Comparable Systems Analysis:
Design and Operation of Advanced Control Centers

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FOREWORD

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This report summarizes the critical input, data processing, and output functions that are expected to be performed by IVHS-class TMC's. It describes how these functions are currently performed by the sample of existing high-technology centers and how the functions might evolve with near-term technology advancements and automation. It addresses a series of important TMC design considerations, including the user-centered design process, operator selection and training, system evolution and advanced automation, user interface design, and job performance aids.

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The authors are grateful to the management and operators of the pioneering facilities we visited for their time, insight, and candor. By sharing with us both their successes and missteps, they will make the path toward IVHS smoother for those who follow.

16. Abstract

This research explored lessons that have been learned involving human factors in the design and operation of control centers that were similar to a generic, IVHS-dass traffic management center (TMC). During an initial phase, brief visits were made at 10 existing operation control centers. Three of these were selected for more detailed study along with 8 additional centers that were strongly recommended by center managers and other researchers, During the second phase, structured interviews were completed with operators and managers at the eleven centers located in the United States, Canada and Europe.

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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

Symbol	When You Know	Multiply By	To Find	Symbol
		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 ACRONYMS AND ABBREVIATIONS

ACMI	Air Combat Maneuvering Instrumentation
AMC	Air Mobility Command
ASC	Allied Services Corporation
ATMS	Advanced Traffic Management System
ATSAC	Los Angeles Automated Surveillance and Control System
AVCS	Automated Vehicle Control System
CAD	Computer Aided Dispatch
Caltrans	California Department of Transportation
CB	Citizen Band
CCTV	Closed Circuit Television
CHP	California Highway Patrol
CMS	Changeable Message Sign
CMZ	Congestion Management Zone
CRT	Cathode Ray Tube
CVO	Commercial Vehicle Operations
DOT	Department of Transportation
ETAK, Inc.	Produces a Digital Mapping System
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMC	Freeway Management Center
FTMS	Freeway Traffic Management System
GDSS	Global Decision Support System
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
IDLS	Incident Detection and Location System
IDOT	Illinois Department of Transportation
IDS	Information Dissemination System
IFR	Instrument Flight Rules
ITMC	Illinois Traffic Management Center
IVHS	Intelligent Vehicle Highway System
LED	Light Emitting Diode
MCSS	Motorway Control and Signaling System
MTO	Ministry of Transportation, Ontario
OD	Origin - Destination
OMS	Operational Management System
PMS	Performance Measurement System
PTCC	Public Transit Control Center
RAS	Response Advisory System
SAAC	Simulator for Air-to-Air Combat
SAT	Systems Approach to Training
TACC	Tanker Airlift Command Center
TMC	Traffic Management Center
TOC	Traffic Operations Center
TravTek	Travel Technology
TSC	Traffic Systems Center
UTCS	Urban Traffic Control Center
VDT	Video Display Terminal
VMS	Variable Message Sign
WATC	Wide Area Traffic Control

Section 1 .
BACKGROUND AND SUMMARY

The traffic management center (TMC) is the primary ganglion in the network of traffic sensors, traffic signals and controllers, voice communications, electronic signs, and other resources that are designed to make traffic run smoothly on our roadways. Older TMC's are already common in most major cities where their functions usually include controlling and maintaining traffic signals and performing other relatively low-technology functions. For the most part, these older centers are largely independent of other traffic-related services and have few communication and coordination requirements.

The IVHS era is bringing advanced technology to traffic management. Many TMC's are expanding their roles and upgrading their capabilities. New, advanced technology TMC's are being designed from scratch. It has been estimated that by the turn of the century, over 200 cities will have adopted some element of IVHS technology.

IVHS TMC's incorporate larger numbers of more capable sensors to provide more detailed and precise data. Then, given the large volume of newly available data, they must employ data fusion and information processing equipment to translate the new information into a form that can enhance operators' situation awareness, i.e., their knowledge of the current status of all relevant elements of the roadway environment and trends toward future states. Situation awareness is a psychological construct that combines such processes as perception, cognition, memory and recognition, and information extrapolation and interpolation.

IVHS TMC's will employ automation of routine decisions and actions to help manage the operators' workload. The degree of automation will be adaptable, providing operators and managers the opportunity to selectively engage or disengage automated systems according to momentary workload levels and roadway situations.

Finally, IVHS TMC's will provide new channels with which to communicate information to vehicles and drivers. This may include direct transmission of data to in-vehicle display systems, presentation of brief messages on variable message signs, and presentation of more complex information on short-range highway advisory radio transmitters.

TRAFFIC MANAGEMENT CENTER (TMC) OBJECTIVES

The overall mission of the TMC is to coordinate and facilitate the safe movement of persons and goods, with minimal delay, throughout the roadway system. In order to perform this mission, the TMC must pursue the following system objectives."'

1. Maximize the available capacity of area-wide roadway systems.

The first objective of the TMC is to create the maximum effective capacity for existing roadways. By distributing the traffic load spatially and temporally and managing queues as they begin to form, the TMC seeks to minimize congestion and delay, and increase effective throughput. For special events, this may include managing parking lot ingress/egress, as well as inbound and outbound traffic.

2. Minimize the impact of roadway incidents (accidents, stalls, debris).

Roadway incidents, particularly during high demand times, have a significant impact on travel times and create a threat to public safety. Reducing the effects of these incidents may involve efforts on two fronts: reducing the likelihood of incidents occurring and minimizing the delays associated with incidents that do occur. This includes planning and procedure development, as well as real-time traffic management.

3. Assist in the provision of emergency services.

Active involvement of the TMC may facilitate the provision of emergency services. Interaction with emergency service providers (police, fire, medical, hazardous materials management) may include incident detection and verification, incident notification, coordination of responses where multiple services are needed, and modification of system parameters to improve speed or accuracy of 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., creating ambulance paths by clearing highways between a disaster site and trauma hospitals as was done in Amsterdam after the 1992 El Al crash into an apartment building).

4. Contribute to the regulation of demand.

The presence of maintenance activities, special events, or major incidents may create conditions in which the overall demand exceeds the available capacity, no matter how efficiently the traffic flow is managed. This objective requires motivating drivers to reschedule trips, reroute trips, or 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.

5. Create and maintain public confidence in the TMC.

In order to fulfill objectives 1 through 4, the TMC must be perceived by the public as reliable and competent. The TMC must be perceived as providing accurate and useful information to the public. Public relations efforts may be conducted in order to reinforce positive public perception of the TMC.

It is important to note that these are the objectives, as viewed by a panel of "IVHS visionaries," of an ideal IVHS-class TMC providing an unusually broad range of services. The traffic management philosophies and needs of individual jurisdictions will govern their specific TMC implementations. One of the most important observations made during the study of existing centers was the broad range of design and operating philosophies. While all centers shared some design and system aspects (largely because of the limited number of contractors and vendors), no two had the same traffic management needs or the same philosophy of design and operation.

DESIGNING THE TMC

The design of complex systems like control centers can be based on any or all of a large number of factors. These factors include:

- Published design standards and guidelines.
- Accepted professional practices.
- Designer's styles and preferences.
- Designer's past experience.
- Experience of other designers.
- Lessons learned from past designs.
- Detailed analyses of requirements.
- Eagerness to try a specific new technology.

One of the best foundations for design of a relatively new class of systems is the body of lessons learned from the design, implementation, and operation of similar systems. In fact, tort lawyers notwithstanding, analysis of past engineering errors and their potential consequences may be considered a crucial element in the evolution of engineering design.[2] Some of the most important human factors studies have centered on identifying and defining lessons learned from accidents and near-accidents that can be related to the engineering design of the system.

The nascent IVHS-class TMC is a complex command, control, and communications (C3) center that is similar, in many respects, to operations control centers used by the military to plan, direct, and monitor battles. It is similar to modern process control centers in the chemical and nuclear industries. It is also similar to dispatch and control centers in other modes of transportation. Because of this similarity, important design lessons for the IVHS TMC may be derived from exploring design processes and operational successes and failures of these centers.

It is to be expected, however, that the IVHS TMC will have most in common with the most modern and progressive of existing TMC's. The most valid view of the IVHS TMC of the year 2000 timeframe can probably be derived by exploring near- and medium-term expansion and upgrade plans of these progressive existing TMC's.

While increasing degrees of automation are becoming feasible in the TMC, near-term designs will share most functions between human operators and automated subsystems. During some subfunctions, the operator will need only to monitor the machine and, if it becomes defective, disconnect and repair it. In other functions, a more equal sharing of workload will be required. To ensure that system operators can effectively use the IVHS traffic management system, that system must be designed to meet the validated requirements of the operators.

Recommendations and guidelines for requirements-driven, user-centered design of the IVHS-class TMC are being developed. Visits to approximately two dozen TMC's and other operation control centers in the United States, Canada, and Europe have provided a knowledge base of technology applications, operator functions and job descriptions, and lessons learned. A detailed series of analyses has defined a set of TMC objectives, the functions necessary to meet those objectives, opportunities for full or partial automation of the functions, and operator performance requirements and tasks within the partially automated TMC.

This report summarizes the functions that might be incorporated into a generic IVHS-class TMC. It discusses how the functions are performed in a sample of existing high-technology TMC's and how they might evolve with near-term technology advancements. It provides human factors-related guidance for this evolution. Finally, it addresses a series of specific, crucial issues, including:

- Automation and user-computer role definition.
- Operator qualifications, selection, and training.
- Methods for graceful evolution of existing centers.
- Design processes for displays and workstations.
- Written documentation, procedures, and job performance aids.
- Current application of human factors information in the design process.

Section 2.
THE COMPARABLE SYSTEMS ANALYSIS METHODOLOGY

The purpose of the comparable systems analysis was to explore operation control centers that are similar, in many respects, to the generic, ideal TMC (ITMC). The three objectives were: (1) to define an appropriate set of dimensions with which existing operation control centers can be compared and contrasted, (2) to define the state-of-the-art in operation control center design with special emphases on operator situation awareness and automation, and (3) to explore lessons that have been learned in the design and operation of operation control centers, and their subsystems, that are similar to those that will be used in the future in traffic management.

The comparable systems analysis method, shown in figure 1, summarizes the methodology used for the comparable systems analysis. The approach consisted of two distinct phases, each ending ‘in a technical report. The initial phase documented features of a number of advanced control centers, assessed their comparability with a notional ITMC, and recommended sites for further detailed study.[3]

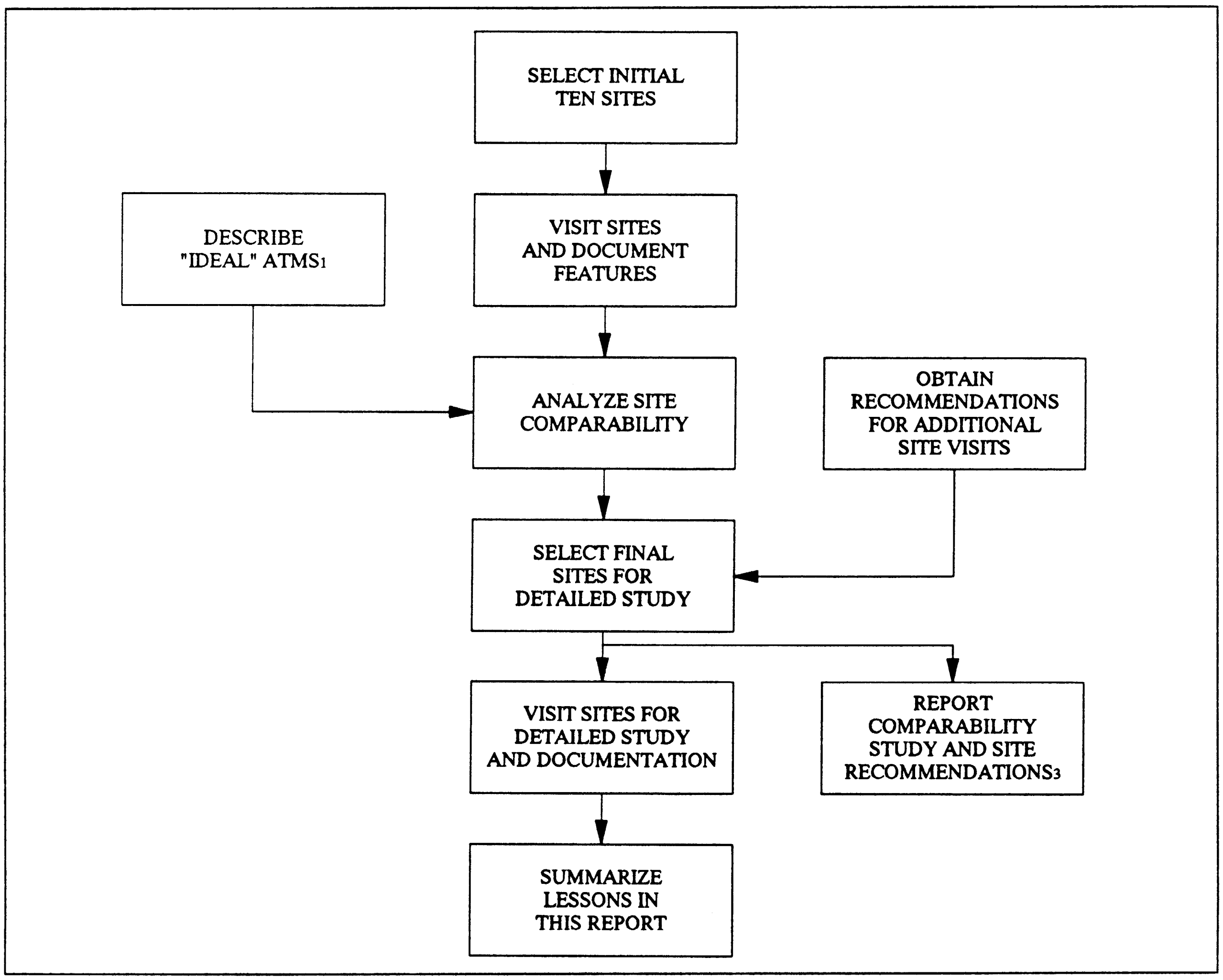


Figure 1. The comparable systems analysis method.

The second phase, documented in this report, involved a detailed study of the sites selected by the comparability analysis and a number of other sites that were strongly recommended as partially representing advanced TMC's. The second phase investigated the selected facilities in more detail, particularly in human factors design features. Three of the sites examined in Phase I were included in Phase II.

PHASE I. IDENTIFYING COMPARABLE SYSTEMS

During Phase I of this task, a preliminary vision of the design and configuration items of a typical, near-term IVHS-class TMC was described. Based on reviews of the literature and discussions with traffic management experts, the following list of characteristics of the IVHS TMC was developed:

- Evolutionary, rather than revolutionary, departure from newer existing TMC's.
- Borrows and adapts existing technologies now being introduced to advanced command and control systems in military and civilian environments.
- Provides an environment of hybrid automation with tasks shared by operator and machine and in which task allocations may be revised in real time. The computer suite will have only limited control authority without operator assent.

Most of the sites chosen for the initial visits were relatively progressive TMC's that had adopted at least one element of IVHS technology. In addition, a set of civilian and military command centers that shared some aspects of TMC design or functionality were visited. Sites chosen for the initial set of visits that were not TMC's met the following criteria:

- Controlled a flow or process.
- Sensed and fused large quantities of data.
- Provided fused data through graphical user interfaces.
- Used (or could use) decision support systems.

During Phase I, half-day visits were conducted at the sites listed in table 1. During these visits, center management and operations personnel were interviewed, providing an overview of the center design, setting, functions, daily operations, and emergency operations. Visits were documented with still and video photography (where allowed). The primary purpose of Phase I site visits was to document the architecture, features, and operator tasks of the visited centers. Identification of human factors lessons was of secondary importance. In many centers, however, human factors issues could not go unnoticed and, in such cases, they were documented in the notes of the team.

Table 1. Phase I site visits.

Site Name	Location
Air Mobility Command Tanker Airlift Command Center	St. Louis, MO
Allied Services Corporation Dispatch Center	Decatur, GA
Anaheim Traffic Management Center	Anaheim, CA
Caltrans District 7 Traffic Operations Center	Los Angeles, CA
FAA Air Traffic Control System Command Center	Washington, DC
Florida Freeway Management System	Orlando, FL
Automated Surveillance and Control System	Los Angeles, CA
Air Combat Maneuvering Instrumentation	Phoenix, AZ
Metro Orlando Traffic Management Center	Orlando, FL
Minneapolis MinnDOT Traffic Management Center	Minneapolis, MN

In a parallel task, a different research team was developing the functional design for a future, IVHS-class TMC. The features of this notional ITMC were described to approximately the same level of detail as the documentation developed during team visits to the real-world TMC's.

Using a comparability assessment method, the sites most similar to the ideal TMC were identified and recommended for more detailed study.[5] During visits and interviews, a number of additional sites were strongly recommended by the managers and other experts with whom we had met. Several of these were also selected for detailed study.

PHASE II. IDENTIFYING LESSONS LEARNED

During Phase II, visits averaging 2 to 3 days were made to the sites listed in table 2. During these visits, structured interviews were conducted with managers and operators of the control centers using a pre-prepared booklet of questions. These questions were based, in part, on the comparability dimensions identified during Phase I. The questions covered such areas as the following:

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

Still photographs were taken at each site. Copies of training documentation, procedures, standard forms, and checklists were also obtained, and their role in the operators' tasks was documented. Where possible, operators were observed during normal operations and notes were taken to describe their tasks, inputs and responses, roadway event history, and any significant successful or clumsy applications of display, control, or automation technology.

Human factors lessons learned in the design and operation of each site were then summarized for inclusion in this document. The following sections provide the results and observations of these site visits. Section 3 provides overviews of all sites visited during both Phase I and Phase II; sections 4 through 10 summarize the observations and lessons learned; section 11 suggests provisional design considerations that are based on the lessons learned.

Table 2. Phase II site visits.

Site Name	Location
Anaheim Traffic Management Center	Anaheim, CA
Minneapolis MinnDOT Traffic Management Center	Minneapolis, MN
Metro Orlando Traffic Management Center	Orlando, FL
Netherlands Motorway Control and Signaling System	Amsterdam, Netherlands
Netherlands Motorway Control and Signaling System	Utrecht, Netherlands
Amsterdam Signal Control Center (old and new)	Amsterdam, Netherlands
Amsterdam Public Transit Control Center	Amsterdam, Netherlands
Chicago IDOT Communication Center	Schaumburg, IL
Chicago IDOT Traffic Information Center	Schaumburg, IL
Chicago IDOT Traffic Systems Center	Oak Park, IL
Toronto 401 Freeway Management Center	Toronto, Canada

Section 3.
SYSTEM OVERVIEWS FOR SITE VISITS

The overview for each command center visit includes:

- *Brief Description* of the center, covering the command center's mission and its primary functional areas of control.
- *Unique Features* of the center, emphasizing aspects of the setting.
- *Human Factors Issues and Problems* of the center, considering center mission, functional areas of control, and unique aspects of its setting.

These centers are presented in alphabetic order below.

AIR COMBAT MANEUVERING INSTRUMENTATION (ACM/')

Brief Description: The function of this facility is to provide training, performance assessment, and debriefing for Air Force fighter pilots. During practice engagements, huge amounts of data concerning position, attitude, maneuvering, and switchology are collected. In order to make these numbers meaningful, they are converted into various dynamic graphical displays that are meaningful to the pilots, instructors, and referees who will use them. The control room must provide real-time displays of air combat occurring many miles away in order to allow the referee to enforce safety rules, score the effectiveness of shots, and direct the aircraft. For research data collection, the system must provide the capability to allow the researcher to enter research data, initiate data collection and analysis, enter comments into the data base, and terminate data collection. For debriefing, the data must be fused to support interactive data visualization and the user must be able to flexibly visualize and understand the data.

Unique Features: A sensor pod is attached to the aircraft that will be flying on the ACMI. Instruments on the pod detect aircraft attitude, maneuvering, and control activity, and radio the data to the ground stations. Radar stations track the aircraft positions and transmit the data by microwave. These data are fused at the ACMI ground station to produce the displays. On the simulator for air-to-air combat (SAAC), system states are captured directly from the simulation computers by the "strap-on" performance measurement computer system. Both training and research real-time data collection, as well as additional off-line analysis, are supported within this system.

Human Factors Issues and Problems: Real-time monitoring and display of air-to-air combat requires highly coordinated operator control and monitoring. Situation awareness by trainers is a significant factor in properly conducting training exercises, which are heavily dependent on the fusion of complex sensor data and voice communication. Debriefing of training exercises addresses important issues in evaluation of complex performance data and provides flexibility in the reporting format. For example, the performance measurement system (PMS) supports both group and individual debriefings with the ability to change point-of-view in the sortie. Maintaining past performance data, and presenting fused data as informative data visualizations, are important human factors issues. A highly intuitive user interface requires a minimum of training and paper documentation; it allows the user to devote maximum attention to the displays. Many of these issues are relevant for the current simulator development.

AIR MOBILITY COMMAND (AMC) TANKER AIRLIFT COMMAND CENTER (TACC)

Brief Description: The mission of the TACC is to maximize the efficiency of the AMC in its role of moving military cargo and personnel around the globe. In addition, the TACC is a "Model Command Center" in which new approaches to design and function are first implemented and demonstrated before they are adopted Air Force-wide. Airlift requirements originate from other DoD centers and are communicated to AMC Headquarters where they are planned and scheduled. Mission requirements normally are planned and scheduled by Current Operations, but some short-term requirements are handled by the operations center. The operations center has responsibility for tracking and directing all AMC aircraft that are in the air including crews, cargo loads, cargo spare capacity, planned routes and schedules, diplomatic clearances, weather, and relevant intelligence information.

Unique Features: The Global Decision Support System (GDSS) is a replicated data base of all current and planned AMC flights. Several key geographic locations are equipped to use replicates of the data base in the event that the primary GDSS center is off-line. Various data base utilities allow the system to be queried from many different directions in order to support planning functions and enroute operations. A graphic display shows all AMC flights in progress (positions based on flight plans rather than real-time tracking). The TACC is staffed 24 h/d.

Human Factors Issues and Problems: The global responsibility for military airlift of cargo and personnel presents unique problems in coordination between remote site facilities and the TACC. Maintaining a global data base of current flight-related events involves many issues of data validity and its security. For example, lack of real-time tracking impacts data validity and real-time intervention. The support systems for current and planned flights may provide useful information on operator decision making and decision support systems potentially relevant to Commercial Vehicle Operations (CVO) human factors requirements.

ALLIED SERVICES CORPORATION DISPATCH CENTER

Brief Description: Allied Services Corporation (ASC) is a major east coast trucking company specializing in the movement of new automobiles from terminals (factories, sea ports, rail heads) to dealers. The Central Dispatch Center is responsible for planning, routing, and incident management for a fleet of over 1000 trucks. The primary function is to minimize cost and delay in the delivery of cargo, within the limits of government regulation and union work rules, through effective central planning and communication. ASC fleet efficiency is a complex combination of performance requirements, including overall volume (both numbers of vehicles hauled and destinations), priorities of cargo, expected locations of available trucks (controlled by planned routes and schedules), and trip load [both full and backhauling (empty)].

Unique Features: Operators are responsible for directing drivers to their next terminal to pick up a load of automobiles. They receive from the terminals a daily list of automobile quantities and their destinations. Using this list, a map, and the data base of driver assignments, drivers/trucks are assigned to pick up automobiles at the terminals. Assignments are based on routing efficiency and union rules. There are no automated sensors; operators rely on telephone conversations and route assignments to locate and track vehicles.

Human Factors Issues and Problems: Lacking automation, operators use complex rules that dictate the assignment of loads, routing, and incident management. Numerous opportunities exist for decision support systems and automation in route planning and optimization. Such decision support systems may be useful for considering CVO human factors requirements.

ANAHEIM TRAFFIC MANAGEMENT CENTER

Brief Description: The primary function of the Anaheim Traffic Management Center is to promote a smooth and delay-free entry and exodus of automobile traffic associated with special events such as conventions, football games, and concerts. As a secondary function, the TMC monitors and controls rush-hour traffic. System performance requirements include planning for special events, incident detection and verification, traffic control, and coordination with other jurisdictions.

Unique Features: Custom graphics have been developed for the display of multiple levels of detailed views from large geographic regions down to the intersection level of detailed view. A concave workstation design focuses attention on the large-screen display and eight closed-circuit television (CCTV) monitors. Three additional 356-mm (14-in) graphics monitors are located in the control room with one mounted at standing eye level on a movable arm near the midpoint of the concave workstation.

Human Factors Issues and Problems: The Anaheim TMC represents innovative control room design concepts, computer graphics, and computer systems to support automation. Issues of integrating police department support into the centers' activities have been addressed. Although multiple levels of views were developed depicting roadway networks, only intersection and regional level views, such as around the convention center or baseball stadium, are considered useful to operators. The convex workstation, as intended for multiple operators, focuses attention on the large-screen display and eight CCTV monitors. Frequently, however, only a single operator is on duty. As a consequence, the design, as intended for multiple operators, is no longer the best design solution for a single operator since the convex surface places other workstation displays and controls partially out of the field of view and reach.

AMSTERDAM PUBLIC TRANSIT CONTROL CENTER

Brief Description: The primary responsibility for the Public Transit Control Center (PTCC) is priority-based control of the trolleys and buses in the Amsterdam area. The centralized facility, using the Operational Management System (OMS), controls trolleys and buses through interconnects to both the traffic signal system and the mass transit traffic management center.

Unique Features: At numerous points on their routes, the vehicles pass over sensors in the road, triggering an information exchange about the vehicle identity, its schedule, and variation from the schedule. If the vehicle arrives late over a sensor, it receives traffic signal priority (green lights) until it is back on schedule. Furthermore, information about the status of each vehicle is transmitted to the control center that contains numerous innovative graphic displays that allow operators to remain aware of the schedule performance of the system at all times. In addition, operators remain in radio contact with each vehicle driver in order to handle major and minor emergencies, dispatch maintenance, or dispatch replacement vehicles. A complicated algorithm is used to schedule vehicles during late evening hours so that at connection points, the two connecting vehicles arrive at the transfer point simultaneously.

Human Factors Issues and Problems: The PTCC recently moved into a new facility. This new facility is unique in that an ergonomic consulting firm had a major design impact. Detailed task analyses were conducted on the operators' activities and ergonomists developed a series of scale mockups of the room and furniture that was iteratively redesigned based on operator comments. The resulting design was observed to be highly functional.

AMSTERDAM SIGNAL CONTROL CENTER

Brief Description: The Amsterdam Signal Control Center controls all of the traffic signals in Amsterdam. Within this responsibility are three primary functions. These include reducing congestion by changing signal timing, detecting maintenance problems with signal systems and dispatching service crews, and maintaining radio contact with emergency vehicles and creating green waves at their request. The operations center is in the process of moving from the old center to a newly completed center.

Unique Features: In the Netherlands, particularly in Amsterdam, pedestrians and cyclists are given a higher priority than in North America. Extensive bicycle-only trails exist throughout the Netherlands, including Amsterdam, and in many cases there are separate lanes and signals for cyclists, and most pedestrian crossings at intersections are signaled. Compliance to signaling is apparently a significant problem. In Amsterdam, red lights are ignored by large numbers of pedestrians and cyclists (some 60 to 80 percent). Detection of cyclists at crossings creates a demand for green, but, given this non-compliance, in many cases the cyclist has already reached the other side of the road when the light turns green (which translates into lost time in the signal timing phases). A complex priority-based control system for trams and buses is used in Amsterdam. It is intended to minimize delays by overriding the current intersection timing in favor of the transponder-equipped trams and buses. This is discussed in detail below, under the Amsterdam Public Transit Control Center.

Human Factors Issues and Problems: Like all Holland centers we visited, there were significant glare problems on the CRT's. This can be attributed to Dutch laws and building practices that require the use of large amounts of glass to conduct sunlight into the workplace. System integration impediments were also noted in workstation design and operator interface usability. Two system vendors failed to provide necessary integration of their products, which has required two separate user interfaces on different hardware platforms. Failure to identify system requirements has resulted in the loss of several key design features that were present in the old control room design, but were not carried forward into the new design specification. Radio and traffic operators sat next to each other in the old control room, allowing a "party line" to exist between them that enabled mutual responsiveness to changing needs. In the new center, these operators are located at too great a distance to hear each other's communication traffic. Placement of video monitors in the old center was below the map display at a convenient eye level. In the new center, these monitors are rack-mounted next to the map display at a less convenient location (with newly introduced glare problems).

AUTOMATED TRAFFIC SURVEILLANCE AND CONTROL SYSTEM

Brief *Description.*= The primary function of the Los Angeles Automated Traffic Surveillance and Control (ATSAC) system is to promote a smooth and delay-free flow of automobile traffic on the major arterial streets of Los Angeles. System performance requirements at ATSAC include incident detection using loop detectors and incident detection algorithms, incident verification using CCTV systems, and control of street traffic using canned timing plans and adaptive control.

Unique Features: The control room layout was rather primitive, with computers and displays stacked roughly according to geography, encircling the operators. ATSAC is equipped with the Urban Traffic Control System (UTCS), enhanced to implement signal timing plans. These provide automatic adaptive control in the "critical intersection" and "traffic-responsive" modes. Occasionally, "manual override" mode is used to allow the operator to respond to unusual traffic conditions, such as sports events or holiday shopping, by creating an custom timing plan. ATSAC interfaces well with Caltrans District 7 and emergency-response personnel via radio, computer-aided dispatch (CAD), and telephone.

Human Factors Issues and Problems: ATSAC's evolutionary control room design allows flexibility and that allows responsiveness to changing needs and requirements by operators. The current design does not consider glare or the advantages of ergonomically designed workstations and seating. Self-labeling of workstation displays and controls and their arrangement are possible indications of confusion resolved by the additional labeling. Regional geographic system control is weakly supported by the efficient arrangement of components and may not support the efficient control of ATSAC by a single operator. Since ATSAC can handle multiple traffic incidents concurrently, voice communication and resource sharing among multiple operators should be investigated.

CALTRANS DISTRICT 7 TRAFFIC OPERATIONS CENTER

Brief Description: The primary function of the Caltrans Traffic Operations Center (TOC) is to promote a smooth and delay-free movement of traffic on freeways in the Los Angeles metropolitan area, including coordinating initial response to freeway incidents. The system performance requirements at the Caltrans TOC include 24-h traffic monitoring and incident detection; incident verification; traffic flow control using ramp metering and variable message signs; and communication via radio, CAD, and telephone.

Unique Features: A large wall map of the region's freeways contains color-coded light-emitting diodes (LED's) representing each loop detector array. Lights turn yellow or red to indicate levels of congestion. This map is said to be heavily used. It interfaces well with local municipality TMC's (e.g., ATSAC and Anaheim) and with other Caltrans districts. The presence of a California Highway Patrol (CHP) liaison enhances the efficiency of emergency response. Operators are formally trained in a continuing education course at California Polytechnic Institute and State University. CHP officers are cross-trained to serve as operators when required.

Human Factors Issues and Problems: With a large mixed staff operating in an absence of automation in such a busy center, Caltrans provides a wealth of potential human factors issues in communication needs of operators for effective interjurisdictional and interagency communication. The impact of automation on operator communication activities is being considered as designers develop plans for their next generation TOC. Only fixed light and color changes can be varied on the big-board display; fusion of any other related data to the big-board display is not possible. Maintenance and update of the big-board display with a static map is labor-intensive, especially for changes in map detail (which require an outside contractor).

CHICAGO IDOT COMMUNICATIONS CENTER

Brief Description: The primary function of the Illinois Department of Transportation (IDOT) Communications Center (ComCenter) is the assignment of emergency and maintenance vehicles and specialized crews to areas throughout District 1 to maintain efficient flow of traffic on the state-maintained roadways and Interstates in the Chicago metropolitan area. As a communication hub, incident-related cellular telephone *999 calls from motorists are received by a separately maintained exchange, summarized, and forwarded to the ComCenter. Communication links are also maintained with the Traffic Systems Center. The Traffic Systems Center provides travel time for major road segments in the freeway system, and congestion information disseminated by a computer link and through a CCTV summarized congestion map of the Chicago area. When the ADVANCE traffic information center becomes operational, it will also provide its data to the ComCenter as well.

Unique Features.= The ComCenter is staffed 24 h/d with the highest level of staffing during the morning (6:00 a.m. until 9:00 a.m.) and afternoon/evening (3:00 p.m. until 7:00 p.m.) rush hours. The ComCenter has an unusually broad range of responsibilities, including computer-based remote control over storm water pump stations, highway lighting, a highway advisory radio network (both AM and FM stations), changeable message signs, and the reversible lane controls of the Kennedy Expressway over radio and telephone links. To assist in handling the large number of telephone calls received, the ComCenter has an automated telephone answering system routing most calls coming into the ComCenter. There also exists the option of directly contacting an on-duty ComSpecialist.

Human Factors Issues and Problems: interjurisdictional issues for 300 municipalities can result in the four corners of an intersection being under different jurisdictional control, complicating maintenance and incident-related interventions. There are problems in control room environmental factors, such as loudness of adjacent operator conversations (especially in high workload-related radio-telephone communications for maintenance dispatch), and ambient lighting levels. Dissemination of routine Highway Advisory Radio (HAR) traveler information is complicated by providing both congestion and travel time information to motorists. These two forms of travel information are broadcast on separate automated radio stations using two different technologies (synthetic voice versus sampled speech from live operator) and hardware systems. Voice gender and speaker coding guidelines need to be established for use with the synthetic voice system. Frequent gender and speaker changes potentially distract from the message content.

CHICAGO IDOT TRAFFIC INFORMATION (ADVANCE) CENTER

Brief Description: The ADVANCE program will provide traffic information to approximately 5,000 equipped vehicles in the metropolitan Chicago area. The control room being designed is currently conceived to be a single console with one or two workstations.

Unique Features: With approximately 5,000 vehicles in the ADVANCE evaluation, this will be the largest test site to date of IVHS smart vehicles.

Human Factors Issues and Problems: As a feasibility study site, the designer's highest priority is to provide traffic information and control to the vehicles, but not to examine control room design issues. Potentially, this approach may prove to impact the intended function of the center by poor implementation of person-machine interface.

CHICAGO IDOT TRAFFIC SYSTEMS CENTER (TSC)

Brief Description: The primary function of the IDOT Traffic Systems Center is freeway traffic-surveillance and control for the metropolitan Chicago area. Freeway and ramp monitoring are included in the summarized traffic flow data presented in a graphic congestion display of the metropolitan Chicago area. This data is communicated to a variety of other agencies and universities, including cable TV. A text-based version of travel time over major road segments is also communicated to agencies over a computer link. A series of changeable message signs (CMS's) are controlled from the TSC that inform motorists of congestion/incident-related problems.

Unique features: One of the largest traffic centers, the TSC monitors 190 km (118 mi) of roadway on eight Chicago area expressways. Since it has been in operation nearly 30 years, the TSC is an evolutionary blend of both old-outdated and state-of-the-art technology.

Human Factors Issues and Problems: Roadway sensors and effectors are the driving technology force in the evolution of the TSC. The TSC presents a difficult challenge in evolving from old technology to new technology. Many human factors issues, such as noise level and system integration, are solved by application of current technology. However, given the TSC's efficient performance, from a cost-benefit perspective it is difficult to justify massive upgrades.

FM AIR TRAFFIC CONTROL SYSTEM COMMAND CENTER (ATCSCC)

Brief Description: The primary role of the Federal Aviation Administration's (FAA's) air traffic control system command center (ATCSCC) is to minimize the number and length of air traffic control-related delays of enroute aircraft operating under instrument flight rules (IFR). The air route traffic control center (ARTCC) enters all IFR flight plans into a data base. The ATCSCC tracks position and status of all enroute aircraft and correlates these factors with flight plans/clearances for airports in the specific region. It projects arrivals at airports and predicts over-capacity periods. Using the Enhanced Traffic Management System (ETMS), the controller develops plans to reduce the number of aircraft approaching these airports at the critical time, and then negotiates and implements these plans.

Unique Features: A substantial amount of automated data fusion and analysis is performed by the ETMS on the raw aircraft position, flight plan, and weather data. These combined and fused data are used to identify congestion problems, produce potential solutions, and carry out those solutions (with the permission of the operator). Operators are assigned control over geographic divisions. The geographic United States is divided into three regions, - east, central, and west. On-site weather meteorological data are available from a National Severe Weather Center staffed by two meteorologists. Except for the meteorologists, all staff members are experienced air traffic controllers on loan from air route traffic control centers.

Human Factors Issues and Problems: The high level of automation in fusion of data addresses potential issues in display of complex detailed data from large geographic areas. Operator workload and a large and varied staff raise potential problems in operator roles and necessary training. Integration of weather data with traffic control-related information addresses important issues in operator decision making and decision support systems. The decision aids and support systems appear to be well-designed from a human factors viewpoint.

FLORIDA FREEWAY MANAGEMENT SYSTEM

Brief Description: The primary function of the Florida Freeway Management Center (FMC) is to promote a smooth and delay-free flow of traffic on the freeway system of metropolitan Orlando. Primary requirements are detection, verification, and clearing of incidents on the freeway system.

Unique Features: No usable automation was evident at this point. Some automated capabilities are planned for later implementation. The FMC is staffed only during morning and evening rush periods. Six quad-split television monitors allow simultaneous viewing of all 18 CCTV cameras on the 17.7-km (11-mi) freeway system. Florida Highway Patrols' communication center shares the control room with the Florida Freeway Management System.

Human Factors Issues and Problems: This center is hampered by poor user-interface and workstation design, reflected in human factors and ergonomics issues in system ease of use and monitoring of workload. For example, operators monitor six quad-split video monitors mounted near the ceiling at an acute angle with individual operators monitoring northbound and southbound lanes during peak traffic hours. Frequently used features of the system are not designed for accessibility through the user-interface design. Interjurisdictional problems, such as the overlapping areas of coverage and redundancies in function, are not efficiently managed between the Metro Orlando TMC and FMC.

MINNEAPOLIS DOT TRAFFIC MANAGEMENT CENTER

Brief Description: The primary function of the Minneapolis DOT Traffic Management Center (TMC) is to promote a smooth and delay-free flow of traffic on the freeway system of the metropolitan Minneapolis-St. Paul area. The TMC controls traffic using adaptive ramp metering. It monitors traffic in order to identify areas of congestion and possible incidents. Units in the field and, when necessary, emergency response providers are alerted to such incidents. The Motorist Information System provides the drivers with information about potential congestion and delays.

Unique features: The Minneapolis TMC is unique in its reliance on closed-circuit television (CCTV) displays. With 96 monitors for 108 cameras, it is almost possible for each camera to have a dedicated monitor. An automated switching system moves camera images among the monitors on the two video walls. Additional banks of 229-mm (9-in) monitors are being added for the traffic radio broadcaster's use in periodic comprehensive broadcasts. A 1829-mm (72-in) BARCO rear-projection monitor can display either graphical map data or CCTV images. Because the number of CCTV surveillance cameras exceeds the number of CCTV channels and monitors, an automated switching process is in place to ensure that each camera receives equal priority. For the variable message sign (VMS) system, selection and presentation of "canned messages" is partially automated. Control of ramp metering is traffic-adaptive with manual override.

Human Factors Issues and Problems: The heavy reliance on CCTV's and the switching of images between monitors requires significant operator monitoring in support of incident management. Given that the monitoring of this large number of CCTV's well exceeds human factors recommendations, the use of these monitors by operators represents an important human factors issue and deserves additional examination. Methods for data fusion and automatic camera selection need to be examined. It may be that operators are utilizing strategies for reducing the complexity of this monitoring task. Both automation enhancements and decision support should be considered for these operators. There is no TMC guideline for the team composition on a shift, in terms of operator roles and the necessity of having a shift supervisor on duty. Currently, shifts work without a designated supervisor on duty and vary in the composition of the experience and background of the operators.

METRO ORLANDO TRAFFIC MANAGEMENT CENTER

Brief Description: The primary function of the Orlando Traffic Management Center (TMC) is to promote a smooth and delay-free flow of traffic on the streets of metropolitan Orlando. A secondary function has been to serve as the control center for the TravTek automobile navigation system operational demonstration, which has been completed and is currently under review. The TMC maintains signals in an effective timing plan, and adjusts the timing plans as necessary. It identifies, verifies, and helps clear incidents on Orlando's streets. It also helps to ensure efficient operation of the TravTek demonstration.

Unique Features: Metro Orlando, as the site for the TravTek demonstration, has evaluated prototype automation and communication needs necessary to support the TravTek system, including fusion of data from information sources of varying reliability to provide real-time incident information, and transfer of updated link travel times to the vehicles.

Human Factors Issues and Problems: Orlando's state-of-the-art TravTek automobile navigation operational test system provides a source of potential human factors issues on this emerging technology. Key issues include integration of TravTek functions into general TMC operational controls and displays, as well as the integration of TMC communications with car drivers. Large, static network maps used in the center are labor-intensive to modify when updates are needed in the display of the infrastructure. There is a significant need for coordination with the Florida Freeway Management Center, but inefficient communication practices sometimes hinder this coordination.

NETHERLANDS MOTORWAY CONTROL AND SIGNALING SYSTEM

Brief Description: The primary function of the Utrecht and Amsterdam Freeway Traffic Management Centers is to provide lane-control management to promote a smooth delay-free flow of traffic. An additional function, with the support of the Motorway Control and Signaling System (MCSS), is to reduce the frequency and effects of both primary and secondary accidents. Messages reflecting reduced speed limits, closed lanes, and required lane changes are displayed for each lane of the freeway on overhead gantry-mounted signs. One significant characteristic of the European approach is an emphasis on incident prevention, rather than incident detection, and management as practiced in North America. European TMC's have little involvement in incident management - where incidents are defined as things or events on the roadway that cause congestion. Rather, European managers suggest that they are more concerned with preventing the incidents from happening (by actively controlling congested traffic) than in managing them after they happen.

Unique Features.= Lane-based control requires dense sensor arrays and numerous gantry mounted signs over each lane of the freeway. Located at approximately 1/2-km intervals is a lane-control system consisting of an array of double-loop detectors, a control box, and a gantry sign. The loop detector array detects changes in traffic speed that signal the beginning of a congested situation. Outstation controllers located near the roadway sense sets of adjacent loop detector arrays, automatically formulate the appropriate pattern of messages, and request permission from a central computer to present the selected messages on the gantries. The central computer will either consent to the changes or will modify the outstation's recommendation to reflect the situation at other outstations or messages manually entered by the operator. In the event that control communication is lost between outstation and central control, the outstation automatically presents the messages on its gantries. This form of "graceful degradation" is a designed feature of the control system. Also, because much of the analysis is done locally, only a modest amount of data needs to be communicated between the outstation and the central computer.

Human Factors Issues and Problems: Control of the lane signs is highly automated because of the complexities created by the rules that govern the proper signing of reduced speed limits, closed lanes, and required lane changes. On the initial installation IO years ago, a single operator was required to consent to each change in sign pattern. Sign changes occurred at the rate of up to 200/h, generating an unnecessarily high workload. Now, all signing decisions are initially made by the automated system based on the detector data, and cannot be easily overridden by the operator. Complexities of automation in operator monitoring and supervision have led to the design of alarms that signal the operator of potential needed interventions. However, the operators are often responding to false alarms. Troubleshooting is assisted by selective activation of CCTV monitors that have coverage over the trouble area causing the alarms. Providing the appropriate information for operator-based troubleshooting is extremely difficult to pre-plan and highly intelligent automation approaches, such as adaptive automation, continue to be impractical to implement.

TORONTO 401 FREEWAY TRAFFIC MANAGEMENT CENTER

Brief Description: The primary purpose of the Toronto Freeway Traffic Management Center (COMPASS), Ministry of Transportation of Ontario (MTO) is 24-h freeway traffic surveillance and control for the 401 freeway segment in the metropolitan Toronto, Ontario area. The design goal for this facility is to be able to run in as automated a manner as possible. Currently, changeable message signs (CMS), response plans, and media information dissemination are partially to fully automated. System evaluation has included examination of system failure rates and response times of operator acknowledgment.

Unique Features: Twelve lanes of roadway, six in each direction for 36 km (23 mi), are divided into a collector/distributor and express lanes of roadway. This roadway is one of the most heavily traveled and complex roadways in North America. An extensive collection of incident response plans has been assembled to automate the response process. The categories of response plans range from the general incident response process, vehicle breakdown, reportable accident, non-reportable accident, and hazardous goods spill, to abandoned vehicles. When a response plan is activated, a descriptive message is composed and added to the list of notices currently being faxed to the subscription base of the media and other agencies, and is also sent to the appropriate CMS's for roadway display. A separate comprehensive CMS message design and taxonomy has also been developed. This CMS message design ties a given CMS's location to a pre-defined portion of the roadway downstream of the CMS, referred to as a congestion management zone (CMZ), so that messages are based on current traffic conditions within the CMZ.

Human Factors Issues and Problems: An impressive level of automation has been implemented and is being considered in the COMPASS center. The level of automation in the issuance of messages on CMS's is highly procedural in form, requiring a complex question-and-answer dialog to issue a message and log an incident. Such an evolving automation environment presents difficult challenges in developing effective human interactions with automated systems. The design goal for such interactions should be to enable brevity in the required interactions, while retaining enough operator control for the proper supervision of actions. Requiring graphics display and command entry through different interfaces presents human factors problems. The operators' preference for monitoring cameras for incident detection, rather than relying on the capabilities of automatic incident detection using the computer graphics-based display system, may be a symptom of this unusable system design.

Some management problems have been noted due to the unique organizational structure. The system design and engineering group who, in fact, make most of the day-to-day procedural and equipment decisions are in a different branch of the Transportation Ministry than the operators and, therefore, have no direct authority over them. A hiring freeze prevented hiring of a TMC Supervisor, so the operators are extremely autonomous. The structure impedes the introduction of revised procedures and methods.

Section 4.
STATE-OF-THE-ART OF IVHS TMC TECHNOLOGIES

OPERATIONAL REQUIREMENTS

On the basis of interviews with a group of IVHS "visionaries," a set of operations that would be performed by an ideal TMC of the next decade that provides a broad range of traffic management services was defined. That study concluded that the full-service IVHS-class traffic management system must perform all of the operations listed in table 3 for data sensing and input, TMC performance, and TMC output.

One major purpose of the present task was to study and assess the state of the art in each of the operational requirements of the visionary TMC in order to validate or calibrate the realism of that vision. Each of these operational requirements was found to be performed in one or more control centers, although, in many cases, the technologies and procedures are more primitive than those of the visionary TMC. In this section, each of the operational requirements is discussed in detail, including the vision, current technology and practice, and near-future prospects.

MONITOR CURRENT TRAFFIC CONDITIONS

Traffic condition sensors can be classified into two main types on the basis of their data input to the TMC, information calculated from (primarily) binary raw data and information in the form of visual images. Binary sensors are, in effect, switches that register "on" when a vehicle is in their zone and "off' when no vehicle is present. Visual sensors such as closed-circuit television (CCTV) under remote control from the TMC provide a direct view of the roadway and are widely used for confirmation of traffic conditions, verification of incident location, and determination of incident severity.

Roadway sensors report data such as traffic flow rates and speeds. The sensors must be able to measure traffic speed as well as traffic volume. In key areas of the roadway system, the sensors must be capable of providing these data by lane and by vehicle size. Currently, these sensors consist of inductive wire loops embedded in the pavement that detect the passage of automobiles by registering variations in the surrounding magnetic fields. By using a pair of the loops a known distance apart, it is possible to compute the speed of each individual vehicle. Generally, binary occupancy data from loop detector arrays are fused for display on a graphical user interface. A measure of the traffic "performance" at a given sensor location can be determined by speed and/or volume of traffic. These performance data are then displayed as a series of histograms or, more typically, as color-coded roadway segments on a map display.

Other traffic detection technologies, such as radar, ultrasound, and visual image processing, are being tested and may be introduced to the roadways in the future.

CCTV monitors are an important feature of TMC's in North America and somewhat less so in Europe. These sensors are not routinely intended as a primary source of information about traffic flow, but are intended to be used as secondary sources to support traffic and incident management, and to check the status of signals and signs. While older installations have generally used black and white CCTV because of its better performance under low illumination, color CClV is generally said to be more effective during daylight hours and is becoming the standard in newer centers. In many centers, banks of dozens of monitors surround the operators. Operators can take control of individual cameras using button boxes or joysticks to pan, zoom, and focus. In the near future, automated aiming and zooming on sites of suspected incidents will be available, relieving the operator of this manual control function.

A third data source; instrumented probe vehicles, including rental vehicles and public transport vehicles, report point-to-point travel times and incidents. Several demonstrations of this technology have been performed in the United States and in Europe. Typically, the location of each member of a fleet of probe

Table 3. TMC operational requirements.

DATA REQUIREMENTS	PERFORMANCE REQUIREMENTS	OUTPUT REQUIREMENTS
Current Traffic Conditions	Predict Traffic Conditions	Influence Route Selection
Current Roadway Conditions	Determine Maintenance Needs	Influence Vehicle Motion/Speed
Location of Incidents	Select Traffic Management Tactics	Control Roadway Access
Select Traffic Management	Select Incident Management Tactics	Dispatch Emergency Resources
Type/Severity of Incidents	Select Demand Regulation Tactics	Dispatch Maintenance Resources
Location of Emergency Resources	Select Public Relations Actions	Influence Trip Decisions
Current/Predicted Weather		Influence Mode Selection
Current and Future Demand		Provide Public Information

vehicles is determined by a global positioning system (GPS) receiver and is transmitted to a TMC computer. The amount of time it takes a vehicle to move between any two of a set of defined points can be used to calculate vehicle speed and estimate the level of congestion. Selection of appropriate vehicles to serve as probes is a major issue. For example, emergency vehicles are a poor choice because they typically travel significantly faster than the traffic stream. Rental vehicles may not be the best choice since they typically travel different routes than the urban commuter. Probe data is only a valid measure when probes are representative of the class of vehicles they are supposedly sampling.

MONITOR CURRENT ROADWAY CONDITIONS

In the future TMC, road condition and weather condition sensors will monitor precipitation and predict its effects on traffic conditions. These sensors will also monitor the friction coefficients of dry pavements, and provide early detection of worn pavements that need resurfacing. Some of these sensors will be maintained at fixed locations, such as on bridges that are likely to freeze. Others may be mobile sensors, perhaps attached to maintenance vehicles. Although not yet widely used in the United States, embedded road sensors now exist that can measure and transmit data on pavement temperature, air temperature, wet pavement, and salt content of pavement moisture.

System monitoring devices and processes are available that identify sensor and effector maintenance needs such as burned-out bulbs in traffic signals and malfunctioning loop detectors. Such technologies exist today, but emerging technologies will increase the credibility of the malfunction reports. A major percentage of centers now depend on complaints from the public as a primary source of information on maintenance needs.

Visibility sensors are also available to detect the onset of fog and to warn drivers and TMC operators. One system, currently implemented in Europe, detects decreased visibility and automatically illuminates a warning sign and reduces the speed limit to appropriate levels. A prototype of a similar system has been installed by the Tennessee Department of Transportation and another is being installed for testing in an area of frequent fog near Adel, Georgia.

IDENTIFY LOCATION OF INCIDENTS

In the visionary TMC, an incident detection and location system (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 the incident. In some cases, the first indications of an incident will be abnormalities in traffic flow in the immediate area. In other cases, especially when traffic volumes are light, the first indications may come from other sources, such as calls over cellular phones that subsequently result in an entry into a dispatch data base. Incidents, as defined by the IDLS, will include not only traffic problems, but also system malfunctions such as traffic signal outages. Upon detection of a probable incident and determination of its apparent location, incident verification is attempted. The IDLS will provide a preliminary estimate of incident severity (perhaps simply yellow or red) based on the data available.

Currently, initial indication of a freeway incident (accident, stall, debris spill, etc.) may come from one of three general sources, - loop detector data; closed-circuit television image; or a radio or telephone report from police, media, or the public.

On heavily instrumented highways, early indication of a problem can be seen in the data from loop detectors. An incident may first appear as unexpected congestion that results in a decrease of speed and volume of traffic. Incident detection algorithms exercise the loop detector data looking for patterns that correlate with incidents, typically, high-occupancy measures. Obviously, with the inherent variability in "normal" traffic flow, it is difficult to distinguish between a "normal" variation and a variation due to an incident. Performance of these algorithms, therefore, is generally poor in terms of the percentage of incidents detected and the time required to detect them. One center found that incident detection performance could be improved by using custom-developed incident detection algorithms that:

- Utilized traffic volume (vehicles per unit of time) as well as loop occupancy (percent of time a loop is "on").
- Screened the data for indications of stuck-on loops that artificially inflate occupancy data.
- Tuned down threshold settings (algorithm values at which an incident is assumed) upstream of major freeway interchanges during peak traffic.
- Adjusted thresholds for seasonal changes.

The philosophy of some centers, especially those outside of the United States, is that unexplained traffic congestion, itself, represents a problem that must be managed. Therefore, the incident detection algorithms have no "false alarms" because they always represent a problem related to congestion that needs to be addressed.

Some centers make heavy use of CCTV assets to make initial detection of incidents. As discussed above, managers often believe that the CCTV systems are overused to the detriment of the incident detection systems based on loop detector data.

In addition to its organic sensor assets, many TMC's receive data from a number of external sources. Voice communications are received from the traveling public via telephone (including cellular phones and roadside emergency phones) and citizens band (CB) radios. The primary use of these data sources is to obtain reports of incidents. One midwestern U.S. TMC placed CB radio receivers at key locations near the roadway. These could be selectively monitored by telephone in the TMC. Unfortunately, the poor quality of these transmissions rendered this innovation impractical for monitoring these local radio transmissions. Voice communications also come from public safety authorities, including radio channels used by police, fire, and ambulance services, as well as telephones. These channels are used to obtain reports of incidents, to verify incident location and severity, and to help coordinate incident response.

CLASSIFY TYPE AND SEVERITY OF INCIDENTS

The ideal TMC will obtain information regarding the nature and severity of the incident in order to select proper responses. The amount and duration of the incident's effect on roadway capacity must be accurately estimated.

Current TMC's obtain this information from four sources, - CCTV, reports from individuals at the incident site, "eye-in-the-sky" traffic helicopters, and commercial radio and television. The news media receives its reports from much the same resources. Several TMC's currently track type and severity of incidents as part of their reporting process for incident management. Characterization of the type and severity has also been found to be useful information to communicate to maintenance units, as is practiced in Amsterdam, to initiate the request for repair. Maintenance units are given type and severity information, with classification categories indicating the degree of damage to the infrastructure, such as failures in intersection controllers, burned-out lights, cut communication lines, and downed poles.

IDENTIFY LOCATION OF EMERGENCY RESOURCES

In the ideal TMC, computer data links are maintained with public safety agencies, commercial railroad companies, commercial vehicle fleet operators, and roadway maintenance/construction providers. These will include dispatch data bases of police, fire, and ambulance services. Any dispatch of a vehicle by these agencies will be entered into the data base as part of the act of dispatching, and will be immediately available to the ITMS.

Currently, TMC's obtain the location of emergency resources by radio, telephone, and occasionally by computer-aided dispatch (CAD). Often, multiple radio channels must be monitored simultaneously because each agency maintains separate systems. Programmable, multi-channel, multi-position, integrated radio and telephone control systems are now available and in use in some TMC's that simplify the monitoring of radio and telephone traffic. These systems address many of the issues of communications integration necessary for improving efficiency and reducing the communications workload. For example, these systems include a CRT-based summary of overall channel traffic status that can be displayed by caller's name (if equipped with automatic number identification). Among its features, it allows dedicated speaker selection for high-priority channels, individual channel volume control, predetermined grouping of channels, and automatic transmittal to the last call received. In addition to vehicle identity, vehicle position is currently tracked in some centers by knowledge of assigned routes and timetables, and in the near future will be tracked by one or more methods of automatic vehicle location, such as Global Positioning System (GPS) satellite-based technology; dead reckoning systems; terrain-following technology, such as ETAK; terrestrial radio location pager systems that use triangulation, such as Lo-jack or Teletrac; or mobile radio modem communication technologies. Besides technology advances is the need for new approaches for increasing transmission bandwidth, since large metropolitan cities such as Chicago have saturated current available bands of the electromagnetic spectrum, such as microwave. The FCC has near-term plans to reassign the frequencies presently used to increase the number of available channels. Moving frequencies closer together will affect both transmitters and receivers because of resulting changes in the bandwidth filters on the receiver for channel reception and the requirements and restrictions in bandwidth of the actual transmitted signal. In fact, some signaling strategies may also be rendered obsolete if they have been relying on signal energy that is outside of their assigned bandwidth (but currently unused). It is anticipated that these changes will render some of the current equipment obsolete in tuning to the new assigned frequencies (old equipment in the worst case would pick up adjacent channels). At one midwestern TMC they are anticipating this FCC change as a stimulus for complete replacement of present communications equipment.

MONITOR CURRENT AND PREDICTED WEATHER

Inclement weather, such as rain or snow storms, can have a greater impact on roadway capacity than any other factor. In the ideal TMC, National Weather Service forecasts and data from other meteorological information services will be used in anticipating or locating weather conditions that will impact driving conditions.

A few TMC's now maintain displays of wide-area weather radar returns indicating strong storm cells and precipitation for use in weather prediction. Typically, TMC personnel are not trained to use this weather data to its full potential. Subscription weather services are now commercially available that provide CRT weather displays with sufficient resolution and accuracy to locate thunderstorm cell boundaries with an accuracy of a few tens of meters. These can be computer-overlaid on a local area map to indicate specific roads currently receiving precipitation.

PREDICT DEMAND

The ideal TMC will have a capability to predict excessive demand in time to identify and implement strategies to reduce the demand to acceptable levels.

Currently, the experienced TMC operator is able to predict and prepare for cyclical demand peaks and peaks in demand resulting from special events largely on the basis of experience. At one center, a weekly meeting is held with TMC management, traffic police, and representatives of all major traffic generators (stadium, coliseum, amusement parks, convention, and trade show venues). During this meeting, special event schedules are exchanged, predictions of the level and volume of extra traffic are presented, and traffic and parking management plans are developed.

Little automation is currently used to support this function. However, the Support Systems Contractor's (SSC's) Integrated Modeling Environment will have the capability to use historical data and traffic simulation models to predict demand.

MONITOR PUBLIC CONFIDENCE

Traffic management systems can be only as effective as the public's confidence in them. The ideal TMC will continuously track measures of confidence using solicited (survey) comments and unsolicited (e.g., complaint letter) comments.

Current practice in most TMC's includes formal reporting and assignment of work details based on complaint calls received at the TMC by the public. Frequently, TMC's rely on public reporting of problems with intersection timing and other signage problems because of the high cost for maintenance crews to continually review the integrity of the infrastructure.

PREDICT TRAFFIC CONDITIONS

In the ideal TMC, a predictive traffic modeling system (PTMS) will use data from the roadway sensors, origin-destination (OD) data from vehicles currently in the roadway system, data about special events traffic, and data about incidents to predict traffic flow a few minutes into the future (from 5 to 30 min). This is done so that preemptive actions can be taken well before an actual problem arises. The current ramp metering and traffic signal timing patterns in use by the Urban Traffic Control System (UTCS) will be incorporated into the predictive model.

The PTMS will be able to predict problems in traffic flow by using a model of current traffic conditions, taking into account incidents, available OD data, and advisories currently in effect. The model will contain expected baseline levels of traffic. The baseline will be time- and day-dependent, and will be adjusted for weather conditions. Many of the specific components of this baseline will be provided by historical data recorded by the TMC. The PTMS will also predict the response of travelers to the implementation of traffic controls by the ITMS. For instance, it will predict the percentage of people that will take an alternate route when it is suggested on a variable message sign (VMS), and use this prediction in its forecast of future traffic conditions.

Support systems with functions similar to the PTMS are under development by the Support Systems Contractor (SSC). These would include the Integrated Modeling Environment in conjunction with the real-time data provided by the TMC Data Base Management System that will allow prediction of traffic conditions. For near real-time predictions, Wide-Area Traffic Control (WATC) will generate demand forecasts a few tens of minutes into the future.

Until such systems are implemented, this function will be performed by the operator who manually alters signal timing plans under UTCS based on accepted procedures and past experience. Experienced and highly motivated operators learn to maintain an acute awareness of the traffic situation and to predict areas of congestion well ahead of time. The PTMS-type system, when implemented, will be of the most use during periods of high levels of mental workload.

DETERMINE MAINTENANCE NEEDS

The ideal TMC will have a means for automated identification of the need for preventive and remedial maintenance of the elements of the infrastructure, including roadway, structures, sensors, computers, and effectors.

Preventative maintenance in TMC's is often contracted with commercial agencies and such maintenance contracts are cost-effective and practical in high-density areas, given that the number of signalized intersections that can be maintained by one technician is in the range of 25 to 35. In the majority of TMC's, computers and much of the mainframe peripheral equipment are under expensive maintenance contracts. The general trend in most TMC's is to re-host systems to relatively inexpensive personal computer-based systems that can be maintained by TMC staff. Such practices may be eliminating preventative maintenance approaches in favor of system replacement at the time of failure.

Remedial maintenance practices differ across TMC's, but include three main methods: patrols, public complaints, and self-diagnosis. Many TMC's employ patrols of government employees who may either be sent out periodically or continually. For example, Los Angeles assigns emergency maintenance crews to routine signal inspection patrols when they are not responding to trouble calls. Routine checks are done frequently, with more involved inspections performed less frequently. Public complaints about signal malfunctions can be a valuable resource in fault detection. In order for this to be effective, however, the public must be educated about the role they play and about where to call to report observed faults. Self-diagnosis routines in computerized control systems may automatically detect malfunctions long before any public complaints are received. Computer control allows for confirmation of public complaints and diagnosis of malfunctions before repair crews are dispatched.

Currently, one European TMC has integrated the process of incident detection/management with recording of outages and maintenance problems. As part of the normal reporting process for an incident, the operator classifies the severity of the incident and enumerates any compromises to the integrity of the intersection traffic control hardware. This entry is part of a data base that automatically issues a repair request to the appropriate maintenance group. Other TMC's have less automated approaches, but are establishing some form of computer-based communications with maintenance groups.

SELECT TRAFFIC MANAGEMENT TACTICS

In the ideal TMC, a response advisory system (RAS) will help determine the appropriate response to current or predicted variations in roadway capacity or traffic flow. The RAS will provide a simulation capability that allows evaluation of various response alternatives, using a version of the PTMS to obtain predictions. This simulation will use current traffic data and must be performed many times faster than real time.

In most current centers, traffic management tactics are chosen based on operator experience. Some centers have developed comprehensive procedures manuals that describe appropriate tactics for various situations.

Two existing systems, COMPASS in Canada and the Motorway Control and Signaling System (MCSS) in Europe, have largely automated the decision process for selecting appropriate VMS message patterns and lane-control strategies, respectively. COMPASS requires the operator to input data in case of an incident, while MCSS can operate without operator intervention.

In the Integrated Modeling Environment Support System, under development by the SSC, various signalization and control models will be used to optimize control parameters on the sub-network or network level. The Wide-Area Traffic Control (WATC) support system will actually implement these tactics with operator capability to influence choice of tactics.

SELECT INCIDENT MANAGEMENT TACTICS

In the ideal TMC, an RAS will help determine the appropriate response to an incident. Responses to an incident can include doing nothing, informing motorists of a slight delay, rerouting some traffic, and, in extreme cases, closing a major freeway and rerouting all traffic. Incident management will also include contacting and coordinating with emergency response agencies in order to clear the incident as quickly as possible.

In the case of the rerouting, the RAS will determine the optimal alternate route(s). The RAS will learn from experience. The RAS will also monitor the clearance of an incident and help determine when to return to normal operation. For example, the RAS will determine when to clear an advisory message from a VMS. The RAS will also provide a simulation capability that allows evaluation of various response alternatives, using a version of the PTMS to obtain predictions. This simulation will use current traffic data and must be performed many times faster than real time. Most current centers have a detailed set of procedures that must be followed in case of an incident. These procedures typically leave little latitude for independent operator decisions.

The Motorway Control and Signaling System (MCSS) architecture, now being implemented in Europe, provides the closest approach to automation of incident responses on freeways. Outstations consisting of loop detectors, computer, and gantry sign are located approximately every 500 m. Each outstation is connected to the upstream and downstream station as well as to a central computer. When a variation in traffic flow meets some threshold, the outstation determines a response strategy that may include stopping traffic, closing a lane, diverting traffic into other lanes, and changing the speed limit on a lane-by-lane basis. The appropriate strategy may include sign changes on upstream gantries. The formulated plan is communicated to the central computer where it may be modified according to information known to the central computer, but not the outstation (e.g., a manually entered operator response). The outstation then carries out the response plan at its location and orders appropriate upstream and downstream signing changes. All of this can be done in approximately 0.4 s without an operator in the loop. Typically, MCSS operators have little coordination with emergency response agencies.

Another highly automated system, COMPASS, uses an extensive network of loop detectors and VMS to influence vehicle movement. Priorities have been established among several classes of signs, including incident management, congestion management, navigation, and public service.

SELECT DEMAND REGULATION TACTICS

In the ideal TMC, the RAS will also select strategies for demand regulation. This is envisioned to include strategies for overall demand reduction as well as specific demand regulation tactics (e.g., for special events). This is a decision-making function in which computer models may suggest a menu of demand regulation options and test them against current or projected traffic levels. Given this decision aiding, the operator will then choose the appropriate strategy. In current TMC's, the option generation and selection is strictly a function of the manager's or operator's knowledge, experience, training, and judgment.

SELECT PUBLIC RELATIONS TACTICS

In Chicago, the commitment to highly responsive inclement weather road surface clearing and treatment has changed the public's expectations on responsiveness. As a consequence, the TMC has utilized weather forecasting and anticipated road conditions to pre-position assets, such as road salting equipment sitting on the highway in anticipation of the impending storm. Public service announcements and videotapes produced by FHWA and the Canadian Ministry of Transportation are providing detailed information to the public on the operation of the TMC's in their area by providing a "users guide" to effective use of VMS signage and other system resources and appropriate motorist responses to common travel situations that can help reduce congestion and potential for incidents.

INFLUENCE ROUTE SELECTION

The ideal TMC will provide outputs that influence drivers' route selection decisions, both pre- trip and enroute. Effective means of communication with drivers must be developed and used.

Variable message signs (VMS), also known as changeable message signs (CMS), will be used to distribute information relevant to the local traffic. They may present information on expected travel times and delays, incidents ahead, and, in some situations, suggest alternate routes. A VMS at a major railroad crossing will provide an estimated time to clearance when traffic is stopped for a train. There are currently numerous theories on the best use of the VMS assets.

The highway advisory radio (HAR) system, consisting of a network of low-powered transmitters, each with a limited coverage region, will broadcast messages that supplement messages displayed on a VMS. This system will take advantage of the conventional radios in most vehicles. It allows localized advisories to be received by traffic in the affected area. These recorded messages may also be heard over the telephone by dialing in; each transmitter is accessible separately.

Smart vehicles will comprise a subset of vehicles on the roadway system. These will include participating commercial fleet vehicles, government-owned vehicles, public transportation vehicles, and some private vehicles owned by individuals who participate on a voluntary basis. Vehicles with navigation systems that use real-time traffic data will be able to report their origin-destination (OD) data to the TMC. Subsequently, reports of current position and planned route will be provided automatically by the vehicles. In return, they will obtain real-time updates on traffic conditions.

Future automated vehicle control systems (AVCS) will. be partially controlled by the TMC, which will send signals that are received by in-vehicle systems. Many AVCS subsystems will require data from the Ideal Traffic Management System (ITMS) to achieve full operability. Some AVCS subsystems will be deployed in the mid term and will require interfaces with the TMC.

In addition to its organic outlets, the TMC will send data to other organizations that will, in turn, transmit information to the public. Commercial radio and TV traffic advisories will continue to disseminate traffic information in the near to mid term. The TMC will provide data for use in preparing these advisories. Commercial radio and TV will also be used in major advertising campaigns to advise the public of major construction or maintenance projects and of traffic conditions associated with special events. The Traffic Channel cable TV outlet will relay TMC messages and data about current traffic conditions. It will also carry information from public transportation authorities. It will be shown at information kiosks at airports, truck stops, hotels, and other places where travelers are making trip and route decisions, as well as in homes and offices. A few installations of traffic kiosks have been made, especially in areas supporting high levels of tourism. A traffic bulletin board service will be accessible by computer over telephone dial-up. This service will contain data on current traffic conditions throughout the metropolitan area. Traffic volumes and rates will be reported by route, and incident locations posted upon verification. Third-party vendors will create software that will take this data and create tailored traffic advisories and route planning assistance for users. Major users will include commercial vehicle operators, but many private individuals will also use the service. The service will be accessible from homes and dispatch centers (for use in trip planning), and also from smart vehicles equipped with intelligent systems that use the data for optimized navigation. Print media, especially local newspapers, will be used to convey information about construction and maintenance projects that will impact traffic, traffic management for special events in the area, and general information on the operations of the ITMS. The TMC will support preparation of print media features concerning such topics as defensive driving and use of public transportation systems.

An Information Dissemination System (IDS) will interface with the communication links to response forces such as police, ambulance, fire department, and towing services, and to the data services supplied to the mass media, the Traffic Channel, and the bulletin board service. The IDS will be capable of posting messages on VMS's and creating voice messages for broadcast on highway advisory radio.

INFLUENCE VEHICLE MOTION

In the visionary TMC, a real-time adaptive traffic control system will take data from the roadway sensors and use it to continuously adjust traffic signal timing and ramp metering plans to optimize flow throughout an entire network. The system will maintain optimal flow by automatically responding to current and predicted stochastic variations in traffic. A key feature, not present in existing systems, is that control will be integrated over surface street and freeway traffic. The algorithms will be robust, and will automatically accommodate unusual traffic patterns, such as those associated with special events.

This vision is highly realistic. Traffic signals will remain a primary means for traffic control in the near to mid term. Using control systems now available or under development, the TMC will have sophisticated control (both manual and automatic) over the timing patterns for traffic signals. Timing patterns may be adjusted to optimize the local flow of traffic through the intersection controlled by that signal, and signals in a given area can be coordinated to optimize flow in accordance with current traffic conditions. While there is considerable discussion about the need to integrate freeway and arterial signals under a single control system, this appears to be several years from reality.

The Motorway Control and Signaling System (MCSS) architecture in Europe provides the closest approach to full automation of a system for influencing vehicle movement on freeways.

In Canada, COMPASS uses an extensive VMS network to influence vehicle movement. Prior to system implementation, a team of experts divided the roadway into several hundred unique zones. They then determined the appropriate VMS response for different types of incidents in each of the unique zones. A large set of VMS messages are preprogrammed. When an incident occurs, the operator enters information about the incident location and type, and the appropriate VMS response plan is automatically carried out.

Roadway traffic control for automobiles may be shared with that for other roadway-based transportation modes. In many European cities, for example, buses and light rail vehicles are given priority (e.g., green signals) when an on-board computer and transponder signals that they are behind schedule.

CONTROL ROADWAYACCESS

The ideal TMC will have the capability to control the access of vehicles to certain segments of the roadway system, or to the roadway system as a whole. The control of roadway access 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., HOV lanes) in accordance with the strategic regulation of demand.

Ramp metering, in some form, will continue to be an important tool for controlling ingress onto limited-access roadways in the near to mid term. A major problem with ramp metering systems, though, is a high degree of noncompliance. In future systems, ramp metering will be coordinated with nearby traffic signals on the arterial network to distribute the overall system load.

Some TMC's now have a capability to remotely close a gate on a ramp leading to a freeway. In other jurisdictions, gates are present on the ramps but they must be physically closed by field personnel or police.

DISPATCH EMERGENCYAND MAINTENANCE RESOURCES

The ideal TMC will have the capability of dispatching emergency and maintenance resources that result in the timely provision of appropriate services. These dispatches must alert available service providers of the type of service required and location of the need on the roadway system.

Some, but not all, TMC's have the responsibility for dispatching emergency services. As mentioned above, TMC's routinely dispatch by radiotelephone, telephone, and occasionally by CAD. In TMC's without such dispatch services, the centers are in phone communication with the dispatcher or, rarely, by computer-aided dispatch (CAD) and may have a police liaison on duty during rush hours (at a minimum) to aid in coordinating with dispatchers. Such police liaisons are also able to assist in coordinating TMC activities directed at an incident scene and make command decisions to close lanes and request additional emergency services such as fire and ambulance. In many centers, tensions exist in the relations between police and the TMC staff, resulting in TMC's providing incident-related information to police, but not receiving any confirmation of actions taken by the police. Because of such tensions, many centers have developed their own emergency patrol services, which are dispatched by the TMC and travel on assigned routes and timetables. Dispatch of emergency services will be greatly enhanced by the emerging vehicle location technologies being developed.

INFLUENCE TRIP DECISIONS AND INFLUENCE MODE SELECTION

The ideal TMC must be capable of providing outputs that influence trip decisions, including whether a trip should be made and when a trip should be made. The influence of these outputs must be strong enough to enable the ideal TMC to contribute to the strategic regulation of demand for the roadway system.

In many TMC's, traffic channels carried by local cable companies inform the public of congestion and travel times. In some instances, it may be valuable to persuade drivers to delay a planned trip for a few minutes or a few hours due to special events, congestion, or major incidents. Several TMC's are also planning dissemination of traffic information kiosks, such as used in Anaheim. HAR and traffic reports are also carried on local radio channels, which may influence trip planning and trip in-route selections. Apparently, such stations are popular with the public as evidenced in Minneapolis where the traffic radio personality has developed his popularity to the level of having name recognition in the metropolitan area.

PROVIDE PUBLIC INFORMATION

The ideal TMC must be perceived as reliable and competent. The ideal TMC must be careful to provide accurate information to the public. For example, motorists are less likely to heed advisories recommending an alternate route if they do not trust the TMC. Through its competency in facilitating the safe movement of persons and goods with minimum delay throughout the TMC's area of influence, the ideal TMC must also continually provide general information to the public regarding its operations. Public relations campaigns are conducted, often in conjunction with the public transportation system, in order to reinforce public perception of the ideal TMC.

All TMC's recognize the importance of public relations and provide frequent tours of their facilities and routinely issue public service announcements and videos of center capabilities to provide public information. Many centers have specific center design objectives to assist in the public tour of facilities and include such assets as big-screen displays, specifically for public relations use, to illustrate the TMC functional systems.

Section 5.
USER-CENTERED AUTOMATION

Designing a complex human-machine system like the TMC from a user-centered standpoint must go far beyond assessing individual display and control components and their arrangement in the workstation. Human factors inputs to the design process should have a significant impact on the high-level design philosophy. In particular, the rationale underlying the allocation of functions among operators and machines must be driven largely by human factors considerations.

Early approaches to function allocation from the human factors perspective divided functions between operator and machine according to which could best perform the function. The MABA-MABA (Men are better at:/Machines are better at:) approach served well for simple systems that did not employ extensive feedback loops between operator and system.

The results of this approach are far too simplistic for today's complex systems because there is no way to share the allocation of functions that are performed jointly by human and machine without extending the analyses to a greater number of levels than is otherwise useful. New approaches to function allocation define the operator's type of interaction with the machine system. 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 TMC.

As a crucial part of TMC configuration trade studies, the role of the human operator in the system must be defined. Each of the selected functions may be allocated to the human operator, an automated system, or some combination of the two. The function allocation becomes a basis for a detailed specification of what the TMC hardware and software systems are expected to do and what the human operator is expected to do in interacting with the system.

The performance of a system function may be described generically in terms of a control loop that involves sensors, effectors, and a decision-making (loop-closing) agent that initiates control actions based on sensed information about the task environment. An operator role in a function can be defined by how loop closing (decision making) is performed by humans versus machines. Using the basic distinction between manual and supervisory control (described below), it is possible to define four generic operator roles in a function, **- Direct Performer, Manual Controller, Supervisory Controller,** and **Executive Controller."** Within each role, there are useful distinctions as described below. The basic distinction between manual control and supervisory control is as follows. In manual control, machine components may be heavily involved as sensors and effectors, but the loop-closing aspect of the function is solely the responsibility of the human. In supervisory control, a machine component is allowed to close the loop under supervision of a human operator who may intervene and adjust or override the machine's decisions.

Using this distinction, it is possible to define a continuum of operator roles in relation to automation of the performance of a function. At one end of the continuum, a function is allocated solely to the human and, at the other end, solely to the machine. In between, performance of the function is shared by human and machine components. It is useful to divide the continuum into four major regions; each region defines a generic operator role in relation to automation. Because it is a continuum, within each region there are degrees of more or less automation. The continuum is illustrated in figure 2.

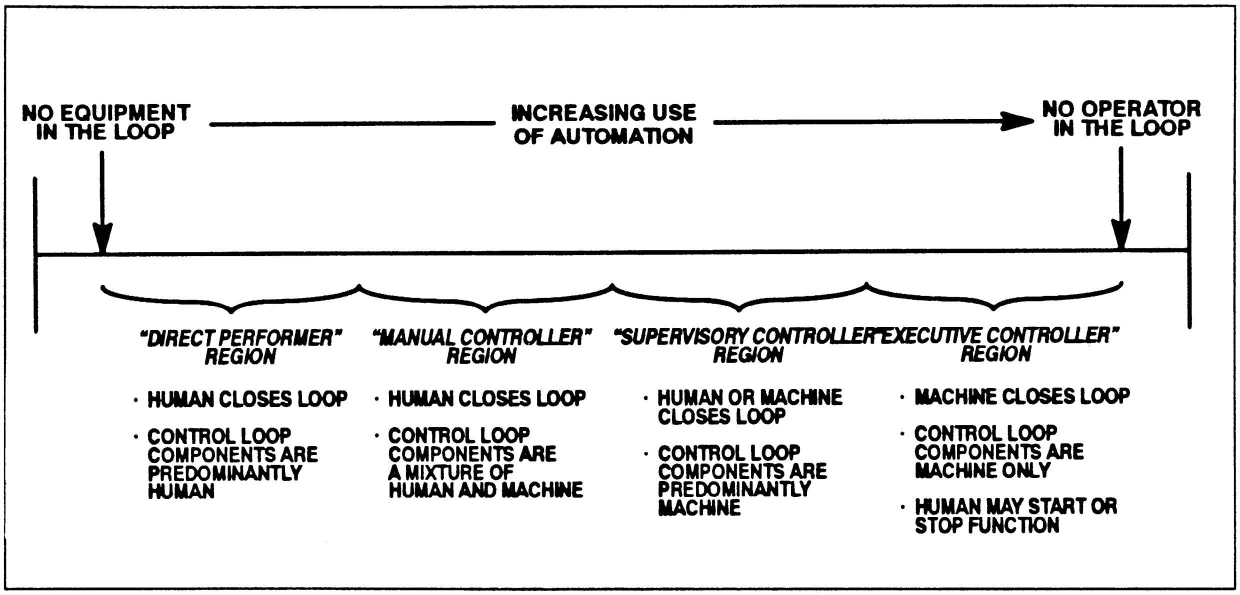


Figure 2. Continuum of operator roles in relation to automation.

VMS AUTOMATION PHILOSOPHIES

The area in TMC operation in which the most automation is found is the management of networks of variable message signs. There are several VMS automation philosophies in use in the TMC's visited, representing the range of hybrid automation approaches.

Manual input. At a few centers, VMS signs are manually keyed into the system. In most cases, the computer screen presents a template that the message must fit and severe limits on vocabulary provide consistency in message content. One center has installed a working model of the actual VMS so that the manually produced signs can be highly refined using variable letter spacing before they are actually displayed. In one instance, the operator was unable to produce a suitable sign for the situation (police had requested a "stronger recommendation" that traffic exit at a certain point) due to the vocabulary restrictions.

Manual input with computer assent. In systems that have complex response plans involving VMS or lane-control signs, there are many rules concerning the acceptable content of adjacent signs. In lane-control systems, for example, speeds may not be stepped down by more than 20 km/h on adjacent signs. Frequently, operators manually request an inappropriate pattern. Decision aids are now reaching the marketplace that reject these inappropriate patterns, explain why they are illegal, and suggest acceptable alternatives. Operators may accept the suggested patterns, try a new pattern, or, at their own risk, insist on installing the illegal pattern.

Choose from selection of canned signs. Some other centers provide the operators with a comprehensive menu of sign messages that may be displayed. The operator picks the most appropriate sign from the menu and inputs the request that it be displayed.

Computer determines response plan, operator assents. In the more highly automated centers, the system becomes aware of congestion or incidents through sensor data or operator input. A response plan, including appropriate messages on a series of signs, is presented to the operator for approval or editing. Only after approval by the operator is the set of messages displayed.

Computer determines and carries out response plan. In the most highly automated centers, the computer network becomes aware of slow or standstill traffic from sensor data. Using internal response logic, an appropriate response plan is determined by outstation computers, approved by a central computer, and implemented without interaction with the operators. The new status is then appended to the operator's display of computer decisions and the operator may manually override the inserted response plan if necessary. Such overrides occur very rarely.

AUTOMATED RESPONSE PLANNING

The COMPASS center on the 401 Freeway in Canada employs a comprehensively pre-planned set of responses (VMS message patterns) to potential incidents. The freeway under control was divided into several hundred unique response zones based on distance upstream or downstream from interchanges, distance upstream or downstream from crossovers between local and express lanes, roadway geometry, location of VMS's, and other similar factors. Appropriate response plans were then developed for multiple incident scenarios within each of the unique response zones.

When no incidents are present, the VMS system automatically displays congestion management information in response to loop detector measures of traffic volume. If no congestion is present, other information, including navigation (e.g., name and distance to next exit) or public safety (e.g., drunk driving admonitions), is displayed.

When the COMPASS operators detect an incident, they initiate an incident screen on their CRT and, according to prompts, key in data describing the location and type of incident. The automated incident response system searches its file of incident templates until it finds one matching the operator's report. The predetermined sign patterns are displayed to the operator who consents (usually) or makes editorial changes (rarely). The automated response, however, is limited to sign displays. The operator must notify and coordinate with incident-response resources by voice.

AUTOMATED LANE CONTROL

Messages reflecting reduced speed limits, closed lanes, and required lane changes are displayed for each lane of the freeway on overhead gantry-mounted signs. Lane-based control requires dense sensor arrays and numerous gantry-mounted signs over each lane of the freeway. Approximately every 1/2 km, there is a lane control system consisting of an array of double-loop detectors, a control box, and a gantry sign. The loop detector array detects changes in traffic speed that signal the beginning of a congested situation. Outstation controllers located near the roadway sense collectives of the loop detector arrays and automatically formulate the appropriate pattern of messages and request permission from a central computer to present the selected messages. The central computer will either consent to the changes or will modify the outstation's recommendation to reflect the situation at other outstations or messages manually entered by the operator. Various rules govern the allowed messages. Adjacent lanes, for example, cannot have speed limits that vary by more than 20 km/h. Speed limits must be stepped down by 20 km/h increments; for example, a 50 km/h limit must be preceded by a 70 km/h sign, which must be preceded by a 90 km/h sign. Control of the lane signs is highly automated. On the initial installation 10 years ago, the lone operator was required to consent to each change in sign pattern. Sign changes occurred at a rate of up to 200 per hour, generating an unnecessarily high workload. All signing decisions based on loop detector data are now made by the computer system and cannot easily be overridden by the operator. (In fact, the relatively less-experienced Amsterdam operator believed that it was not possible to override the computer and she wouldn't do it even if she could.) The operator frequently orders changes in the signs, for example, to close lanes for work zones. Given an operator-closed lane, the system makes a check on the legality of the operator's inputs and then changes neighboring signs to take the closure into account. If the operator requests an "illegal" sign (e.g., diverting traffic into a median) the system will refuse and will provide an explanation. The operator can then override the system, if desired, and continue the "illegal" procedure. In the event that control communication is lost between outstation and central control, the outstation automatically presents the messages on its gantries. This form of "graceful degradation" is a designed feature of the control system. Also, because much of the analysis is done locally, only a modest amount of data needs to be communicated between outstation and the central computer.

FLEXIBLE FUNCTION ALLOCATION

In modern, computer-based systems, allocations of function are not necessarily static, but may be altered in response to operator learning and proficiency, system efficacy, and momentary workload.

Dynamic function allocation may be categorized according to which actor (the operator or the machine) initiates the reallocation. In many current systems, the operator may switch automated systems on or off at will (e.g., components of an aircraft autopilot). This may be seen as one aspect of supervisory control. The inverse situation, in which the function reallocation is done by the automated system (known as adaptive automation), has been explored philosophically and in controlled laboratory studies, but it remains not much more than an interesting user-system interface concept.[5,6]

Dynamic reallocation of functions under supervisory control is relatively common in many automated systems in TMC's. Operators may cancel an automated timing plan and manually insert a substitute. Operators may intervene if they notice that an automated response system is implementing an inappropriate response plan. Operators may grant the automated system greater authority if their workload in approving responses becomes too high and they expect the automated system to make no critical errors.

Dynamic reallocation of functions under adaptive automation has been explored most vigorously in the context of the fighter aircraft cockpit. In this environment, peaks in workload can momentarily exceed the pilot's capabilities; the pilot's capabilities may change due to physiological factors. It would be helpful to have a computer that can sense when the workload is about to exceed the capabilities and reallocate those functions to reduce the workload peak.

Morrison and Gluckman defined adaptive automation as "automation which is capable of engaging and disengaging itself in response to either (1) the occurrence of a critical event or events, or (2) based on the performance of the human component in a person-machine system."[5] The change may also be based on a dynamic assessment of the human's physiological state.[6] Adaptive automation can promote improved situation awareness, increased task involvement, regulated workload, enhanced vigilance, and the maintenance of basic job skills. It can increase mission effectiveness by better management of resources in a complex task environment.

There are three basic strategies for adaptive automation, including (1) allocation, in which entire tasks are reallocated between person and machine; (2) partitioning, in which subtasks are reallocated from operator to machine while the operator remains responsible for performing the overall task; and (3) transformation, in which the task structure is altered. Each may be more practical than the others under certain conditions. In an *allocation* strategy, for example, a support system might assume responsibility for selecting and inserting VMS messages instead of recommending patterns and awaiting approval. In a *partitioning* strategy, a support system might allow operators to manually control traffic signals in a problem area of the city, while placing those in the rest of the city under automated adaptive control. In a *transformational* strategy, an information fusion support system might automatically adjust the granularity (level of detail) of information presented to correspond to its current criticality (e.g., automatically activate appropriate CCTV cameras and monitors in response to a suspected incident).

Adaptive aiding by a support system could be used to improve the quality of decision making. For an adaptive aiding system, specifications need to be developed in the following areas?

(1) *Motivation for specifying adaptive aiding.* This could include predicted operator performance degradation, projected workload, criticality of the decision, or ease of implementation.

(2) *Tasks to be aided.* Either foreground (high criticality) tasks, background tasks (low criticality), or a combination of these could be aided.

(3) *Type of adaptive aiding.* Can be allocation, partitioning, or transformation.

(4) *Method of aid invocation.* Could be unacceptable system performance, operator workload, the nature of the task, or other factors.

(5) *User-system communication requirements.* Includes the amount of information the operator needs about what the aid is doing, the aid's output product, and the aids functional process.

Adaptive automation currently exists in concept more than in reality. There have been some relatively limited laboratory demonstrations, but the technology to implement it has yet to be refined for use outside the laboratory.[8,9] The substantial computing power and software requirements required to implement an adaptive automation system may be prohibitively costly for the traffic management community.

Numerous crucial human factors questions remain before a useful implementation of the concept can be made. These include:

(1) How to eliminate automation-induced complacency.

(2) What type of automation strategy is best for the TMC environment.

(3) Measures of operator workload and performance to trigger aiding.

(4) Effects of automation on other, operator-performed tasks.

(5) Interface designs for aiding systems.

AUTOMATION TO SUPPORT THE HUMAN

An important aspect of user-centered design is that system automation should be designed to assist and support the operator. The operator must always remain "in the loop" and fully aware of: (1) what information the computer has, (2) what the automated system is doing, (3) why it is doing it, and (4) what it is going to do next. The operator must have, at a minimum, the ability to switch off the automated system to prevent a future problem.[8]

Clumsy automation can increase the operator's workload and induce frustration. At one center using Urban Traffic Control System (UTCS) software, all signal timing plans are operated on time-of-day schedules with automatic changes of all intersections at 11:00 a.m. and 6:00 p.m. Operators can manually override the system and customize the timing plans for individual intersections. Beginning at about 10:30 a.m., the operator was observed to make extensive timing plan alterations in response to congestion from a major special event. At 11:00 a.m., without warning, the automated system erased the operator's manually programmed timing plans and inserted the pre-programmed mid-day timing plan. Later that same day, the operator's manually programmed timing plans (prepared for evening special events) were erased when the normal evening timing plans came on at 6:00 p.m. The operator received no indication that the time-of-day changes were about to be made and, in any event, had no way to prevent the changes.

Many routine functions can be automated in the TMC. Successful implementation of the automation appears to work well when a gradual, iterative process is used. Initially, an operator should be present in the control room to review and approve all automated system actions. A detailed log of automation failures should be kept. Early in the life of the MCSS, for example, automated system errors were very common. Frequently, maintenance equipment moving in a closed freeway lane was interpreted by the computer as wrong-way drivers and all traffic was brought to a stop. The TMC operator had to take control and quickly restore order; a new version of the automation software contained a fix that, in effect, ignores traffic in closed lanes.

As such errors are eliminated from the software, it is possible to become increasingly less dependent on the operator. Newer operators consider the MCSS to be faultless and one firmly stated that she was not capable of overriding system control functions (not true) and, in any event, would never do so for liability reasons. While total automation is the goal of several centers and some are operating at night without an operator, we have seen none that are considered ready to run automatically during daylight hours.

Section 6.
SYSTEM EVOLUTION

During the next decade, dozens of traffic control centers and traffic management centers that were established in the 1970's and early 1980's will be upgrading their computer suites and software systems, increasing levels of automation, and modernizing other equipment and procedures. In some centers, this will be a revolutionary process in which most of the older technology will be discarded. In many, however, the IVHS era will arrive one step at a time with the introduction of, perhaps, a VMS system in 1 year and a new support system a couple of years later. The third form of system evolution is development of an IVHS-class traffic management system for a small area initially, and continuously extending the boundaries of the controlled area and the functions of the operators.

In many ways, modernizing an existing center can be more challenging, from a human factors design viewpoint, than building a new TMC from scratch. The existing center will have a staff of operators who are well accustomed to the existing equipment and procedures. There may be great resistance to change, especially if the new technologies seem exotic and threatening. It is crucial that the existing operators be fully enrolled in the modernization by involving them heavily in a user-centered design process.

The user-centered design process can be used even more effectively during systematic upgrades to a TMC than during initial design. During planning for an upgrade, there is an available cadre of operators who have experience with the roadway network, TMC operating philosophy, and the capabilities and constraints of the existing system. Only one of the upgraded centers that were visited had used a formal user-centered design process involving the existing operators. Function and tasks analyses were completed based on operator interviews and examination of documentation. Workstation mockups were constructed based on the defined job requirements and were iteratively refined using operator recommendations.

Other centers used less formal methods of integrating user recommendations. One center asked operators to estimate the number of CCTV monitors that they could effectively use and based the design on the answers. A small-scale mockup of a proposed center layout was constructed and operators were encouraged to experiment with different console and equipment layouts using the model.

Another center that is highly dependent on VMS messages for incident and congestion management became justifiably concerned that the semantic content of messages be understood by the public. Focus groups were developed from among local drivers to discuss their perception of the meaning of candidate VMS messages. The final message philosophy and suite of messages was based on the results of these focus groups.

PLAN FOR EVOLUTION

As new centers are designed, plans for expansion and evolution should be incorporated into those designs. Several centers that were visited need to expand their areas and responsibilities, but have insufficient floor space to support the new operators and consoles such an expansion would require.

At one new traffic signal center, on the other hand, management has foreseen a major advantage in the possibility of co-locating with the existing Freeway Traffic Management Center in order to improve coordination of operations. Substantial coordination of incident management procedures are required because resources assigned to the signal center are responsible for management of incidents on the freeway as well. The new center was designed with sufficient floor space to incorporate the Freeway Traffic Management System (FTMS) if such a move should occur.

INTEGRATION OF THE OLD WITH THE NEW

One of the key issues in system evolution is that of system compatibility; the new systems must be easily integrated with the old. A new set of VMS's must be able to be controlled by the same interface and procedures as the existing set. A new set of sensors must be able to display data on the same screen and in the same format as the existing ones.

One signal control center was operated using detectors, controllers, and software developed by one vendor. When their system was expanded to several hundred more intersections, a new vendor was selected. Only after installation was complete was it found that there is no user interface compatibility and the center now has two separate signa-operator consoles with very different user interfaces.

It should be noted that introduction of high-end PC computers may provide a solution to some of these compatibility problems. It is possible under new PC operating systems to develop a common user interface replacing the individual interfaces of hardware that runs on different computers and operating systems.

Another important factor in the upgraded system design is the informal procedures and practices that have been developed by operators to optimize performance. Where possible, the system upgrade should recognize and support these practices and procedures.

MORE IS BETTER?

There is frequently a tendency in TMC design to think that more of a good thing is necessarily a better thing. A center in which 20 CCTV monitors have been effectively used has developed a growth path toward 50 monitors. Discussion with the designer indicated the increased workload due to the extra monitors would require considerable analysis. Perhaps, more attention should now be paid to summary graphic displays of situation information or other form of data fusion introduced. More of the same isn't necessarily the proper approach.

Section 7.
USER SYSTEM INTERFACES AND WORKSTATIONS

(Designing USI's and workstations to improve individual and team situation awareness)

Maintaining awareness of the traffic situation on a complex roadway network provides a significant challenge to the TMC operator. With the large amount of information and communication technology that is available to the IVHS-class TMC, it is possible to provide the TMC with all of the necessary data to paint a detailed picture of the dynamic traffic situation. The perceptual and cognitive limitations of the human operators, however, allow them to attend to a relatively small portion of this picture at a given time.

The data available to the TMC can be aggregated at various levels of granularity to meet the immediate needs of the operator. For example, the binary status of an individual loop detector may be of interest during maintenance troubleshooting; the volume and speed of traffic passing that individual loop detector may be of interest during incident location activities; the volume and speed of vehicles passing a series of detectors may be of interest during most traffic monitoring; and a signal from a support system that no indication of anomalous traffic flows are seen in the network may be sufficient when the operator is busy with other duties.

For each different function the operator must perform, the ideal is to provide all the necessary information, but no more. New graphical user interfaces to information processing systems allow a significant amount of tailoring of data granularity, display content, and display techniques. Use of these tools can promote improved operator situation awareness, but only if the displays are developed to meet validated user information needs.

For example, in one TMC, multiple levels of zoom were defined for the surrounding geographic region in which the TMC was located. Several geographic sources were consulted and the data were merged, then a series of zooms and granularities were defined from large geographic region down to an intersection level. Five levels, typical of the available zooms are illustrated in figures 3 through 7.

Operators with experience in using these zooms found that only two zooms, intermediate regional display (figure 5) and an intersection display (figure 7) were actually useful. In addition, the distances between the objects displayed were not made accurate with respect to true geographic distances and did not later appear to be problematic. What appears to be important are the spatial relationships, not the actual distances between displayed objects.

There may be significant individual differences between operators in the amount of detail they want to see on the screens. Inexperienced operators, for example, may want to have street names displayed, while experienced operators have these memorized. One form of dynamic screen redesign, a "declutter" capability, can help solve this problem. Using declutter, the operator can change the amount of detail on the screen by toggling the display through, say, three pre-defined levels of detail.

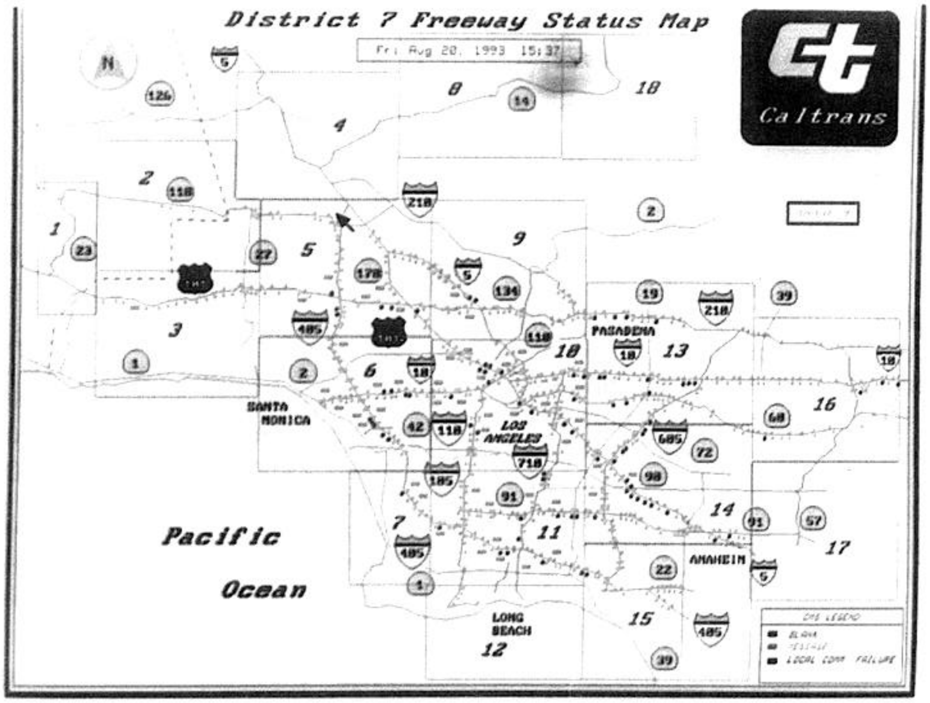


Figure 3. Example of a broad region zoomed-out with low granularity.

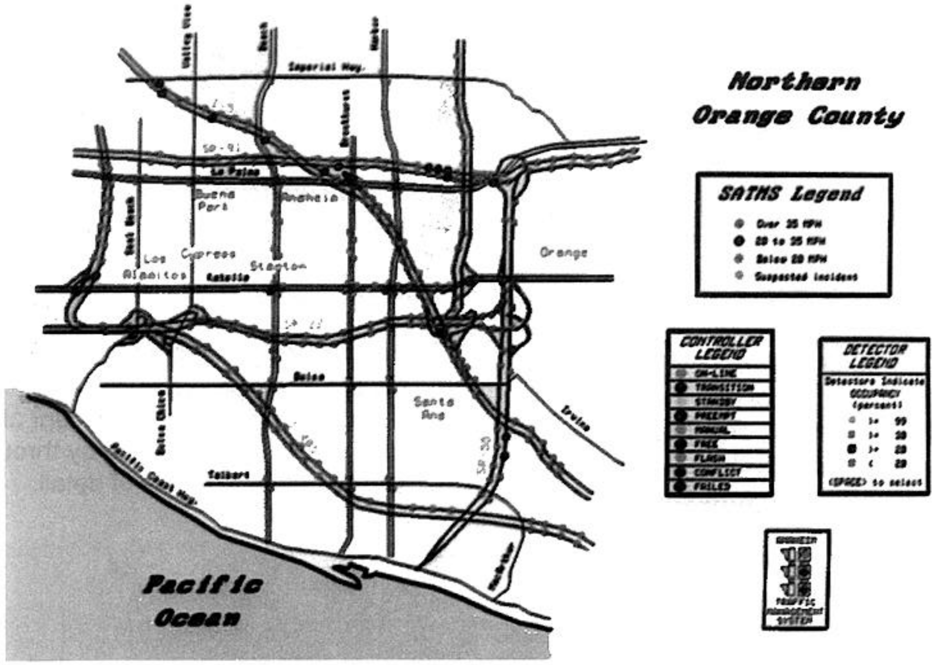


Figure 4. Example of a region zoomed-in with medium granularity.

Figure 5. Example of an intermediate region with medium granularity.

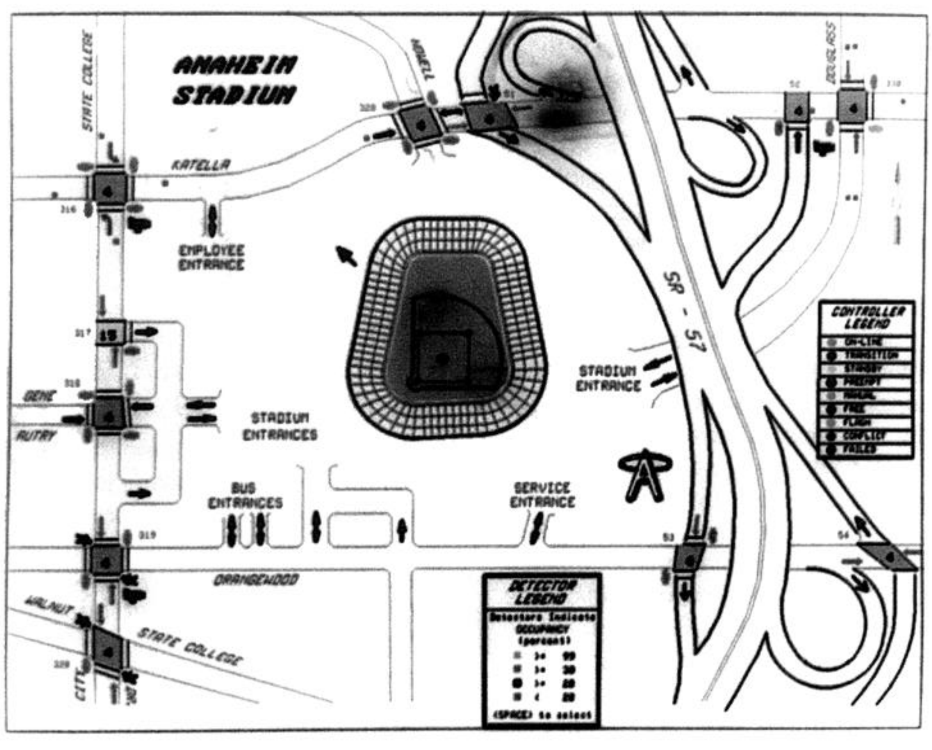


Figure 6. Example of a local area zoom-in with high granularity.

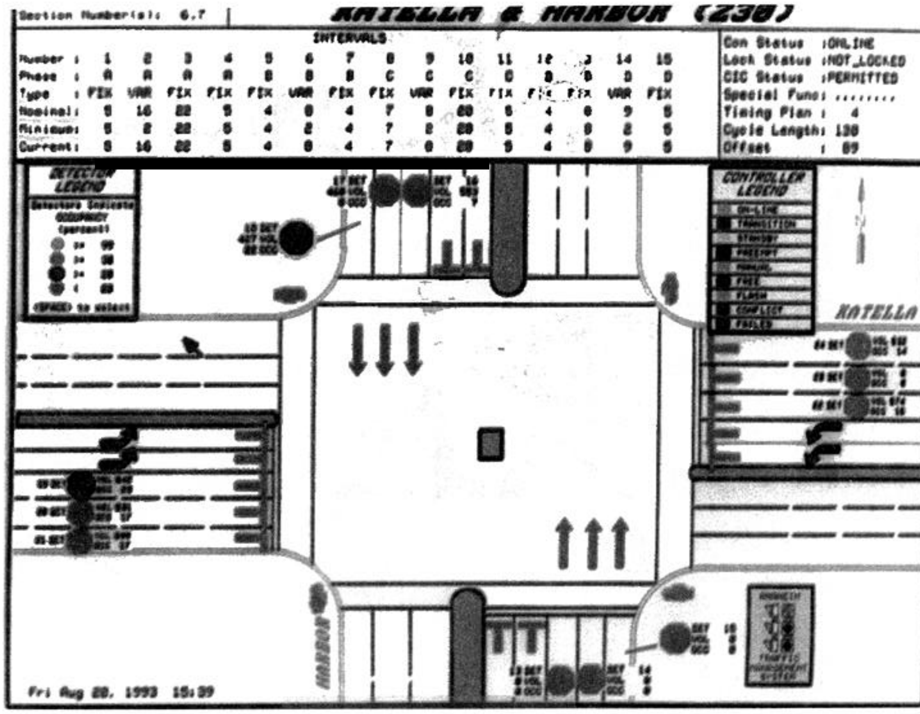


Figure 7. Example of an intersection zoom-in with high granularity.

RAPID PROTOTYPING OF DISPLAYS DURING TMC DESIGN

As the large amounts of incoming data are fused into meaningful chunks, it is usually necessary to provide summaries in graphical format to support the operators' situation awareness. The use of maps, graphs, color coding, and blink-pattern coding can allow the operator to assimilate large amounts of data as well as providing a warning when something needs immediate attention. Numerous software packages with which replicas of candidate display screens can be programmed off-line and displayed for operator critique or performance testing are now available. The screens can be easily refined until they are acceptable and then, with many packages, display software is produced for rehosting to the real TMC. Such prototyping can eliminate display characteristics that might cause human performance difficulties before they become part of the TMC. In some TMC displays, 10 or more conditions had to be discerned on the basis of color coding alone. One interface, for example, used a 12-color scale to indicate system status. Different elements of the system had different numbers of descriptive levels. One subsystem might have three levels and use the top three colors; another might use all 12 available colors. As a consequence, the color that meant "worst possible" in the three level subsystem was encoded as "pretty good" in the 12-level system. The cognitive workload of the operator was increased by this design and the likelihood of interpretation errors was increased. User testing of a screen prototype most likely would have discovered and corrected the confusion that this coding created.

THE CARDINAL RULE: HUMANS MAKE ERRORS

The primary rule to keep in mind during user-centered design process is that people make errors while doing their jobs. The design of jobs and systems, however, can have a powerful effect on the frequency and criticality of errors. It is relatively easy for an operator to make a "typo" while keyboarding system commands, and such errors should be guarded against.

At one center, the operator types <1> to invoke an ordinary setup and <1> to invoke a full system shutdown requiring several minutes to recover. An error trap in the software ("Do you really want to shut the system down? Y N”) would eliminate the serious error this entry would cause.

The design approach should be to minimize both the frequency and criticality of operator errors.

HOW MANY OPERATORS?

A major issue in control console and workstation design is the number and role of operators who will run the center during different shifts and conditions. Numerous centers that were visited were-designed to be run using multiple workstations, each with its own role. Yet, on evenings and weekends, the staff is reduced to a single operator who not only must be cross-trained on each of the job roles, but who must move between a series of workstations and retain awareness of a series of displays and communication systems.

One center solves this problem by having one multi-function “supervisory” workstation that can be used during the day by the supervisor to support any of the operators and can be used at night to combine the functions of all workstations into one.

BIG BOARD DISPLAYS

A dominant feature of nearly every center visited was some type of big board display. Typically used to present a broad overview system map, these displays are readily visible to all operators in the TMC. Three different kinds of big board displays were seen: static wall maps, active wall maps, and projection television screens.

Most managers readily admitted that the primary purpose of the big board was to provide a display of large proportions to impress center visitors. At smaller centers with single operators, the big boards did seem to be superfluous to center operation. At larger centers in which operators walk between workstations to coordinate, some big board installations were seen to provide a useful communication tool. Dynamic big boards allow operators to maintain partial situation awareness when away from their workstations.

Of the three kinds of displays, static wall maps appear to be the least useful (see figure 8). These can provide the geographic layout of the roadway system, and the location of ATMS resources, such as detector stations, signals, signs, and cameras. Most of these data are memorized by operators and they have no need to have it prominently presented before them. Dynamic wall maps are somewhat more useful in traffic management because they provide some kinds of current traffic-related information (see figure 9). Tiny holes are drilled into the large panels at appropriate locations through which tiny light bulbs or light-emitting diodes (LED’s) connected to sensors in the field are inserted from the back of the map. In traffic signal-related centers, these maps provide information on signal status (illuminating, for example, when the signal turns green for east-west traffic at that intersection). In freeway-oriented centers, the lights may represent traffic flow (illuminating when congestion is detected at the location).

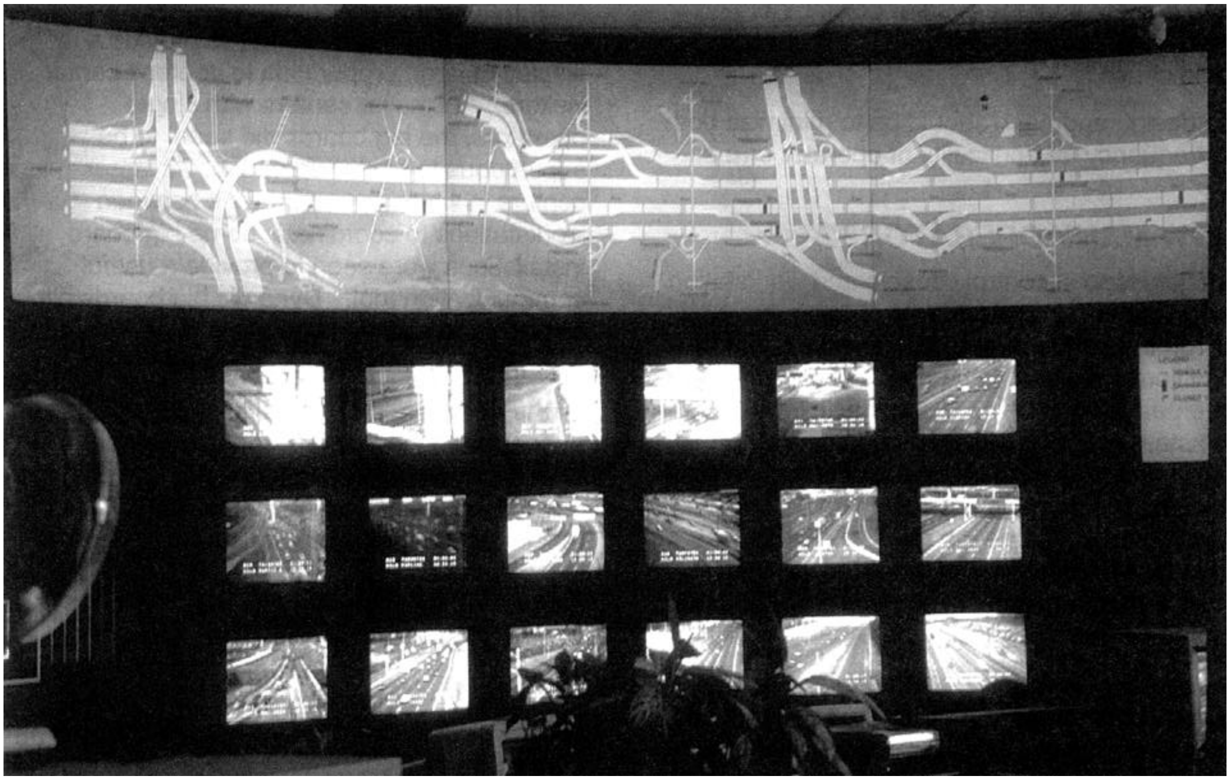


Figure 8. Example of a static wall map.

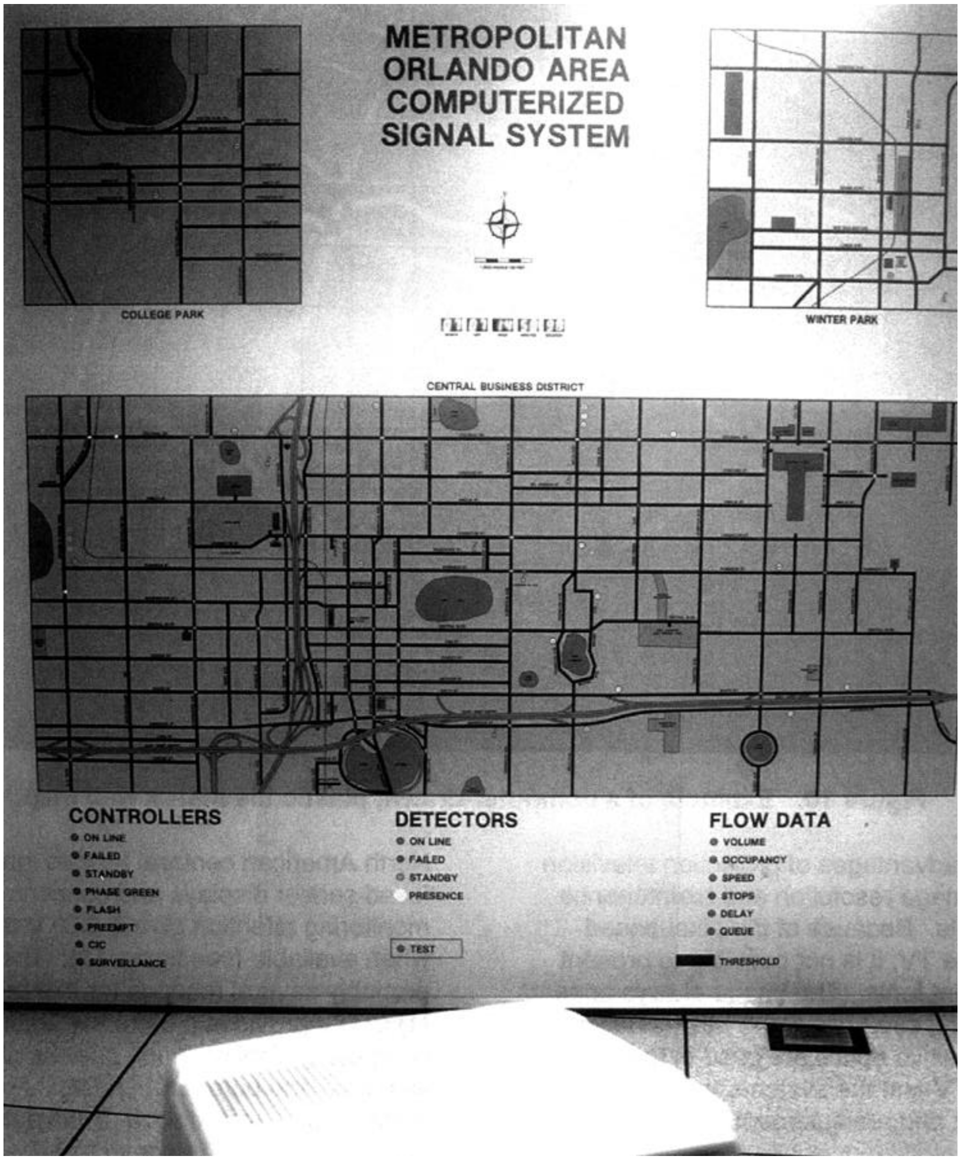


Figure 9. Example of a dynamic wall map.

One standard complaint about dynamic big board displays, since they usually consist of large painted maps, is that it is difficult and costly to change them to match infrastructure changes. In one ingenious solution to this problem (see figure 10), the map is computer-drawn on a matrix of plastic tiles, each about 2.4 cm square. When a change in infrastructure is made, the appropriate tile can be snapped out of the matrix and returned to the vendor for updating.

The projection television provides both advantages and disadvantages as a big board medium. One major advantage is its flexibility. It can be (and usually is) used to present a wide-area map with dynamic traffic flow or signal status information (see figure 11). It has the ability, however, of displaying anything that might appear on any other TMC graphics monitor, including maps with various views and levels of zooming, graphics of individual intersection status (if available in the software), live video from CCTV cameras, TV images of officials at other sites for teleconferencing, or even combinations of these.

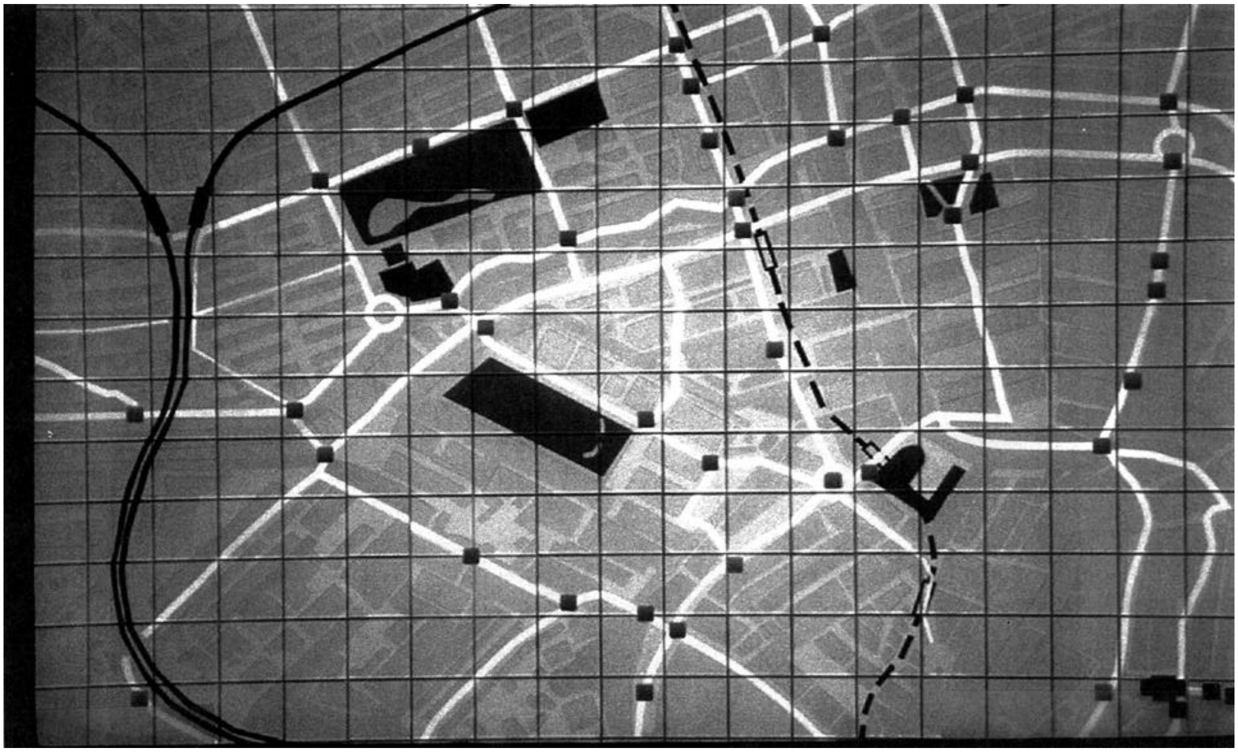


Figure 10. Example of a computer-drawn, plastic tile matrix wall map.

Primary disadvantages of projection television are in the image resolution and maintenance requirements. Because of the pixel-based nature of the TV, it is not possible to present very fine print fonts. The image always appears slightly blurry, even under the best conditions. Finally, sensitive optics are used in the projection TV and the systems frequently require realignment and readjustment.

A fourth kind of big board that was not seen during any visits, but is being installed in some not-yet-open TMC's, is the video wall. A matrix of television monitors becomes the display rather than a single monitor. This has the effect of multiplying the number of pixels available for the display by the number of monitors. This approach substantially reduces the resolution problems of the projection screen while maintaining display flexibility. The disadvantage is the dark lines that appear where the monitors abut each other.

CCTV SYSTEMS

CCTV displays usually are intended to support loop detector data. Operators (especially in North American centers) tend to ignore the fused sensor displays and concentrate their monitoring attention on the CCTV monitors when available (see figure 12). There are probably several reasons for this preference: (1) CCTV provides a more interesting and compelling display during periods of low workload and boredom, (2) CCTV provides a more natural and intuitive display, and (3) it is potentially possible to detect traffic-flow problems slightly earlier with the CCTV than with the fused detector data.

Overdependence on CCTV, however, can have a major impact on operator performance during periods of heavy workload, and some centers are trying to force operators to use the graphical traffic-flow displays. In one center, the color monitors are adjusted to provide only monotone images to make them less visually compelling. According to the philosophy of one major vendor, the number of monitors in the TMC should be limited to some minimum number and they should not be turned on until there is an indication, in the detector data, of a problem.

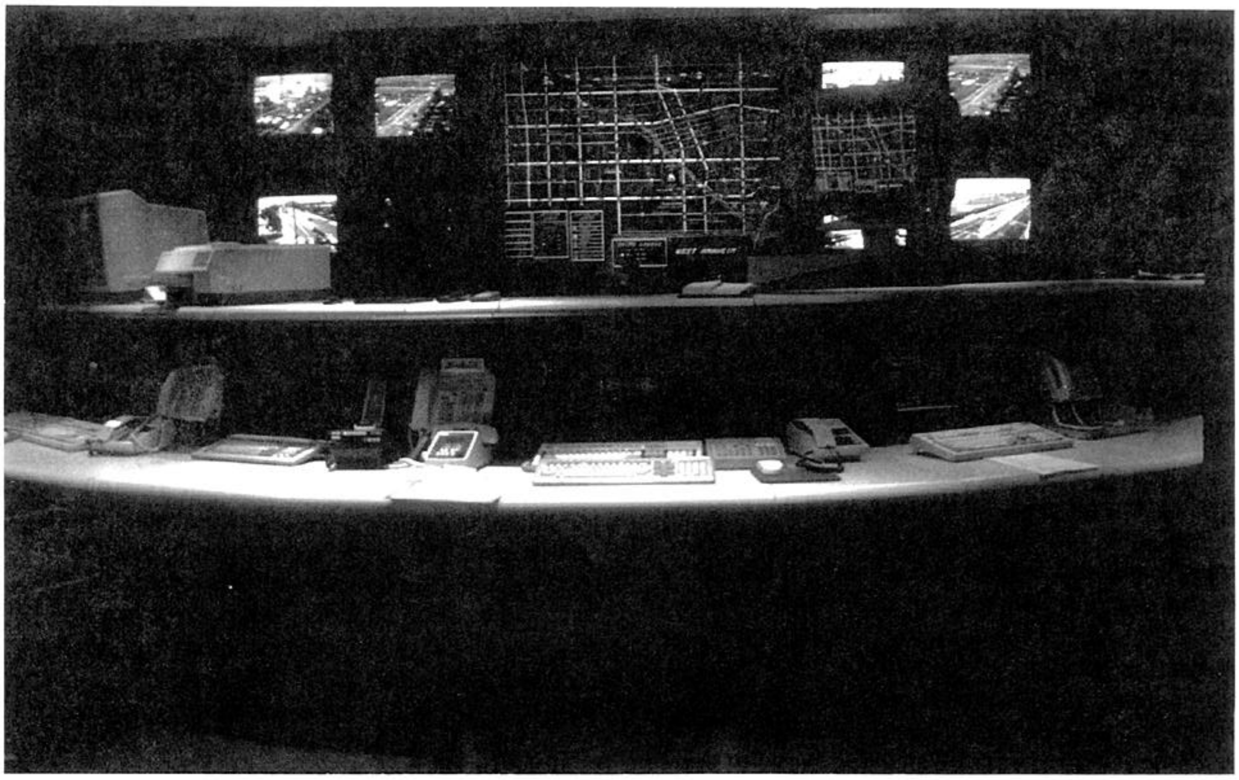


Figure 11. Example of a projection television system (left center, large screen).

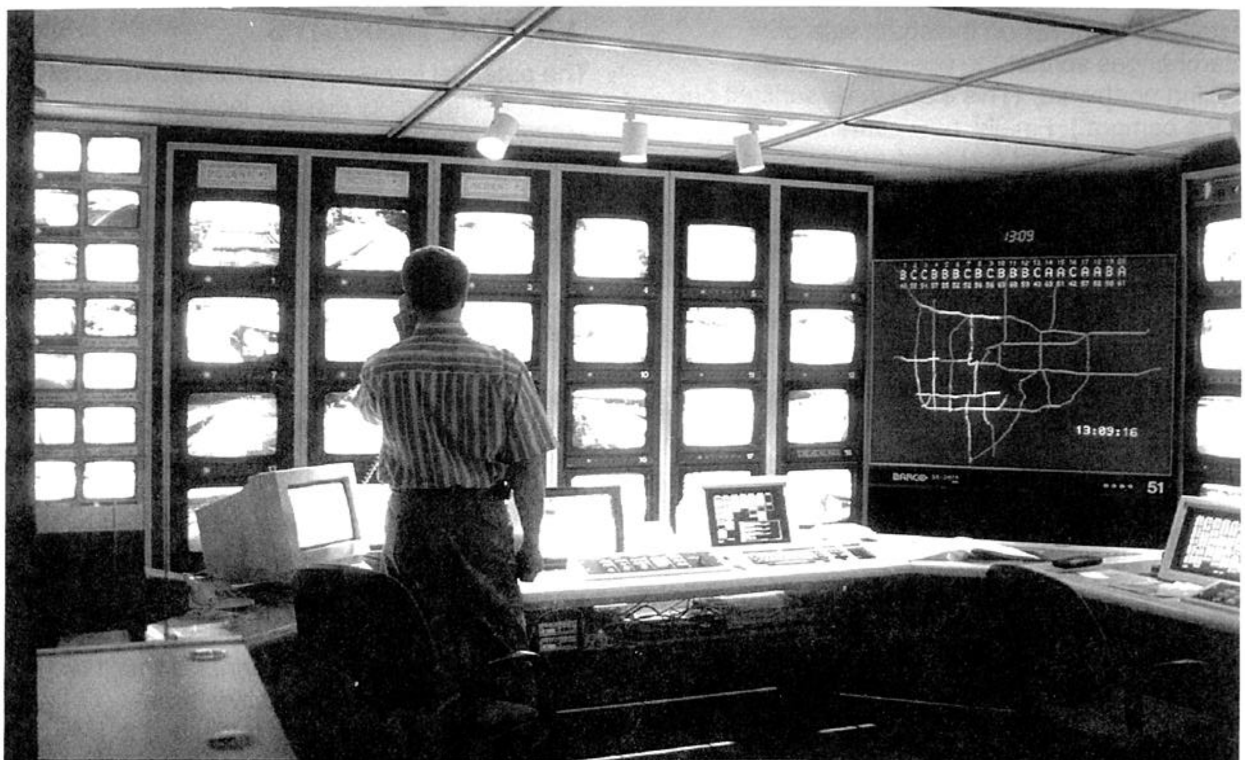


Figure 12. Example of a large matrix of CCTV monitors.

In many facilities, locations of cameras are determined more by convenience than by strategy. Existing vantage points, such as roofs of tall buildings, are prime candidates for a camera location. In these facilities, an extra increment of workload is added to the task of camera control and monitoring because operators must mentally determine the location of the camera and its direction of regard in order to know what street or roadway they are viewing. In the daytime, this is a minor problem; at night, when fewer landmarks are visible, it becomes more difficult. Substantial training and experience is required to learn this skill.

There are at least four solutions to this dilemma. First, on the graphical map display of the area of interest, the camera icon should be placed at the proper location and the icon should rotate, in concert with the camera, to indicate the camera’s angles of regard. Second, the geographic location of the camera should be superimposed over the monitor image of the traffic scene. A compass display may also be superimposed to show the pointing angle of the camera. Third, a consistent location for cameras should be used. One center, for example, that manages an east-west freeway, installs all cameras on the south side of interchanges so that the operator is always looking northward. (This also keeps sunlight out of the camera.) Finally, new cameras are reaching the market that have preset pointing angles that can be labeled on the controller. To look at Central Street to the west, the operator pushes the appropriate button rather than using an analog controller. These systems can also be programmed to be responsive to an incident detection algorithm to automatically turn to the location of a possible incident.

Another major issue with CCTV’s is the assignment of responsibility for control of the cameras. In many settings, cameras may be controlled by more than one operator and even by more than one center. Problems have resulted when two or more operators were simultaneously fighting for control of the common camera. It is difficult to establish guidelines for control but some schedule should be set, based on the function and task analyses, to give priority to the operator with greatest need.

VARIABLE MESSAGE SIGNS

Variable Message Signs (VMS) can help to support the driver’s situation awareness by providing information about the conditions ahead. Drivers may be influenced to alter their routes in response to major delays. They may be influenced to decrease speed and become more alert in response to more minor congestion and delays.

TMC operators who control a network of signs need to be aware of the message content of those signs to ensure that they are appropriate and up to date. There are frequent stories about operators who forgot that a temporary message was left on a sign for hours longer than planned because operators forgot to remove it. There are several potential approaches to this problem. First, signs containing temporary messages may be indicated by special color coding on the map display of system resources common to most TMC’s. Second, an aging time might be applied to different messages and, after the appropriate time period, the operator would be cued as to the presence of the message.

VIRTUAL DISPLAYS

The potential to present the operator of a TMC with a virtual-reality display, including the roadway and cars, and potentially to present a “face-to-face” conversation with other operators at remote locations is a compelling vision. Operators could view a roadway scene of an accident through special goggles that provide a combination of computer graphics and real images. Operators might locate an emergency vehicle by circling the area with a gesture and dispatch it by touching the designator on the CRT screen for the emergency patrol closest to the scene. High-resolution views of an incident might be obtained from a CCTV camera mounted on a “robot” vehicle dispatched by the TMC operator and controlled by the operator’s gestures.

Although virtual reality has become a popular buzzword with “frivolous” connotations, it is rapidly becoming an interactive three-dimensional world of great relevance to many scientific and industrial endeavors.“” There is a desire to make a very natural interface between humans and computers, where the realism created by three-dimensional imagery, spatial sounds, and even physical forces from motion to crude touch (possibly even smell), are available to produce a compelling immersion of the user into the synthetic environment. The basic building blocks for a virtual reality include a display, a tracking device for interactivity, a computer image generator, a three-dimensional data base, and the application software. However, virtual reality still needs much work and assessment before it can become a common tool for industry. For example, to "build" a virtual mockup of a car may take just as long as building a real mockup (and with less resolution).

Experts in the field of virtual reality expect that problems in human tolerance of such an environment for extended periods (stress and fatigue are among the current problems) and selections of appropriate and specific applications are needed to clarify the industry. Methods and devices must be standardized and developed from a human factors perspective considering the specific design requirements for the systems being designed. Virtual reality may not be feasible today, but the gap is closing quickly.

Section 8.
STAFFING, SELECTION, AND TRAINING
(Operator/maintainer initial and proficiency training; staffing and personnel selection)

WHO'S ON DUTY IN THE TMC

One crucial question for designers and operators of the newly designed TMC involves selection of operators. The qualifications of the TMC staff must be directly related to the design and function allocation philosophy. If the operators' functions are relatively repetitive, predictable, and non-critical, operators with a lower level of qualifications may be acceptable. If unique problems are frequent, rapid reaction is needed, and/or criticality is high, operators with higher levels of training and experience are indicated.

The minimum qualification for a TMC operator would seem to be good verbal skills, a degree of computer literacy, and good reasoning skills according to the practices of several centers here and abroad. One center, as a result of a formal job study, defined their requirements as "good oral and written communication skills, good interpersonal skills, and a working knowledge of the local freeway system." A few centers employ part-time students as operators, usually under the supervision of a manager or senior operator. Centers that are active in incident management generally require more highly qualified operators than signal control centers or those that see their role as congestion management. At some centers, operators come from a technical staff of traffic engineers or computer scientists who have other assigned technical duties or who may be given special projects. One European center was totally staffed by police personnel; others had police liaison officers on duty to handle interactions with officers in the field. A small number of centers require college engineering or technical degrees.

INITIAL TRAINING

In the vast majority of centers, initial operator training is an on-the-job activity. Trainees are provided with procedures manuals and equipment manuals.

Three formal training courses for TMC operators were identified. The COMPASS TMC has a self-contained training room with its own training simulator for training COMPASS operators. California Polytechnic Institute at San Luis Obispo (Cal Poly) provides a simulator-based training course for Caltrans operators. Chicago Communications Center has a 3-month program of text and videotape.

At **COMPASS,** trainees undergo a 3-week training course consisting of 1 week of lectures, 1 week of operational training in the simulator, and 1 week of supervised operator training on the job. Classroom topics are:

(1) Introduction to Traffic Engineering, including inventories, capacity and traffic volume calculation, travel times and delays, and driver characteristics.

(2) Freeway Traffic Operations, including traffic characteristics, problems associated with freeways, and accident data and reporting.

(3) FTMS Theory and Purpose, including system components, software, field hardware, overview of FTMS in North America, MTO approach in Ontario, and other traffic engineering strategies.

(4) Traffic Management, including incident management, congestion management, and special situations.

(5) Overview of Highway 401 FTMS, including the system schematic, field subsystems, communications, central subsystems, and potential for future growth, including lane control.

(6) FTMS Software, including control room computers, FTMS software terminology, software systems, color graphics, and operator functions.

(7) Dealing with Other Agencies, including visits to fire, ambulance, and metro traffic communication centers.

(8) Day-to-Day Operations, including normal operations, interagency incident coordination response, traffic response plan guidelines, operational code, the operator's workstation, and operational procedures.

Cal Poly has designed a three-stage training program for Caltrans and CHP operators that centers around their Traffic Operations Center (TOC) simulator. The TOC simulator consists of the simulation room containing four operator workstations and appropriate computers, monitors, displays, controls, and communication devices, as well as a control room from which various realistic traffic management scenarios can be run. The simulation room can be reconfigured, as needed, to resemble the home TOC of the trainees. Figure 13 shows one floor plan of the Cal Poly TOC simulator.

Training scenarios were designed to promote meeting the following major objectives:

(1) Critical contacts will be made on a timely basis.

(2) incident response and traffic management resources will be appropriately allocated.

(3) Inquiring agencies will be provided with the most timely and accurate information.

(4) A professional image will be projected.

Initial scenarios included a mixture of incidents that are relatively common, including minor collisions, an overturned truck with cattle on the highway, and a zero-visibility fog bank.

The introductory-level program is a 3-day session consisting of 30 percent classroom lectures; 40 percent laboratory, workshops, and demonstrations; and 30 percent simulator training exercises. Subjects include:

(1) Comprehending CHP radio dialogue.

(2) Using call signs and brevity codes.

(3) Operating two-way radio consoles.

(4) Interpreting traffic information.

(5) Utilizing TOC software.

(6) Operating TOC equipment.

(7) Working with the incident command system and other standard operating procedures.

(8) Maintaining appropriate records and documentation.

(9) Communicating with the media and other agencies.

The intermediate-level training course is for TOC operators and supervisors who have at least 6 months of experience and is centered on major incident and disaster response. This class lasts 3 days, consisting of 30 percent lectures and 70 percent simulation training. It covers the following:

(1) Incident command system.

(2) Multi-vehicle accident investigation.

(3) Hazardous spill procedures.

(4) Earthquake emergency response.

(5) Roadside fire response.

(6) Multi-jurisdictional extended pursuits.

(7) Release of information to the media.

The advanced-level training course is a custom-developed course addressing specific IVHS topics that are required by a specific jurisdiction.

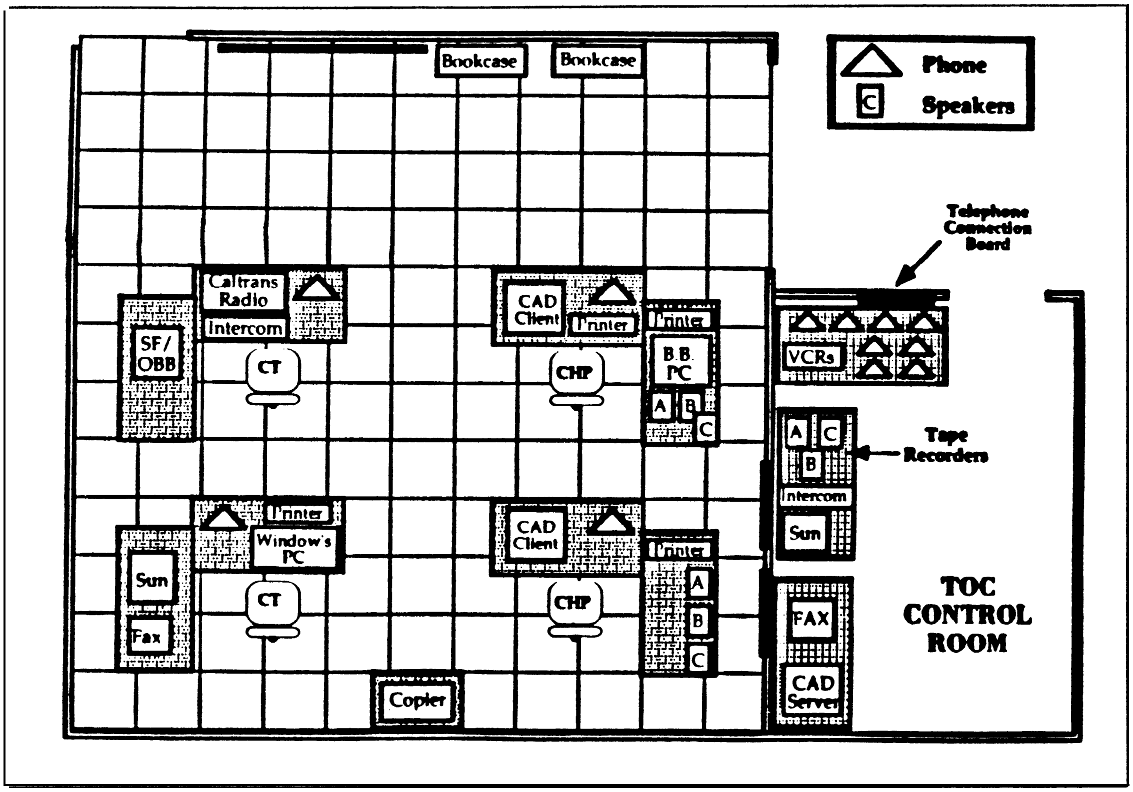


Figure 13. Floor plan of a Cal Poly TOC simulation room.

The management at the IDOT Communications Center **(ComCenter)** at Schaumburg, IL, has formulated a 3-month training program for their operators. The training regime is centered around a series of modules that incorporate booklets with accompanying audio tapes. The training approach utilizes distributed practice over short training sessions and is limited in content coverage to about seven items in a given session. For example, operators must memorize the names of more than 100 roads in the Chicago metropolitan area. In this training module, the operator learns seven road names at a time, continuing with successive modules until the entire Chicago road network is learned. Some content areas are limited to memorization of essential details, such as the dozen of the over 100 radio codes that have been determined to be the most commonly used by the operators. The less commonly used codes are available for ready reference. These simple learning principles applied to training operators have proven effective for the ComCenter's needs. In addition to the training modules, in cooperation with FHWA, other video-based modules are available that provide an overview of the ComCenter's functions and proper management of specific incidents, such as those involving hazardous materials. Simulator time is also part of the training approach for communication operators. Hands-on training is available at a fully functioning console. The console is located in the main communications room, but is separate from the four main stations. The "training" console is used during regular operations to record HAR messages. This console also serves two additional purposes. First, it provides a place for engineers and technicians to monitor system performance. Second, during major incidents, managers and other staff members can use the console as an extension of the regular facilities.

SYSTEMS APPROACH TO TRAINING

In order to ensure that the training program produces operators with the full set of knowledge, skills, and experience necessary to perform their job, a systematic approach to designing and developing the training program must be used. Such approaches, known as systems approach to training (SAT), have long been specified as the approach to developing military training. Most approaches to developing civilian training are less effective because they are not as rigorous.

A detailed analysis of the operator's tasks and activities should be developed as a part of the user-centered TMC design. This analysis can provide a foundation for the selection and training of the operators. Based on the task analysis, the training developer can prepare a highly detailed list of things the operator must know and things they must be able to do.

Personnel with the appropriate combination of knowledge and skills may be obtained through selection, training, or, most likely, a combination of these. After defining the likely level of entry skills the new trainees will have, the training developer can, by subtraction, determine the necessary content of the training program.

Then, the training program is built around the required knowledge and skills. Training modules are specified for each of the required knowledge and skill elements. These modules are then ordered in terms of prerequisite knowledge. For example, the skill in troubleshooting a failing controller (Module B) may depend on first knowing the differences between normal and abnormal controller data (Module A). The instructional medium for each module (e.g., lecture, self-study, videotape, or simulation training) is selected according to expected effectiveness and the medium of adjoining modules. The instructional content of the modules is then developed and tested. Training development is an iterative process. The initial training package must be carefully tested for efficacy, revised, and re-tested until satisfactory results are obtained.

Critical, complex, or infrequently performed tasks described by the task analyses should be documented in a concise, accessible, well-indexed procedures manual.

RECURRENT TRAINING

Nothing in the way of formalized recurrent training programs was seen at any of the sites visited. In general, when a new system is added that changes the operator's functions or procedures, the vendor will supply sufficient training to allow some degree of proficiency. Most centers schedule detailed debriefings at the termination of major incidents so that performance deficiencies can be recognized and rectified as necessary.

As discussed above, Cal Poly is instituting a series of operator training programs, including some on advanced topics for more experienced operators and supervisors, including major incident and disaster management and specialized topics based on the needs of individual TOC's as they are upgraded to IVHS status.

The high degree of automation and computer technology being introduced into traffic management systems should make this an ideal candidate for the use of embedded training, employment of the operational workstation as a training device during periods of low workload. Embedded training has been widely accepted in the military to allow recurrent training in the field. Using the multimedia capability of future graphical workstations, it should be possible to present training lectures, practice realistic scenarios, and receive diagnostic feedback on performance without ever leaving the TMC.

Section 9.
PROCEDURES, DOCUMENTATION, AND JOB AIDS

Nowhere is user-centered design more important than in the "paperware" that is part of the TMC system. There were several distinct trends among the TMC's visited.

Where design was imperfect, there is extensive evidence of practical use of job aids and "home improvements." Although it is possible that some of the design consulting firms who originally developed the facilities had consulted human factors guidelines, the resident design and operations staff were most often unaware of human factors and human-system interface considerations. They typically copy the existing practice (established by the consultant or system vendor), and extend or modify any practice by applying their own knowledge and judgment to the remediation of procedural design flaws and shortcomings of obsolescent systems.

Cost-benefit considerations are typical of the TMC's visited. All the TMC's are severely limited in funds for operational staffs and training, several had experienced recent freezes or cutbacks in their workforce. Some of the TMC's have the capability to automate many of their job aids. There are concerns, however, that moving away from paper-intensive procedures toward a paperless office would be a costly endeavor with little improvement in efficiency.

Nearly all centers visited had detailed, formally prepared procedures manuals. Many of the formally prepared manuals emphasized principles and procedures directed at the traffic or computer engineer. The most usable and readable procedures manuals, though, were prepared by the operators and emphasized the procedures. Several operators reported that they had rewritten system documentation in concise, checklist format so that they could understand the procedures when they were needed. These manuals varied from the use of text-based lists to inventive visually formatted displays of procedures. For example, at one TMC, several operators with military training developed standard operating procedures for some of the more confusing and difficult operations. Figure 14 illustrates the operator-developed procedures.

At this same TMC, the supervisor was uncomfortable with the operator's reliance on exclusively procedure-based instructions because strict procedural lists did not address new and varied problems. Whenever the procedural remedy failed for the operator, the supervisor was called in to solve the problem (sometimes in the middle of the night).

For incident management, response plans for typical incidents were both formalized in the computer system and provided to the operators in flow-chart form as illustrated in figure 15.

SYSTEM MALFUNCTION CHECKLIST

In the event of a system malfunction, the existing conditions need to be noted to facilitate the understanding and reparation of the problem. A checklist follows which should be utilized when a system problem is encountered and prior to corrective action being taken. This may not be possible or even convenient but every bit of information helps in diagnosing the problem.

1. Does traffic control panel work?, i.e.
   (a) Can you request reports?
   (b) Is the computer malfunction indicator "on"?

2. Are any routines paused?
   (a) Check VCF
   (b) Display Map: D M
   (c) Verify system volume: V

3. Are any peripherals offline?
   (a) line printer (LP600)
   (b) log printer (DECWRITER)
   (c) disk (DSC3:)
   (d) CRT

4. Are any error messages displayed?
   (a) Check VCF
   (b) Check log printer

Note: Record error messages before clearing display

5. Are both CCU's polling the street equipment?
   (a) SDNEX (left communication cabinet)
   (b) WINKOMATIC (right communication cabinet)

Note: The LED's should be blinking once per second

Figure 14. Example of a procedural checklist developed by TMC operators.

Traffic incidents are most commonly unexpected events. Effective incident-related job aids are brief in presentation and contain only the essential details. At one TMC, operators and management have jointly designed some excellent lists and forms. Two examples are presented in figures 16 and 17.

Notice that these forms not only include the essential details for each incident type, but also contain the approval chain and appropriate distribution list for the completed forms.

Good help systems are rare. None of the software systems we examined had good HELP systems. Those that did exist were often written with arcane traffic engineering or computer jargon that would be difficult to interpret by the average operator with little education beyond high school.

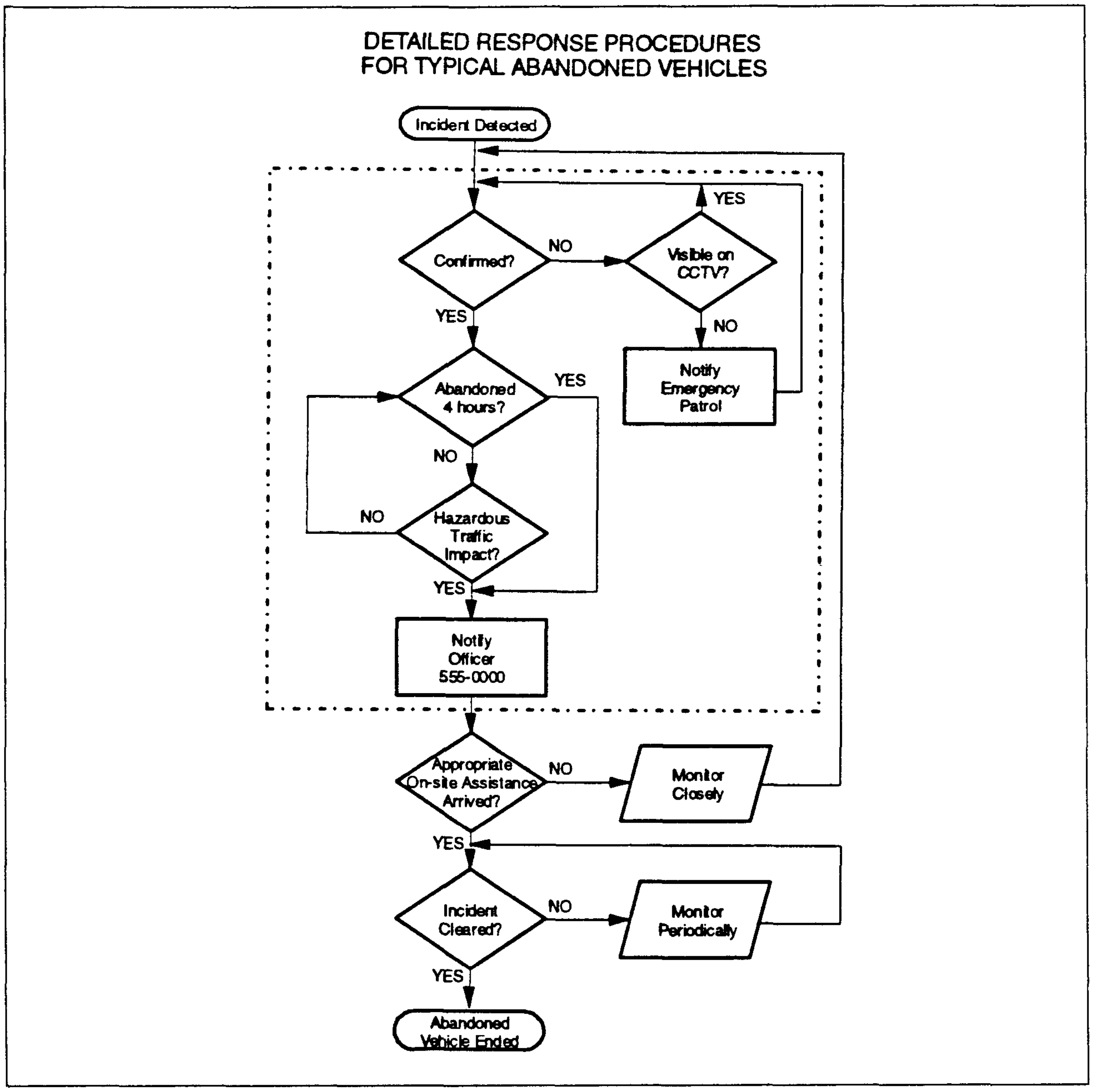


Figure 15. Example of a flow chart for a detailed response plan.

Incidents which require but are not limited to Springfield notification are: ALL FULL CLOSURES, ALL FATALITIES, ACTIVATION OF POPEYE (RC 921), NUCLEAR DISATERS & DRILLS, SCHOOL BUS ACCIDENTS, RAILROAD ACCIDENTS ON STATE ROADS, CONSTRUCTION ACCIEDENTS WITH SERIOUS INJURY OR FATALITY....If you are unsure of any type of call-out notification on an incident, call your supervisor to determine the next step.

• ONLY PROCEED FURTHER IF UNABLE TO CONTACT ANY OF ABOVE PERSONNEL
•• NOTIFY BETWEEN THE HOURS OF 7AM AND 10PM - 7 DAYS A WEEK

NOTIFICATION/CALLOUT CHECKLIST

EXPRESSWAY MAJOR INCIDENT

ETP MANAGER (SMITH)	( )
MAINTENANCE (IF APPLICABLE)	( )
PUBLIC - HAR PROGRAMMED	( )
MEDIA - CRT PROGRAMMED	( )
MOTORISTS - CMS PROGRAMMED	( )
PUBLIC - DOT-INFO PROGRAMMED	( )
SPRINGFIELD STATION ONE	( )
COMMUNICATIONS SUPERVISOR	( )
MORE THAN 1 HOUR OR FULL CLOSURE CONTINUE	
•• MAINT. AREA OPERATIONS ENGINEER	( )
•• DISTRICT MAINTENANCE ENGR. (J.KOS)	( )
•• EXPY TRAFFIC CONTROL SUP. (SCHMIDT)	( )
•• EXPY TRAFFIC OPER. ENGR. (JONAK)	( )
•• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )

UNAUTHORIZED LANE CLOSURES EXPRESSWAYS ONLY

CHECK 24 HOUR LANE CLOSURE BOOK	( )
• EXPY TRAFFIC CONTROL SUP. (SCHMIDT)	( )
• EXPY TRAFFIC FIELD ENGR. (ANGELOS)	( )
• EXPY TRAFFIC OPERATIONS ENGR. (JONAK)	( )
• DISTRICT TRAFFIC ENGINEER (MCDERMOTT)	( )
• DIST. TRAFFIC & MAINT. (KLAFETA)	( )
• COMMUNICATIONS SUPERVISOR	( )
• COMMUNICATIONS MANAGER (KOZIOL)	( )
• COMMUNICATIONS SECTION CHIEF (BRADLEY)	( )
• DISTRICT ENGINEER (CARLSON)	( )

CONSTRUCTION/ EXPRESSWAY ONLY

ETP FOREMAN ON DUTY	( )
BARRICADE CONTRACTOR (SIGN/BARRICADES)	( )
CONTRACTOR	( )
••RESIDENT ENGINEER	( )
••PROJECT ENGINEER	( )
• EXPY TRAFFIC CONTROL SUPERVISOR (SCHMIDT)	( )
• EXPY TRAFFIC OPERATIONS ENGR. (JONAK)	( )
• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )

FATALITIES

STATION ONE	( )
COMMUNICATIONS SUPERVISOR	( )
ETP MANAGER (SMITH) (EXPY ONLY)	( )
••EXPY TRAFFIC CNTRL SUP.(SCHMIDT - EXPY ONLY)	( )
••EXPY TRAFFIC OPERATIONS ENGR(JONAK-EXPY ONLY)	( )
••DIST. TRAFFIC & MAINT. MGR. (KLAFETA)	( )

HAZARDOUS MATERIAL INCIDENTS

ETP FOREMAN ON DUTY (EXPY ONLY)	( )
ETP MANAGER (SMITH) (EXPY ONLY)	( )
MAINTENANCE CALL OUT (IF APPLICABLE)	( )
STATION ONE	( )
MAINTENANCE YARD TECH/ENGR. (IF APPLICABLE)	( )
MAINT. OPERATIONS ENGR. (IF APPLICABLE)	( )
ARTERIAL TRAFFIC FIELD ENGR. (RAMMACHER)	( )
COMMUNICATIONS SUPERVISOR	( )
•• DISTRICT MAINTENANCE ENGR. (J.KOS)	( )
•• DISTRICT TRAFFIC ENGINEER (MCDERMOTT)	( )
•• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )
•• EXPY TRAFFIC OP. ENGR. "EXPY ONLY" (JONAK)	( )

OVERHEAD SIGN DAMAGE

APPLICABLE SIGN SHOP CALL OUT UNDER GLASS	( )
ELECTRICAL CONTRACTOR	( )
ETP MANAGER (SMITH) (EXPY ONLY)	( )
BRIDGE CALL OUT (IF ON BRIDGE)	( )
EXPY TRAFFIC FIELD ENGR. (ANGELOS)	( )
• EXPY TRAFFIC CONTROL SUPERVISOR (SCHMIDT)	( )
• EXPY TRAFFIC OPERATIONS ENGR. (JONAK)	( )

EMERGENCY TRAFFIC PATROL

ROAD FOREMAN	( )
ETP MANAGER (SMITH)	( )
•• EXPY TRAFFIC OPERATIONS ENGR. (JONAK)	( )
•• DISTRICT TRAFFIC ENGR. (MCDERMOTT)	( )
•• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )

ARTERIAL MAJOR INCIDENT

MAINTENANCE CALL OUT (IF APPLICABLE)	( )
MAINT. YARD TECH/ENGR. (IF APPLICABLE)	( )
MAINT. OPER. ENGR. (IF APPLICABLE)	( )
ETP FOREMAN (ON DUTY)	( )
MEDIA - CRT PROGRAMMED	( )
PUBLIC - DOT-INFO PROGRAMMED	( )
STATION ONE	( )
ARTERIAL TRAFFIC AREA ENGINEER (UNDER GLASS)	( )
• ARTERIAL TRAFFIC FIELD ENGINEER (RAMMACHER)	( )
• TRAFFIC OPERATIONS ENGR. (EVERS)	( )
(NOTIFY RAMMACHER OR EVERS DURING OFFICE HOURS OR IF THE AREA ENGINEER CANNOT BE REACHED)	
•• DISTRICT TRAFFIC ENGR. (MCDERMOTT)	( )
•• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )
•• DISTRICT MAINTENANCE ENGR. (J.KOS)	( )

TRAFFIC SIGNAL

ELECTRICAL CONTRACTOR (SEE CRT)	( )
• TRAFFIC SIGNAL/CONSTRUCTION BOOK/SHEET	( )
• TRAFFIC SIGNAL CALL-OUT (UNDER GLASS)	( )
• TRAFFIC SIGNAL ENGINEER (SCHWARZ)	( )

STOP SIGN KNOCKDOWNS

SIGN SHOP CALL-OUT SHEET (UNDER GLASS)	( )
• SIGN SHOP MANAGER (SLADEK)	( )
• TRAFFIC OPERATIONS ENGINEER (EVERS)	( )
• DISTRICT TRAFFIC ENGINEER (MCDERMOTT)	( )
• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )

PERMIT/UTILITY CALL-OUT

PERMIT CALL-OUT (UNDER GLASS)	( )
• UTILITY ENGR SUP.(HOLTZ - OFFICE HRS ONLY)	( )
• DISTRICT PERMIT ENGINEER (EHART)	( )
• DISTRICT TRAFFIC ENGINEER (MCDERMOTT)	( )
• DIST. TRAFFIC & MAINT.MGR. (KLAFETA)	( )

CONSTRUCTION/ARTERIAL

BARRICADE CONTRACTOR (SIGNS/BARRICADES)	( )
CONTRACTOR	( )
• RESIDENT ENGINEER	( )
• PROJECT ENGINEER	( )
• ARTERIAL TRAFFIC CONTROL SUP. (OBERLE)	( )
• TRAFFIC OPERATIONS ENGINEER (EVERS)	( )
• DISTRICT TRAFFIC ENGINEER (MCDERMOTT)	( )
• DIST. TRAFFIF & MAINT. MGR (KLAFETA)	( )
MAJOR INCIDENT ONLY - CONTINUE	
ARTERIAL TRAFFIC CONTROL ENGINEER (OBERLE)	( )
RESIDENT ENGINEER	( )

MAINTENANCE

MAINTENANCE CALL-OUT SHEET UNDER GLASS	( )
MAINTENANCE YARD TECH/ENGR.	( )
• MAINTENANCE AREA OPERATIONS ENGINEER	( )
•• DISTRICT MAINTENANCE ENGR. (J.KOS)	( )
• ADJACENT YARD CALL-OUT	( )
• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )

BRIDGE INCIDENTS

BRIDGE CALL-OUT UNDER GLASS	( )
• DISTRICT BRIDGE ENGINEER (KRAWARZ)	( )
• MAINTENANCE AREA OPERATIONS ENGINEER	( )
•• DISTRICT MAINTENANCE ENGR. (J.KOS)	( )
• DIST. TRAFFIC & MAINT. MGR (KLAFETA)	( )

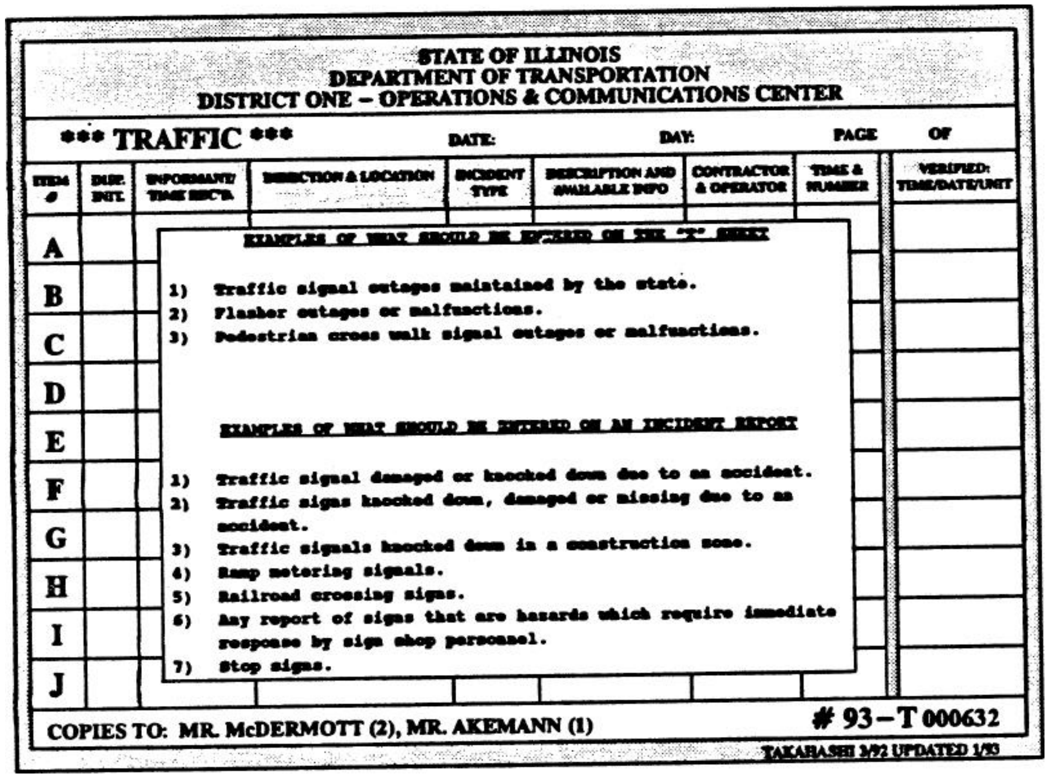
CENTER COURT CALL-OUT (BUILDING)

BUSINESS SERVICES MANAGER (RYDER)	( )
• ADMINISTRATION SUPPORT MANAGER (SMITH)	( )
• COMMUNICATIONS SUPERVISOR	( )
• ADMINISTRATION MANAGER (FONDA)	( )
• DISTRICT ENGINEER (CARLSON)	( )

ELECTRICAL - HIGHWAY LIGHTING

ELECTRICAL CONTRACTOR	( )
• RESIDENT ENG. (IF CONSTRUCTION PROJECT)	( )
• ELECTRICAL MAINTENANCE ENGINEER (MURPHY)	( )
• ELECTRICAL OPERATIONS ENGINEER (SABOURIN)	( )

Figure 16. Example of a traffic incident checklist.



STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION
DISTRICT ONE – OPERATIONS & COMMUNICATIONS CENTER

*** TRAFFIC *** DATE: DAY: PAGE OF

ITEM #	DISP. INIT.	INFORMANT/ TIME REC'D.	DIRECTION & LOCATION	INCIDENT TYPE	DESCRIPTION AND AVAILABLE INFO	CONTRACTOR & OPERATOR	TIME & NUMBER	VERIFIED: TIME/DATE/UNIT
A								
B								
C								
D								
E								
F								
G								
H								
I								
J								

EXAMPLES OF WHAT SHOULD BE ENTERED ON THE "T" SHEET

1) Traffic signal outages maintained by the state.
2) Flasher outages or malfunctions.
3) Pedestrian cross walk signal outages or malfunctions.

EXAMPLES OF WHAT SHOULD BE ENTERED ON AN INCIDENT REPORT

1) Traffic signal damaged or knocked down due to an accident.
2) Traffic signs knocked down, damaged or missing due to an accident.
3) Traffic signals knocked down in a construction zone.
4) Ramp metering signals.
5) Railroad crossing signs.
6) Any report of signs that are hazards which require immediate response by sign shop personnel.
7) Stop signs.

COPIES TO: MR. McDERMOTT (2), MR. AKEMANN (1) # 93–T 000632

TAKAHASHI 3/92 UPDATED 1/93

Figure 17. Example of an incident report form.

CCTV control requires complex procedural job aids. Figures 18 through 20 illustrate three general problem areas encountered in the control of CCTV cameras: (1) selection of camera through non-intuitive mapping of camera location and identification number [figure 18]; (2) camera display on monitors that have multiple modes (full screen or quadrant display) [figure 19]; and (3) camera display on a matrix of monitors where an individual camera image may be shifted periodically (especially when there are more cameras than display monitors) [figure 20].

SOUTH STATION CAMERA I.D. NUMBERS

T.H. 62		
43RD AVE.	111 N	
28TH AVE.	112 S	(1D2)
BLOOMINGTON AVE.	113 N	(1D3)
PORTLAND AVE.	114 S	(1D4,5C1)
XERXES AVE.	115 N	(1B4,1E4)
FRANCE AVE.	116 S	(1B3,1E5)
T.H. 100.	117 N	(1B2,1F2)
TRACY AVE.	118 S	(1A8,1F3)
GLEASON RD.	119 S	(1A7,1F4)
T.H. 169.	120 S	(1A5,1A6)
SHADY OAK RD.	121 N	(1A1,1A2)
T.H. 100		
66TH ST.	210 W	(2A2,2H4)
BENTON AVE.	212 W	(2A4,2A5)
50TH ST.	213 W	(2A7,2H1)
T.H. 212		
VALLEY VIEW RD.	320 N	(1A3)
SHADY OAK RD.	321 W	(1A4,1G1)
T.H. 169		
VALLEY VIEW RD.	322 W	(3A1,3H1)
BREN RD.	324 W	(3A4,3G7)
7TH ST.	325 W	(3B1,3G6)
T.H. 7.	326 E	(3B3,3G3)
MINNETONKA BLVD.	327 W	(3B5,3G2)
CEDAR LK.	328 E	(3B6,3G1)
T.H. 5		
AIRPORT RD.	416 M	
T.H. 77		
OLD SHAKOPEE RD.	510 W	(5D5,5B1)
KILLEBREW DR.	511 W	(5D1)
66TH ST.	512 E	(5B4,5C2)
I-494		
T.H. 5.	417 S	(4G1)
24TH AVE.	418 N	(4F1,4G2)
T.H. 77	419 N	(4G4,5B2)
12TH AVE.	420 S	(4E6,4G6)
LYNDALE AVE.	421 S	(4E4,4G8)
PENN AVE.	422 N	(4E1,4H2)
FRANCE AVE.	423 S	(4D4,4H4)
T.H. 100.	424 S	(4D2,4H5)
E. BUSH LAKE RD.	425 S	(4D1,4H6)
W. BUSH LAKE RD.	426 N	
T.H. 169.	427 S	(4I1)
FLYING CLOUD DR.	428 S	(4C3,4I2)
VALLEY VIEW RD.	429 W	(4C2,4I3)
T.H. 62	430 W	(4C1,4J1)
BAKER RD.	431 W	
T.H. 7.	433 W	(4B5,4J2)
MINNETONKA BLVD.	434 E	(4B3,4J4)
STONE RD.	435 W	(4B3,4J4)
I-35W		
110TH ST.	610 W	(6B1,6N9)
98TH ST.	611 E	(6B2,6N8)
94TH ST.	612 W	(6B3,6N7)
86TH ST.	613 W	
76TH ST.	614 W	(6C1,6C2)
66TH ST.	615 E	(6C3,6N2)
T.H. 121.	616 S	(1E2,6N1)
LYNDALE AVE.	617 S	(6D1)
PORTLAND AVE.	618 S	(1D4,6D2)
55TH ST.	619 W	(6D3,6M7)
50TH ST.	620 W	(6D4,6M6)
42ND ST.	621 W	(6D4,6M5)
35TH ST.	622 W	(6D5,6M4)
LAKE ST.	623 W	(6M4)
26TH ST.	624 E	

Figure 18. Camera-related job aids: location-camera number lookup.

CAMERA CONTROL INSTRUCTIONS 2/3/92

- TO VIEW SINGLE SCREEN:
  <MON>
  \# (# = 2)
  <MON>
  \# (# OF DESIRED CAMERA: 1-1B)
  <CAM>

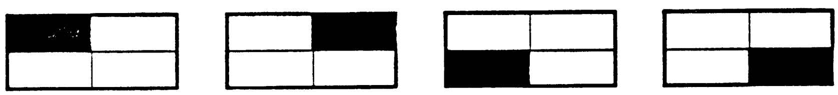
(THE KEYPAD DISPLAY WILL SHOW **MON1**, CAM #)

- TO SEQUENCE CAMERAS, FROM THIS POINT PUSH
  <SEQ>

(THE KEYPAD DISPLAY WILL SHOW **MON5**, CAM # WILL SEQUENCE FROM 1 TO 18).

- TO GET FULL SCREEN DISPLAY, PUSH CORRESPONDING QUADRANT BUTTON (SCREEN SELECT) ON APPROPRIATE QUAD UNIT (LOCATED BEHIND MAPS).

CHOOSE:



A B C D

- TO RETURN TO QUAD DISPLAY, PUSH BUTTON ON FAR LEFT OF APPROPRIATE UNIT. (QUAD).

Figure 19. Camera-related job aids: camera-control instructions.

SOUTH STATION PEAK PERIOD CAMERA PATTERN

THE FOLLOWING LAYOUTS FOR MONITORS 25 - 48 ARE TO BE USED DURING THE AM PEAK PERIOD. USE THE FOLLOWING COMMANDS TO SET THE CAMERAS INTO SALVO.

A.M. PEAK PERIOD:

25 [MON] 5 [RUN] [ACK] [HOLD]

29 [MON] 13 [RUN] [ACK]

320	421	422	833	834 320 121	624 321 120
623 435 119	622 434 118	621 433 117	620 431 116	619 430 115	618 429 114
617 428 113	616 427 112	615 426 111	614 425 213	613 424 212	612 423 210
611 422 328	610 421 327	512 420 326	511 419 325	510 418 324	416 417 322

P.M. PEAK PERIOD:

25 [MON] 6 [RUN] [ACK] [HOLD]

29 [MON] 13 [RUN] [ACK]

320	421	422	833	834 320 121	624 321 120
623 435 119	622 434 118	621 433 117	620 431 116	619 430 115	618 429 114
617 428 113	616 427 112	615 426 111	614 425 213	613 424 212	612 423 210
611 422 328	610 421 327	512 420 326	511 419 325	510 418 324	416 417 322

Figure 20. Camera-related job aids: camera pattern-CCW monitor layout.

LEADING-EDGE TRENDS

Effective job aids can support teamwork and can integrate center activities. Figure 21 illustrates a documentation carousel at a communications center of **a** TMC. Designed jointly by the staff, the carousel allows the same forms and reference materials to be easily shared among all the operators. The carousel can be turned from any operator's workstation, with compartments on the side for all of the routine forms used in the center. Under the Plexiglas top, the carousel contains the detail maps and references for common referral. The currently active incident forms are placed on the carousel for other operators to access and elaborate as events unfold.

A well-written, on-line help system can also eliminate many errors. However, such on-line-based systems were never observed. This is a byproduct of the observation that no TMC visited had conducted any systematic analysis of error sources. Each of the centers visited would benefit from more attention to the potential for human error and measures that might be used to reduce that potential. At most, operators employed user aids (such as terse notes and stick-on post-its) to treat error sources at the most obvious levels. Managers tended to see error in machine terms, such as a faulty system output, rather than as human mistakes. **Any system can be designed for good on-line help to address human errors with the assistance of human factors guidelines.** The growing trend in the use of relatively inexpensive personal computers in the workstations of TMC's provides ready access to adequate development tools for the easy development of such help systems.

Figure 21. Illustration of a documentation carousel.

Workstations should be designed with spaces reserved for operator-designed job aids. Operators frequently have a need to post miscellaneous pieces of information for their later use. This may be an informal reminder to perform a task, a list of commonly used telephone numbers, a list of communication 10-codes, or other such data. These notes may be temporarily posted using pads of commercially available sticky-backed paper or may be more permanently applied by taping on neatly typed notes. Operator-designed stick-on job aids were extremely common at all TMC's as illustrated in figures 22 and 23. The use of such homemade labels should be viewed as an indication of weaknesses in TMC workstation and documentation design. TMC management should explore means of eliminating the need for informal labels, including modification of procedures, control devices, computer screens, or documentation. Where a real need for the information is identified, durable labels in a standardized format should be considered.

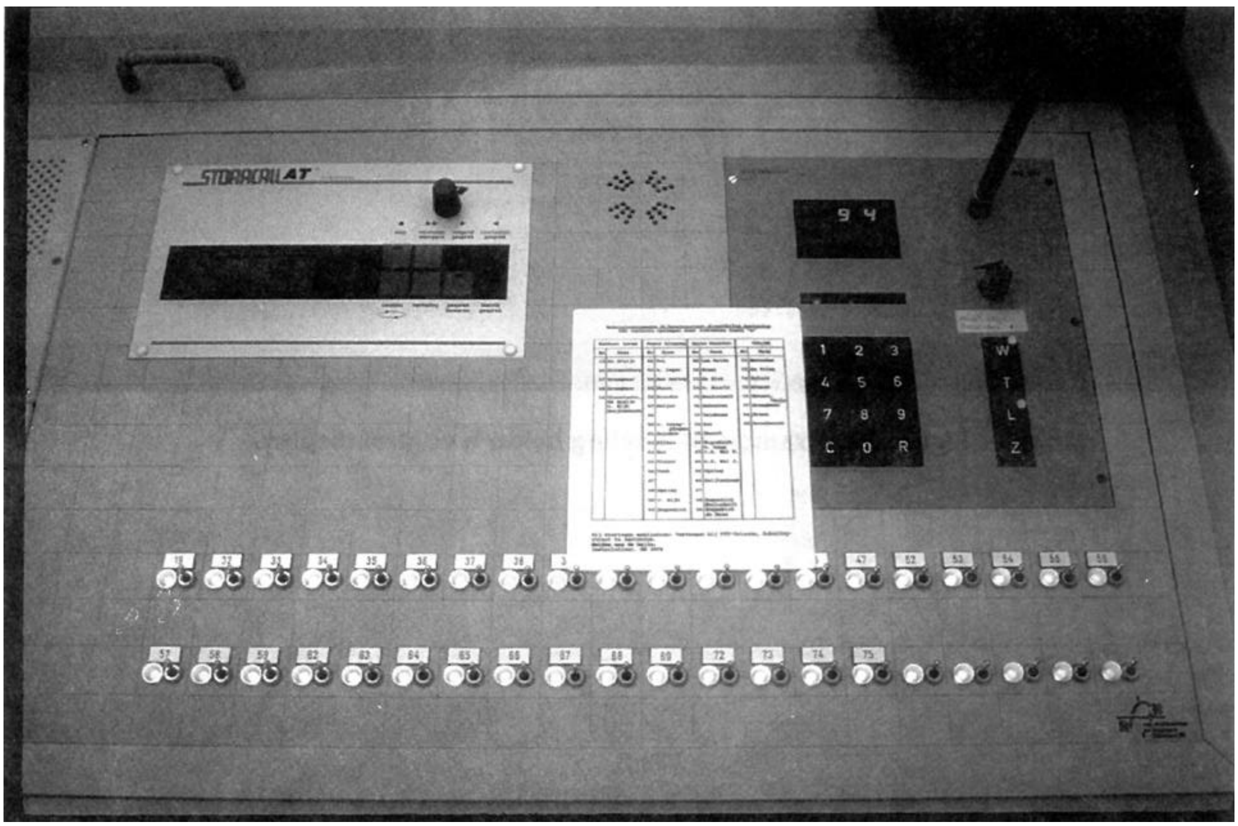


Figure 22. Example of labeling on the control panel.

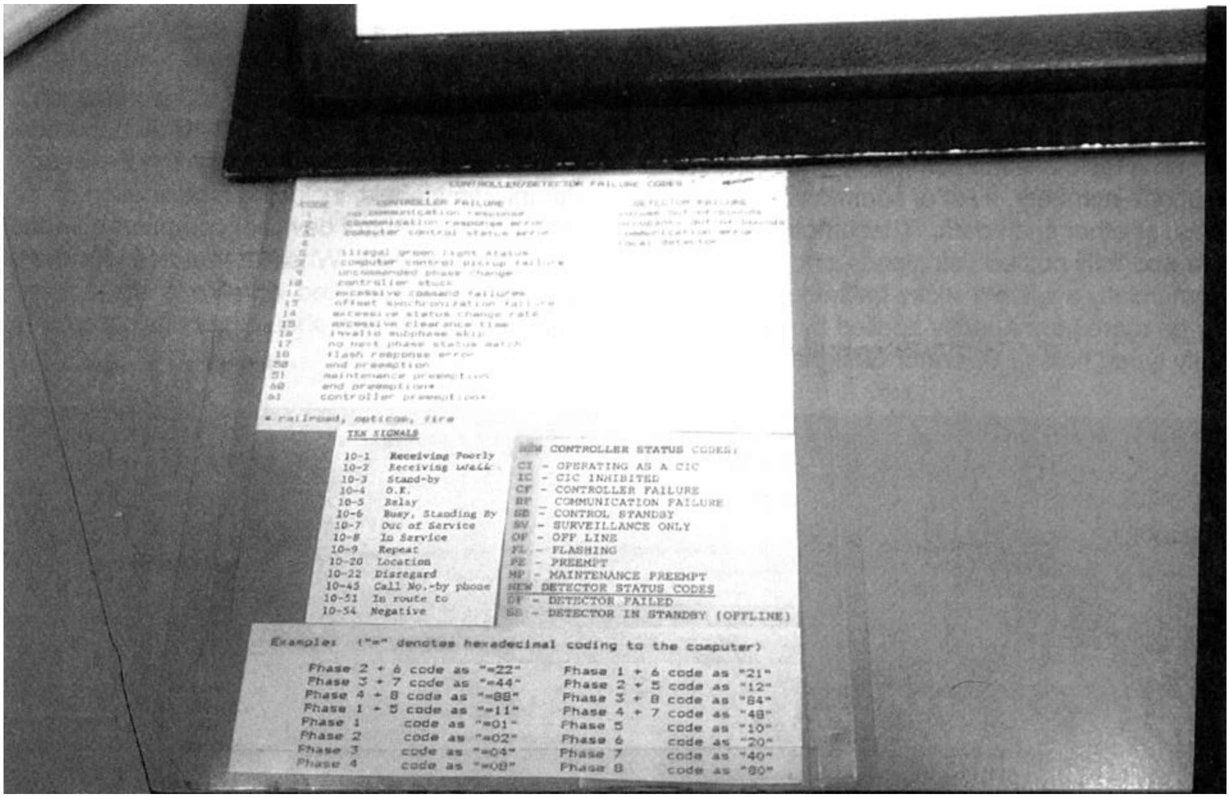


Figure 23. Example of labeling below a control display.

Section 10.
OTHER DESIGN AND PRIVACY ISSUES

This report has demonstrated the importance of the human operator in efficient operation of the TMC. Centers and systems must be designed to aid the operator in performance of the allocated tasks. The movement toward automation only emphasizes the challenge of human factors design.

Of the centers studied, only one center was largely designed by an ergonomics consultant. The full user-centered design process was successfully employed. A few centers are using local university consultants and some seek inputs from existing operators. In most centers, however, designs are simply evolutions of the architects' previous work and are likely to include many of the previous mistakes. None of the centers we visited was familiar with any use of human factors design documents in their design.

The process used to design a complex system like a TMC can be classified as either **requirements-oriented design** or **technology-oriented design.** The most efficient method of designing a TMC is a **requirements-oriented** and **user-centered** design process. The requirements-oriented design process carefully analyzes the objectives and performance requirements of the TMC. Once all of the requirements have been documented, a trade study of available technologies is performed and the best, and most integrated, approach to meeting those requirements is determined. In technology-oriented design, a particular technology suite that is favored by the designer becomes the centerpiece of the design process and the TMC's objectives are built around it.

One mistake frequently made by TMC designers, or by agencies soliciting TMC design and development, is to define specific configuration items too early in the engineering analysis process. **Technology-oriented design** often neglects one or more of the critical operational or functional requirements, resulting in sub-optimal achievement of the overall system objectives. At best, technology-oriented design neglects to perform full tradeoff studies of the available ways of meeting the objectives, often ignoring new or not widely known approaches.

Vendors suggest that solicitations for TMC development should provide detailed functional requirements and allow potential contractors to suggest how the requirements might be met. This approach would encourage vendors to provide innovative system architectures and user interfaces, keyed to each TMC's unique requirements, rather than trying to make old solutions fit new requirements.

User-centered design brings in the operators very early in the design process. While requirements analyses for the configuration items are being conducted, requirements analyses for the operator's performance and tasks are also conducted. User-centered design is an iterative process, beginning during the requirements definition phase, in which user comments are incorporated into the design of the user-system interface. The new interface is tested by the users and, based on results and comments, refinements are made. The process continues until a stable design is reached.

User-centered design was effectively applied in a remodeled European control center. A design consultant performed requirements, function, and task analyses using interviews with the operators, procedures manuals, and job aids. Based on these analyses, three candidate mockups of the new control room were prepared. Operators selected their favorite and then worked with the designer to refine the design. Based on our observations, a very functional center was the result (see figure 24). The workstation design placed all required displays, controls, and communication devices on an arc with the operator at the center. The infrequently used CCTV monitors were mounted high on a wall, within view of all four workstations. Innovative, fully integrated displays, using extensive color coding, could inform operators aware of system problems with a brief glance.

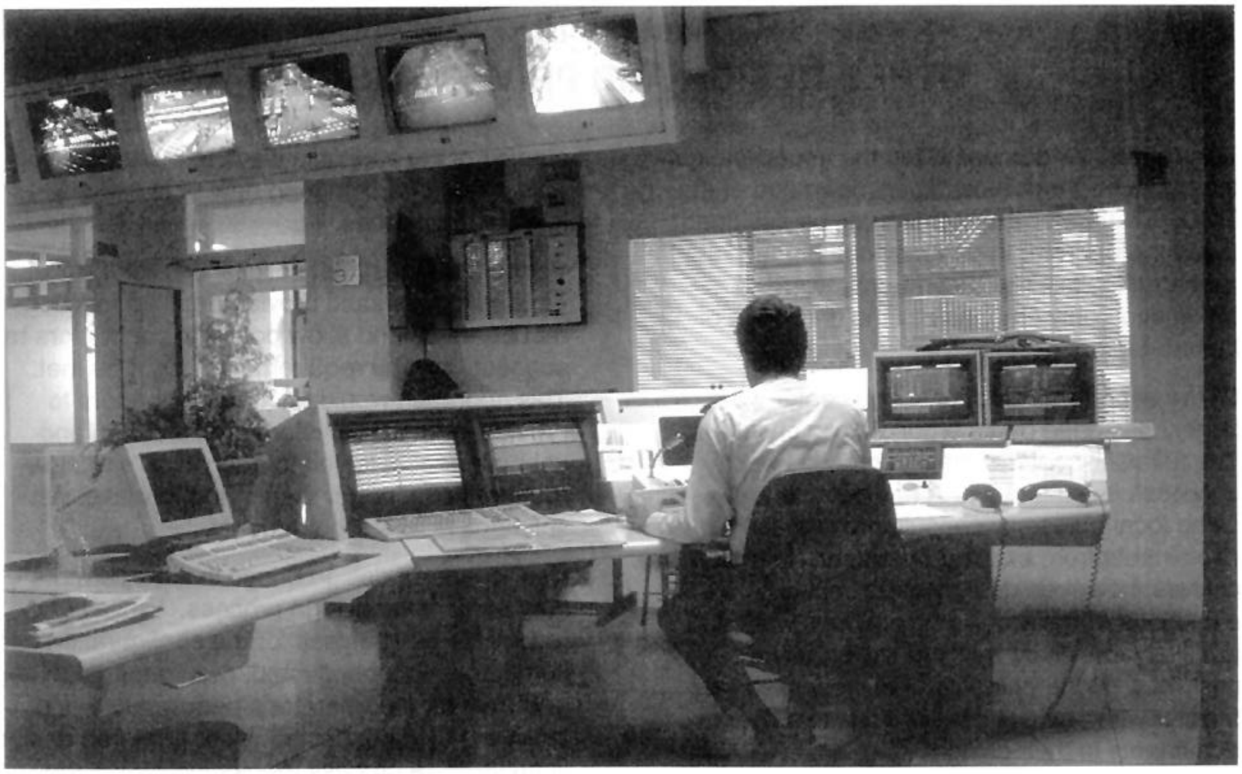


Figure 24. Example of a control room developed using a user-centered design process.

Figure 25. Example of a monitor located above the operator's seated line of regard.

ERGONOMICS IN CENTER DESIGN

Many centers have relatively poor ergonomic design of workstations and systems. These can contribute to operator stress. At one center, for example, there were consistent complaints of neck pain. Inspection revealed that one of the primary graphics monitors was located substantially above the operators' seated line of regard (see figure 254, creating stress on the operators' neck muscles. At many of the centers, operators had to look over consoles, monitors, and other equipment to view monitors on the wall. In many cases, a bottom row of monitors was not fully visible from a seated position.

Glare is one of the most common problems with video display terminal (VDT) workstations. There are numerous ways of attacking this problem, including glare shields between VDT's and light sources; covering of light sources, including windows; and depending on task lighting. A major percentage of the centers did little to address the glare problem (see figure **26).**

Console work surfaces were generally at an appropriate height for average-sized operators, but there was no adjustability. One short-statured operator had to raise his chair seat to the top of its adjustability in order to work effectively and see over the console. This left his feet dangling, a common cause of leg discomfort. A footrest should have been available for this operator.

PRIVACY ISSUES

The sensors and information processing equipment available in the IVHS-era TMC provide unprecedented opportunities for invading the privacy of individual drivers and other citizens. It would be feasible, using GPS and cellular phone technology, to track an individual driver from trip origin to trip destination, including any stops for errands. It would be possible to calculate each driver's speed along the route. All this information could be recorded and archived for later use.

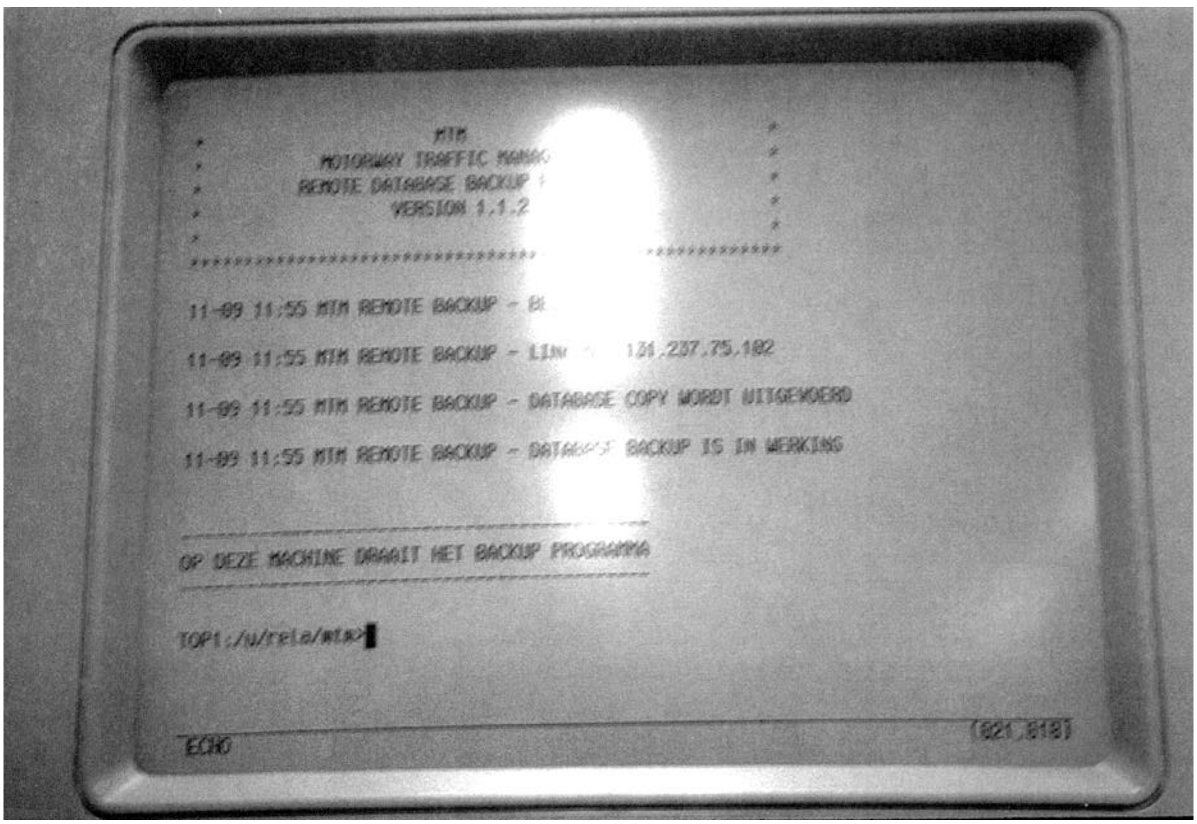


Figure 26. Example of glare on a VDT.

Such a data base of origin and destination (O-D) would be very useful to help predict congestion if many drivers were found to be converging on a particular destination (perhaps for a special event). However, the data base could be misused by police departments to automate the issuance of speeding citations.

Managers also expressed concern that an O-D data base would be subject to frequent subpoena by attorneys wanting to show the routes and stops of citizens involved in divorce cases or other litigation. For these reasons, system developers are hesitant to collect and utilize O-D data in central data processing and storage.

The large batteries of CCTV cameras, with their high magnification zoom capabilities, provide another opportunity for privacy invasion. Several jurisdictions have already faced the dilemma of operators using the cameras for non-highway-related activities. Metal masks mounted around the cameras now limit the CCTV field of view. This solution both serves as a deterrent to unauthorized use and provides visible proof to the public that their privacy has been restored.

A more serious dilemma is presented when privacy is invaded on the roadway itself. What, for example, is the proper TMC response when a crime is seen taking place on the highway shoulder? Should a tape be made of the incident? Should police be called? Should a close-up view of the incident be taped, including vehicle license numbers and faces of assailants and victims? Are such tapes considered to be public records available to the media? Do the appropriate answers depend on whether the operator is also a police officer? These thorny issues are now being addressed by some of the pioneering TMC’s.

Section 11 .

DESIGN CONSIDERATIONS BASED ON COMPARABLE SYSTEMS ANALYSIS

The lessons learned from the comparable systems analysis lead to a number of tentative conclusions about the human factors of TMC design and operation. Some of these conclusions are based on existing human factors design standards, the importance of which were underscored during site visits. Other conclusions are more specific to the TMC and were reached on the basis of successes and failures reported by TMC personnel. Finally, some conclusions were reached by investigators based on their training and experience. These lessons are briefly summarized here in the form of provisional design considerations.

USER-CENTERED DESIGN

Formal human factors inputs into TMC design can enhance the efficiency of the center (section 10)

User-centered design in the modernization of an older center may be especially important because it serves to enroll existing operators in the design of the new center, thereby reducing any operator resistance (section 6).

The users (operators) should be involved in defining the content of specific TMC displays to ensure that unneeded display screens are not incorporated (section 3).

Consoles should be designed to accommodate the extreme ranges of staffing levels. If a single operator is on duty during the night shift, for example, one single workstation combining all of that operator's anticipated functions should be available (section 3).

Operator self-labeling of workstations provides clues to human factors design problems in the original designs (section 9).

High-granularity data in a geographic information system need to be fused to be of use to the operator. The operator should have some control of the degree of fusing that is performed before display (section 3).

Allocation of tasks between operator and computer should remain flexible until the impact of the allocation is tested. Some automation schemes, for example, may actually result in unexpected increases in operator workload (section 3).

Informal procedures and communication methods developed by operators to simplify their jobs should be considered and, where possible, kept in place during TMC upgrade and remodeling (section 4).

Use of prototypes and control-room models that can be altered by operators appears to be a useful approach to user-centered redesign of a center (section 4).

Early use of computer rapid prototyping packages to design and redesign display screens can prevent many costly human factors problems from appearing late in the implementation cycle (section 7).

Procedures manuals, written in the language of the operator (not the traffic engineer or software developer) are an important element in TMC operation (section 9).

STAFFING

Centers whose functions include significant interaction with police officers in the field should consider including a police liaison officer on their staff (section 3).

Minimum qualifications for a TMC operator are good verbal skills, good reasoning skills, a working knowledge of the roadway system, and some degree of computer literacy (section 8).

Initial operator training is typically on-the-job (section 8).

MANAGEMENT

Where two or more TMC's share geography and resources, staff members at each TMC need to be fully aware of the capabilities, limitations, and procedures of the other (section 3).

The effectiveness of the TMC in meeting its goals is strongly impacted by the compliance level of the public (section 3).

The TMC must continuously ensure that it maintains the trust of the public (section 3).

When two or more software systems are meant to be used together, it is important to ensure that they run on compatible platforms and have a common user interface. A significant penalty in operator workload and error rate results from the use of redundant workstations and procedures for closely related functions (section 3)

IVHS technology provides unique hazards for invasion of privacy. Center managers must identify and address these issues (section IO).

Centers should be designed with future evolution in mind, including sufficient spare floor space for potential expansions (section 6).

In centers for which special events represent the major source of traffic variation, regularly scheduled meetings of major traffic generators are helpful in developing and coordinating traffic and parking management plans (section 3).

In selecting message suites for VMS installations, focus groups of typical drivers may be used to define the "meanings" of candidate words and messages (section 5).

AUTOMATION

Older practices of assigning tasks between humans and automated systems using simple lists comparing capabilities are not effective with complex systems like TMC's. A hybrid automation function allocation approach is necessary (section 5).

Allocations of function should not be unchanging; they should be changeable by either operator initiative or computer initiative in response to changing situations, workload, or operator performance (section 5).

Automated systems should keep the operator "in the loop" and, at a minimum, report the next major action (something that would take substantial time to undo) and allow the operator to veto it (section 5).

Impleme ntation of automation should be a gradual, iterative process, proceeding to the next step only when it approaches full reliability on the previous step (section 5).

USER-SYSTEM INTERFACES

Big board displays are primarily of use in public relations in smaller centers. In larger centers, they may assist communication and coordination between operators (section 7).

Static wall maps are the least useful type of big board display. Dynamic wall maps using LED boards or computer-generated images can provide more useful data (section 7).

Projection television should not be used when small, very precise text or symbols must be read (section 7).

Maintaining operator awareness of the direction in which the camera is pointed is difficult, especially at night when many landmarks are not visible (section 7).

In some situations, two or more operators may be competing for control of the same camera or monitor. Methods of prioritization need to be established (section 7).

Operators must be made aware of VMS signs whose content is no longer appropriate (section 7)

For automated voice messages, whether sampled or synthetic, the "speaker" should remain consistent in gender and other voice qualities to avoid distraction (section 3).

Use of gender change to draw attention to an important voice message, or coding of message type by gender, however, may be a useful approach (section 3).

An effective "help" system in TMC software would reduce error potential (section 9).

Vocabulary limitations on VMS sign content can restrict the usefulness of the message boards (section 5).

Operators should not be prevented from taking an action that the computer considers unacceptable; neither should such actions be made easy for them (section 5).

Error traps should be used in system command software to prevent catastrophic errors. (section 7)

Operators, by preference, will monitor traffic using color closed-circuit television systems rather than well-designed support systems with graphical user interfaces when both are available. This preference may result in high visual workload (section 3).

In architectures in which support systems use sensor data to detect congestion or incidents, it is not necessary to activate the CCTV cameras and monitors until a problem is identified. This approach, though, has a relatively high false alarm rate and incidents are not detectable as early as with CCTV's alone (section 7).

Various levels of data fusion may be appropriate for different tasks. The operator should have control over the degree of data granularity (section 7).

ENVIRONMENTAL AND ERGONOMIC CONSIDERATIONS

Centers that require significant voice communication may be impaired by high noise levels. Some means of noise control should be considered by such centers (section 3).

Glare on computer workstations should be avoided through appropriate placement of light sources (section 7).

Line-of-sight problems (e.g., monitors that cannot be easily seen behind consoles) should be avoided (section IO).

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