of operator involvement (H, Hm, Mh, or M) assigned to each of its information processing stages.

SUMMARY

Our function allocation process yielded operator role designations for each ATMS function. In conjunction with these role designations, all functions were defined in terms of four processing stages (input, processing, response selection, output). Further analysis generated the level of operator involvement essential for successful completion of each stage (i.e., H, Hm, Mh, or M). Operator role theory prescribed a formal procedure for (1) specifying operator performance requirements for the ATMS and (2) designating the appropriate level of automation for each ATMS function.

In spite of an expected desire to relieve the operator of workload (and impose as much automation as possible), the direct performer role was the most frequently assigned role. Note, however, that the direct performer designations were essentially balanced by assignments of higher levels of automation: 45 functions received either executive controller or supervisory controller role designations.

When considered as a whole, the combination of machine involvement levels assigned to the information processing stages of a given function suggests a level of automation. Specifically, functions predominated by levels M or Mh are more highly automated than those predominated by levels H or Hm. Consequently, results of the function allocation exercise (providing information on automation) will enable us to predict the nature of the tasks specified for each function.

SECTION 4.
OPERATOR PERFORMANCE REQUIREMENTS

INTRODUCTION

In this section, operator performance is considered. Information requirements, as well as operator decision-making and response requirements, are analyzed within the context of four reference scenarios. These scenarios, used to describe the prominent ATMS vision (section 2), depict a range of traffic conditions, extending from routine (standard) events to unanticipated (sometimes infrequent) events. In this manner, we are afforded an opportunity to assess operator performance during extreme traffic conditions (for which workload demands are increased), as well as during conditions that are less demanding. Additionally, this range of scenarios has enabled us to exercise system functionality to its full extent. Recall that a scenario example is provided in appendix B.

ANALYSIS OF SCENARIOS

In the discussion to follow, operator performance is considered with respect to information requirements, decision-making requirements, and output (response) requirements. These requirements are evaluated within the context of four reference scenarios:

- Normal operations during rush hour traffic.
- A major freeway incident during rush hour traffic.
- Special event planning and traffic management during the planned event.
- A major winter storm during rush hour traffic.

These scenarios, initially conceptualized in reference 5, demonstrate functional capabilities of the ATMS. They also suggest the range of performance demands placed on system operators.

Information Required

An analysis of each of the four scenarios suggests that, in the course of responding to scenario events, TMC operators typically interact with three types of incoming information: (1) data incorporated in TMC analyses, (2) analysis results, and (3) information employed in the operators' conduction of "real-time" traffic management. The reason for using quotation marks in conjunction with the term *real-time* will be clarified later in this section.

Analyses (quantitative as well as qualitative in nature) performed by the TMC and its human operators support real-time traffic management, near-term traffic management (predictions for events that will occur minutes or several hours in the future), and long-term traffic management (simulations, "dry runs", "dress rehearsals"). Quantitative analyses incorporate algorithms yielding optimized traffic control strategies, traffic flow rates, current load conditions (traffic volume), and motorists' levels of compliance with TMC advisories. Qualitative analyses provide information on preventive and remedial maintenance needs, identify traffic pattern anomalies, prescribe appropriate responses to incidents, and suggest strategies for transportation planning (where one example is regulation of demand). The data incorporated in TMC analyses are likely to be stored in text and graphics-based formats, as well as numerical formats. Examples of text and graphics formats may be weather forecasts provided by the National Weather Service, or a map identifying the site of a traffic flow anomaly, respectively.

Analysis results, as a consequence of the broad spectrum of analyses conducted, may also be provided in text, graphics, or numerical formats. Frequent results are predictions (e.g., state of traffic (volume, flow rate, effectiveness of current control strategy) for designated times in the future) and recommendations (e.g., "implement a control scheme more consistent with normal traffic conditions," "employ alternate routing strategies," "post messages to upstream traffic"). Note that the same types of results can be obtained from simulation analyses.

Examination of the four scenarios suggests that the third category of required information (information employed in TMC operators' conduction of "real-time" traffic management) is the primary source of incoming data. (The term *real-time* is placed in quotations in order to suggest that here, real-time is a relative phenomenon. In other words, during a simulated traffic scenario, operators must access information supportive of traffic management activities; however, these activities are performed in a simulated real-time environment.) Quality of the information assigned to this category has a significant impact on operators' abilities to effectively manage traffic, where information quality is measured with respect to the ease with which operators access, interpret, and apply information, as well as the *accuracy* with which they interpret information.

Operator Decisions

Information received by TMC operators is subsequently processed, and one of the outcomes of such cognitive processing activities is a set of decisions. In other words, operators' decisions reflect their responses to the large amounts of information they receive. Analysis of the four traffic scenarios revealed that operators make four types of decisions:

- Accept or reject system recommendations.
- Initiate activities.
- Transmit information.
- Assess information.

Analysis of the four scenarios revealed that operators dedicated the greatest proportion of their decision-making opportunities (38 percent) to assessments. Additionally, they dedicated relatively equivalent proportions of their decision-making time to acceptance/rejection decisions (17 percent) and to decisions concerning the initiation of activities (25 percent) and information transmission (20 percent).

Recommendations (or suggestions) presented to TMC operators are frequently an outcome of quantitative and qualitative system analyses. Recall that analysis results were one form of required incoming information discussed in the previous subsection. Thus, upon receiving results, operators must evaluate their validity. Operators may be required to evaluate a single recommendation or a prioritized list of recommendations. Given a list of recommendations, an operator must ensure validity of the list itself (whether all listed recommendations are appropriate, and that no appropriate recommendations have been excluded), as well as validity of the prioritization of recommendations. While the operator is ultimately responsible for deciding either to accept or reject a recommended solution, time constraints may be flexible enough to enable the operator to delay an acceptance/rejection decision. In such instances the operator is allowed to continue with the solution approach currently being applied to a given traffic problem. The desire to delay an acceptance/ rejection decision is likely to occur when the operator recognizes that (1) the knowledge required for solving a traffic problem is incomplete and (2) the overall well-being of the traffic system would benefit from delaying the acceptance or rejection decision until a more comprehensive knowledge base is obtained.

Operator decisions to initiate an activity occur in reaction to system events. Note that initiated activities include those to be (1) effected by the operators themselves, (2) managed and executed by the system (software and hardware controlled outputs), and (3) completed by external entities (special services, motorists). Operators detect system events as a result of their monitoring activities, the traffic control problems they recognize, administrative duties for which they are responsible, and their participation in simulated traffic scenarios.

An operator decides to transmit information in response to demands for data. Note that operators are required to provide a broad range of data, including public relations materials, briefings to external organizations, information for media campaigns, as well as standard traffic advisories. The demand for some forms of data (public relations and media campaign materials, briefings) may arise from specific requests (issued by external entities) to the TMC, while demand for other forms of data (standard traffic advisories) may be generated from within the system, where existing or impending traffic conditions require information to be posted to travelers.

Information assessment decisions result from TMC needs, specifically, the TMC's need for operator expertise. Information assessments require the operator to examine incoming information, evaluate it, and respond appropriately. The types of responses the operator provides are a consequence of data assessment, system-generated results, or communication activities.

Operator Responses

Any decision reached by a TMC operator is followed by some form of output. Thus, each output is a manifestation of an operator's cognitive processing activities. Operator outputs are displayed via a range of media. Scenario analyses identified five types of outputs that TMC operators oversee: messages, strategies, simulations, traffic control commands, and data.

Messages are relayed to motorists, as well as to special services personnel. They include travel advisories, incident information, and customized instructions to special services personnel. Under special circumstances, a TMC operator may issue information requests to individual motorists. (A situation of this nature occurred in scenario 2 when an operator requested a cellular phone user to obtain the license or DOT placard number for a tanker involved in an incident.)

Strategy outputs correspond to the development of management approaches (e.g., administrative policies, traffic management schemes), planning efforts (e.g., media campaign development, plans to incorporate occupancy data into TMC data base), and the distribution of public relations materials.

Simulations enable TMC operators to investigate traffic conditions for which operators have gained no prior experience. These simulations provide predictions regarding multimodal demands.

Traffic control commands are used to influence the flow of traffic during routine and crisis situations. Finally, TMC operators are frequently requested to provide data to internal and external agencies.

Users of Traffic Information

Note that a subset of operator responses will involve the distribution of traffic information to various users. Consequently, in order to ensure the appropriateness of such operator responses, we must "know the traffic information users" and understand their information requirements. The authors of reference 13 produced an initial set of traffic information users and included them in functional flow diagrams that represented the four reference scenarios described earlier. Example members of this target group included city planners and city government officials, traffic control hardware, maintenance providers, roadway drivers, special event traffic, and TMC personnel.

Our continuing analysis of TMC operator performance requirements enabled us to enhance the initial definition of traffic information users. [8] The resulting taxonomy classifies traffic information users according to four categories:

- Institutional users.
- Traffic data users
- Special service providers.
- Public users.

Institutional users include city officials/ planners, other agencies (e.g., school districts, public safety organizations), public transportation systems, future special event hosts, and commercial vehicle operations systems. Users of traffic data include TMC personnel, the traffic control system, and information services (e.g., the media and traffic bulletin board services). Special service providers are members of the following group: incident responders (e.g., hazardous materials response teams, utility vehicles, emergency medical vehicles), maintenance providers, pre-positioned assets (e.g., snow plows, salt trucks), and emergency (non-incident) responders (e.g., fire service vehicles, emergency medical vehicles). Special event traffic, roadway drivers, the general public, public transportation operators, and commercial vehicle operators represent the category referred to as public users.

The information required by all defined user groups (i.e., institutional users, traffic data users, special service providers, and public users) encompasses advisories, specialized training, reports and analysis results, data, and

Table 10. Types of information required by users.

Information Category	*Information Type*
Advisories	- route selection advisories - special advisories - speed limit advisories - transportation mode selection advisories - travel advisories
Specialized Training	- incident management training - special event training - traffic management training
Reports and Analysis Results	- incident management reports - incident reports - public relations information - simulation reports and recommendations - transportation planning results
Data	- historical traffic data - instructions for resolving incidents - multimodal capacities - multimodal demands - pick-up/drop-off points - route information - software-controlled commands - special event parking information
Requests	- incident service requests - maintenance requests

requests. Table IO specifies the types of advisories, training materials, reports/analysis results, data, and requests required by the defined traffic information user groups.

Institutional Users. Information requirements of city officials/planners include simulation reports and recommendations, results obtained from transportation planning efforts, and special events training. Other agencies (e.g., school districts or public safety organizations) require incident management reports. Public transportation systems must obtain simulation reports and recommendations, transportation planning results, and incident management training. Hosts of future special events require historical traffic data, simulation reports and recommendations, transportation planning results, and training in the management of incidents and special events. Commercial vehicle operations systems require simulation reports and recommendations, travel advisories, special advisories (e.g., freeway closures), and route selection advisories.

Traffic Data Users. TMC personnel require traffic and incident management training, special events training, and information reflecting multimodal demands and capacities. Any traffic control system must receive software-controlled commands (to implement control of roadway access and traffic signals). Information services require incident management reports, public relations information, transportation mode selection advisories, route selection advisories, speed limit advisories, travel advisories, and special advisories (e.g., freeway closures).

Special Service Providers. Incident responders must receive incident service requests, incident reports, incident management reports, and route information. Maintenance providers receive maintenance requests. Pre-positioned assets require instructions for resolving incidents, incident reports, and special events training. Emergency vehicles require route selection advisories and special advisories.

Public Users. Special event traffic must receive speed limit advisories, travel advisories, transportation mode selection advisories, special event parking information (location, capacity), and route selection advisories. Roadway drivers must receive route selection advisories, speed limit advisories, travel advisories, and special advisories. The general public requires public relations information, route selection advisories, travel advisories, and transportation mode selection advisories. Operators of public transportation must receive route selection advisories, speed limit advisories, travel advisories, and special advisories. Commercial vehicle operators (e.g., taxi drivers, truckers) require route selection advisories, speed limit advisories, travel advisories, special advisories, and pick-up/ drop-off points (specific to taxi drivers).

SECTION 5
OPERATOR TASK ANALYSIS

INTRODUCTION

This section offers our most detailed assessment of operator performance: a task analysis. We begin with a set of task analysis objectives and subsequently discuss the means by which our research has satisfied each objective. A brief description of our task analysis methodology is followed by a discussion of results. Implementation of the task analysis methodology is demonstrated through an example. In this example, the tasks defined for Function 2.1.1.2 (Anticipate Near-Term Traffic Conditions) are presented. Recognize that no discussion of operator task performance would be complete without a discussion of operator workload. Consequently, this section concludes with such a discussion.

TASK ANALYSIS OBJECTIVES

The primary objectives of the operator task analysis are to:

- Identify the operator tasks required for successful execution of each ATMS function.
- Ensure that the operator tasks associated with a given function satisfy the performance requirements imposed by the operator role assigned to that function.
- Provide an organizational framework (categorization) for operator tasks.
- Identify significant maintenance tasks.
- Describe operator tasks in sufficient detail (and context) to support the preparation of a human factors specification.

A detailed task analysis, the results of which are to follow, identified a total of 363 required operator tasks and 485 related tasks.[9] (Related tasks are subtasks of required tasks. More detailed definitions of these two task categories are provided in the discussion focusing on methodology.) Each ATMS function, in addition to being defined in terms of a four-stage information processing model (input, processing, response selection, output), is represented by a list of operator tasks. The nature of the tasks assigned to a given function reflect the demands imposed (on an operator) by that function's designated operator role. In this manner, task analysis objectives one and two are satisfied. A good example of the "matching" of task nature to operator role can be demonstrated through the Executive Controller functions. Executive Controller functions are fully automated, and operators have no control capabilities other than enabling or disabling function execution. Consequently, operators are required to (1) monitor function output, (2) determine if a function disable (enable) is required, and if necessary, (3) disable (enable) the function. All Executive Controller functions are characterized by this sequence of tasks.

Our task analysis also yielded an organizational framework for operator tasks, where each task was assigned to one of six categories. These task categories are *communications, coordination, decision-ma king, information processing, observation,* and *outcome.* Appendix E lists the 363 required operator tasks, and Appendix F lists the 485 related tasks according to these categories, satisfying task analysis objective three.

ATMS functionality supports a range of maintenance capabilities, and from these maintenance functions, we can derive a set of maintenance-related operator tasks. A total of 10 ATMS functions are based on maintenance capabilities. These functions are listed below:

Function 1.1.2.2.1. Receive BIT Reports
Function 1.1.2.2.2. Receive Ad Hoc Component Status Reports
Function 2.2.2.1. Determine Remedial Maintenance Needs
Function 2.2.2.2. Determine Preventive Maintenance Needs
Function 2.2.3.1. Determine Software Upgrade Needs
Function 2.2.3.2. Determine Hardware Upgrade Needs
Function 3.2.1.1. Transmit Electronic Maintenance Requests
Function 3.2.1.2. Issue Special Maintenance Requests
Function 3.2.2. Issue Upgrade

Requests
Function 4.2.2. Provide Maintainer Training

Note that maintenance activities are distributed across all four function types: input functions (1.1.2.2.1 and 1.1.2.2.2), throughput functions (2.2.2.1, 2.2.2.2, 2.2.3.1, and 2.2.3.2), output functions (3.2.1.1, 3.2.1.2, and 3.2.2), and support functions (4.2.2). Results of the most detailed analysis of maintenance tasks are to follow, and a summary of maintenance tasks is presented in appendix G. Through these analysis results and the task summary presented in appendix G, task analysis objective four is satisfied.

The authors of reference 9 accompany the task list defined for each ATMS function with a detailed task description. The intent of such a description, together with its respective task list, is to provide sufficient context to support preparation of the human factors specification for TMC configuration items (task analysis objective five). Reference 10 documents the human factors specification.

METHODOLOGY: OPERATOR TASK ANALYSIS

Here, the methodology employed in the derivation of operator tasks is presented. The task analyses conducted as a result of this research effort were of an analytical nature and were performed by a team of human factors specialists. A two-phased analysis was conducted.

Phase One

In the initial phase, a *context-free* task analysis was conducted. That is, each function was assessed solely in terms of its designated operator role and information processing model description. From this description, a set of operator activities and responsibilities was derived. Note that a function's role designation, as well as the levels of automation (levels of operator involvement) assigned to its information processing stages, motivated the kinds of tasks derived for that function. Fully automated functions, for example, require an operator to monitor (oversee) function execution, rather than to take direct responsibility for function execution.

Once the operator activities were derived, they were assigned to one of two categories of task type. These categories are referred to as required tasks and related tasks. Required tasks represent a core set of activities the operator must perform in order for successful execution of the associated function. In other words, when a given function is executed, an operator performs all of the required tasks associated with that function. Required tasks also represent a high level set of activities. This reference to high level activities has particular meaning when one considers the second category of task type: related tasks.

Related tasks are subtasks of required tasks. They are performed during the course of the operator's completion of required tasks. In essence, related tasks support completion of required (high level) tasks. A related task may be unique to a given function, or it may appear as a related task in more than one function. In some instances, related tasks are required tasks of other functions. Note that completion of all related tasks associated with a given function may not be required for successful execution of that function. Execution of the function may require completion of only a subset of related tasks. This particular operator performance requirement (i.e., completion of related task subsets) has the following implication: The context in which a function is executed will determine the related tasks that are appropriate for completion of that function.

The initial phase of this task analysis also yielded a task description. This description provides an overview, a global perspective, of the required operator tasks. The task description serves as an introduction to the list of required tasks.

Phase Two

Phase two of the task analysis validated the results of our context-free analysis. During phase two, each of the four reference scenarios documented in reference 5 was analyzed according to operator tasks, where this analysis was anchored to the scenario's milestones. Note that each milestone is associated with a set of functions, and in turn, each function is associated with the tasks derived in phase one. Thus, the scenarios were used as a means of applying the results obtained in phase one.

The scenarios also enabled us to impose a sense of context onto the task analysis, and consequently, a number of tasks (unidentified in the context-free analysis) were recognized once their respective functions were placed within the context of a traffic scenario. Any newly identified operator task (for a given function) was assigned to the list of required tasks or to the list of related tasks specified during phase one. If the new task represented a high level (core) task, it was assigned to the list of required tasks; however, if the new task represented a subtask, it was assigned to the list of related tasks. Thus, the results obtained from each scenario task analysis enabled us to update (in an iterative fashion) our required and related tasks.

Scenario task analyses were of an analytical nature and were performed by a team of human factors specialists. In summary, the task analysis results to follow represent the outcome of the two-phased process.

TASK ANALYSIS RESULTS

Each ATMS function was analyzed in terms of the operator tasks associated with successful execution of that particular function. In this analysis, a given task was assigned to one of two categories: required task or related task. Required tasks represent a core set of activities the operator must perform in order for successful execution of the respective function. In other words, when a given function is executed, an operator performs all of the required tasks assigned to that function. Required tasks also represent a high level set of activities.

An assessment of all operator tasks (required and related) enabled us to establish six categories of task type: communications tasks, coordination tasks, decision-making tasks, information processing tasks, observation tasks, and outcome tasks. Each required and related task was assigned to one of these six task types. Appendixes E and F provide the results of this assignment exercise, where required tasks (appendix E) and related tasks (appendix F) are listed according to task type. Note that maintenance-related tasks appear in boldface type.

Communications tasks represent those activities that require TMC operators to receive and transmit information, where this information arrives from (and is distributed to) internal and external sources. Communications tasks encompass the following actions: distribute, exchange, initiate, issue, provide, receive, report, transmit (and retransmit).

Coordination tasks reflect activities requiring the TMC operators to plan, formulate strategies, and cooperate with other individuals or agencies that may be internal or external to the TMC. Coordination tasks encompass the following actions: conduct, continue, initiate, maintain, acknowledge, comment on, conform to, designate, interact with, share.

Decision-making tasks suggest activities that are performed as a result of reasoning strategies or cognitive processing implemented by the TMC operator. Decision-making tasks are performed once the operator recognizes that (1) the ATMS is awaiting a response or (2) intervention of ongoing system functions is necessary. Decision-making tasks incorporate the following actions: determine, enter, implement, interact with, modify, override.

Information processing tasks require the operator to analyze incoming information such that some form of reasoning strategy is implemented. These tasks encompass the following actions: assess (and reassess), assimilate, compare, evaluate, review, select

Observation tasks involve the TMC operator's ability to oversee (and manage) ATMS events, where such events may be anticipated or unanticipated. The following actions are associated with observation tasks: confirm, detect, ensure, identify, monitor, recognize, validate, verify.

Outcome tasks represent end products. Typically (within the context of ATMS activities), end products are analysis results. The operator's performance of outcome tasks ensures that these results are conveyed. Such tasks characterize the types of end products generated from traffic management activities. The following actions are associated with outcome tasks: create, develop, devise, establish, formulate, manipulate, prioritize (and reprioritize), program, reassign, recommend, retrieve, simulate, specify, store, update, write.

Our task analysis identified a total of 363 required tasks and 485 related tasks. Required operator tasks were distributed in the following manner: 116 communications tasks (32 percent), 7 coordination tasks (2 percent), 22 decision-making tasks (6 percent), 46 information processing tasks (13 percent), 125 observation tasks (34 percent), and 47 outcome tasks (13 percent). Related operator tasks were distributed in the following manner: 154 communications tasks (32 percent), 29 coordination tasks (6 percent), 25 decision-making tasks (5 percent), 56 information processing tasks (11 percent), 113 observation tasks (24 percent), and 108 outcome tasks (22 percent).

Results of the task analysis suggest that the configuration of human and machine components assigned across the four processing stages of a given function will enable us to predict the general nature of the tasks specified for that function. Consider, for example, fully automated (executive controller) functions. In such functions, rather than executing a given activity, an operator monitors machine-execution of that activity.

Maintenance Tasks

ATMS functionality encompasses a number of maintenance-related responsibilities. A total of IO lowest-level ATMS functions reflect requirements for maintenance activities. Of these IO functions, 8 are subfunctions of 4 higher order maintenance functions. These four high level functions are Function 1.1.2.2: Sense Electronic Component Status, Function 2.2.2: Determine Maintenance Needs, Function 2.2.3: Determine Upgrade Needs, and Function 3.2.1: Issue Maintenance Requests. The eight maintenance subfunctions corresponding to this set of higher order functions, as well as each subfunction's designated operator role, are provided below.

- Function 1.1.2.2. Sense Electronic Component Status
  - Function 1.1.2.2.1. Receive BIT Reports (Executive Controller)
  - Function 1.1.2.2.2. Receive Ad Hoc Component Status Reports (Direct Performer)

- Function 2.2.2. Determine Maintenance Needs
  - Function 2.2.2.1. Determine Remedial Maintenance Needs (Supervisory Controller)
  - Function 2.2.2.2. Determine Preventive Maintenance Needs (Supervisory Controller)

- Function 2.2.3. Determine Upgrade Needs
  - Function 2.2.3.1. Determine Software Upgrade Needs (Direct Performer)
  - Function 2.2.3.2. Determine Hardware Upgrade Needs (Direct Performer)

- Function 3.2.1. Issue Maintenance Requests
  - Function 3.2.1.1. Transmit Electronic Maintenance Requests (Executive Controller)
  - Function 3.2.1.2. Issue Special Maintenance Requests (Manual Controller)

The two remaining maintenance functions and their respective operator roles are provided below.

- Function 3.2.2. Issue Upgrade Requests (Direct Performer)
- Function 4.2.2. Provide Maintainer Training (Manual Controller)

A summary of all required maintenance tasks is provided in appendix G. A total of 47 maintenance tasks (i.e., 13 percent of all required operator tasks) are specified. Note that the percentage of required maintenance tasks is approximately equal to the proportion of maintenance functions derived as a result of the function analysis reported in reference 13. That is, 10 of 113 functions (9 percent) were related to maintenance functionality.

Note that ATMS functionality does not encompass maintenance activities directly related to the repair of components in the field. Rather, the ATMS focuses on (1) receiving adequate levels of information on current conditions such that data reflecting system degradations and malfunctioning components are available, (2) identifying maintenance needs in a timely manner, (3) issuing maintenance requests to the appropriate set of service providers, and (4) conducting maintenance training. These functional requirements were derived in response to the guidance we received from our IVHS experts. [11] One feature of the ATMS environment that guided functional development toward the *overseeing* of maintenance activities, rather than the actual *implementation* of such activities, is reiterated in the following statement.

"Multiple political jurisdictions comprise the area served by the ATMS, including a large central city plus smaller surrounding cities, and scattered unincorporated areas under the control of the various counties in the metropolitan area." [11,page7]

Due to the various political boundaries over which the ATMS is likely to operate, our IVHS experts considered maintenance implementation issues to be most appropriately addressed by individual localities. Consequently, such issues are not included in the existing ATMS functionality derivation.

Required maintenance activities are distributed across all task categories in the following manner: 17 communications tasks, 1 coordination task, 3 decision-making tasks, 2 information processing tasks, 17 observation tasks, 7 outcome tasks. The majority of maintenance-related activity (72 percent) is dedicated to receiving component status data, receiving system upgrade information (hardware as well as software upgrade data), issuing maintenance requests, and overseeing (recognizing, identifying) maintenance needs. To a lesser, but not insignificant, degree (15 percent), operator tasks focus on the results (outcomes) of various maintenance analyses (e.g., the prioritization of maintenance requirements, the development of maintainer training materials, and the prioritization of hardware/software procurement efforts).

Fifty-six of the 485 related tasks specified in appendix F (i.e., 12 percent of all related tasks) reflect maintenance activities. These tasks appear in boldface type. Of these 56 tasks, the following distribution of task categories is apparent: 26 communications tasks (46 percent), 3 coordination tasks (5 percent), 2 decision-making tasks (4 percent), 4 information processing tasks (7 percent), 15 observation tasks (27 percent), and 6 outcome tasks (11 percent). Once again, the majority of maintenance activity (among the related tasks) is assigned to communications and observation responsibilities (73 percent). Furthermore, six of all related maintenance tasks (11 percent) focus on outcomes.

These distributions of maintenance tasks do indeed reflect the maintenance focus suggested by our IVHS experts.

Task Analysis Example

Consider once again Function 2.1.1.2: Anticipate Near-Term Traffic Conditions. (Recall that in Section 3 this function was used to demonstrate the function allocation methodology.) The task description established for Function 2.1.1.2, as well as the required and related tasks derived from implementation of the two-phased task analysis approach, are provided in the example to follow.

Example

Function 2.1.1.2: Anticipate Near-Term Traffic Conditions

<u>Operator Role</u>: Supervisory Controller

<u>Task Description</u>: Current load assessments and roadway status reports are reviewed. Input data are processed via a near-term traffic model, and inaccuracies are identified and modified. Predictions are recorded. If necessary, traffic predictions are overridden.

<u>Required Tasks</u>: monitor near-term traffic predictions (traffic volumes, densities, speeds), identify predictions that must be overridden (inaccuracies imprecision), determine alternative predictions, modify input information (if necessary), override traffic predictions (if necessary)

<u>Related Tasks</u>: monitor traffic prediction information, monitor input information (current load assessment, current roadway system status, external report information), validate input information, identify invalid input information, monitor traffic control information

DISCUSSION OF OPERATOR WORKLOAD

The term *workload* refers to the cognitive, as well as physical, demands placed on an operator as a function of task performance.

Consider the nature of ATMS operator tasks (as characterized by the categories established as a result of this research effort -- *communications, coordination, decision-ma king, information processing, observation,* and *outcome).* Within the context of the ATMS environment, an assessment of mental workload has more relevance than one of physical workload.

According to Gopher and Donchin, workload characterizes the interaction between an operator and a given task?[15] Specifically, any task is performed with respect to specified structural features. That is, the task is defined in terms of stimuli and responses, where a set of rules defines the manner in which stimuli are mapped to responses. Additionally, expectations regarding the quality of operator task performance are important. Expectations of task performance quality are derived from our knowledge of the relationship between task structure (the rules mapping stimuli to responses) and human capabilities and skills. Expectations may also be based on our knowledge of operators' previous performance or on our knowledge of operators' performance of similar tasks. In some cases (even under circumstances in which an operator is sufficiently motivated to perform a given set of tasks and intends to perform these tasks according to the expected standards) the established expectations are not satisfied. Such performance failures can be attributed to increased task difficulty or to limitations in attentional resources. Workload assessment represents an attempt to explain these performance failures.

Current interpretation of the mental workload concept suggests the existence of limitations in operators' abilities to process information. Given a target task and the potential for such limitations to be realized, an operator may find his information processing capabilities ineffectual in performing the target task. One assumption associated with task performance is described as follows. Task performance is dependent upon *effectors* (through which responses are made) and *sensors* (through which stimuli are intercepted). The path from sensors to effectors is represented via a complex information processing "structure." Associated with this structure are various properties, one of them being a limited capacity. Thus, mental workload may be defined as the difference between two quantities: the capacity that is required to ensure expected task performance and the capacity available at any given time. In other words,

$$W = C_{required} - C_{available}, \tag{1}$$

where

W = mental workload (2)
$C_{required}$ = required capacity (3)
$C_{available}$ = available capacity. (4)

Task difficulty and attentional resource limitations are manifested by a difference between expected and actual performance.

According to Meister, workload can be imposed in a number of ways.[16] At the input of a system, workload may be imposed by stimuli that drain attentional resources and load an operator, causing that operator to perceive a burden. Workload is also defined in terms of the internal sense of difficulty and discomfort experienced by an operator. Note that workload is detected only when the operator recognizes difficulty and discomfort and subsequently formulates a strategy to overcome the burden. At the output of a system, workload affects not only operator performance but system performance as well. Meister characterizes workload in the following manner?

- System feature forcing an operator to work harder.
- Perception of stress (on the part of the operator).
- Recognition (on the part of the operator) of the requirement to work harder.
- Operator errors occurring as a result of stress and increased work effort.

Recognize that workload (imposed as a result of operator-task interaction) is of relevance only within the context of a designated set of events. That is, assigning a workload rating to an isolated task (without considering the environmental conditions that may affect task performance) is somewhat meaningless. Within the bounds of our ATMS research, contextual information is afforded by the four second-generation scenarios. Results of our scenario task analysis suggest the following: If we assume a single-operator TMC, the single operator will experience an inordinately high level of workload. Workload can be reduced with the introduction of additional operators. At this stage of our research, however, the optimal number of operators is unknown. Consequently, as researchers, we believe that an accurate assessment of workload can be conducted only when empirical results from a detailed analysis of job design, job allocation, and team performance, (i.e., results from an analysis of multiple-operator TMC's) are available. The TMC simulator experiments described in reference 17 will address issues of job design and allocation, as well as team performance, and are intended to yield assessments of workload.

A proposed approach for conducting an initial assessment of workload was to consider each task (as it appears within the context of a given scenario) and assign a performance time to that task. Recall that scenario events are specified according to a set of milestones (timeline events). Our initial approach was to consider consecutive milestones (M_x and M_{x+1}) and calculate the time difference between them. In this manner, we could establish time constraints for a given set of operator tasks. That is, the tasks performed between M_x and M_{x+1} would be completed during the time window M_{x+1}-M_x. Once our analysis began, however, we determined that a given milestone only suggests the time at which its respective set of tasks must begin; it does not necessarily indicate the end point of task performance. In other words, task performance might extend beyond an M_{x+1} milestone. Given such conditions, our alternative was to estimate task performance times. With no available empirical or expert data to guide us, such an approach appeared to be ad hoc at best and unscientific in general. Consequently, our intent is to rely on empirical data obtained from the TMC simulator experiments to provide more meaningful evaluations of operator workload!')

SECTION 6.
HUMAN FACTORS SPECIFICATION

INTRODUCTION

This section presents a human factors specification developed for the ATMS. [10] Development of a human factors specification represents the sixth and final step of the top-down system analysis process. In general, any human factors specification is driven by analyses of operator performance requirements and operator tasks (Steps 4 and 5 of the top-down system analysis). Furthermore, results obtained from these analyses of the human operator are driven by the function allocation process (Step 3 of the top-down system analysis).

The human factors specification developed for the ATMS was no exception. That is, results of the function allocation process enabled us to define appropriate operator performance requirements and operator tasks for each ATMS function. Specifically, task analysis results suggest that the configuration of human and machine components assigned across the four processing stages of a given function (i.e., the manner in which human and machine components are allocated to a given function) will enable us to predict the general nature of the operator tasks specified for that function. Consider, for example, fully automated (executive controller) functions. In such functions, rather than executing a given activity, an operator only monitors machine-execution of that activity. Consequently, tasks defined for executive controller functions reflect this form of human-ATMS interaction.

In defining ATMS functionality, completing the function allocation process, and then in turn conducting analyses specific to the human operator, we considered the following question. Through what means will ATMS functionality be executed? That is, what machines, apparatus, or devices will facilitate the satisfactory execution of ATMS functions? In addressing the issue of function execution, we defined a set of support systems. Consequently, support systems represent the means by which ATMS functionality is executed. In general, a support system is a tool (hardware and/or software) through which an operator interacts in order to ensure that ATMS functions are satisfactorily executed.

Our initial support systems analysis yielded a set of nine idealized (conceptual) support systems. [5] Capabilities required for the following support systems were defined:

- Adaptive Traffic Control System (ATCS).
- Predictive Traffic Modeling System (PTMS).
- Incident Detection and Location System (IDLS).
- Incident Response and Advisory System (IRAS).
- Information Dissemination System (IDS).
- Intermodal Transportation Planning System (ITPS).
- Traffic Management Training System (TMTS).
- Maintenance Tracking System (MTS).
- Traffic Data Management System (TDMS).

Based on further analyses of operator performance requirements, we identified the need for three additional support systems. Capabilities required for these support systems were defined: [8]

- Communications Support System (CSS).
- Administrative Support System (ADSS).
- Maintainer Training Support System (MTSS).

The resulting 12 support systems (and the capabilities assigned to each system) provide a mechanism by which all 113 ATMS functions can be executed. In other words, these 12 support systems reflect (completely) ATMS functionality. Note that the capabilities analyses documented in references 5 and 8 focused on idealized support systems, where the capabilities of such systems are conceptual in nature. In other words, the capabilities assigned to a given idealized support system serve as a model for those ultimately implemented and incorporated in an operational ATMS.

In developing the ATMS human factors specification, we first defined the capabilities appropriate for each of the 12 support systems and then established a set of human interface requirements for each system. [10] Each set of interface requirements identified and described the information to be provided to the system by operators. Associated with the support systems is a set of hardware configuration items used by operators for voice and text communication, information/data collection, information processing, and data archiving. Some of these configuration items represent stand-alone systems (e.g., electronic mail or fax systems), while other items are incorporated into a given multipurpose system, where such a system is typically computer based.

In the following subsection, the human factors specification derived for each support system is documented. The specification derived for a given support system includes a detailed description of the system's capabilities, as well as results of the human interface requirements analysis conducted for that system. Following our analysis of support system capabilities and interface requirements is a discussion of the hardware configuration items associated with the support systems. Note that by developing the human factors specification such that it focuses on the support systems, we ensure that the specification reflects all functional characteristics of the ATMS, as well as the operator performance requirements and operator tasks defined by ATMS functionality.

SUPPORT SYSTEMS

In this subsection the capabilities and interface requirements derived for each support system are presented. System capabilities are analyzed with respect to global functionality, as well as specific activities. [9] The list of activities accompanying each system's global description is not intended to be exhaustive. Rather, it introduces the reader to the duties assigned to a support system and the types of information to which ATMS operators will be exposed. Each capabilities analysis suggests (1) the nature (and format) of the information an operator receives, (2) the range of decisions an operator must make (including the types of events the operator must resolve), and (3) the responses (outputs) required of an operator. The intent of the capabilities descriptions is not to specify an implementation strategy but to specify a set of attributes and activities we believe are appropriate for future implementations. The interface requirements derived for each support system identify and describe the information displayed to operators via the support system interface, as well as information to be provided to the system by operators.

Adaptive Traffic Control System (ATCS)

System Capabilities

The ATCS will optimize current traffic flow. It will receive roadway sensor data and use it to control traffic signal timing and ramp metering. The ATCS will maintain optimal flow by automatically responding to current traffic. A key feature will be the ability of the ATCS to *integrate control across surface streets and freeway traffic.* When, for example, ramp meter cycle times are increased to dampen flow onto a freeway, traffic signal cycle times at intersections feeding the freeway ramp are adjusted appropriately. The algorithms used by the ATCS will be sufficiently robust to automatically accommodate unusual traffic patterns (e.g., special event patterns). The ATCS will be assigned the responsibility of making low-risk "predictions," where any traffic condition forecasts provided by the ATCS have a low risk of being inaccurate. Control strategies to be implemented by the ATCS require neither operator review nor approval. Rather than describe the ATCS's look-ahead capabilities as predictive, we suggest that the ATCS only *anticipates* near-term traffic conditions (c. 1 to 5 min). ATCS activities include the following:

- Anticipate near-term traffic conditions.
- Coordinate passage of rail vehicles.
- Determine roadway access control measures required by an optimal control scheme.
- Implement traffic control options.
- Receive "best" traffic control option.
- Receive current road conditions.
- Receive current traffic conditions.
- Receive ATMS responsibilities in responding to/managing incidents.
- Receive predicted road conditions.
- Receive predicted traffic conditions.
- Receive recommended level of ATMS support for special vehicles.
- Request network data.
- Request roadway sensor data.

- Specify traffic signal timing sequences required by an optimal control scheme.
- Specify traffic signal timing sequences required by incident response approaches.
- Support development of feasible incident response strategies.
- Translate control measures into commands issued to control devices.

Human Interface Requirements

The ATCS will be assigned the responsibility of making low risk predictions. In other words, traffic condition forecasts provided by the ATCS will have a low probability of inaccuracy. The ATCS will typically implement control strategies without operator review or approval. Operators will be provided the capability to review currently implemented strategies on an intersection-by-intersection basis via a signal status display. Multi-intersection signal status displays (employing appropriate icons and color coding) will enable operators to review wider regions of the network.

The operator can disable the ATCS if ineffective or erroneous control actions are implemented. Once the ATCS is disabled, traffic signal timing plans will default to predefined demand or time-of-day strategies. An "error trap" will be incorporated in the process for disabling the ATCS such that (at least) a two-step sequence will be required. In most instances, the Predictive Traffic Modeling System (PTMS) will recognize when ATCS responses are inappropriate and must be overridden. Once ATCS control actions are disabled or overridden by the PTMS, a message to that effect will be conspicuously displayed on the operator's primary displays.

Operators will be provided limited access to the direct control of individual intersection controllers (e.g., creating a "green wave" of signals for emergency vehicles). Operator functions will be implemented via keyboard or mouse input devices.

Predictive Traffic Modeling System (PTMS)

System Capabilities

The PTMS will use current data, historical data, and weather forecasts to predict traffic flow a few minutes into the future (c. 5 to 30 min). PTMS predictions will allow *preemptive actions* to be taken well before an actual traffic problem arises. The following current data will be used by the PTMS: traffic data, data from roadway surface condition and visibility sensors, O-D data from vehicles currently traveling the roadway system, and incident data. Historical data will include time-of-day and day-of-week profiles, appropriately adjusted for special conditions (e.g., inclement weather and special events). Ramp metering and traffic signal timing patterns currently implemented by the ATCS will be used in making predictions. Predictions will also consider existing ATMS advisories. For instance, the PTMS will predict the percentage of people taking an alternate route once it is suggested on a variable message sign (VMS), and use this prediction in forecasting future traffic conditions. The PTMS will also be used to predict the effects of changes in traffic control timing patterns and of changes in advisories issued by the ATMS. Thus, it will be used to evaluate candidate traffic management techniques in unusual conditions (a *what if* capability) such as those generated by the presence of a major incident. Knowing what control strategy the ATCS will implement in response to a given traffic condition, the PTMS will recognize when that response must be modified. PTMS forecasts will have a higher risk of being inaccurate than forecasts provided by the ATCS. Consequently, any recommendations that suggest how the ATMS should respond to PTMS predictions must be reviewed and approved by an operator. PTMS activities include the following:

- Assess incident data (negative impact on traffic flow).
- Assess quality of a control option.
- Assess weather pattern's impact on traffic flow.
- Assess weather service data.
- Assess effectiveness of traffic management strategies.
- Conduct tactical traffic planning.
- Derive control option scores.
- Perform near-term simulations.
- Predict traffic conditions given options.
- Predict rail traffic location.
- Prioritize control options.
- Prioritize rail traffic information (assess negative impact on traffic flow).

- Prioritize roadway conditions (assess negative impact on traffic flow).
- Receive traffic control options currently in effect.
- Request incident data.
- Request network data.
- Request O-D data.
- Request roadway sensor data.
- Track special vehicles.

Human Interface Requirements

The PTMS will serve as a decision aid from which operators are to obtain information on predicted traffic flows. (Decisions related to control actions and information dissemination options are to be reached.) Information will be presented via a color coded roadway map at two levels of detail: a large-scale presentation of the entire roadway network or a detailed ("zoomed-in") presentation of a 13 to 26 km^2 (5 to 10 mi^2) region of the network. PTMS predictions will be conspicuously identified as such in order to preclude confusion with actual traffic data.

Operators will have the ability to review predictions of 5, 10, 15, 20, or 30 min into the future. An option for rapid display of these predictions (in sequence) will be provided. This option will enable operators to visualize projected changes in traffic flow patterns as a function of time. A menu-based interface will enable operators to initiate this sequencing of predictions.

The PTMS will also have the ability to operate in a simulation mode. In this mode simulations of traffic conditions, indicating the manner in which traffic can be expected to respond to a range of candidate input conditions, are performed (a *what if* mode). Note that the PTMS will have a parallel processing capability. Such a capability will enable the PTMS to continue its prediction activities while it conducts simulations requested by an operator. In other words, routine prediction capabilities are not suspended when the PTMS is placed in its simulation mode. Most important, the operator will have ready access to ongoing predictions (that rely on current traffic flow measures, incident parameters, ramp meter and signal timing plans, and VMS/HAR advisories) independent of the support system's current mode of operation. The PTMS will be placed in its simulation mode via a menu command. Subsequently, operators will enter all information required by the simulation (e.g., timing plan changes and advisory changes) via menu and keyboard inputs. Operators must have the option of recording simulation results. A single menu entry will terminate the simulation mode and enable the operator to view information solely associated with the prediction mode.

Information presented during each of the two operating modes (prediction mode versus simulation mode) must be clearly distinguishable. Operators will have access to predicted traffic conditions and simulation results. Both types of information are to be displayed. Consequently, the potential for operators to confuse existing/projected traffic conditions and simulated conditions must not exist.

The PTMS will have complete knowledge of the control strategy repertoire available to the ATCS. Furthermore, the PTMS will have knowledge of the control strategy to be implemented by the ATCS in response to given traffic conditions, and will recognize when that response must be adjusted. The operator must be aware of those instances in which the PTMS recognizes the need to override ATCS control strategies. Any recommendation that suggests a TMC response to a given PTMS prediction must be reviewed and approved by the operator.

The PTMS may also have a capability to evaluate, recommend, or prioritize TMC actions. The results of such analyses, and the basis for these outcomes, will be displayed to the operator for approval, modification, or rejection. Approval/rejection may be implemented via mouse or keyboard commands; modification may be implemented via keyboard entry.

Incident Detection and Location System (IDLS)

System Capabilities

The IDLS will receive data from roadway sensors and from external data links. Its purpose will be to detect and verify the presence of incidents on the roadway system and to determine the *exact location of an incident.* In some cases the first indications of an incident will be abnormalities in traffic flow in the immediate area. (Thus, it will identify anomalies characteristic of a potential incident.) In other cases, especially when traffic volumes are light, the first indications may come from other sources (e.g., calls from cellular phone users) that subsequently result in an entry into a dispatch data base. Incidents, as defined by the IDLS, will include system malfunctions (e.g., traffic signal outages) as well as traffic problems. Upon detection of a probable incident and determination of its apparent location, the IDLS will attempt incident verification. The IDLS will provide a preliminary estimate of incident severity (perhaps via a simple color-coding scheme -- yellow or red) based on the data available. The IDLS will have the capability to learn from experience. IDLS activities include the following:

- Correlate traffic flow data with dispatch and maintenance information.
- Detect traffic pattern anomalies.
- Determine anomaly location.
- Determine anomaly source.
- Nominate anomaly as a potential incident.
- Report anomalies.
- Report anomaly location.
- Report anomaly source.
- Request network data.
- Request roadway sensor data.
- Request traffic flow data.
- Support preparation of incident reports.
- Validate incident information.

Human Interface Requirements

The IDLS will alert operators to the occurrence of potential incidents. Based on the data it receives from roadway sensors and external data links, the IDLS will detect and verify the presence of roadway anomalies. It will also determine the exact location of the detected anomaly. Incidents, as defined by the IDLS, will include system malfunctions (e.g., traffic signal outages, signal timing phase problems), as well as traffic problems (e.g., major/minor freeway accidents, major/minor surface street accidents, hazardous waste spill).

A key component of the IDLS will be a roadway map displayed at an operator's workstation. Upon initial detection of a potential incident, the IDLS will alert an operator of its findings. One means of providing incident awareness is through a flashing indicator (color coded according to the support system's preliminary estimate of incident severity) displayed on the operator's map. This type of indicator, appearing at the anomaly location determined by the IDLS, would serve as an initial alert. In this manner, an immediate indication of both the existence and location of a potential incident can be provided. Depending upon resolution (level of detail) of the map display, incident location may be imprecise; that is, the map may only indicate a general region for the incident.

A more precise specification of incident location must be reported automatically (and in conjunction with the flashing indicator) via a separate "incident report" display in which the location of a potential incident is provided. In this manner the detection of a potential incident is reiterated, and a more precise location specification is provided. An audible tone, signaling the presence of a new incident report, would alert the operator to this recent change in traffic conditions. For freeway incidents, location must be specified according to a freeway identifier, heading information (direction), and freeway "coordinates". Freeway coordinates may be represented through exit numbers (e.g., potential incident: I-85 North between exit 8 and exit 9). In some instances, names of interchanges may be more meaningful (e.g., potential incident: I-85 North between Lenox Road and North Druid Hills Road). Under these conditions, interchange names represent an alternative coordinate scheme. Surface street anomalies will be reported in a similar manner, where a street identifier, heading information, and street coordinates define incident location.

The "incident report" might reinforce the color coded information of the flashing indicator (preliminary severity estimate) by displaying a severity measure. (One such measure reveals roadway blockage: the number of lanes blocked or percentage of the roadway blocked.) The "incident report" display might also be used to specify a camera or set of cameras that could provide views of the incident site. Such views would enable the operator to verify the existence of an incident, obtain more detailed incident information (e.g., anomaly source (hazardous waste spill, equipment malfunction, single vehicle accident, multiple vehicle collision), types of vehicles involved, existence/status of injuries), and to monitor conditions at the site. Note that not all incident sites will be afforded an appropriate (useful) camera view, and in such instances, the operator must rely on other communication links in order to obtain sufficiently detailed information (e.g., onsite law enforcement officers, emergency service providers summoned to the incident site, passing motorists).

In some instances, specifically when traffic volumes are light, the first indications of a potential incident may not arrive via roadway sensors, but from the communication links typically available to the TMC (e.g., reports from cellular phone users, camera views). Under these conditions (i.e., when an "incident report" is not automatically generated), the IDLS must facilitate the manual entry of incident parameters.

Incident Response Advisory System (IRAS)

System Capabilities

The IRAS will assist in determining the appropriate response to an incident. IRAS advice will include options for controlling traffic and disseminating information. Responses to an incident may include (1) informing motorists of a slight delay, (2) re-routing a portion of traffic, (3) no action on the part of the ATMS, or, in extreme cases, (4) closing a major freeway and re-routing all traffic. In the case of traffic re-routing, the IRAS will determine optimal alternate route(s). It maintains the following knowledge: which incident responders to request for a given type of incident, the direction from which incident responders will come, how to direct responders to the incident site, whether special support measures will be required (e.g., closing a downstream exit ramp and directing service vehicles to enter the incident scene (from the wrong direction) via this ramp). The IRAS will learn from experience. It will also monitor incident clearance and assist in determining the point at which normal operations should resume. The IRAS will, for example, determine when to clear an advisory message from a VMS. The IRAS will also provide a simulation capability that allows evaluation of various response alternatives. (Under these conditions it will use a version of the PTMS to obtain predictions. This type of simulation will use current traffic data and must be performed many times faster than real time.) IRAS activities include the following:

- Assess interagency incident data.
- Determine appropriate levels of support for special vehicles.
- Identify point at which normal operations should resume (detect incident clearance).
- Formulate incident management report.
- Formulate incident service requests.
- Formulate instructions to incident responders.
- Monitor incident clearance.
- Receive anomaly detections/locations.
- Receive incident data.
- Receive information regarding interactions between rail and roadway vehicles (current and predicted).
- Receive interagency incident data.
- Recommend levels of support for special vehicles.
- Support development of feasible incident response strategies.
- Support formulation of traffic management response (due to rail traffic data).
- Support ATMS in determining its role in managing/responding to an incident.
- Support preparation of incident management reports.
- Support preparation of incident service requests.

Human Interface Requirements

The IRAS will support operators in establishing an appropriate set of incident responses. The IRAS will recommend options for controlling traffic (e.g., re-routing traffic, adjusting parameters of signal controllers, defining one-way thoroughfares, closing a major freeway and subsequently establishing detours to accommodate the closed freeway) and suggest information appropriate for dissemination to motorists (e.g., information indicating that motorists will experience a slight delay, incident severity messages, re-routing instructions). In some instances the optimal incident response will require no action on the part of the TMC, and the IRAS will recommend that no action be initiated. The IRAS also supports the timely arrival of appropriate emergency service providers at an incident site. It has knowledge of (1) what incident responders to request for an incident of a given type and severity, (2) the direction from which incident responders will come, (3) how to direct responders to the incident site, and (4) whether special support measures will be required to ensure that incident responders arrive at the incident site.

The primary responsibilities of the IRAS are to support the timely resolution of incidents and to facilitate operator situation awareness as incidents are resolved. Information provided by the IRAS will be presented through an "incident response" display. This display will recommend traffic control strategies and indicate the type of information most appropriate for dissemination to motorists. The implementation of system-determined traffic control strategies will not be contingent upon operator approval; however, the operator will have an override option. (Such a feature will enable specialized or heuristic knowledge acquired by the operator to be incorporated into the incident management process.) In situations where several control strategies are appropriate, the IRAS will prioritize them according to a standard criterion (e.g., greatest flow rate) or set of criteria. The most highly ranked strategy will be implemented unless the operator initiates an override. For those instances in which the operator overrides an IRAS-recommended control strategy, the operator must have the ability to either select an alternative strategy (if a lower priority strategy is desired) or specify a strategy not recommended by the system and then execute an "implement control strategy" command.

The IRAS may be designed such that the criteria for ranking traffic control strategies are operator-specified. That is, the operator designates a single criterion (from a list of predefined criteria) against which control strategies are to be ranked. Another option might be for the operator to designate multiple criteria (rather than a single criterion) against which control strategies are to be ranked. Under this option, final rankings are the result of a concurrent consideration of the designated criteria. Given a feature in which criteria are selectable, the operator might also define multiple criteria sets, review the IRAS-generated recommendations associated with each criteria set, and compare across these recommendations. Note that accompanying any IRAS recommendation or prioritized list of recommendations must be a clear indication of the criteria considered in developing recommendations.

The IRAS will also provide a simulation feature through which operators will have an ability to predict the outcome of recommended response alternatives. Note that this type of simulation will use current traffic data and must be performed faster than real time. Simulations will run in parallel to the response advisory activities for which the IRAS is responsible.

The IRAS is responsible for suggesting the types of information appropriate for dissemination to operators and for determining emergency service requirements. Unless instructed otherwise, the IRAS will specify the information to be disseminated and will initiate requests for incident service providers. Note that in performing these activities, the IRAS must interact with the Information Dissemination System (IDS).

Because much of the functionality assigned to the IRAS can be performed without operator approval (e.g., implementation of recommended traffic control strategies, specification of information to be disseminated, requests for incident services), a high level design requirement for the IRAS's user interface is that it must maintain an adequate level of operator situation awareness. Consequently, the IRAS must facilitate ready access to all incident status information. Such information might include the following:

- The effectiveness of all implemented incident response strategies (traffic control techniques and information dissemination).
- The effect of recommended responses (i.e., traffic flow data at the incident site as well as at locations upstream and downstream of the site).
- Incident status (the degree of progress made in resolving the incident).
- Notification that incident responders (of given types) have been dispatched.
- Notification that incident responders (of given types) have arrived at the incident site.
- Notification that advisory messages displayed on VMS's (at given locations) have been posted, modified, or cleared.
- Notification of incident clearance and a return to normal traffic flow conditions.

With this information the operator will have an ability to monitor the status of incident clearance procedures.

Note that the IRAS will be required to support the management of multiple (simultaneous) incidents. Thus, incident management and status information associated with a given incident must be clearly identified as such.

Information Dissemination System (IDS)

System Capabilities

The IDS will interface with established communication links to response forces such as police departments, ambulance services, fire departments, and towing services. It will also interface with data services supplied to (1) the mass media, (2) the Traffic Channel, and (3) bulletin board services. The IDS will be capable of posting messages on VMS's and creating voice messages for broadcast via highway advisory radio (HAR). IDS activities include the following:

- Assign/match mode selection advisories to information outlets.
- Assign/match route selection advisories to information outlets.
- Assign/match speed limit advisories to information outlets.
- Assign/match travel advisories to information outlets.
- Broadcast roadway condition report.
- Broadcast special event report.
- Download software upgrades to components in the field.
- Issue incident management reports.
- Issue incident reports.
- Issue incident service requests.
- Issue instructions to incident responders.
- Post mode selection advisories.
- Post route selection advisories.
- Post speed limit advisories.
- Post travel advisories.

Human Interface Requirements

The IDS will interface with established communication links to a set of response agencies. These agencies may include law enforcement offices, emergency medical services, fire departments, towing services, maintenance providers, and any other emergency service providers deemed appropriate (e.g., hazardous waste disposal units, special crisis management teams). The IDS will also interface with those data services accessed by (1) the mass media, (2) traffic channels, and (3) bulletin board services.

A built-in diagnostics capability could provide one means of detecting failures at IDS-data service and IDS-communication link interfaces. Interface failure reports, if provided to an operator, would notify the operator of the IDS's inability to interface properly with an established communication link(s) and/or a designated data service(s). Results of these diagnostic tests would provide the operator additional IDS status information and thus enhance situation awareness. Note that a heightened sense of situation awareness is a particular advantage under conditions of high operator workload (e.g., the occurrence of a major incident or a serious weather situation). Certain tests may be running continuously in the background, and for these tests, any detected failures (and an identification of their respective tests) should be automatically reported to the operator when they are detected. Other tests may require a specific operator-initiation. In both cases the operator should have access to status information.

IDS responsibilities will include the posting of VMS messages and the creation of voice messages for broadcast via highway advisory radio. The IDS will be notified by other support systems, namely the IRAS and the Maintenance Tracking System (MTS), of a posting requirement. The type of information to be posted, in addition to the location of its designated VMS(s), will be specified. The IDS will retrieve appropriate messages from a data base of messages and issue "post message" commands. Such commands will initiate the message posting process. The IDS will also facilitate operators' access to historical records of all message-posting activities (i.e., messages posted, message locations, status of messages (currently posted, cleared, modified), and message time stamps). Note that a number of time stamps can be associated with a given message: time at which message is posted, time at which message is cleared, time of most recent modification.

In some instances the operator may be required to initiate a “post message” command, independently of support system instructions of this nature. A straightforward manner in which to facilitate this type of user activity is desirable. One means of providing an operator-initiated “post message” option might be to allow the operator to select the required message from a predefined list (a menu list) of standard VMS messages. In other words the IDS would be designed with an established repertoire of messages from which operators could select. Most likely, messages will be assigned a filename (identifier). Filenames should facilitate easy recognition of message contents; however, a “read” option would allow the operator to review message contents for appropriateness. The operator may be required to compose a VMS message, rather than select a predefined message. Under these conditions, the IDS could provide a template enabling the operator to compose a new message appropriate for a previously unspecified traffic condition.

The IDS must also provide a means for creating voice messages to be broadcast via highway advisory radio (HAR). This requirement suggests a “digitize message” command in which predefined messages (stored in the message data base), as well as operator-composed messages, could be digitized and either transmitted for immediate broadcast or stored for broadcast at some later time.

Intermodal Transportation Planning System (ITPS)

System Capabilities

The ITPS will supply the simulation capability to support strategic planning for the ATMS. It will, for example, have the capability to simulate different configurations of roadway systems. Its simulation capability will also support coordinated strategic planning (performed in conjunction with public transportation systems) and special event planning. ITPS activities include the following:

- Assess multimodal demand predictions.
- Assess traffic management effectiveness.
- Assimilate/compile alternate transportation mode data.
- Conduct strategic simulations.
- Maintain simulation results.
- Receive alternate transportation mode data.
- Receive interagency special event information.
- Receive weather service information.
- Recommend multimodal demand regulation strategy.
- Support development of transportation plans.
- Support formulation of responses to public comments (transportation planning issues).

Human Interface Requirements

Through its simulation capabilities, the ITPS supports strategic planning. Note that the simulation capabilities of the ITPS are distinct from those available within the PTMS and IRAS. Simulations conducted from within the PTMS and IRAS are based on current traffic data and existing roadway conditions/ configurations; additionally, they are conducted in parallel to ongoing traffic and incident management activities. Because PTMS and IRAS simulation results are intended to support traffic and incident management, they must be available within a “faster than real time” time window. ITPS simulations, on the other hand, represent a more general, less specialized simulation capability than do the simulations performed by the PTMS or the IRAS.

ITPS simulations will be performed in support of strategic planning exercises, and because “faster than real time” results are not as critical to strategic planning activities as they typically are to traffic and incident management activities, such stringent time constraints can be relaxed. Four primary simulation capabilities are required in the support of strategic planning: a capability enabling planners to simulate roadway system configurations that are currently nonexistent, a capability supportive of coordinated strategic planning, a capability enabling planners to simulate anticipated special events, and a capability that will enable planners to simulate rare (but critical) emergency situations. Examples of roadway system configurations include a planned sports arena, the extension of an existing Interstate highway, the construction and eventual addition of a tollway, or the addition of a major shopping complex. If alternate sites for a given configuration are under consideration, simulation analyses could focus on the identification of an optimal site.

Coordinated strategic planning might yield (1) a set of routes for all modes of public transportation, (2) public transportation schedules that are based on projected multimodal demands, or (3) a recommendation on the modes of public transportation that are most appropriate and cost effective for a given region. Special event planning provides the means for operators to anticipate traffic conditions that are likely to occur as a result of a major sporting event, a concert, a parade or motorcade, or visits made by national/ international dignitaries. Emergency situations might include a severe winter storm, a hazardous waste spill, a terrorist attack, or a major incident.

Given a range of simulation capabilities, operators must be provided the ability to specify a simulation type (i.e., roadway system configuration, coordinated strategic planning, special event planning, emergency planning), specify a set of parameters associated with the simulation type, and assign values to these parameters. Parameters associated with a simulation type may be selected from a set of default parameters. In some instances a feature enabling the operator to define parameters might be appropriate. Parameter values may also be assigned according to an established set of defaults; however, an option that facilitates the operator's ability to assign parameter values would be useful.

Within a single simulation run, operators may choose to define multiple parameter sets (and respective parameter values). Upon completion of the run, results are compared. Each result is associated with a given set of parameters (input conditions). Operators must also be provided a means of specifying simulation outputs, that is, the types of traffic measures to be reported. Such outputs may be specified in addition to (or perhaps rather than) a set of default outputs. For certain types of output data (e.g., measurements that reflect trends), a feature enabling selection of output format (tabular versus graphic) would be useful. Simulations are to be conducted from operator workstations. Intermediate results should be displayed as feedback. Final results will be displayed at operator workstations and will be available in hardcopy form via a "print" command.

The ITPS must provide functionality enabling operators to either manipulate historical (traffic, weather) data or to simulate such data for use as simulation input. Manipulation actions might include data access, data retrieval, data transformation, or downloading of data. Simulation results are to be archived; they must be readily accessible/ retrievable and clearly identified for future reference.

Traffic Management Training System (TMTS)

System Capabilities

The TMTS will provide training for traffic management center (TMC) operators. The TMTS will have the ability to conduct training in routine traffic management, incident management, and in the management of special events. Operators will also use the TMTS to develop and maintain skills needed in rare but critical situations (e.g., major incidents or severe winter storms). TMTS activities include the following:

- Assess trainee performance.
- Conduct incident management training.
- Conduct special event training.
- Conduct traffic management training.
- Conduct training requirements analysis.
- Maintain case studies.
- Receive incident management report.
- Receive interagency special event report.
- Record instructor comments.
- Record trainee performance.
- Specify course content for trainees.
- Specify training method for trainees.

Human Interface Requirements

The TMTS will support training of routine traffic management, incident management, and special event management. In addition the TMTS will support the maintenance of those operator skills required during rare but extremely critical situations. The TMTS will include a function that facilitates the analysis of training requirements. The initial phase in any training program development effort typically involves the specification of appropriate training requirements. When requesting a training requirements analysis from the TMTS (by issuing a "conduct training requirements analysis" command), an instructor will be prompted for the delineating characteristics of the anticipated training program. These characteristics will define program boundaries and might include the following: time constraints, the number of trainees anticipated, the number of instructors available for supervision of the program, skills (and skill levels) currently retained by trainees, skills (and skill levels) desired upon a trainee's completion of the program, hardware and software resource constraints (availability of a high fidelity TMC simulator, access to an interactive traffic model, availability of graphics workstation technology, availability of personal computer-based technology, access to real-time traffic video information).

Based on input characteristics, the TMTS will recommend a training method or in some cases a set of feasible training methods (ranked according to some measure of training effectiveness). The TMTS may be designed such that this effectiveness measure is selected from a list of system defaults; however, in some instances, operator-specification of this measure might be appropriate. While functioning in a training requirements analysis mode, the TMTS should provide a feature that enables a weight assignment to each characteristic. In this manner a relative importance (criticality) scale will be derived for the set of input characteristics. The TMTS, for example, might facilitate the performance of a paired comparison study, in which characteristics are ranked. Note that for those instances in which the requirements analysis recommends a set of feasible training methods, the relative importance scale (i.e., the ordering of characteristics according to importance) is likely to impact the ranking of training methods. The training requirements analysis will suggest a course syllabus, as well as a set of dependent measures that will serve as the best indicators of trainee performance. Results of all training requirements analyses will be presented in a consistent format; they will be available online or in hardcopy form through execution of a "print requirements analysis results" command.

The TMTS will support the development of required course materials. When, for example, a high fidelity TMC simulator is available for training purposes, the TMTS will support the scripting of various traffic scenarios. The TMTS will support the development of testing materials and will facilitate automatic recording and assessment of trainee performance. It will identify trainees' satisfactory attainment of performance criteria. The TMTS will maintain trainee performance records and will enable an instructor to append comments to trainees' performance scores. Confidentiality of these records must be assured. In order to prevent unauthorized access to such files, a security system must be imposed. A password system is one approach for maintaining security. A password would enable a trainee to access his or her own file.

The TMTS will also maintain a data base of case studies. The reviewing of case studies is one method of instruction. By reviewing individual case studies, trainees can examine the conditions surrounding a given traffic scenario and assess the effectiveness (or ineffectiveness) of the traffic/incident management strategies implemented as a result of various scenario events. This type of instructional method will provide a forum in which trainees begin to develop a degree of intuition with respect to traffic and incident management and to formulate heuristic knowledge.

Maintenance Tracking System (MTS)

System Capabilities

The MTS will track remedial and preventive maintenance needs and schedules. It will support the issuing of maintenance requests and monitor the status of maintenance activities. The MTS will track maintenance of roadway surfaces and of electronic components such as traffic signals and sensors. The MTS will receive reports from diagnostic tests of electronic components. MTS activities include the following:

- Determine remedial maintenance requirements.
- Issue maintenance requests.
- Maintain preventive maintenance schedules, records.
- Prepare/format maintenance requests.
- Process BIT data.
- Provide remedial/preventive maintenance needs reports.
- Provide system component evaluations.
- Receive BIT data.
- Receive preventive maintenance need reports.

Record maintenance request.

Human Interface Requirements

The MTS is responsible for monitoring and maintaining the "health" of the roadway system. It ensures the satisfactory operation of electronic components (e.g., traffic signals, sensors, variable message sign LED's) and the physical integrity of the roadway itself. The MTS addresses remedial as well as preventive maintenance needs and consequently must support maintenance scheduling.

By issuing a "show preventive maintenance schedule" command, an operator could review the types of preventive maintenance activities scheduled for a given day (or a given time period), the respective date(s) and time(s) for activity initiation, and the location of each scheduled activity. Accompanying each listed activity with an expected completion time would also be helpful. Consider, for example, those maintenance activities that are to disrupt normal traffic flow. The time-to-completion information will assist operators in developing strategies to accommodate the anticipated disruptions to traffic flow. Advanced notification of preventive maintenance activities (e.g., 24 to 48 h in advance) would enable operators to prepare for nonroutine traffic flow conditions and develop any necessary contingency plans. By issuing a "show remedial maintenance schedule" command, an operator could review analogous remedial maintenance information. In order to review a more generic list of scheduled maintenance activities (remedial and preventive) for a given day (or time period), an operator might issue a "show maintenance schedule" command. Additional details associated with each scheduled event (e.g., start time, duration, location) could be displayed at the operator's request. For generic lists the distinction between remedial and preventive maintenance activities should be clear.

The MTS will be responsible for detecting system failures and in some cases performing preliminary diagnostics (e.g., identifying the source of a failure). As it detects a failure, the MTS should automatically report its occurrence (along with its preliminary diagnostics report), record that the failure occurred (at a given date, time, and location), identify the maintenance providers capable of resolving the failure condition, issue a maintenance request, and record that the request was issued (at a given date/time and to a given maintenance provider). The MTS must also have an ability to receive notifications regarding the status of failures. By issuing an "obtain failure status" command, an operator could obtain, for a single failure or set of failures, the following status information:

- Maintenance procedures in progress.
- Maintenance procedures completed; failure resolved.
- Maintenance procedures begun; "temporary fix" implemented; replacement part scheduled to arrive on _____.
- Maintenance procedures begun; time-to-completion extended; anticipated completion on ______.

Note that any recent diagnostic developments could be included in this status report. The MTS maintains a record of all remedial maintenance requests issued. Once such a remedial maintenance request is issued, the MTS initiates a status record for the respective failure. Through status records, an operator has the ability to monitor the progress of remedial maintenance activities.

The MTS must follow a slightly different procedure in issuing preventive maintenance requests. Preventive maintenance activities are scheduled *a priori* and are performed at regular time intervals. (These time intervals may be recommended by a manufacturer or based upon historical reliability data.) In other words preventive maintenance activities are not scheduled in response to a failure detection. The MTS should assist in the development of preventive maintenance schedules. It might provide a template in which the operator identifies (1) the entity to be maintained (e.g. system, subsystem, electronic component), (2) additional identifying features of the entity (e.g., part number), (3) the time between maintenance procedures, (4) the date/time of the initial maintenance procedure, and (5) the appropriate maintenance provider. With such information, the MTS could project a preventive maintenance schedule. The MTS should also have the capability to interpret preventive maintenance schedules such that it recognizes (or perhaps is alerted to) an impending activity. Upon recognition of this impending maintenance activity, the MTS could automatically issue an appropriate maintenance request. Note that the interval of time between initial recognition by the MTS and the scheduled start-time of the maintenance activity would be established *a priori* such that all maintenance providers would be given sufficient notice.

Maintenance activities are not always the result of automated failure detection or established schedules. In some instances operators may receive reports from motorists (e.g., a malfunctioning traffic signal, a road sign in need of repair) or perhaps become aware of maintenance problems through direct observation of the roadway system (e.g., video camera views). Under these conditions, the operator must be provided a means of manually reporting maintenance needs.

The MTS must provide operators with access to BIT information (i.e., status, results). BIT information will be available online or in hardcopy form through execution of a “print BIT information” command. In some instances, the operator may wish to initiate a BIT for a given set of system entities, and the MTS must provide operators with a means of selecting entities and issuing a “initiate BIT” command. Reliability data provide a maintenance history, and by providing access to such data, the MTS could enhance operators’ awareness of the system’s “health.” Finally, the MTS must provide the functionality to generate maintenance reports and ensure that they are archived within the Traffic Data Management System.

Traffic Data Management System (TDMS)

System Capabilities

The TDMS will serve as the ATMS information hub. It will accept all roadway sensor data and perform validity/integrity checks of such data. The TDMS will maintain historical records of traffic and associated incidents. When required, the TDMS will aggregate data. The TDMS will also analyze compliance measurement data (advisory and general compliance) and will maintain compliance information. The PTMS and IRAS will have the ability to access roadway sensor data, historical traffic data, and incident data. Historical data will also be accessed as appropriate by the ITPS in its conduction of transportation planning simulations. TDMS activities include the following:

- Analyze advisory compliance measurements.
- Analyze general compliance measurements.
- Archive data.
- Assess current load data.
- Classify vehicle types.
- Compile roadway condition sensor information.
- Compile roadway conditions.
- Compute traffic volume.
- Compute travel times.
- Compute vehicle speed.
- Maintain anomaly data.
- Maintain BIT data.
- Maintain compliance analyses (advisory, general).
- Maintain compliance data (advisory, general).
- Maintain incident management heuristics.
- Maintain incident response strategies.
- Maintain reports.
- Maintain sensor data.
- Maintain traffic management heuristics.
- Perform data validity/integrity checks.
- Process visibility sensor data.
- Provide roadway condition information when requested.
- Provide traffic data when requested.
- Receive BIT reports.
- Receive compliance data (advisory, general).
- Receive component status information.
- Receive current load data.
- Receive incident data.
- Receive O-D data.
- Receive rail traffic data.
- Receive roadway condition sensor data.
- Receive roadway sensor data.
- Receive special vehicle information.
- Receive surface condition sensor data.
- Receive traffic volume data.
- Receive vehicle speed data.
- Receive visibility sensor data.
- Receive weather service data.
- Report results of advisory compliance analyses.
- Report results of general compliance analyses.
- Summarize O-D data.

Human Interface Requirements

The TDMS serves essentially as an information hub and is a repository for all roadway network data, including the following:

- Sensor data (in raw form).
- Weather service data.

- Traffic data (load data, classifications of vehicle type, compliance data, O-D data).
- Anomaly data.
- Incident data.
- BIT data.
- Roadway condition sensor data.
- Rail traffic data.
- Component status data.

In some instances operators might require access to TDMS data archives. Consequently, the TDMS must facilitate ready operator-access to stored data. Roadway network data might be categorized according to type (e.g., sensor, weather, or BIT). Upon issuing a "view archives" command, the operator could be presented a list of available (and accessible) data types, and by selecting from that list could indicate a need to review data of the selected type. Further selection within a selected data type might be required. Operators, for example, might wish to view weather data from a designated period of time, or might wish to access only load data and O-D data (from the traffic data category). Note also that operators may have a need to review multiple types of data simultaneously or perhaps the same data type but from different time periods. Under these conditions the TDMS interface must facilitate multiple selections (1) from the list of data types and (2) from within a single data type.

The TDMS also has computation, data analysis, and data manipulation capabilities. It is responsible for assessing advisory and general compliance data, as well as current load data; it processes visibility sensor data and roadway condition sensor data. The TDMS computes traffic volumes, travel times, and vehicle speeds. It performs data manipulation tasks: vehicle classification and O-D data summarization. Results obtained from TDMS computations, analyses, and data transformations are archived. Consequently, operators are likely to require ready access to such results (in report form), and the TDMS interface must facilitate access to these reports.

The TDMS maintains all information generated by the ATMS that is of a "report" or "documentation" nature. Specific reports generated by the ATMS include remedial and preventive maintenance reports, incident reports, results of advisory compliance analyses, results of general compliance analyses, and roadway condition reports. Information of a documentation nature that is archived by the TDMS includes incident and traffic management response strategies, incident management heuristics, and traffic management heuristics. Operators could be provided access to such information by issuing "view reports" or "view documentation information" commands. Reports and documentation information would be available for online viewing or in hardcopy form through operators' execution of a "print" command.

Much of the data maintained by the TDMS, particularly data received automatically (e.g., sensor data, weather reports, traffic data, BIT results, rail traffic data), are continuously updated at regular (predefined) intervals. Once current data (recorded at time t) are updated, the updated information (obtained at time t + At) is regarded as current data. The data measured at time t become historical data. Operators should, at all times, have access to current data, and a "current data" display should be the default display option. The current data display should be dynamic in nature. That is, as new data measurements are taken (at time $t + n\Delta t$), they should be received by the TDMS such that the "current data" display is updated. The data formerly displayed (and measured at time $t + (n - 1)\Delta t$) will be archived as historical data.

The TDMS will also perform data validity/integrity checks, and any questionable data must be clearly identified as such. In other words the operator should be aware of any deficiencies in the data collection process. Such information could be presented via the "current data" display. Operators would also benefit from information that identifies those analyses, algorithms, procedures relying on questionable data. In this manner the operator will be alerted to (1) potentially invalid results or (2) potential difficulties in interpreting results.

Communications Support System (CSS)

System Capabilities

The CSS will manage the channels for two-way communications (1) within a single TMC (e.g., communications among its TMC operators) and (2) between TMC operators and entities external to the ATMS (including operators in other TMC's, operators in other agencies, the media, and the public at large). Voice communications, teleconferencing, electronic mail, data base links (e.g., links to police dispatch data base), and fax communications will be supported by the CSS. CSS activities include the following:

- Confirm ad hoc incident data.
- Confirm weather reports.
- Issue incident service needs.
- Issue remedial/preventive maintenance needs (telephone/radio, hardcopy reports, e-mail).
- Issue request for incident management report.
- Issue request for incident report.
- Issue request for onsite traffic control.
- Issue software, hardware, personnel upgrade needs (telephone/radio, hardcopy reports, e-mail).
- Notify of incident clearance
- Receive ad hoc alternate transportation mode information.
- Receive ad hoc component status reports.
- Receive ad hoc emergency response reports.
- Receive ad hoc incident data.
- Receive ad hoc incident response information.
- Receive ad hoc special event information.
- Receive ad hoc travel time reports.
- Receive public comments.
- Receive requests for historical data.
- Receive requests for public relations activities.
- Receive requests for simulation studies.
- Receive telephone, fax, e-mail, radio weather reports.
- Receive verbal/written assessments of existing hardware capabilities.
- Receive verbal/written assessments of existing software capabilities.
- Receive verbal/written assessments of personnel upgrade requirements.
- Receive voice-based incident data.
- Receive voice-based rail traffic data.
- Receive voice-based reports revealing anomaly sources.
- Receive voice-based volume data.
- Validate ad hoc alternate transportation mode information.
- Validate ad hoc emergency response reports.
- Validate ad hoc incident response information.
- Validate ad hoc special event information.
- Validate ad hoc travel time reports.
- Validate ad hoc visibility condition reports.
- Validate ad hoc volume data.
- Validate ad hoc component status reports.
- Validate remedial maintenance requirements.

Human Interface Requirements

The CSS will manage all two-way communications channels. Two-way communications will occur within a single TMC (e.g., among TMC operators or between a TMC operator and other TMC personnel) and between TMC operators and entities external to the TMC. Entities external to the TMC may include personnel associated with other agencies (e.g., emergency service personnel), the media, and the public at large. The CSS will be responsible for managing several modes of communication, including voice, teleconferencing, electronic mail, fax, and data base links.

For any mode involving direct intervention on the part of an operator (i.e., any mode requiring an explicit operator action to ensure information transfer), the CSS must provide appropriate communications interfaces. Voice transfers may be accommodated through telephone and radio interfaces, while teleconferencing mode transfers will require appropriate teleconferencing hardware devices. Electronic mail transfers will require communications and/or networking software. Such software will most likely be installed at operator workstations. Fax transfers may be effected either through fax units located within the TMC or via operator workstations installed with built-in fax/modem capabilities. Note that information transfers effected through established data base links are automated (i.e., the operator is only made aware that a data transfer has occurred).

The CSS facilitates operator-validation of certain types of data. An operator, for example, may obtain incident information (severity, number of vehicles involved, type(s) of vehicles involved, type(s) of injuries sustained) from a cellular phone user who is located at an incident site. If the operator is aware of this particular incident (i.e., the IDLS has detected it), the cellular phone user's information can be validated against the IDLS report (or may supplement the IDLS report). Other forms of communication, in particular, video cameras that afford useful views of the incident site, may enable the operator to validate existing incident information (available from IDLS reports, cellular phone users, or emergency service providers located at the incident site), as well as obtain further details of the incident.

Administrative Support System (ADSS)

System Capabilities

The ADSS will provide TMC operators with features required for performing administrative duties. It will include specialized software (e.g., data base tools, graphics software, word processing applications, spreadsheet software), fiscal planning information (e.g., budgets, financial plans), and personnel files. The ADSS may also include an online data base (perhaps containing softcopy documents and the locations of hardcopy documents) or online procedures manuals. ADSS activities include the following:

- Assess public comments.
- Assess survey data.
- Assimilate/compile public comments.
- Assist in making personnel upgrade decisions (requirements).
- Maintain a record of agencies and their respective missions.
- Maintain a record of directives.
- Maintain a record of public comments.
- Maintain a listing of incident responders.
- Maintain assessments of public comments.
- Maintain fiscal information.
- Maintain hardcopies/softcopies of procedures manuals.
- Maintain personnel files.
- Maintain policy/procedural information on personnel upgrades.
- Maintain hardware upgrade procedures.
- Maintain ATMS hardware configuration data.
- Maintain ATMS software configuration data.
- Maintain software upgrade procedures.
- Perform budget tracking.
- Perform fiscal planning.
- Report upgrade needs (hardware, software, personnel).

Human Interface Requirements

The ADSS will be an integrated software environment providing the operator with a number of functional capabilities. These functionalities, implemented through specialized software applications, may include data base management, word processing, graphics development, spreadsheet computations, financial planning, charting, presentation authoring, and programming. Note that the communications and networking feature previously described as a CSS capability could be incorporated within the ADSS.

The functionality required by the ADSS may be provided through a commercially available integrated applications tool. This functionality may also be implemented via independent software applications (e.g., word processors, graphics packages, programming language environments, data base management tools). Under the latter implementation approach, the ADSS would serve as a high level "manager," coordinating the operation of applications contained within its domain. In other words, the ADSS would be regarded as a shell, providing software hooks to each individual application. Another approach for ADSS implementation may involve a major software development effort in which commercially available products are not employed, where functional requirements of the ADSS are satisfied through the design and development of customized software.

The ADSS environment must facilitate multi-tasking, where operators are provided the capability to access (and run) several functions simultaneously. All functional capabilities contained within the ADSS must be clearly identified such that operators are aware of the administrative activities supported by the ADSS.

Maintainer Training Support System (MTSS)

System Capabilities

The MTSS will provide training for maintenance providers. It will also be used to develop and sustain skills or procedures required for the maintenance of ATMS assets. These assets include signal controllers, roadway sensors, VMS's, highway advisory radio, probe vehicle instrumentation, ATMS computers, and ATMS software. MTSS activities include the following:

- Assess maintainer performance.
- Conduct maintainer training.
- Conduct training requirements analysis.
- Record instructor comments.
- Record maintainer performance.
- Specify course content for maintainers.
- Specify training method for maintainers.

Human Interface Requirements

The MTSS will support maintenance provider training and will also be used to develop and sustain skills or procedures required for the maintenance of ATMS assets, including signal controllers, roadway sensors, VMS's, HAR, probe vehicle instrumentation, ATMS computers and other hardware items, and ATMS software. In addition, the MTSS will include functionality necessary for the analysis of training requirements. Recall that the initial phase in any training program development-effort typically involves a detailed, indepth analysis of training requirements. When requesting a training requirements analysis from the MTSS (by issuing a "conduct maintainer training requirements analysis" command), an instructor will be prompted for information that more specifically characterizes the anticipated training program: time constraints, the number of trainees expected, the number of instructors available for supervision of the program, skills (and skill levels) currently retained by trainees, skills (and skill levels) desired upon a trainee's completion of the program, hardware and software resource constraints.

Based on input characteristics, the MTSS will recommend a training method or, in some cases, a set of feasible training methods (ranked according to some measure of training effectiveness). The MTSS may be designed such that the effectiveness measure is selected from a list of system defaults; however, in some instances, operator-specification of this measure might be appropriate. While functioning in a training requirements analysis mode, the MTSS should provide a feature that enables a weight assignment to each characteristic. In this manner a relative importance (criticality) scale will be derived for the set of input characteristics. (The MTSS might, for example, facilitate performance of a paired comparison study). For those instances in which the requirements analysis recommends a set of feasible training methods, the relative importance scale (i.e., the ordering of characteristics according to importance) is likely to impact the ranking of training methods. The training requirements analysis will suggest a course syllabus, as well as a set of dependent measures for evaluating trainee performance. Results of all training requirements analyses will be presented in a consistent format, and they will be available online or in hardcopy form through execution of a "print requirements analysis results" command.

The MTSS will support development of required course materials. When, for example, graphics workstation hardware is available for training purposes, the MTSS could provide intelligent computer-based trainers featuring sophisticated drawing and animation capabilities. Such capabilities might be used to instruct maintenance providers in hardware assembly/disassembly procedures. The MTSS will support the development of testing materials and will facilitate automatic recording and assessment of trainee performance. It will identify trainees' satisfactory attainment of performance criteria. The MTSS will maintain trainee performance records and will enable an instructor to append comments to trainees' performance scores. Confidentiality of these records must be assured. In order to prevent unauthorized access to such files, a security system must be imposed. A password system is one approach for maintaining security. A password would enable a trainee to access his or her own file.

The MTSS is also responsible for sustaining maintenance provider skills. Consequently, it must facilitate a continuing education process. The MTSS must have the capability to conduct training requirements analyses for "refresher" courses and subsequently provide the support necessary to develop materials for such training exercises.

CONFIGURATION ITEMS

Associated with the support systems is a set of hardware configuration items used by operators for voice and text communication, information/data collection, information processing, data archiving, and control of external ATMS devices.[10] Some of these configuration items represent stand-alone systems (e.g., electronic mail systems or fax systems), while other items are incorporated into a given multipurpose system (typically a computer-based system). To be resolved by a TMC designer is the following issue: whether a given configuration item is implemented via a dedicated computer-based system or if implementation of the item requires only the addition of specialized software to an existing system. The following hardware configuration are defined: [10]

- Electronic mail system.
- Cable television system.
- Facsimile communication system.
- Hardcopy document system.
- Closed-circuit television cameras, monitors, controls.
- Computer workstations.
- Telephone system.
- Radio transmitters/receivers.

The electronic mail (e-mail) system transmits (receives) urgent and routine messages to (from) external agencies and other TMC's. The cable television system is used in the monitoring of weather service data. The facsimile (fax) communication system facilitates fax transmissions (receipts) to (from) TMC's and external agencies. The hardcopy document system focuses on the production and dissemination of paper-based files (e.g., documents, records). Closed-circuit television (CCTV) capabilities provide operators with views of the roadway network via remote cameras, where camera views are displayed on designated monitors. Control devices facilitate camera selection, camera movement (horizontal panning, vertical movement), and specialized camera functions (zoom, focus). Camera controls may enable operators to place CCTV images on specified monitors. TMC operators will have access to one or more workstations that consist of graphics monitors, computer systems, and peripherals (e.g., keyboard, joystick, mouse). Workstations facilitate the management, monitoring, and operation of automated support systems. They may also be interfaced to other configuration items. The telephone system exchanges information within a single TMC, as well as between (1) the TMC and other TMC's, (2) the TMC and external agencies, and (3) the general public. Radio transmitters and receivers supplement the telephone system, facilitating communication between (1) the TMC and personnel from external agencies and (2) the TMC and traffic management personnel (including maintainers and incident managers).

SUMMARY

Our analyses of support system capabilities and human interface requirements suggests that the technology underlying each support system will evolve to progressively more advanced states. Our feeling is that such technology evolution has the following implications for ATMS function allocation.

While the technology (and capability) to facilitate the performance of ATMS functions will become progressively more enhanced, the operator roles (Direct Performer, Manual Controller, Supervisory Controller, Executive Controller) assigned to each function, as well as the levels of operator involvement (H, Hm, Mh, M) essential for completion of the function's processing stages, will remain stable. In other words, increasing advancements in future ATMS technology will primarily impact the quality of this technology's output (e.g., greater precision in traffic models, faster and more accurate traffic prediction algorithms, fewer false alarms in detecting incidents, more accurate identification of traffic flow anomalies). In our view such advancements will not impact, at least to a great extent, the level of automation currently assigned to the ATMS functions. Operator roles assigned to each function and the degree to which operators are involved in the function's processing stages will remain the same.

In this section, we present a human factors specification developed for the ATMS. In developing this specification, we first defined the capabilities appropriate for each of 12 idealized support systems and then established a set of human interface requirements for each system. System capabilities were analyzed in terms of global functionality, as well as specific activities. In establishing human interface requirements, we considered the information required by human operators during their performance of anticipated operator-system interaction tasks. Each set of interface requirements identified and described the information displayed to operators via the respective support system interface, as well as information to be provided to the system by operators. Potential information presentation strategies, functional capabilities, interface features, and data entry strategies appropriate for each system were proposed. The

capabilities and interface requirements associated with the set of 12 support systems are summarized in tables 11 and 12, respectively.

Support system operation is sustained, in part, by a set of configuration items. Such items are used for voice and text communication, information and data collection, information processing, data archiving, and control of external ATMS devices. A configuration item may represent a stand-alone system or a subsystem of a larger, multipurpose system. Eight hardware configuration items were specified: electronic mail system, cable television system, facsimile communication system, hardcopy document system, CCTV system (cameras, monitors, controls), computer workstations, telephone system, radio transmitters/receivers.

Through our consideration of (1) support system capabilities, (2) human interface requirements, and (3) specific hardware configuration items, we have, in effect, prepared the initial framework for an ATMS human factors specification. Note that development of this type of specification is a dynamic process. By continuing empirical research efforts that focus on the human factors aspects of ATMS design, we will maintain the specification. That is, through further research efforts, the specification will be refined and updated.

Table 11. Support system capabilities.

Support System	*Support System Capabilities*
ATCS	optimize current traffic flow; control traffic signal timing and ramp metering; integrate control of surface street and freeway traffic; make low-risk predictions
PTMS	predict traffic flow 5 to 30 min into the future; evaluate candidate traffic management techniques (i.e., techniques that might be implemented in unusual conditions -- a *what if* capability); make high risk predictions
IDLS	detect and verify the presence of incidents; determine the exact location of an incident
IRAS	determine the appropriate incident response; provide recommendations for controlling traffic and disseminating information; monitor incident clearance procedures and determine the point at which normal operations should resume; evaluate various incident response alternatives (faster than real-time simulation)
IDS	interface with established communications links (i.e., links to response forces; interface with data services; post VMS messages; create voice messages for broadcast via HAR
ITPS	support strategic planning for the ATMS; support coordinated strategic planning (performed in conjunction with public transportation systems); support special event planning
TMTS	provide training for TMC operators (traffic management, incident management, special event management); develop and maintain skills required during infrequently-occurring but critical situations
MTS	track remedial and preventive maintenance needs and maintenance schedules; issue maintenance requests; monitor the status of maintenance activities (maintenance of roadway surfaces and electronic components); receive results of diagnostic tests
TDMS	serve as the ATMS information hub; accept roadway sensor data; perform validity/integrity checks of data; maintain historical records of traffic events and associated incidents; aggregate data; analyze compliance measurement data; maintain compliance information
CSS	manage the channels for two-way communications (1) within a single TMC and (2) between TMC operators and entities external to the ATMS; support voice communications, teleconferencing, electronic mail, data base links, and fax communications

Table 11. Support system capabilities (continued).

Support System	*Support System Interface Requirements*
ADSS	support administrative activities (e.g., fiscal planning, personnel management)
MTSS	provide training for maintenance providers; develop and sustain skills or procedures required for maintenance of ATMS assets

Table 12. Support system interface requirements.

Support System	*Support System Interface Requirements*
ATCS	forum for reviewing the effects of currently implemented control strategies; a means for enabling/disabling ATCS operation; limited access to the direct control of individual intersection controllers
PTMS	forum for presenting traffic flow predictions (predictions for 5, 10, 15, 20, or 30 min into the future); a means for initiating/terminating simulation *(what if)* mode; forum for entering simulation parameters; a means for initiating review/approval of any recommendation suggesting an ATMS response to a given PTMS prediction
IDLS	notification of potential incident occurrence; indication of incident location (presentation of incident coordinates); indication of incident severity; access to other communications links (e.g., onsite law enforcement); forum for manual entry of incident parameters
IRAS	presentation of recommended traffic control strategies; indication of information most appropriate for dissemination to motorists; a means for initiating operator overrides of recommended traffic control strategies; a means by which operator-selection of traffic control strategies is facilitated; a means for initiating/terminating simulation mode; ready access to incident status information
IDS	notification of communications interface failures; presentation of diagnostic test results; access to historical records of message-posting activities; a means for initiating a “post message” command; a message composition template; a means for initiating a “digitize message” command
ITPS	a means for specifying simulation type and simulation parameter values; a means for specifying simulation outputs; presentation of simulation results; forum for manipulating historical data; ready access to archived simulation results
TMTS	forum for implementing a training requirements analysis; recommendation of training method(s); a means for initiating a “print requirements analysis results” command; forum for supporting the development of required training materials; a means for maintaining trainee performance records; access to a data base of case studies
MTS	forum for reviewing preventive and remedial maintenance schedules; notification of detected system failures; access to failure status information; a means for developing preventive maintenance schedules; forum for manual reporting of maintenance needs; access to BIT information; a means for issuing an “initiate BIT” command

Table 12. Support system interface requirements (continued).

Support System	*Support System Interface Requirements*
TDMS	access to archived data (e.g., sensor data, weather data, anomaly data, component status data); access to data manipulation results; access to ATMS-generated reports and reference information; access to current traffic data; notification of deficiencies in data collection process
CSS	communications interfaces (telephone/radio, teleconferencing, electronic mail, fax); forum for validating traffic data (e.g., cellular phone calls, video cameras)
ADSS	a means for coordinating the operation of applications within the ADSS; a means for conducting multi-tasking activities; a means for clearly identifying functional capabilities contained within the ADSS
MTSS	forum for implementing a training requirements analysis; recommendation of training method(s); a means for initiating a "print requirements analysis results" command; forum for supporting the development of required training materials; a means for maintaining trainee performance records; forum for implementing a training requirements analysis for "refresher' courses

APPENDIX A.
BLANK SURVEY FORM

This section contains a blank copy of the survey form from which the traffic management experts were questioned. It begins with an introduction, where relevant background material and the purpose of the interview were discussed with the participant. Any questions posed by the participant were then answered, prior to continuing with the survey questions.

Survey No. __________

HUMAN FACTORS IN ADVANCED TRAFFIC MANAGEMENT SYSTEMS EVOLUTION

Survey of Experts in Traffic Management

Performed by

Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, GA 30332

Sponsored by
Federal Highway Administration
Office of Safety and Traffic Operations R&D

Contract No. DTFH61-92-C-00094

Date:____________

Interviewers: ___

___

Thanks in advance for participating in this survey. This will be a structured interview, so I've got a set order of questions for us to go through. I'll start out by describing our research project, and tell you specifically what we're looking for from you today. Then I'll ask you to tell us a little about yourself, and then we'll go through the questions. After that, we'll open it up for you to elaborate on your answers and give us any general comments you might have. Finally, I'll answer any questions you might have at that point. Ready to start?

1. Introduction

Georgia Tech is under contract to the Federal Highway Administration to conduct an R&D program to examine human factors issues in future Advanced Traffic Management Systems -- that is, the traffic management systems that will be needed for Intelligent Vehicle-Highway Systems to be implemented. So, our research is a part of the R&D now underway related to IVHS.

By "human factors", I mean the jobs that humans will have to perform in Advanced Traffic Management Systems. There are other contracts that are examining human factors issues in other aspects of IVHS, such as automated highways, commercial vehicle operations, and of course private automobiles. But our piece of this big puzzle is the Advanced Traffic Management System -- or ATMS, for short. Our contract started at the end of September, so we're just underway.

The first task in our project is to perform a functional analysis of traffic management -- not traffic management as it's done now, but how it might be done, and could be done, once the advanced technologies related to IVHS are implemented on the highways and in vehicles. So, we're looking into the future, maybe 10 to 20 years ahead. Some aspects of what we're looking at are maybe only 5 years or so away, but widespread implementation of the more advanced technologies is probably IO to 20 years away.

The first step in this functional analysis is to interview experts in various aspects of traffic management. We've got a list of about 2 dozen people, with a good mix of people from industry, local governments, Federal Highway, and other research organizations. There's probably not anyone on this list that is an expert in all the things we're interested in, but each one of you will have an important contribution to make.

When we're finished with all the interviews, we're going to generate a functional description of a "visionary" ATMS. By "visionary", I mean a somewhat idealized ATMS that's not constrained by lack of funding, by political disputes, by technology that doesn't perform as well as hoped, or by any other real-world constraint. Later on in this project, we have to revise this visionary ATMS to reflect real-world constraints, but at this stage we are supposed to be uncontaminated by the real world. So, for purposes of this interview today, we want you to be very optimistic about the future of traffic management.

As we go through this interview, keep a couple of things in mind. First, we are here to listen to your opinion. We understand that what you tell us will be simply that -- your opinion. Don't feel like you need to hold back your opinion just because it might be different from other people's opinions, or because you might not be able to back it up with data, or any other reason. Second, at this stage we are not concerned with implementation issues. We aren't concerned with what kind of systems or technologies would ultimately be used to accomplish the things we're going to be talking about. So, don't feel like you need to know how these traffic management functions that we'll talk about would actually be accomplished.

Also, let me mention that your identity will be kept completely confidential. There will be absolutely no association of your name with these forms that we're going to write on, and there will be no way for anyone on the project or in the Government to know which opinions are yours.

The main thing we want to leave with today is an understanding of your vision of this "visionary" ATMS -- of what its goals ought to be, how it would perform, and of the top-level functions that would be required to achieve those goals. To get at that vision, we've got a few questions that we want your opinion on. When I ask you a question, think about it as much as you'd like, and we can talk about it informally as much as you like, and when you're satisfied, I'll write down your answer. Before I start asking you these questions, do you have any questions for us about our project, or what we're expecting from you today?

2. Start out by telling us about yourself, your current position here and how it's related to traffic management, and any previous positions or other experience related to traffic management. This will help us understand your perspective, and also will let us document in generic terms the different types of experts that participated in these interviews.

a. Current position and relevance to traffic management:

b. Past positions and experience relevant to traffic management:

3. Next, let's get together on terminology.

What does the term "traffic management" mean to you?

What does the term "traffic management system" mean to you?

What does the term "traffic management center" mean to you?

4. Keep in mind that we're talking about an idealized ATMS, that is, a traffic management system that would be part of a future IVHS 10 years or more in the future. In your opinion, what are the major problems that an ATMS should help solve or at least improve?

5. What is the single most important objective (or goal) of an ATMS?

6. What are other very important objectives or goals of an ATMS?

7. Now we're going to get more specific. I've got 5 scenarios. I'll describe each scenario for you, and for each one I'd like you to think about it, and give us your opinion on three issues: what the specific performance goals of the ATMS should be, what major ATMS functions are important in the scenario, and your idea of what the flow of data in the system would be.

A. The first scenario is simply normal rush hour traffic. There are no weather problems, no traffic accidents, no malfunctioning traffic lights, no abnormalities of any kind. The traffic volume on the highway system is very near capacity.

Performance goals of the ATMS:

Important functions:

Data flow:

B. The second scenario is a variation on the first. Again, there is normal rush hour traffic. There are no weather problems, no malfunctions or abnormalities. The traffic volume on the highway system is very near capacity. There is a minor traffic accident on a freeway. One lane of the freeway is blocked. There are no injuries, no need for an ambulance.

Performance goals of the ATMS:

Important functions:

Data flow:

C. The third scenario is a variation on the second. Again, there is normal rush hour traffic. There are no weather problems, no malfunctions or abnormalities. The traffic volume on the highway system is very near capacity. There is a major traffic accident on a freeway. Multiple lanes of the freeway are blocked. There are serious injuries, including a life-threatening emergency.

Performance goals of the ATMS:

Important functions:

Data flow:

D. The fourth scenario is altogether different. This scenario involves a planned special event on the weekend -- the Super Bowl, on a Sunday evening. There are no weather problems, no malfunctions or abnormalities. The event has, of course, been scheduled well in advance, allowing ample time for planning. Think about ATMS functions during the planning stages as well as during the event itself.

Performance goals of the ATMS:

Important functions:

Data flow:

E. The fifth scenario is again quite different. This scenario involves a heavy snowstorm, severe enough to have a major impact on traffic. The weather forecasters start predicting the snowstorm about 24 hours in advance, so there is some time for short-term planning. The storm hits mid-afternoon on a weekday, and continues on through the evening rush hour. In answering these questions, think about ATMS performance before, during, and after the storm.

Performance goals of the ATMS:

Important functions:

Data flow:

8. In the 5 scenarios we just went through, you thought about the major ATMS functions that were involved. Now, I want you to think about other functions that will be important for an ATMS to operate effectively. The scenarios we just went through mainly emphasized operations, and if you can think of any more ATMS functions associated with operations, then tell us about them. But also think about other functions, for example, functions related to strategic planning, or maintenance, or law enforcement, or anything else you can think of. Let's list these functions as you think of them, and come up with a brief description of what each function entails. It's okay to include functions that you've already mentioned when we went through the scenarios.

9. Now concentrate on the TMC itself -- on the control room where the operators and computers that control the system are located, the command center of the ATMS.

A. In your opinion, ideally, what kind of equipment do you think would be in there?

B. What roles would human operators play? What would they be responsible for?

C. What kind of education and training would these operators have?

10. Complete the picture. Elaborate on anything you've said so far, or comment on anything else you think we should know. Suggest other things we should look into. You talk, we'll listen.

APPENDIX B.
SCENARIO 2: MAJOR FREEWAY INCIDENT DURING RUSH HOUR TRAFFIC

Scenario 2 illustrates the capabilities of the ATMS to manage a major freeway incident that virtually closes the freeway and therefore has a major impact on a large segment of the roadway system. Scenario 2 begins as did Scenario 1: normal morning rush hour traffic, with no weather problems and no malfunctions of ATMS components. During peak volume, a major accident occurs on the freeway involving a tanker, a semi-trailer, and two passenger vehicles. Two car occupants are trapped inside their car but are not seriously injured. One truck driver is unconscious and bleeding. The tanker has not ruptured but one of the vehicles next to it is on fire. The driver of the vehicle on fire and the tanker driver have escaped relatively unharmed. All lanes are blocked except part of the right-most lane and the right emergency shoulder.

Real-time traffic data, identified by location, are continually received, monitored, and processed for possible incidents within the TMC. Within 20 s, an anomaly in flow is detected on the freeway and the TMC is notified of the location of the anomaly. Close, detailed observation of the area by the TMC is initiated. The data, showing a rapid reduction in flow, signal a potential red alert in the source of the flow direction. Through their observation, the TMC confirms that there is a multiple vehicle accident, including a vehicle on fire near a tanker truck. This observation prompts the TMC to issue an all-service bulletin, requesting immediate dispatch of police, fire, and ambulance services, and placing the hazardous materials (HAZMAT) team, State EPA, and the Medevac helicopter on alert. Based on the real-time data being sensed on the freeway, access control mechanisms are automatically altered to begin restricting flow onto the freeway.

The TMC consults with the emergency response forces, including police and fire department officials, regarding management of the incident. This communication confirms the policy directive that incident management responsibility reside within the TMC until appropriate onsite presence is established.

Within 1 min, traffic on the freeway comes almost to a standstill. A few cars get by in the right lane and shoulder, but the flow rate at the nearest upstream sensor is reduced to near 0 percent. An analysis of the real-time traffic situation suggests extensive traffic control responses to best manage the traffic conditions. These control suggestions include closing proximal upstream freeway entrances and posting appropriate messages to upstream traffic. The suggestions are approved by the incident manager and implemented. Appropriate data are also provided to the other metro-wide information outlets, to affect trip decisions and route planning for traffic not yet in the area.

A significant number of calls from cellular phone users caught in the backup are being received. The calls are coded and posted in a data base. The TMC request that one of the callers obtain the license number or DOT placard from the tanker involved in the incident. Once the information is obtained, the TMC connects to a commercial fleet data base to get information on the load carried by the tanker. The preliminary indication is that there is a potential chlorine gas hazard given the presence of fire near the tanker. This information is relayed to the HAZMAT response team and they are dispatched.

The backup area continues to grow, with the flow rate below 20 percent at the next three upstream sensors. Since detection of incidents through processing of roadway sensor data becomes mostly ineffective in the backup area, and secondary incidents are of concern, the TMC maintains close observation of the affected area.

Sensor data shows the virtual standstill of traffic in all lanes. An analysis of the situation suggests that the freeway be closed at the site and emergency vehicles be routed so they approach the incident from the nearest downstream exit ramp, going the wrong way on the freeway. This suggestion is approved by the incident manager. When the first police officer arrives on the scene, two-way communication between the TMC and the officer is established. The officer is advised of the potential HAZMAT situation and instructed to close the right lane and shoulder until further notice. TMC reflects this information in updated messages provided to the upstream traffic.

Through observation, the TMC confirms that the downstream freeway segment is free of traffic, and the routing of emergency vehicles to approach from that direction is implemented. Traffic controls are overridden by the TMC to create priority control on the surface streets in order to get them to the appropriate ramp.

Traffic on the freeway is now backed up for 9.66 km (6 mi). The real-time traffic data received by the TMC are used to make predictions about the state of traffic 5, 10, and 20 min into the future. These predictions are dire, and an analysis of various responses is performed to determine the response leading to the best predicted outcome. The recommended solution includes completely shutting down several upstream entrance ramps, adjusting the flow control of off-ramps to accommodate the very heavy flow off the freeway, and updating all appropriate information outlets. The incident manager accepts this solution and it is implemented. Traffic controls on affected surface streets automatically respond to the increased traffic flow.

Because of the possible HAZMAT condition, the TMC initiates an analysis to determine the best evacuation plan. This analysis uses real-time traffic data to develop a detailed contingency plan for this situation.

The incident manager orders the entire freeway from the nearest upstream interchange with another freeway down to the incident site to be closed. TMC performs a quick analysis to determine the best alternate routes for the displaced vehicles. The order is implemented via TMC override of automated traffic controls, closing all affected entrance ramps. Traffic advisories reflecting the closing and alternate routes are posted on all area and metro-wide information outlets. Based on the real-time sensing of increased flow, traffic controls along the alternate routes automatically adapt.

Response forces arrive at the scene, including fire, ambulance, the HAZMAT team, and additional police. Incident management responsibility is passed to the appropriate onsite personnel according to standard procedures. The TMC confirms that all upstream traffic in the backup has been diverted off the freeway, except for the vehicles trapped between the nearest upstream exit and the incident site. Police are informed of the situation and the need to begin removing those vehicles, in case the HAZMAT situation is serious. The police begin manually directing those cars to turn around and proceed to the last entrance in order to exit the freeway.

The TMC continues to monitor the backup for secondary incidents, but concentrates on managing the abnormal traffic patterns created by the closed freeway. Algorithms used to adjust traffic controls in attempt to maintain optimal flow are adapted to the situation, reflecting the closed freeway. The TMC maintains communication with onsite personnel, and as information is obtained from the incident site, it is filtered and passed on to appropriate information outlets.

Once the vehicle fire is extinguished and the HAZMAT team clears the tanker, the HAZMAT condition is canceled. The incident manager opens the right lane and shoulder to allow remaining vehicles trapped in the backup to pass. The TMC is made aware of these changes and update the messages provided to those vehicles stuck in the area. The TMC is also made aware of road surface damage caused by the vehicle fire. The TMC places a priority work order with the appropriate road maintenance agency, who is immediately dispatched.

When all injured individuals have been transported from the scene, tow trucks begin removing the wreckage. The road crew arrives on the scene and sets up barricades. Once all vehicles and debris are removed from the roadway, the onsite incident manager returns control to the TMC. It is ordered that the freeway be reopened, but that all information outlets, area and metro-wide, be updated to include information as to the damaged roadway and the maintenance activity underway.

When the repairs are completed, the posted advisories are deleted and the roadway system returns to normal in time for the evening rush hour. The following day, an event debriefing is held with representatives of all involved agencies.

APPENDIX C.
ATMS FUNCTIONAL DEFINITION

	OBJECTIVES: 1	2	3	4	5
1.0 Input					
1.1 Monitor Roadway System	x	x	x	x	x
1.1.1 Detect vehicles	x	x	x	x	x
1.1.1.1 Detect vehicle locations	x	x	x	x	x
1.1.1.2 Detect vehicle speeds	x	x	x	x	x
1.1.1.3 Detect vehicle types	x	x	x	x	x
1.1.2 Sense roadway conditions	x	x	x	x	x
1.1.2.1 Sense roadway surface conditions	x	x	x	x	x
1.1.2.2 Sense electronic component status	x	x	x	x	x
1.1.2.2.1 Receive BIT reports	x	x	x	x	x
1.1.2.2.2 Receive ad hoc component status reports	x	x	x	x	x
1.1.2.3 Sense visibility conditions	x	x	x	x	x
1.1.3 Observe incident sites		x	x	x	x
1.1.3.1 Verify incident data		x	x	x	x
1.1.3.2 Monitor incident clearance		x	x	x	x
1.2 Receive External Information	x	x	x	x	x
1.2.1 Receive external traffic reports	x	x	x	x	x
1.2.1.1 Receive traffic volume reports	x	x	x	x	x
1.2.1.2 Receive travel time information	x	x	x	x	x
1.2.1.2.1 Receive probe vehicle reports	x	x	x	x	x
1.2.1.2.2 Receive ad hoc travel time reports	x	x	x	x	x
1.2.1.3 Receive ad hoc roadway condition reports	x	x	x	x	x
1.2.1.4 Receive O-D data	x	x	x	x	x
1.2.2 Receive commercial rail traffic reports	x	x	x	x	x
1.2.2.1 Receive commercial rail traffic data	x	x	x	x	x
1.2.2.2 Receive ad hoc commercial rail reports	x	x	x	x	x
1.2.3 Receive weather reports	x	x	x	x	x
1.2.3.1 Receive weather service data	x	x	x	x	x
1.2.3.2 Receive ad hoc weather reports	x	x	x	x	x
1.2.4 Receive incident reports		x	x	x	x
1.2.4.1 Receive interagency incident data		x	x	x	x
1.2.4.2 Receive ad hoc incident reports		x	x	x	x
1.2.5 Receive incident response reports		x	x	x	x
1.2.5.1 Receive interagency response data		x	x	x	x
1.2.5.2 Receive ad hoc incident response reports		x	x	x	x
1.2.6 Receive other emergency response reports			x	x	x
1.2.6.1 Receive interagency emergency response data			x	x	x
1.2.6.2 Receive ad hoc emergency response reports			x	x	x
1.2.7 Receive data from other transportation systems				x	x
1.2.7.1 Receive interagency data from alternate transportation modes				x	x
1.2.7.2 Receive ad hoc reports from alternate transportation modes				x	x
1.2.8 Receive special event reports				x	x
1.2.8.1 Receive interagency special event reports				x	x
1.2.8.2 Receive ad hoc special event reports				x	x
1.2.9 Receive public comments					x
1.3 Receive Requests for Information				x	x

1.3.1 Receive requests for historical data				x	x
1.3.2 Receive requests for simulation studies				x	x
1.3.3 Receive requests for public relations activities					x
2.0 Throughput					
2.1 Select Traffic Management Tactics	x	x	x	x	x
2.1.1 Assess network conditions	x	x	x	x	x
2.1.1.1 Assess current load	x	x	x	x	x
2.1.1.2 Anticipate near-term traffic conditions	x	x	x	x	x
2.1.2 Determine optimal control scheme	x	x	x	x	x
2.1.2.1 Identify traffic control options	x	x	x	x	x
2.1.2.2 Predict traffic conditions given options	x	x	x	x	x
2.1.2.3 Assess predicted traffic conditions given options	x	x	x	x	x
2.1.2.4 Select best traffic control option	x	x	x	x	x
2.1.3 Determine special vehicle support measures			x	x	x
2.1.3.1 Determine need for ATMS support			x	x	x
2.1.3.2 Track special vehicles			x	x	x
2.2 Determine System Welfare Needs	x	x	x	x	x
2.2.1 Assess traffic management system effectiveness	x	x	x	x	x
2.2.2 Determine maintenance needs	x	x	x	x	x
2.2.2.1 Determine remedial maintenance needs	x	x	x	x	x
2.2.2.2 Determine preventative maintenance needs	x	x	x	x	x
2.2.3 Determine upgrade needs	x	x	x	x	x
2.2.3.1 Determine software upgrade needs	x	x	x	x	x
2.2.3.2 Determine hardware upgrade needs	x	x	x	x	x
2.2.3.3 Determine personnel upgrade needs	x	x	x	x	x
2.3 Assess Anomalies		x	x	x	x
2.3.1 Identify anomalies in traffic patterns		x	x	x	x
2.3.2 Determine source of anomalies		x	x	x	x
2.4 Select ATMS Responses to Incidents		x	x	x	x
2.4.1 Determine ATMS responsibilities		x	x	x	x
2.4.2 Determine need for incident services		x	x	x	x
2.4.3 Determine appropriate ATMS responses		x	x	x	x
2.5 Conduct Simulations to Support Transportation Planning				x	x
2.5.1 Assess multimodal demand and capacity				x	x
2.5.2 Determine optimal demand regulation scheme				x	x
2.5.2.1 Identify demand regulation options				x	x
2.5.2.2 Predict multimodal demand given options				x	x
2.5.2.3 Assess predicted multimodal demand				x	x
2.5.2.4 Formulate demand regulation recommendation				x	x
2.6 Assess Public Confidence					x
2.6.1 Monitor compliance with advisories					x
2.6.1.1 Monitor compliance with current advisories					x
2.6.1.2 Monitor general compliance with advisories					x
2.6.2 Assess public comments					x
2.6.2.1 Assess survey data					x
2.6.2.2 Assess ad hoc public comments					x
2.6.3 Plan public confidence enhancements					x
3.0 output					
3.1 Influence Traffic	x	x	x	x	x
3.1.1 Implement traffic controls	x	x	x	x	x
3.1.1.1 Control access to roadway segments	x	x	x	x	x
3.1.1.2 Control intersections	x	x	x	x	x
3.1.1.3 Control railroad crossings	x	x	x	x	x

3.1.2 Issue advisories	x	x	x	x	x
3.1.2.1 Issue route selection advisories	x	x	x	x	x
3.1.2.1.1 Post route selection advisories on information outlets	x	x	x	x	x
3.1.2.1.2 Post route selection advisories to other users	x	x	x	x	x
3.1.2.2 Issue speed limit advisories	x	x	x	x	x
3.1.2.2.1 Post speed advisories on information outlets	x	x	x	x	x
3.1.2.2.2 Provide speed advisories to other users	x	x	x	x	x
3.1.2.3 Issue travel advisories				x	x
3.1.2.3.1 Post travel advisories on information outlets				x	x
3.1.2.3.2 Provide travel advisories to other users				x	x
3.1.2.4 Issue mode selection advisories				x	x
3.1.2.4.1 Post mode advisories on information outlets				x	x
3.1.2.4.2 Provide mode advisories to other users				x	x
3.2 Issue Requests	x	x	x	x	x
3.2.1 Issue maintenance requests	x	x	x	x	x
3.2.1.1 Transmit electronic maintenance requests	x	x	x	x	x
3.2.1.2 Issue special maintenance requests	x	x	x	x	x
3.2.2 Issue upgrade requests	x	x	x	x	x
3.2.3 Issue incident service requests		x	x	x	x
3.2.3.1 Transmit electronic incident service requests		x	x	x	x
3.2.3.2 Issue special incident service requests		x	x	x	x
3.2.4 Issue requests for information		x	x	x	x
3.2.5 Issue requests for onsite traffic control	x	x	x	x	x
3.3 Provide Information		x	x	x	x
3.3.1 Provide incident reports		x	x	x	x
3.3.1.1 Transmit electronic incident reports		x	x	x	x
3.3.1.2 Issue special incident reports		x	x	x	x
3.3.2 Provide incident management reports		x	x	x	x
3.3.2.1 Transmit electronic incident management reports		x	x	x	x
3.3.2.2 Issue special incident management reports		x	x	x	x
3.3.3 Provide historical traffic data				x	x
3.3.4 Provide simulation reports and recommendations				x	x
3.3.5 Provide public relations information					x
4.0 support					
4.1 Maintain Records	x	x	x	x	x
4.1.1 Store network data	x	x	x	x	x
4.1.2 Retrieve network data	x	x	x	x	x
4.1.3 Store incident data		x	x	x	x
4.1.3.1 Store electronic incident data		x	x	x	x
4.1.3.2 Store hard copy of incident reports		x	x	x	x
4.1.4 Retrieve incident data		x	x	x	x
4.1.4.1 Retrieve electronic incident data		x	x	x	x
4.1.4.2 Retrieve hard copy of incident reports		x	x	x	x
4.1.5 Perform Data base Management	x	x	x	x	x
4.2 Provide Training	x	x	x	x	x
4.2.1 Provide traffic management training	x	x	x	x	x
4.2.2 Provide maintainer training	x	x	x	x	x

4.2.3 Provide incident management training		x	x	x	x
4.2.4 Provide special events training				x	x
4.3 Develop Traffic Management Plans	x	x	x	x	x
4.3.1 Develop strategic traffic management plans	x	x	x	x	x
4.3.2 Develop special event traffic management plans	x	x	x	x	x
4.3.3 Develop traffic management contingency plans	x	x	x	x	x
4.4 Perform Administrative Duties	x	x	x	x	x
4.4.1 Formulate Policy and Procedures	x	x	x	x	x
4.4.1.1 Receive directives	x	x	x	x	x
4.4.1.2 Develop policy	x	x	x	x	x
4.4.1.3 Specify procedures	x	x	x	x	x
4.4.1.4 Implement policy and procedures	x	x	x	x	x
4.4.2 Manage Financial Resources	x	x	x	x	x
4.4.2.1 Perform fiscal planning	x	x	x	x	x
4.4.2.2 Perform budget tracking	x	x	x	x	x
4.4.3 Manage Personnel	x	x	x	x	x
4.4.3.1 Perform evaluations	x	x	x	x	x
4.4.3.2 Perform personnel selection	x	x	x	x	x
4.4.3.3 Maintain personnel records	x	x	x	x	x
4.5 Provide Interagency Coordination		x	x	x	x
4.5.1 Maintain communications with incident responders		x	x	x	x
4.5.2 Coordinate multi-agency incident response		x	x	x	x
4.5.3 Coordinate multi-agency response to other emergencies			x	x	x
4.5.4 Coordinate multi-agency transportation planning				x	x

APPENDIX D.
SUMMARY OF FUNCTION ALLOCATION

Function	Role Designation	Input	Processing	Response Selection	Output
1. 1.1.1.1 Detect vehicle locations	Executive Controller	M	M	M	M
2. 1.1.1.2 Detect vehicle speeds	Executive Controller	M	M	M	M
3. 1.1.1.3 Detect vehicle types	Executive Controller	M	M	M	M
4. 1.1.2.1 Sense roadway surface conditions	Supervisory Controller	M	Mh	Mh	M
5. 1.1.2.2.1 Receive BIT reports	Executive Controller	M	M	M	M
6. 1.1.2.2.2 Receive ad hoc component status reports	Direct Performer	H	H	H	Hm
7. 1.1.2.3 Sense visibility conditions	Supervisory Controller	M	Mh	Mh	M
8. 1.1.3.1 Verify incident data	Manual Controller	Hm	H	H	Hm
9. 1.1.3.2 Monitor incident clearance	Manual Controller	Hm	H	H	Hm
10. 1.2.1.1 Receive traffic volume reports	Direct Performer	Hm	H	H	Hm
11. 1.2.1.2.1 Receive probe vehicle reports	Executive Controller	M	M	M	M
12. 1.2.1.2.2 Receive ad hoc travel time reports	Direct Performer	Hm	H	H	Hm
13. 1.2.1.3 Receive ad hoc roadway condition reports	Direct Performer	Hm	H	H	Hm
14. 1.2.1.4 Receive O-D data	Executive Controller	M	M	M	M

Function	Role Designation	Input	Processing	Response Selection	output
27. 1.2.8.1 Receive interagency special event reports	Executive Controller	M	M	M	M
28. 1.2.8.2 Receive ad hoc special event reports	Direct Performer	Hm	H	H	Hm
29. 1.2.9 Receive public comments	Direct Performer	Hm	H	H	Hm
30. 1.3.1 Receive requests for historical data	Direct Performer	Hm	H	H	Hm
31. 1.3.2 Receive requests for simulation studies	Direct Performer	Hm	H	H	Hm
32. 1.3.3 Receive requests for public relations activities	Direct Performer	Hm	H	H	Hm
33. 2.1.1.1 Assess current load	Supervisory Controller	M	Mh	Mh	M
34. 2.1.1.2 Anticipate near-term traffic conditions	Supervisory controller	M	Mh	Mh	M
35. 2.1.2.1 Identify traffic control options	Supervisory Controller	M	Mh	Mh	M
36. 2.1.2.2 Predict traffic conditions given options	Supervisory Controller	M	Mh	Mh	M
37. 2.1.2.3 Assess predicted traffic conditions given options	Supervisory Controller	M	Mh	Mh	M
38. 2.1.2.4 Select best traffic control option	Supervisory Controller	M	Mh	Mh	M
39. 2.1.3.1 Determine need for ATMS support (for special vehicles)	Supervisory Controller	M	Mh	Mh	M
40. 2.1.3.2 Track special vehicles	Executive Controller	M	M	M	M

Function	Role Designation	Input	Processing	Response Selection	output
41. 2.2.1 Assess traffic management system effectiveness	Supervisory Controller	M	Mh	Mh	M
42. 2.2.2.1 Determine remedial maintenance needs	Supervisory Controller	Mh	M	Mh	M
43. 2.2.2.2 Determine preventative maintenance needs	Supervisory Controller	M	M	Mh	M
44. 2.2.3.1 Determine software upgrade needs	Direct Performer	H	H	H	H
45. 2.2.3.2 Determine hardware upgrade needs	Direct Performer	H	H	H	H
46. 2.2.3.3 Determine personnel upgrade needs	Direct Performer	H	H	H	H
47. 2.3.1 Identify anomalies in traffic patterns	Supervisory Controller	M	M	Mh	M
48. 2.3.2 Determine source of anomalies	Manual Controller	Hm	Hm	H	Hm
49. 2.4.1 Determine ATMS responsibilities (in response to incidents)	Manual Controller	Hm	Hm	H	Hm
50. 2.4.2 Determine need for incident services	Manual Controller	Hm	Hm	H	Hm
51. 2.4.3 Determine appropriate ATMS responses	Manual Controller	Hm	Hm	H	Hm
52. 2.5.1 Assess multimodal demand and capacity	Manual Controller	Hm	M	H	M
53. 2.5.2.1 Identify demand regulation options	Manual Controller	Hm	Hm	H	M

Function	Role Designation	Input	Processing	Response Selection	output
54. 2.5.2.2 Predict multimodal demand given options	Supervisory Controller	Mh	M	Mh	M
55. 2.5.2.3 Assess predicted multimodal demand	Supervisory Controller	M	M	Mh	M
56. 2.5.2.4 Formulate demand regulation recommendation	Direct Performer	Hm	H	H	Hm
57. 2.6.1.1 Monitor compliance with current advisories	Supervisory Controller	M	M	Mh	M
58. 2.6.1.2 Monitor general compliance with advisories	Manual Controller	Hm	M	H	M
59. 2.6.2.1 Assess survey data	Manual Controller	Hm	M	H	M
60. 2.6.2.2 Assess ad hoc public comments	Direct Performer	Hm	H	H	H
61. 2.6.3 Plan public confidence enhancements	Direct Performer	Hm	H	H	H
62. 3.1.1.1 Control access to roadway segments	Executive Controller	M	M	M	M
63. 3.1.1.2 Control intersections	Executive Controller	M	M	M	M
64. 3.1.1.3 Control railroad crossings	Executive Controller	M	M	M	M
65. 3.1.2.1.1 Post route advisories on information outlets	Executive Controller	M	M	M	M
66. 3.1.2.1.2 Provide route advisories to other users	Direct Performer	Hm	H	H	Hm
67. 3.1.2.2.1 Post speed advisories on information outlets	Executive Controller	M	M	M	M

Function	Role Designation	Input	Processing	Response Selection	output
68. 3.1.2.2.2 Provide speed advisories to other users	Direct Performer	Hm	H	H	Hm
69. 3.1.2.3.1 Post travel advisories on information outlets	Executive Controller	M	M	M	M
70. 3.1.2.3.2 Provide travel advisories to other users	Direct Performer	Hm	H	H	Hm
71. 3.1.2.4.1 Post mode advisories on information outlets	Executive Controller	M	M	M	M
72. 3.1.2.4.2 Provide mode advisories to other users	Direct Performer	Hm	H	H	Hm
73. 3.2.1.1 Transmit electronic maintenance requests	Executive Controller	M	M	M	M
74. 3.2.1.2 Issue special maintenance requests	Manual Controller	Hm	Hm	H	Hm
75. 3.2.2 Issue upgrade requests	Direct Performer	Hm	H	H	H
76. 3.2.3.1 Transmit electronic incident service requests	Executive Controller	M	M	M	M
77. 3.2.3.2 Issue special incident service requests	Manual Controller	Hm	Hm	H	Hm
78. 3.2.4 Issue requests for information	Direct Performer	Hm	H	H	H
79. 3.2.5 Issue requests for onsite traffic control	Direct Performer	Hm	H	H	H
80. 3.3.1.1 Transmit electronic incident reports	Executive Controller	M	M	M	M
81. 3.3.1.2 Issue special incident reports	Manual Controller	Hm	Hm	H	Hm

Function	Role Designation	Input	Processing	Response Selection	output
82. 3.3.2.1 Transmit electronic incident management reports	Executive Controller	M	M	M	M
83. 3.3.2.2 Issue special incident management reports	Manual Controller	Hm	Hm	H	Hm
84. 3.3.3 Provide historical traffic data	Manual Controller	Hm	Hm	H	Hm
85. 3.3.4 Provide simulation reports and recommendations	Manual Controller	Hm	Hm	H	Hm
86. 3.3.5 Provide public relations information	Manual Controller	Hm	Hm	H	Hm
87. 4.1.1 Store network data	Executive Controller	M	M	M	M
88. 4.1.2 Retrieve network data	Executive Controller	M	M	M	M
89. 4.1.3.1 Store electronic incident data	Executive Controller	M	M	M	M
90. 4.1.3.2 Store hardcopy of incident reports	Direct Performer	H	H	H	H
91. 4.1.4.1 Retrieve electronic incident data	Executive Controller	M	M	M	M
92. 4.1.4.2 Retrieve hardcopy of incident reports	Direct Performer	H	H	H	H
93. 4.1.5 Perform data base management	Manual Controller	Hm	Hm	H	Hm
94. 4.2.1 Provide traffic management training	Manual Controller	H	Hm	H	Hm

Function	Role Designation	Input	Processing	Response Selection	output
95. 4.2.2 Provide maintainer training	Manual Controller	H	Hm	H	Hm
96. 4.2.3 Provide incident management training	Manual Controller	H	Hm	H	Hm
97. 4.2.4 Provide special events training	Manual Controller	H	Hm	H	Hm
98. 4.3.1 Develop strategic traffic management plans	Manual Controller	H	Hm	H	Hm
99. 4.3.2 Develop special event traffic management plans	Manual Controller	Hm	Hm	H	Hm
100. 4.3.3 Develop traffic management contingency plans	Manual Controller	Hm	Hm	H	Hm
101. 4.4.1.1 Receive directives	Direct Performer	H	H	H	H
102. 4.4.1.2 Develop policy	Direct Performer	H	H	H	H
103. 4.4.1.3 Specify procedures	Direct Performer	H	H	H	H
104. 4.4.1.4 Implement policy and procedures	Direct Performer	H	H	H	Hm
105. 4.4.2.1 Perform fiscal planning	Manual Controller	H	Hm	H	Hm
106. 4.4.2.2 Perform budget tracking	Manual Controller	H	Hm	H	Hm
107. 4.4.3.1 Perform evaluations	Direct Performer	H	H	H	H
108. 4.4.3.2 Perform personnel selection	Direct Performer	H	H	H	H
109. 4.4.3.3 Maintain personnel records	Manual Controller	H	Hm	H	M

Function	Role Designation	Input	Processing	Response Selection	output
110. 4.5.1 Maintain communications with incident responders	Direct Performer	Hm	H	H	H
111. 4.5.2 Coordinate multi-agency incident response	Direct Performer	H	H	H	H
112. 4.5.3 Coordinate multi-agency response to other emergencies	Direct Performer	H	H	H	H
113. 4.5.4 Coordinate multi-agency transportation planning	Direct Performer	H	H	H	H

APPENDIX E.
BREAKDOWN OF REQUIRED TASKS BY TASK TYPE

Task Type	Required Tasks
Communications	- distribute electronic historical traffic data - distribute electronic simulation report - distribute electronic system recommendations - distribute text-based (hardcopy, electronic mail) historical traffic data - distribute text-based (hardcopy, electronic mail) simulation report - distribute text-based (hardcopy, electronic mail) system recommendations - distribute voice-based (telephone, radio) historical traffic data - distribute voice-based (telephone, radio) simulation report - distribute voice-based (telephone, radio) system recommendations
	- exchange information between ATMS personnel and personnel from agencies conducting transportation planning
	- initiate verbal request for hardcopies of incident reports - initiate written request for hardcopies of incident reports
	- issue electronic mail request for incident services - issue electronic mail request for preventive maintenance - issue electronic mail request for remedial maintenance - issue text (hardcopy, electronic mail) incident report - issue text (hardcopy, electronic mail) request for information - issue text (hardcopy, electronic mail) request for on-site traffic control - issue voice (telephone, radio) request for incident services - issue voice (telephone, radio) request for information - issue voice (telephone, radio) request for on-site traffic control - issue voice (telephone, radio) request for pre-positioning of maintenance assets - issue voice (telephone, radio) request for preventive maintenance - issue voice (telephone, radio) request for remedial maintenance - issue voice-based (telephone, radio) incident management report - issue voice-based (telephone, radio) incident report - issue written (hardcopy) request for incident services - issue written (hardcopy) request for preventive maintenance - issue written (hardcopy) request for remedial maintenance - issue written (hardcopy, electronic mail) incident management report - issue written (hardcopy, electronic mail) request for hardware upgrade - issue written (hardcopy, electronic mail) request for personnel upgrade - issue written (hardcopy, electronic mail) request for software upgrade
	- provide appropriate instructions to the emergency responders - provide appropriate instructions to the incident responders - provide incident data to responders - provide operator-derived assessments (if necessary) - provide public relations information via voice (telephone) communication - provide public relations information via written report or electronic mail message
	- receive alternate transportation mode information via electronic mail - receive alternate transportation mode information via fax transmission - receive communications from entities responding to an incident - receive directives via voice (telephone, radio) communications

Task Type	Required Tasks
Communications (cont.)	- receive directives via written report - receive electronic mail report of current weather - receive electronic mail report of predicted weather - receive electronic mail requests for historical data - receive electronic mail requests for public relations activities - receive electronic mail requests for simulation analyses/reports - receive fax report of current weather - receive fax report of predicted weather - receive fax requests for historical data - receive fax requests for public relations activities - receive fax requests for simulation analyses/reports - receive fax transmissions of incident data - receive fax transmissions of incident response reports - receive fax transmissions of special event information - receive incident data via electronic mail message - receive incident response reports via electronic mail - receive public comments - receive public comments via electronic mail - receive public comments via fax transmission - receive public comments via voice (telephone, radio) communication - receive public comments via written communication - receive special event information via electronic mail - receive survey results - receive video traffic volume reports - receive voice-based (telephone, radio) alternate transportation mode information - receive voice-based (telephone, radio) commercial rail traffic data - receive voice-based (telephone, radio) component status report - receive voice-based (telephone, radio) emergency response reports - receive voice-based (telephone, radio) incident data - receive voice-based (telephone, radio) incident response information - receive voice-based (telephone, radio) report of current weather - receive voice-based (telephone, radio) report of predicted weather - receive voice-based (telephone, radio) reports on status of roadway conditions - receive voice-based (telephone, radio) requests for historical data - receive voice-based (telephone, radio) requests for public relations activities - receive voice-based (telephone, radio) requests for simulation analyses and accompanying reports - receive voice-based (telephone, radio) special event information - receive voice-based (telephone, radio) traffic volume reports - receive voice-based (telephone, radio) travel time data - receive written component status report - receive written requests for historical data - receive written requests for public relations activities - receive written requests for simulation analyses/report
	- report hardware upgrade requirements - report ATMS incident response/management responsibilities (via Traffic Data Management System) - report personnel upgrade requirements - report software upgrade requirements - report source of traffic anomaly
	- retransmit hardware upgrade request

Task Type	Required Tasks
Communications (cont.)	- retransmit historical traffic data - retransmit incident management report - retransmit incident report - retransmit incident service request - retransmit information request - retransmit mode selection advisories - retransmit personnel upgrade request - retransmit preventive maintenance request - retransmit remedial maintenance request - retransmit request for onsite traffic control - retransmit route selection advisories - retransmit simulation report - retransmit software upgrade request - retransmit speed limit advisories - retransmit system recommendations - retransmit travel advisories
	- transmit mode selection advisories via radio - transmit mode selection advisories via telephone - transmit route selection advisories via radio - transmit route selection advisories via telephone - transmit speed limit advisories via radio - transmit speed limit advisories via telephone - transmit travel advisories via radio - transmit travel advisories via telephone
Coordination	- conduct incident management training - conduct maintainer training - conduct special events training - conduct traffic management training
	- continue media campaign
	- initiate media campaign
	- maintain media campaign
Decision Making	- determine alternative predictions (if necessary) - determine degree to which the ATMS should become involved in an incident - determine extent to which incident services are necessary - determine generalizability of analysis results - determine if prioritization of options must be overridden - determine if traffic flow threshold must be modified - determine whether incident management trainee's performance meets criteria for successful performance - determine whether maintainer trainee's performance meets criteria for successful performance - determine whether the traffic management trainee's performance meets criteria for successful performance
	- enter new data
	- implement termination actions (if required)
	- interact with simulation (if necessary)

Task Type	Required Tasks
Decision-Making (cont.)	- modify input information (if necessary) - modify preventive maintenance requirements (if necessary) - modify remedial maintenance requirements (if necessary) - modify set of control options (if necessary) - modify system-generated demand regulation options (if necessary) - modify threshold
	- override computer-assigned control option rankings (if necessary) - override computer-derived assessments (if necessary) - override software-designated support levels (if necessary) - override traffic predictions (if necessary)
Information Processing	- analyze incident management training requirements - analyze maintainer training requirements - analyze special event training requirements - analyze traffic management training requirements
	- assess analysis results - assess characteristics of an incident (location, severity, vehicle type(s) involved, source of anomaly) - assess differences in characteristics of the detected anomaly and those anomalies with identified sources - assess effectiveness of most recently implemented traffic management strategy - assess effectiveness of previous traffic management strategies - assess importance of ad hoc public comments - assess prioritization of options and simulation results associated with each option - assess public comments - assess survey results - assess urgency of ad hoc public comments
	- assimilate the following: incident detection/location information, acquired heuristics, observed information, voice reports, and Traffic Data Management System information - assimilate incident/traffic information
	- compare personnel records and personnel requirements
	- evaluate accuracy of computer-based assessments of current load data - evaluate assembled incident/contingency information - evaluate fiscal information - evaluate individual's training and/or personnel information against the minimum requirements - evaluate information relevant to development of special event traffic management plans - evaluate information relevant to development of strategic traffic management plans - evaluate information relevant to policy development
	- reassess effectiveness of traffic management strategy (if necessary)
	- review alternate transportation mode information - review computer-generated demand regulation options - review existing contingency plans - review historical data to assess effectiveness of most recently implemented traffic management strategy

Task Type	Required Tasks
Information Processing (cont.)	- review historical data to assess effectiveness of previous traffic management strategies - review incident performance data from previous rush hour - review lessons learned from implementation of previous incident management strategies - review lessons learned from implementation of previous traffic management strategies - review lessons learned from most recent special event - review lessons learned from most recently implemented incident management strategies - review lessons learned from most recently implemented traffic management strategies - review lessons learned from previous maintenance approaches - review network data - review prioritized demand regulation options, review simulation results associated with each option - review requested incident data - review results of survey data analysis - review special event information
	- select anomaly identification algorithm - select appropriate hardcopy of incident report - select a demand regulation option - select personnel
Observation	- confirm that data are being stored
	- detect errors in transmission of hardware upgrade requests - detect errors in transmission of historical traffic data - detect errors in transmission of incident management reports - detect errors in transmission of incident reports - detect errors in transmission of incident service requests - detect errors in transmission of information requests - detect errors in transmission of onsite traffic control requests - detect errors in transmission of personnel upgrade requests - detect errors in transmission of preventive maintenance requests - detect errors in transmission of remedial maintenance requests - detect errors in transmission of route selection advisories - detect errors in transmission of simulation reports - detect errors in transmission of software upgrade requests - detect errors in transmission of speed limit advisories - detect errors in transmission of system recommendations - detect errors in transmission of travel advisories
	- identify agencies required to resolve the emergency - identify agencies required to resolve the incident - identify appropriate threshold (if modification is desired) - identify assessments that must be overridden (through heuristic rules or direct observation available from camera views) - identify assigned support levels that must be overridden (if any) - identify control options overlooked by software - identify discrepancies between planned and actual budgets - identify existing hardware limitations (with respect to capability, efficiency, effectiveness) - identify existing personnel limitations (with respect to capability, efficiency, effectiveness, competence)

Task Type	Required Tasks
Observation (cont.)	- identify existing software limitations (with respect to capability, efficiency, effectiveness) - identify inaccurate or outdated personnel data - identify inappropriate control options - identify individuals with skills and experience that match the personnel needs - identify ATMS activities that cause misperceptions - identify ATMS activities that yield negative public reaction - identify minimum requirements for the individual's job position - identify needed training program results and other evaluations contained in the personnel records - identify predictions that must be overridden (inaccuracies, imprecision) - identify probable anomaly source ("match") - identify questionable compliance indicators - identify questionable measurements - identify type(s) of incident services required - identify undetermined anomaly source ("mismatch")
	- monitor alternate transportation mode information - monitor assessments of incident data for major corridors - monitor assessments of incident data for roadway segments - monitor BIT data (status and failure) - monitor calculations of average travel time per roadway segment - monitor comparisons of simulation results - monitor compilations of incident response data - monitor compliance measurement calculations - monitor computer-based assessments of current load data - monitor computer-calculated measurements of general compliance with route selection advisories - monitor computer-calculated measurements of general compliance with speed advisories - monitor computer-calculated measurements of general compliance with transportation mode advisories - monitor computer-calculated measurements of general compliance with travel advisories - monitor computer-derived traffic control options - monitor data storage - monitor data validity - monitor data base's ability to satisfy operational requirements and other user needs - monitor effectiveness of traffic management strategy (through parameters such as traffic throughput, ratio of traffic volume to capacity) - monitor emergency response information - monitor incident clearance procedures (via surveillance camera views or interaction with onsite personnel) - monitor incident detection/location information - monitor information on visibility conditions - monitor ATMS functions' receipt of requested incident data - monitor level of support assigned to each special vehicle - monitor multidimensional "score" assigned to each control option (and its associated set of predictions) - monitor multimodal capacity calculations - monitor multimodal demand calculations - monitor near-term traffic predictions (traffic volumes, densities, speeds) - monitor network data retrieval process - monitor O-D data summaries

Task Type	Required Tasks
Observation (cont.)	- monitor overrides of roadway access control measures in vicinity of railroad crossings - monitor overrides of traffic signal timing sequences in vicinity of railroad crossings - monitor posting of mode selection advisories - monitor posting of route selection advisories - monitor posting of speed limit advisories - monitor posting of travel advisories - monitor preventive maintenance records - monitor preventive maintenance schedules - monitor prioritization of demand regulation options - monitor prioritization of traffic control options - monitor rail traffic data (O-D, location, speed, train length) - monitor return of roadway access controls to their initial states - monitor return of traffic signal timing sequences to their initial states - monitor road surface condition sensor data - monitor roadway segment images captured by surveillance cameras - monitor simulation analyses (and accompanying predictions) performed by the Intermodal Transportation Planning System - monitor special event information - monitor special vehicle location data - monitor special vehicle O-D data - monitor status of posted mode selection advisories - monitor status of posted route selection advisories - monitor status of posted speed limit advisories - monitor status of posted travel advisories - monitor status of roadway access control devices - monitor status of traffic signal control devices **- monitor system-specified remedial maintenance requirements** - monitor that the Traffic Data Management System receives the data - monitor traffic condition predictions derived from input data - monitor traffic control information - monitor traffic volume information (calculations performed by the Adaptive Traffic Control System) - monitor transmission of incident management report - monitor transmission of incident reports - monitor transmission of incident service requests - monitor transmission of maintenance requests - monitor vehicle classification information - monitor vehicle speed information (calculations performed by the Adaptive Traffic Control System) - monitor weather service data
	- recognize occurrence of a difference threshold - recognize point at which the incident is cleared and normal ATMS operation should resume **- recognize when/if hardware upgrades are required** **- recognize when/if personnel upgrades are required** - recognize when/if software upgrades are required
	- validate analysis results - validate assignment of scores **- validate preventive maintenance requirements** **- validate prioritization of preventive maintenance requirements** **- validate prioritization of remedial maintenance requirements** - validate public comments

Task Type	Required Tasks
Observation (cont.)	- validate simulation results - validate software-generated demand and capacity calculations - validate specified remedial maintenance requirements - validate system-computed advisory compliance measurements - validate system-computed compliance measurements - validate system's effectiveness assessment
	- verify incident occurrence (via surveillance camera views of incident site or interaction with onsite personnel)
Outcome	- create set of special event traffic management plans
	- develop fiscal plan - develop incident management training materials - develop maintainer training materials - develop operator-derived control options (if necessary) - develop plans/strategies for enhancing public's confidence in the ATMS - develop policy - develop set of feasible incident response strategies - develop set of strategic traffic management plans - develop special event training materials - develop traffic management contingency plan - develop traffic management training materials
	- devise modified assessment strategy (if necessary) - devise modified prioritization approach (if necessary) - devise prioritization scheme for response strategies - devise prioritization strategy (if necessary) - devise strategy for reassigning scores (if necessary) - devise strategy for reassigning support levels (if necessary)
	- establish role of the ATMS in incident management
	- formulate procedures
	- manipulate fiscal information (for example, "what ifs" using a spreadsheet)
	- prioritize hardware procurement efforts - prioritize hardware upgrade needs - prioritize personnel upgrade requirements (if multiple requirements are specified) - prioritize software procurement/development efforts - prioritize software upgrade needs
	- program systems to implement the selected policy and procedures
	- reassign scores (if necessary)
	- recommend options overlooked by the software - recommend strategy for enhancing public confidence
	- reprioritize demand regulation options (if necessary) - reprioritize preventive maintenance requirements (if necessary) - reprioritize remedial maintenance requirements (if necessary)
	- retrieve external data base information - retrieve information relevant to policy development - retrieve information relevant to procedure specification

Task Type	Required Tasks
Outcome (cont.)	- simulate implementation of the directives iteratively - simulate implementation of the policy iteratively - simulate special event traffic management plans iteratively - simulate strategic traffic management plans iteratively - simulate traffic management contingency plan iteratively
	- specify ATMS responsibilities in incident management - specify qualifications of required personnel
	- store incident reports
	- update information reflecting performance of ATMS personnel
	- write a summary justifying personnel selection - write a summary of the evaluation

APPENDIX F.
BREAKDOWN OF RELATED TASKS BY TASK TYPE

Task Type	Related Tasks
Communications	- consult probe vehicle operators - consult Incident Response Advisory System - consult Intermodal Transportation Planning System - consult Maintenance Tracking System - consult onsite personnel - consult Traffic Data Management System - consult Traffic Management Training System
	- contact personnel selected
	- ensure the users that required data are available
	- exchange information needed to develop transportation plans
	- hand-deliver memoranda documenting removal of hardcopies of incident reports
	- mail memoranda documenting removal of hardcopies of incident reports
	- notify special services of incident clearance via telephone or radio
	- operate appropriate communications channels
	- provide electronic incident response reports - provide electronic reports specifying incident service requirements (via Traffic Data Management System) - provide verbal ATMS responsibility reports - provide verbal reports specifying incident service requirements - provide verbal (telephone, radio) incident response reports - provide written incident response reports - provide written ATMS responsibility reports - provide written reports specifying incident service requirements
	- receive budget tracking information - receive Communications Support System information - receive computer reports of anomalies - receive contingency information from sources external to the ATMS - receive current policy/procedure specifications - receive electronic incident clearance reports - receive electronic incident reports - receive electronic incident/traffic information from Adaptive Traffic Control System - receive electronic incident/traffic information from Incident Detection and Location System - receive electronic incident/traffic information from Predictive Traffic Modeling System - receive electronic incident/traffic information from Traffic Data Management System - receive electronic mail notification of incident service needs - receive electronic mail notification of need for historical traffic data - receive electronic mail notification of need for incident management report - receive electronic mail notifications of need for incident reports

Task Type	Related Tasks
Communications (cont.)	- receive electronic mail notifications of preventive maintenance needs - receive electronic mail notification of remedial maintenance needs - receive electronic mail notifications of system upgrade requirements - receive electronic mail request for information - receive electronic mail request for onsite traffic control - receive electronic notification of need for public relations information - receive electronic notification of need for simulation reports - receive electronic notification of need for system recommendations - receive electronic policy statements - receive electronic procedures - receive electronic responsibility reports - receive electronic survey data - receive emergency status reports - receive fiscal information - receive hardware upgrade policy statements - receive hardware upgrade procedures - receive historical advisory compliance data - receive incident reports based on electronic and hardcopy information - receive incident response reports - receive incident status reports - receive information on traffic anomaly sources - receive information provided by the Incident Response Advisory System - receive information that may be helpful for creating special event traffic management plans - receive information that may be helpful for creating strategic traffic management plans - receive multimodal capacity calculations - receive multimodal capacity data - receive multimodal demand calculations - receive multimodal demand data - receive notification of incidents - receive personnel selection decisions and evaluations - receive personnel upgrade policy statements - receive personnel upgrade procedures - receive planning functions and policy decisions relevant to procedure specification - receive prioritized multimodal demand regulation options - receive requests to perform data base management - receive software upgrade policy statements - receive software upgrade procedures - receive survey data - receive survey results - receive traffic control information - receive Traffic Data Management System information - receive verbal assessment of ATMS hardware - receive verbal assessments of ATMS personnel - receive verbal assessments of ATMS software - receive verbal requests for hardcopies of incident reports - receive verbal (telephone, radio) incident/traffic information - receive video incident data - receive video information on incident clearance activities - receive voice-based policy statements

Task Type	Related Tasks
Communications (cont.)	- receive voice-based procedural information - receive voice-based responsibility reports - receive voice-based (telephone, radio) information on incident clearance activities - receive voice (telephone, radio) communication from incident responders - receive voice (telephone, radio) notifications of incident service needs - receive voice (telephone, radio) notifications of need for historical traffic data - receive voice (telephone, radio) notifications of need for incident reports - receive voice (telephone, radio) notifications of need for incident management report - receive voice (telephone, radio) notifications of preventive maintenance needs - receive voice (telephone, radio) notifications of remedial maintenance needs - receive voice (telephone, radio) notifications of system upgrade requirements - receive voice (telephone, radio) request for information - receive voice (telephone, radio) request for on-site traffic control - receive written assessment of ATMS hardware - receive written assessments of ATMS personnel - receive written assessments of ATMS software - receive written (hardcopy) notification of incident service needs - receive written (hardcopy) notification of need for historical traffic data - receive written (hardcopy) notifications of preventive maintenance needs - receive written (hardcopy) notifications of remedial maintenance needs - receive written (hardcopy) notifications of system upgrade requirements - receive written (hardcopy) notifications of the need for incident reports - receive written (hardcopy) notifications of the need for an incident management report - receive written (hardcopy) request for information - receive written (hardcopy) request for on-site traffic control - receive written incident reports - receive written incident/traffic information - receive written policy statements - receive written procedural information - receive written reports and plans relevant to policy development, - receive written requests for hardcopies of incident reports - receive written responsibility reports - receive written survey data
	- record component status information into electronic data base - record emergency response report via telephone or radio communication - record hardware upgrade request - record incident report via telephone or radio communication - record incident response information via telephone or radio communication - record incident service request - record information request

Task Type	Related Tasks
Communications (cont.)	- record instructor comments - record local weather information via telephone or radio communication - record mode selection advisories transmitted (historical data) - record onsite traffic control request - record personnel upgrade request - record preventive maintenance request - record public comments through interaction with the Administrative Support System - record rail traffic reports via telephone or radio communication - record remedial maintenance request - record results of incident management training exercise - record results of maintainer training exercise - record results of special events training exercise - record results of training exercise - record route selection advisories transmitted (historical data) - record software upgrade request - record special event information via telephone or radio communication - record speed limit advisories transmitted (historical data) - record status information via telephone, radio, or written communication - record storage location of hardcopies (via computer or procedures manual) - record system-wide weather information via telephone or radio communication - record travel advisories transmitted (historical data) - record unusual traffic volume information via telephone or radio communication
	- report incident clearance activities to appropriate special services - report incident information to appropriate special services - report roadway conditions via telephone or radio communication - report travel time data via telephone or radio communication
	- request data base management - request incident reports based on electronic and hardcopy information
Coordination	- acknowledge historical data requests - acknowledge requests for public relations activities - acknowledge simulation study requests
	- comment on information needed to develop transportation plans
	- conform to formatting specifications required by designated agency - conform to formatting specifications required by designated entities - conform to formatting specifications required by designated maintenance provider - conform to formatting specifications required by designated sites/control providers - conform to formatting specifications required by designated special service provider(s) - conform to formatting specifications required by requester (external agency or ATMS function)
	- designate agencies to receive incident report - designate agencies to receive incident management report - designate agencies to receive upgrade request - designate entities to receive information requests

Task Type	Related Tasks
Coordination (cont.)	- designate maintenance provider(s) - designate special service provider(s) to receive incident service request - designate sites to receive control requests - designate type of traffic control to be implemented
	- interact with Administrative Support System - interact with users and computer data base software to decide how data will be represented in data base - interact with users and computer data base software to specify what information is stored in data base
	- meet and/or communicate with people in ATMS and other agencies involved in transportation planning
	- share budget tracking summary with other individuals and agencies - share fiscal plan with other individuals and agencies - share justification summary with appropriate administrators - share special event traffic management strategy with other individuals and agencies - share summary with appropriate administrators - share traffic management strategy with other individuals and agencies - share transportation plans with other individuals and agencies
Decision-Making	- assign mode selection advisories to appropriate information outlets - assign route selection advisories to appropriate information outlets - assign speed limit advisories to appropriate information outlets - assign travel advisories to appropriate information outlets
	- decide if storage of incident reports (hardcopies) is required - decide where to store hardcopies of incident reports
	- determine access strategy to be used for data retrieval - determine if "new hires" are required - determine if requester is an external agency or an ATMS function - determine means by which established policy and procedures are to be effected - determine whether information is consistent with ATMS budget - determine whether software products should be procured or developed - determine whether special events trainee's performance meets criteria for successful performance
	- distinguish between rail traffic data requiring immediate response and data that are less urgent - distinguish roadway conditions requiring immediate response from those that are less urgent
	- implement backup and archiving strategy
	- initiate alternative clearance procedures (if current procedures are ineffective)
	- match mode selection advisories to appropriate network locations - match route selection advisories to appropriate network locations - match speed limit advisories to appropriate network locations - match travel advisories to appropriate network locations
	- set criteria for successful incident management trainee performance

Task Type	Related Tasks
Decision-Making (cont.)	- set criteria for successful maintainer trainee performance - set criteria for successful special events trainee performance - set criteria for successful traffic management trainee performance
Information Processing	- apply heuristic rules
	- assess budget data - assess policy and planning decisions in order to identify personnel requirements - assess procedures' effectiveness in resolving incident - assess relevant specifications of current policy and procedures - assess validity of directives
	- assimilate alternate transportation mode information - assimilate information describing emergency response - assimilate information describing incident response - assimilate public comments - assimilate special event data
	- compare planned budget to actual ATMS budget
	- define backup and archiving strategy
	- evaluate effectiveness of instructions in resolving incident - evaluate effect(s) of incident on traffic flow - evaluate information reflecting performance of ATMS personnel
	- interpret historical data requests (identifying historical data required) - interpret results of incident management trainee performance - interpret results of maintainer trainee performance - interpret results of special events trainee performance - interpret results of traffic management trainee performance - interpret simulation analysis requests (identifying type of analyses/reports required)
	- respond to changes in requirements
	- review assessments of traffic management system effectiveness (provided by Traffic Data Management System) - review directives - review incident data - review incident detection and location information - review incident management data - review incident performance data from previous rush hour - review information available from Incident Response Advisory System - review instructions to transmit incident reports - review instructions to transmit incident management reports - review personnel records available within Administrative Support System - review public comments - review roadway access control measures required by optimal control scheme - review software-generated comparisons between detected anomaly's characteristics and characteristics of anomalies whose sources have been established - review traffic control information - review traffic prediction information

Task Type	Related Tasks
Information Processing (cont.)	- review traffic signal timing sequences required by optimal control scheme and incident response strategy
	- select appropriate camera view(s) - select appropriate communications channels - select appropriate mode selection advisories - select appropriate route selection advisories - select appropriate speed limit advisories - select appropriate travel advisories - select incident management training content that has been developed - select incident management training method - select maintainer training content that has been developed - select maintainer training method - select traffic management training content that has been developed - select traffic management training method - select special events training content that has been developed - select special events training method
	- understand relationships between agencies that affect transportation planning - understand relationships between emergency responders - understand relationships between incident responders
Observation	- identify agencies appropriate for receipt of incident report - identify agencies appropriate for receipt of incident management report - identify agencies appropriate for receipt of upgrade request - identify agencies required to conduct transportation planning - identify anomalous traffic volume situations - identify appropriate budget tracking information - identify appropriate communications channels - identify appropriate maintenance provider(s) - identify appropriate special service provider(s) - identify entities appropriate for providing desired information - identify hardware products to be procured - identify incident data that have not been reported but are required for accurate incident assessment/response - identify information relevant to procedure specification - identify information that may be helpful for creating special event traffic management plans - identify information that may be helpful for creating strategic traffic management plans - identify information to communicate - identify invalid input data - identify most efficient means of implementing the policy and procedures - identify needed contingency information available from the ATMS - identify other information relevant to policy development - identify relevant fiscal information - identify relevant personnel records, policy decisions, and planning reports - identify responder with greatest need for ATMS instructions - identify roadway segments that will receive the most serious impact (in terms of traffic flow reduction) - identify sites appropriate for receipt of traffic control requests - identify software products to be procured (if necessary)

Task Type	Related Tasks
Observation (cont.)	- identify specifications relevant to those policies/procedures to be implemented - identify types of activities appropriate for given request - identify types of information appropriate for public distribution - identify unusual (inordinately long, excessively rapid) travel times
	- monitor assessments of weather data - monitor assignment of mode selection advisories to information outiets - monitor assignment of route selection advisories to information outlets - monitor assignment of speed limit advisories to variable message signs - monitor assignment of travel advisories to information outlets - monitor available system memory for storing data - monitor changes in transportation planning strategies - monitor Communications Support System information - monitor current load data - monitor current storage against storage limits - monitor data base performance - monitor demand regulation options passed to Intermodal Transportation Planning System - monitor effectiveness assessments - monitor entry of incident data - monitor entry of traffic data - monitor identification of invalid data - monitor information provided by Incident Response Advisory System - monitor information provided by Intermodal Transportation Planning System - monitor information provided by Maintenance Tracking System - monitor information provided by Traffic Management Training System - monitor information provided to Traffic Management Training System - monitor information reflecting performance of ATMS personnel - monitor information response reports - monitor input information (current load assessment, current roadway system status, external report information) - monitor ATMS budget - monitor maintenance tracking information - monitor matching of advisories to network locations - monitor mode selection advisories - monitor multimodal demand predictions passed to Intermodal Transportation Planning System - monitor network for incidents requiring traffic management contingency plans - monitor network volumes/speeds - monitor predictions of rail traffic location - monitor preparation/formatting of incident service requests - monitor preparation/formatting of incident management report - monitor preparation/formatting of incident reports - monitor preparation/formatting of maintenance requests - monitor preventive maintenance needs - monitor radio link data (travel time information provided through Information Dissemination System) - monitor receipt of data for following support systems: Traffic Data Management System, Predictive Traffic Modeling System, Incident Detection and Location System, Incident Response Advisory System, the Intermodal Transportation Planning System, Traffic Management Training System

Task Type	Related Tasks
Observation (cont.)	- monitor receipt of historical incident data requests - monitor remedial maintenance needs (for electronic components) - monitor remedial maintenance schedules - monitor reports indicating preventive maintenance needs - monitor reports indicating remedial maintenance needs - monitor roadway condition reports - monitor simulation results passed to Intermodal Transportation Planning System - monitor status of roadway conditions (for maintenance purposes) - monitor system component evaluations - monitor system's responses to weather data - monitor traffic prediction information - monitor Traffic Data Management System information - monitor vehicle locations (maintained by Traffic Data Management System) - monitor vehicle movement reports - monitor vehicle occupancy information (from surveillance cameras) - monitor vehicle speeds (maintained by Traffic Data Management System) - monitor violations of potential vehicle-type restrictions
	- observe incident site - observe road images via surveillance cameras
	- recognize data link failures - recognize formatting requirements for each route selection advisory - recognize formatting requirements for each speed limit advisory - recognize formatting requirements for each travel advisory - recognize formatting requirements for each mode selection advisory - recognize potentially severe weather patterns - recognize type of historical traffic data required - recognize type of public relations information required - recognize type of simulation report required - recognize type of system recommendations required
	- validate alternate transportation mode information - validate component status report - validate incident information - validate information describing emergency response - validate information describing incident response - validate input information - validate rail traffic data - validate roadway condition reports - validate special event data - validate traffic volume reports - validate travel time reports - validate visibility condition information - validate weather reports
	- verify incident reports using other information sources
	- view video scenes from surveillance cameras
Outcome	- access historical data - access historical traffic data - access public relations information - access simulation report

Task Type	Related Tasks
Outcome (cont.)	- access system recommendations
	- compile public comments
	- create information to communicate
	- design incident management training method - design maintainer training method - design special events training method - design traffic management training method
	- develop incident management training course content - develop information needed to develop transportation plans - develop maintainer training course content - develop special events training course content - develop traffic management training course content - develop transportation plans
	- document location in computer data base or procedures manual - document location of budget tracking summary - document location of policy - document location of procedures - document location of summary - document storage location of fiscal plan - document traffic management contingency plan - document traffic management strategy
	- enter alternate transportation mode information into electronic data base - enter emergency response report into electronic data base - enter incident clearance procedures into electronic data base - enter incident report into electronic data base - enter incident response reports into electronic data base - enter incident verification into electronic data base - enter local weather information into electronic data base - enter public comment assessments into the Traffic Data Management System - enter roadway condition information into electronic data base - enter special event information into electronic data base - enter system-wide weather information into electronic data base - enter traffic volume report into electronic data base - enter travel time data into electronic data base
	- establish degree to which external agencies will be involved in transportation planning
	- formulate an appropriate response (if appropriate)
	- locate appropriate historical data (within Traffic Data Management System) - locate appropriate simulation analyses/reports (within Traffic Data Management System) - locate historical traffic data - locate information relevant to policy development - locate information relevant to procedure specification - locate information that may be helpful for creating strategic traffic management plans

Task Type	Related Tasks
Outcome (cont.)	- locate information that may be helpful for creating special event traffic management plans - locate needed training program results and other evaluations contained in personnel records - locate public relations information - locate relevant fiscal information - locate required budget tracking information - locate simulation report - locate specifications relevant to policies/procedures to be implemented - locate system recommendations
	- log errors in transmission of mode selection advisories - log errors in transmission of route selection advisories - log errors in transmission of speed limit advisories - log errors in transmission of travel advisories
	- obtain needed contingency information available from ATMS - obtain needed training program results and other evaluations contained in personnel records - obtain relevant personnel record, policy decisions, and planning reports - obtain information to communicate
	- prepare data for distribution to requester (external agency or ATMS function) - prepare for notification of violations to vehicle-type restrictions - prepare hardware upgrade request - prepare incident management report - prepare incident report - prepare incident service request - prepare information request - prepare memoranda documenting removal of hardcopies of incident reports - prepare personnel upgrade request - prepare preventive maintenance requests - prepare public relations information for distribution to requesting agency - prepare remedial maintenance requests - prepare request for onsite traffic control - prepare simulation report for distribution to requesting agency - prepare software upgrade request - prepare system recommendation for distribution to requesting agency
	- print incident reports based on electronic and hardcopy information - print memoranda documenting removal of hardcopies of incident reports
	- prioritize historical data requests - prioritize incidents (those having most negative impact on traffic flow take precedence) - prioritize rail traffic information (where data requiring immediate responses receive highest priority), - prioritize requests for public relations activities - prioritize roadway conditions (where most urgent conditions receive highest priority) - prioritize simulation study requests

APPENDIX G.
BREAKDOWN OF REQUIRED MAINTENANCE TASKS BY TASK TYPE

Task Type	Maintenance Tasks
Communications	- issue electronic mail request for preventive maintenance - issue electronic mail request for remedial maintenance - issue voice (telephone, radio) request for pre-positioning of maintenance assets - issue voice (telephone, radio) request for preventive maintenance - issue voice (telephone, radio) request for remedial maintenance - issue written (hardcopy) request for preventive maintenance - issue written (hardcopy) request for remedial maintenance - issue written (hardcopy, electronic mail) request for hardware upgrade - issue written (hardcopy, electronic mail) request for software upgrade
	- receive voice-based (telephone, radio) component status report - receive written component status report
	- report hardware upgrade requirements - report software upgrade requirements
	- retransmit hardware upgrade request - retransmit preventive maintenance request - retransmit remedial maintenance request - retransmit software upgrade request
Coordination	- conduct maintainer training
Decision-Making	- determine whether maintainer trainee's performance meets criteria for successful performance
	- modify preventive maintenance requirements (if necessary) - modify remedial maintenance requirements (if necessary)
Information Processing	- analyze maintainer training requirements
	- review lessons learned from previous maintenance approaches
Observation	- detect errors in transmission of hardware upgrade requests - detect errors in transmission of preventive maintenance requests - detect errors in transmission of remedial maintenance requests - detect errors in transmission of software upgrade requests
	- identify existing hardware limitations (with respect to capability, efficiency, effectiveness) - identify existing software limitations (with respect to power, efficiency, effectiveness)
	- monitor BIT data (status and failure) - monitor preventive maintenance records - monitor preventive maintenance schedule - monitor system-specified remedial maintenance requirements - monitor transmission of maintenance requests
	- recognize when/if hardware upgrades are required - recognize when/if software upgrades are required

Task Type	Maintenance Tasks
Observation (cont.)	- validate preventive maintenance requirements - validate prioritization of preventive maintenance requirements - validate prioritization of remedial maintenance requirements - validate specified remedial maintenance requirements
Outcome	- develop maintainer training materials
	- prioritize hardware procurement efforts - prioritize hardware upgrade needs - prioritize software procurement/development efforts - prioritize software upgrade needs
	- reprioritize preventive maintenance requirements (if necessary) - reprioritize remedial maintenance requirements (if necessary)

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