MODULE 10. CONTROL CENTER

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Figure 10-1. The Control Center of the TranStar Freeway Management System in Houston, TX.

10.1 INTRODUCTION

The control center is the hub or nerve center of a freeway management system. It is where data about the freeway system is collected and processed, and fused with other operational and control data to produce "information." The information is then used by system operators to monitor the operations of the freeway and initiate control strategies to affect changes in the operations of the freeway system. It is also where agencies can coordinate their responses to traffic situations and incidents. Furthermore, the control center is also the focal point for communicating traffic flow information to the media and the motoring public. Because of its critical role in the successful operation of a freeway management system, it is essential that the control center be designed to allow operators to control and manage the functional elements of the freeway management system.

All too often, system designers have viewed technology and/or automation as the design goal for the control center. Unfortunately, this view is not supported by experience, and can cause operational problems when it is allowed to bring undue influence on the design of the control center. In one operational control center, for example, expert design resulted in an automation scheme in which the support system would determine the "best" pattern of variable message signs to present motorists with warnings of wrong-way drivers in the travel lanes. Under the design principle, the operator would review the automatic decisions and could change them after they were initiated, if necessary. After the system became operational, however, it was found that the surveillance system could not detect the difference between roadway maintenance equipment working in a closed lane and wrong-way drivers in the travel lane. The error resulted in the automatic closure of a large area of a freeway. This problem arose from a faulty *allocation of functions* to a higher level of automation than was feasible, a common design flaw. Its primary cause was that the design emphasis was on technology rather than on the performance of the total system. (1)

One way to avoid such design problems is to begin with a user-centered approach to designing a control center. (1) A user-centered approach applies system engineering and human factors principles to developing a system design that focuses on what the system is supposed to accomplish rather than on technology. The distinguishing features of a user-centered design philosophy as compared with other approaches include the following: (1)

- **The design focus is on the operator, not the designer.** In the user-centered design, the user (i.e., the operator) is viewed as a critical system component. The characteristics, capabilities, and limitations of the user need to be defined and considered during the requirements analysis and design of the system. Ideally, the user should be involved in the design process at its earliest stages and this involvement should continue throughout the design and testing phases.

- **The selection and acquisition of system components are based on validated functional requirements.** Many control centers have been designed adhering to a *technology-centered design approach* where the focus in designing the system has been on hardware and software. The user-centered design focuses on *what* needs to be accomplished by the system, not *how*. Therefore, system components are selected on the basis of an analysis of the functional requirements of the system. A *validated requirement* is a functional capability (e.g., identify sensor locations at which occupancy exceeds 30 percent during a 2-minute period) that has been formally stated and objectively evaluated.

- **The process is iterative.** Systems are best developed through an *iterative* process, in which a design is tested and validated in a series of stages. This is particularly important in control center design, where the multiple iterations can uncover problems — and opportunities — that are not apparent until they are viewed in the total system.

- **The process extends throughout the life cycle of the control center.** The fact that a new control center has been built and put into operation does not suggest that it is "complete." As the managers and operators of the control center become familiar with the system, they will make recommendations for adding many excellent design features and procedural changes to improve their abilities to control traffic on the freeway.

A user-centered design approach applies system engineering principles to develop a system that views the user (i.e., the operator) as critical to the overall success of the system. Figure 10-2 illustrates how the user-centered design process can be used to identify the elements of a control center. The first step in the design process is a mission analysis, which uses the goals and objectives of the system to define what it is the control center is supposed to do. After the mission analysis, a functional analysis identifies which functions will be performed by various elements (both human and technological) in the control center. Once the functional analysis has been completed, the tasks needed to accomplish each function can be analyzed. The task analysis involves breaking tasks down into their individual elements to include a detailed description of both manual and mental activities that the operators must do, and their duration, frequency, and complexity. The task analysis leads directly to defining operational characteristics and needs for the control center.

MODULE OBJECTIVE

The goal of this module is to identify some major factors and issues that should be considered in the planning and design of a control center. The specific objectives of this module are to identify the some major issues that must be considered designing, operating, and maintaining a control center for a freeway management system.

MODULE SCOPE

The purpose of this module is to help system planners and designers identify some major issues and factors affecting the design and operations of a control center for a freeway management system. It focuses on how the characteristics, capabilities, and limitations of the operators should be accounted for in the design of the control center. This module is not intended to be a detailed discussion of the human factors requirements affecting the design of the control center. For detailed information about the human factors requirement, the user should consult the *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) or other references. [1,2,3]

10.2 DECISION PROCESS

PROBLEM IDENTIFICATION

The first step in the design process for a control center is to identify its purpose or role in the overall freeway management system. The functions of a control center can vary from location to location, depending upon the local operating goals and philosophies for the freeway management system. For example, some agencies may be more interested in disseminating information about traffic and travel conditions to travelers, while other agencies may want to influence traffic behavior through control mechanisms, or to manage incidents by closely interacting with other agencies. The design of the control center needs to support the desired operating philosophy. An agency whose primary goal is information dissemination may want to design a control center that allows easy access to the information in the system by users outside the control center. An agency that wants close interaction with other operating agencies (fire, police, emergency services, etc.) may want to provide a physical location in the control center for those agencies to dispatch their emergency responses. Common roles/functions of a control center in freeway management systems include the following:

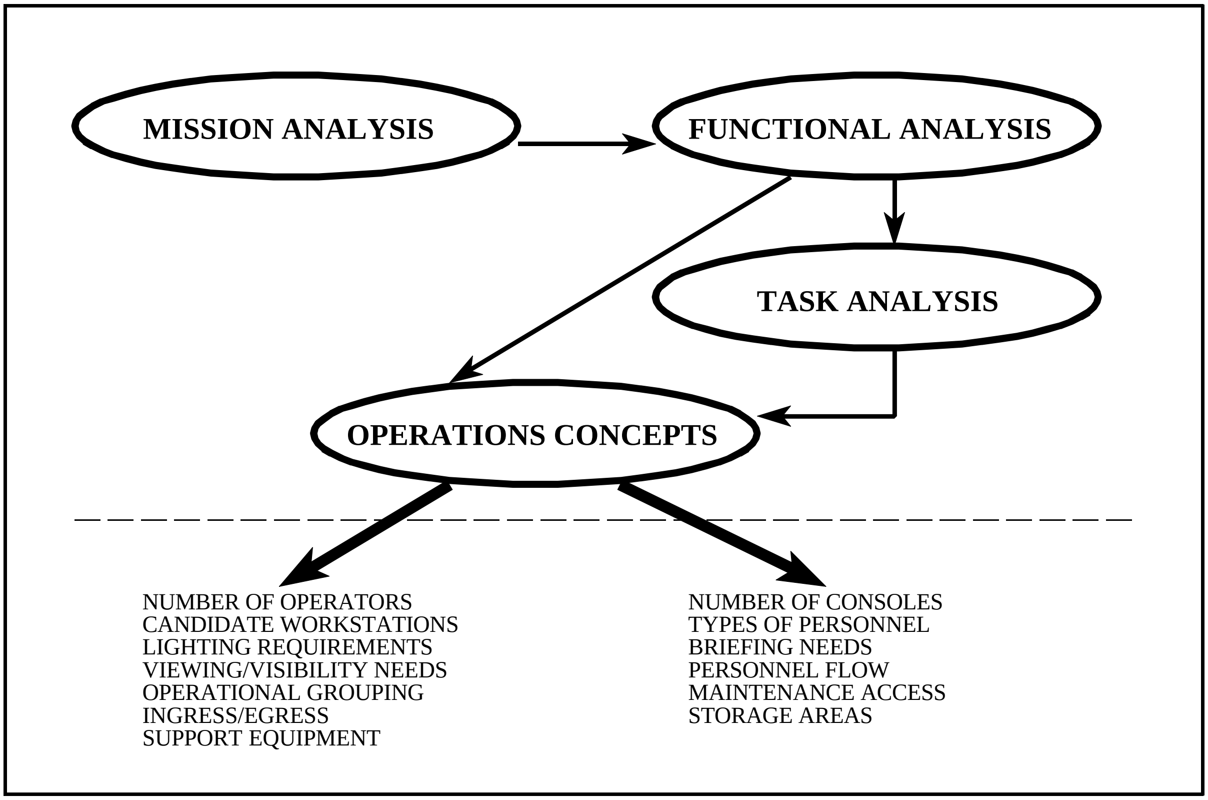

Figure 10-2. A User-Centered Design Approach. [1]

- A location for coordinating and implementing freeway management strategies and controls.
- A dispatching center for incident management and maintenance forces.
- A location for doing maintenance and repairs of malfunctioning or damaged field equipment.
- A central location for distributing freeway traffic and travel information to travelers, elected officials, and the media.
- A command post for coordinating the response to major emergencies.

Designing and constructing a control center can be costly (often millions of dollars). In the past, some agencies have found that their control center facilities have been inadequate to satisfy future growth. Planning accordingly for system expansion is important for agencies. Systems can expand their operations in many ways, including the following:

- Increase the number of freeways and/or roadway facilities covered.
- Add new freeway management functions to the existing functions of the system.
- Permit joint or cooperative operations of several agencies from one location.
- Serve as command post for major emergencies.

With these potentials in mind, agencies can plan for future expansion in the control center by providing the following:

- Adequate space in the operations room to install additional operator consoles/ workstations.

- Sufficient space and capacity to install additional computers and peripherals.

- Spare or expandable communications capabilities.

- Additional office space for operations and maintenance personnel from different operating agencies.

IDENTIFICATION OF PARTNERS AND CONSENSUS BUILDING

Regardless of whether the control center will be operated by a single agency or by several agencies in a joint operation, agencies need to identify potential partners, and build consensus and support within these organizations. A big question that must be addressed in the initial planning stages is who needs to be in the control center. Depending upon local needs and operating philosophy, operating personnel can come from the following agencies:

- State transportation agencies.

- Local transportation agencies.

- Police and emergency service providers.

- Local transit authorities.

- Private media and traffic reporting services.

Joint operations can be structured administratively to occur in different ways, such that varying levels of functional and management control are centralized or individual control is maintained. Joint operation can be structured through the following: [4]

- Sharing physical resources that are common to each agency's operation, but operating each system or agency component individually. This could occur through use of a common communications system (e.g., the TranStar System in Houston, TX).

- Operating individual or multiple systems under one designated management structure where operational control is centralized. This could occur by time of day where peak periods are under central control and off-peak is under local jurisdictional or functional agency control. Typically, the participating parties establish operating guidelines that are carried out by an individual agency or group, with the goal being to establish coordinated ongoing operations.

- Delegating day-to-day operations to another agency or group (including a private entity). This type of operation could entail turning the operations and maintenance of individual devices over to another agency under a defined set of conditions (e.g., Transcom operation of certain DMSs and HARs in the region surrounding New York City).

The ability to engage in joint operations is not an easy objective and usually occurs from ongoing relationship building. While a variety of strategies can be undertaken to foster cooperative joint operations, no single technique or action is always appropriate. Each community must assess its unique situation and develop a specific strategic plan that conforms to that situation. [4]

ESTABLISH GOALS AND OBJECTIVES

Before beginning on the actual design of the control center, participating agencies need to establish common goals and objectives for the control center. These common goals and objectives are used to develop principles for designing the functional and physical components of the control center. Examples of the types of issues that agencies need to address in establishing goals and objectives for a control center include the following:

- The functions to be carried out in the control center (e.g., traffic management, dispatching, incident management, etc.).
- The degree to which various elements in the system can be accessed and controlled by potential users of the system.
- The level of automation and the role of the operator in the system.
- The level and types of access that users outside the system (e.g., media, administrative, traffic reporting services, etc.) have to the information (i.e., databases, video, incident reports, etc.) produced by the system.
- The amount and type of customized equipment and software that will be permitted in the design of the control center.
- The level and manner in which existing and planned elements of the system will be integrated.
- The types of operator interfaces (i.e., displays, data entry screens and devices, etc.) that will be provided.
- The hours and operating conditions under which the control center will be staffed.

DEFINE FUNCTIONAL REQUIREMENTS

After establishing design goals and objectives, the functional requirements of the control center can be defined. Functions are broad statements that describe every operation and activity required to meet the defined objectives. Table 10-1 lists some possible generic functions of freeway management control centers. Note that these functions describe what it is the system does, and do not define whether activities are done by humans, by automated equipment, or by a human using a computer.

A *Mission Analysis* is an exercise that may be useful to agencies in identifying the functions of a control center. A mission analysis is used by system planners and designers to identify the operational capabilities required in the control center. Traditionally, two methods are used to conduct a mission analysis: a mission profile and scenario development. A mission profile is a detailed description of normal system operations that occur during a given system activity or over a given interval of time. It consists of listing all the activities to be done by various elements in the total system—operators, supervisors, automated subsystems, sensors, etc. The list also includes any activities done simultaneously (e.g., automated tasks done by system hardware, operator assessments, operator decisions). Activities are described at a high level and no attempt is made to define the roles of the operators or automated system in doing them. This technique provides an organized, high-level framework of system requirements that will support subsequent, detailed design analysis. (1)

With the scenario development technique, descriptions of specific scenarios—nonroutine but typical situations that would burden (challenge) the capabilities of the control center—are sometimes useful in providing an understanding of the control center's functions. The scenarios should describe what actions and information are needed to manage traffic during different

Table 10-1. List of Possible Generic Functions Performed in Freeway Management Control Center. [1]

Input	Throughput	Output	Support
• Detect vehicle locations • Detect vehicle speeds • Detect vehicle types • Sense roadway surface conditions • Receive BIT reports • Receive ad hoc component status reports • Sense visibility conditions • Verify incident data • Monitor incident clearance • Receive traffic volume reports • Receive probe vehicle reports • Receive ad hoc travel time reports • Receive ad hoc roadway condition reports • Receive O-D Data • Receive commercial rail traffic data • Receive ad hoc commercial rail traffic reports • Receive weather service data • Receive ad hoc weather reports	• Assess current load • Anticipate near-term traffic conditions • Select best traffic control option • Determine need for ITMS support • Track special vehicles • Predict traffic conditions given options • Determine remedial maintenance needs • Assess predicted traffic conditions given options • Assess traffic management effectiveness • Determine software upgrade needs • Determine hardware upgrade • Determine personnel upgrade needs • Determine preventative maintenance needs • Determine source of anomalies • Identify anomalies in traffic patterns	• Control railroad crossings • Post route advisories on information outlets • Provide route advisories to other users • Post speed advisories on information outlets • Provide speed advisories to other users • Post travel advisories on information outlets • Provide travel advisories to other users • Post mode selection advisories on information outlets • Provide mode selection advisories to other users • Transmit electronic maintenance requests • Issue special maintenance requests • Issue upgrade requests • Transmit electronic incident services requests	• Store electronic network data • Retrieve electronic network data • Store electronic incident data • Store hardcopy of incident reports • Retrieve electronic incident data • Retrieve hardcopy of incident reports • Perform database management • Provide traffic management training • Provide maintainer training • Provide incident management training • Provide special events training • Develop strategic traffic management plans • Develop special event traffic management plans

Table 10-1. List of Possible Generic Functions Performed in Freeway Management Control Center (Cont.). [1]

Input	Throughput	Output	Support
• Receive interagency incident data • Receive ad hoc incident response reports • Receive interagency emergency response data • Receive ad hoc emergency response data • Receive interagency data from alternate transportation modes • Receive ad hoc reports from alternate transportation modes • Receive interagency special events reports • Receive ad hoc special event reports • Receive public comments • Receive requests for public relations activities • Receive requests for historical data • Receive requests for simulation studies	• Predict multimodal demand given options • Determine ITMS responsibilities • Determine need for incident services • Determine appropriate ITMS responses • Assess multimodal demand and capacity • Identify demand regulation options • Assess predicted multimodal demand • Monitor compliance with other advisories • Monitor general compliance with advisories • Assess survey data • Assess ad hoc public comments • Plan public confidence enhancements	• Issue special incident services requests • Issue requests for information • Issue requests for on-site traffic control • Transmit electronic incident reports • Issue special incident reports • Transmit electronic incident management reports • Issue special incident management reports • Provide historical traffic data • Provide simulation reports and recommendations • Provide public relations information	• Develop traffic management contingency plans • Receive directives • Develop policy • Specify procedures • Implement policy and procedures • Perform fiscal planning • Perform budget tracking • Perform evaluations • Perform personnel selection • Maintain personnel records • Maintain communications with incident responders • Coordinate multi-agency incident response • Coordinate multi-agency response to other emergencies • Coordinate multi-agency transportation planning

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operating situations such as freeway incidents, major traffic stressors (e.g., large athletic events, inclement weather), or strategic planning episodes.

DEFINE FUNCTIONAL RELATIONSHIPS, DATA REQUIREMENTS, AND INFORMATION FLOWS

In defining the functional relationships, data requirements, and information flows for a control center, the following three tasks must be done:

- Allocating control center functions the operators, computer/machine components in the system, or a combination of both.
- Analyzing the tasks required to complete each function.
- Establishing how data flow from one function to the next.

Each of these tasks is discussed below.

Function Allocation

In the design of the control center, function allocation involves assigning system functions to machine components, human operators, or a combination of human and machine components. Using criteria similar to those shown in table 10-2, each function (or process) is assigned to a human or machine component. Properly allocating functions is critical to ensuring that operators in the control center perform tasks that are within their capabilities and do not become overloaded. The *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) presents techniques for allocating functions to human operators and machine components. The reader is referred to this document for details on the allocation procedures.(1)

The allocation of functions in the control center is usually the first point in the design process at which critical decisions must be made about the role of the operator. It is also a point at which mistakes, if not identified and corrected in design iterations, can cause serious design deficiency. One common misconception that occurs in allocating functions is that designers presume that a single set of functions should be handled solely by an operator and another set should be handled solely by machines. In fact, many critical functions in the control center can best be handled by the integrated efforts of humans and machines. Identifying these partly automated tasks requires detailed study and analysis. Failing to identify them properly and assign proper interface strategies causes serious operational problems. General guidelines and design considerations for allocating functions in a control center include the following:(1)

- If environmental constraints limit human performance, the function should be allocated to a machine.
- Events that cannot easily be perceived by humans (such as changing levels of traffic moving past a point on a freeway) should be allocated to machines.
- When a function requires a response that is beyond the speed or accuracy of human capabilities, it should be allocated to a machine.
- If the speed and volume of information derived or needed by a function is beyond the capabilities of a human, it should be allocated to a machine.

Table 10-2. Criteria for Assigning Functions to Humans and Machines. [1]

Humans Excel in ...	Machines Excel in ...
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Ability to store large amounts of information for long periods — and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time periods
Ability to exercise judgement where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improving and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves, etc.)
Ability to react to unexpected low-probability events	Doing many different things at one time
Applying originality in closing problems (i.e., alternative solutions)	Exerting large amounts of force smoothly and precisely
Ability to profit from experience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipulation, especially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period
Ability to continue to perform when overloaded	Operating in environments that are hostile to man or beyond human tolerance
Ability to reason inductively	Deductive processes

- If the information produced by a function is beyond the memory capabilities of a human, it should be allocated to a machine.
- If a function is to be performed continuously, it should be allocated to a machine.
- If the interruption of, and response to, unusual or unexpected events are

required, the function should be allocated to a human.

Following is a list of additional guidelines that can be used to help in allocating functions in a control center:[1]

- Allocate functions so that they make the best use of human abilities.
- Avoid decisions based solely on the ease or difficulty of automation; consider how allocating different functions between humans and machines affects total system performance.
- Avoid allocating functions in such a way that both humans and machines are forced to work at their peak limits all or most of the time.
- Allocate functions to humans so that they can recognize or feel that they are making an important and meaningful contribution to the performance of the system.
- Allocate functions between humans and machines so that a natural flow and processing of information can occur.
- Assign tasks that require extremely precise manipulations, continuous and repetitive tasks, or lengthy and laborious calculations to a machine.
- Design human/system interfaces on the presumption that the human might at some point have to take control of the system.
- Use hardware and software to aid the operator; do not use the operator to complement a predetermined hardware/software design.

Task Analysis

After functions have been allocated to human operators and system components, the next step in designing a control center is to identify the tasks that make up system functions. Each function includes one or more tasks. A task is an independent action, carried out either by an operator or by a machine, that results in an identifiable outcome. Tasks can frequently be decomposed into discrete subtasks that represent activities that are distinct enough to be analyzed separately, but are clearly contributing to the completion of an identified task.[1]

Once the tasks have been identified, they can be grouped to form operational flow or process diagrams. The operational flow diagrams allow designers to identify the actions, information requirements, processes, and decisions that need to be made to accomplish a function. Figure 10-3 illustrates an operational flow diagram for dealing with traffic incidents. Operational flow diagrams are useful tools in the design process, because they allow designers to identify the following elements easily:

- The types of data and communications requirements in the control center.
- The decision-support aids needed to complete operational tasks.
- The data-storage requirements of various processes and tasks in the control center.
- The types of outputs and decisions produced by each task.

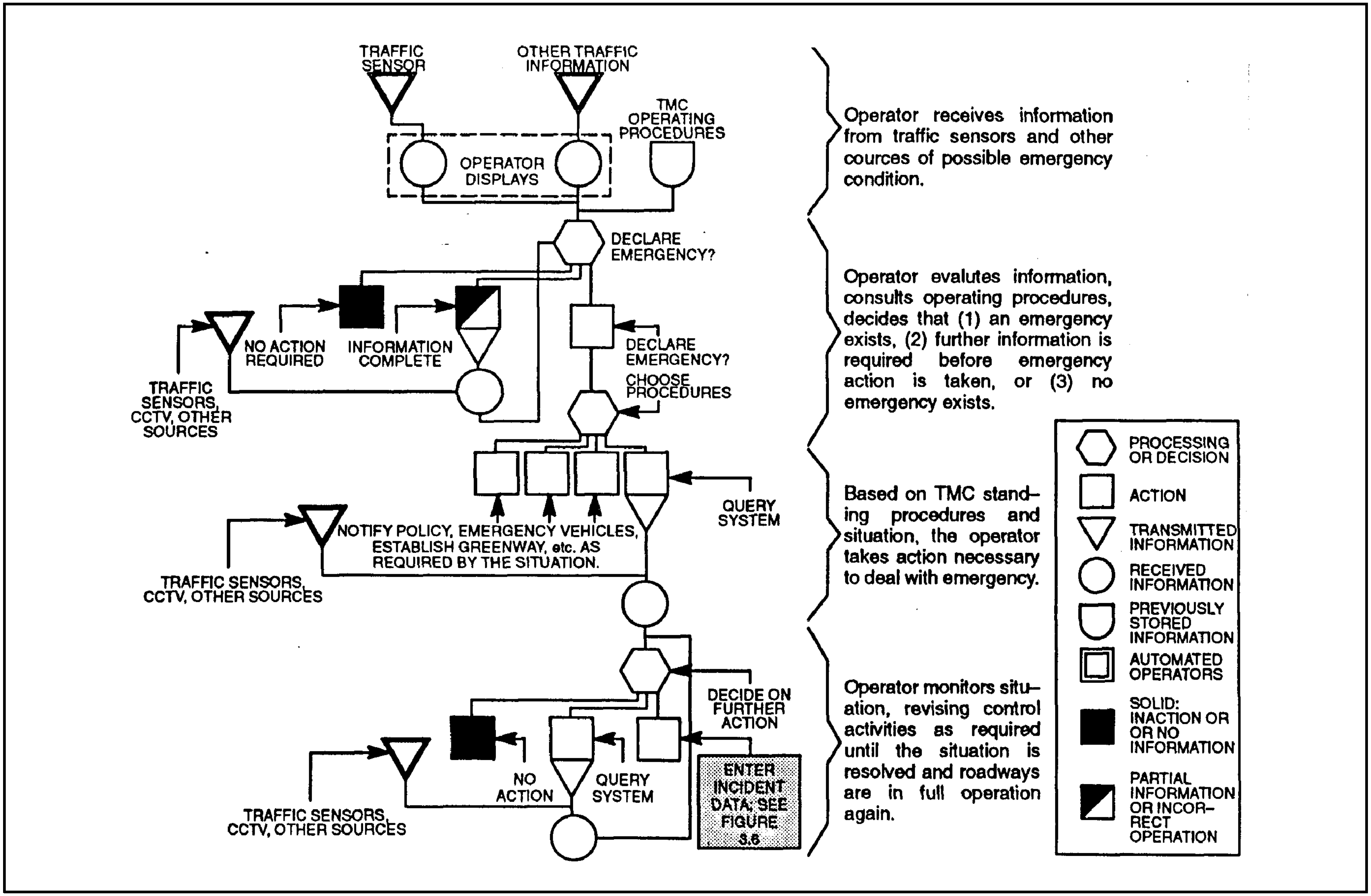

Figure 10-3. Example of Operational Flow Diagram for Managing an Incident. [1]

Data Flows

Establishing data flows is a critical step in designing a control center. Data flows describe the type and frequency of data needed to execute each function of the control center. This step in the design process is important because it allows system designers to assess the communications requirements of each component in the control center. Establishing the data flows also helps to identify the structure of the data streams needed to operate each function of the system.

One way to depict data flow is through data flow diagrams. With data flow diagrams, large circles are used to represent sources and destinations of data. The sources/destinations can be either subsystems or functions within subsystems. Lines connecting data sources and destinations are used to represent the type of data that flows between two elements of the system. Each data type is labeled so that designers know what information is flowing between components. An example of a typical data flow is provided in figure 10-4. Data flow diagrams need to be prepared for each level of design detail and for each subsystem within the control center.

IDENTIFY AND SCREEN TECHNOLOGIES

Only after the functions of the control center have been identified and the data flow requirements have been assessed should designers begin designing the physical layout and the support elements and related technologies of the control center. In planning the control center, system designers need to be concerned with the following elements:

- The physical environment in which the operators and equipment will function.
- The design and operations of the operators' workstations.
- The design of the controls and displays that the operators will use to operate the system.
- The design of the interfaces through which the operators will be presented with information and initiate control decisions.

The following sections relating to these issues were extracted from the *Human Factors Handbook for Traffic Management Center Design* (First Edition).[1]

Physical Environment

The control center's physical environment consists of design elements that allow the system — both human and machine components — to function effectively. The following lists some physical elements that designers must consider:

- Atmospheric (heating, ventilation, and air conditioning).
- Visual (primary and supplementary lighting).
- Acoustic (background noise and interior acoustical properties allowing operators to communicate).
- Physical design of the work space (access, dimensions, and fixtures).

The requirements for some of these elements are mandated by public law (e.g., access for the disabled). The design of other features of the control center should be based on established design practices (e.g., lighting

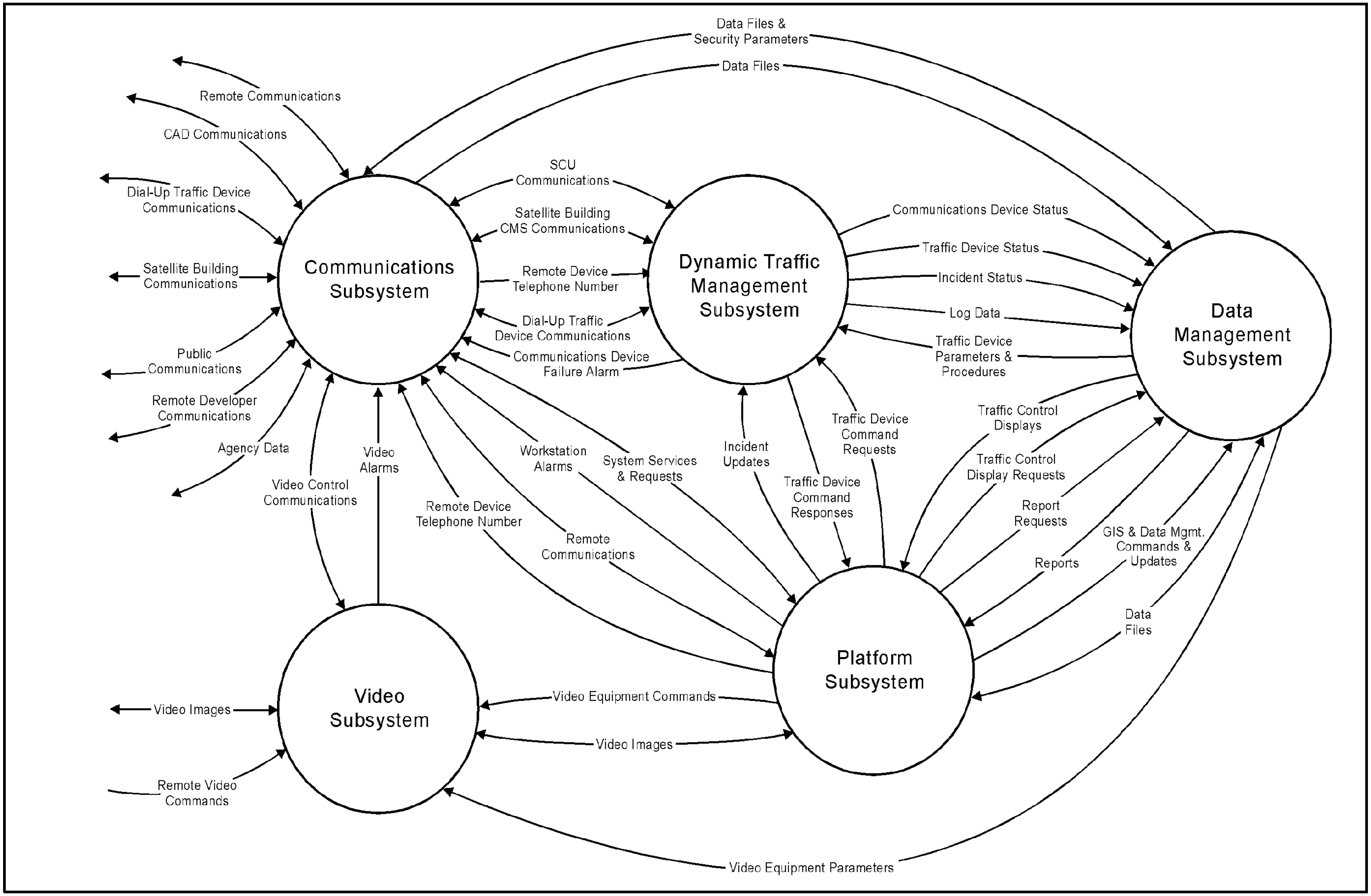

Figure 10-4. Data Flow Diagram of the TranStar System in Houston, TX. [5]

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standards for designated work areas). The *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) provides guidelines and requirements that can be used to design the physical environment of a control center.[1]

Workstations

At the same time the design team is considering how the control center work space will be used, it should begin designing and specifying the workstations that will be used in the control center. A typical operator workstation is shown in figure 10-5.

When workstations are to be configured from commercial off-the-shelf components, this task will require catalog searches and negotiations with vendors. Sometimes—when, for example, the control room is too small to hold separate workstations—customized fixtures designed specifically for the control center under development may be required. The layout of workstations and other furniture and fixtures should be specified as part of the overall work space design. In designing workstations, comfort and suitability should be considered as separate issues, both of which are supported with many experience-based guidelines. The *Human Factors Handbook for Traffic Management Center Design* (First Edition) summarizes many of these guidelines. [1]

Poorly designed workstations and supplemental furnishings (e.g., chairs) can cause discomfort and perhaps occupational injuries (e.g., back strain, cervical stress disorder, carpal tunnel syndrome, and repetitive stress disorders). Poor workstation design can also limit productivity. A good design will contribute to productivity and employee health and morale. Designing the workplace to accommodate the characteristics and capabilities of human operators is sometimes called *ergonomics*. The strong movement toward ergonomic suitability has created many sources of information that support proper workstation design; however, an experienced ergonomist or human factors engineer should be consulted before a large investment is made in workstations.[1]

Controls and Displays

Integral to any control center workstation are the means by which operators enter and retrieve information. Controls allow the operators to guide certain traffic parameters (e.g., traffic flow) within the limits of the center's mission. Displays provide information that operators need to monitor the status of the system and make control decisions. Several methods used to display information to operators in a control center including the following:

- Static display boards.
- Video/CRT monitors.
- Projection television systems.
- Video walls.

Advantages and disadvantages of each of these display devices are discussed in the section 10.3 of this module.

Poorly designed controls and displays can affect the operations of the control center and the operators themselves. Inadequate controls and displays can cause cognitive information processing deficiencies, faulty situation assessments and decisions, inaccurate data and command entry, occupational stress, and a general loss of operating efficiency.

Figure 10-5. Typical Operator Workstation in the Houston TranStar Freeway Management Control Center.

Activities associated with the design and specification of controls and displays are actually subprocesses of the workstation design effort. Controls and displays are considered separately because of the established body of knowledge and standards associated with each of them.

Control center controls and displays should be designed according to (1) the type and quantity of information that they must process and (2) the capacities and demands of the operators who will use the information they provide.(1) Results of a task analysis will suggest information requirements. In turn, these requirements will drive control and display designs.

Once display types have been determined, the guidelines and standards presented in the *Human Factors Handbook of Advanced Traffic Management Center Design* (First Edition) can be used to specify display quality.(1) Emphasis should be placed on the development of display performance standards. Brightness, contrast, and resolution of visual displays, for example, should satisfy operators' requirements for clarity and visual comfort. Designers should be aware, however, that designing controls and displays is an iterative process. A given display, although acceptable when viewed on its own merits, may represent an inappropriate design solution when it is integrated into the control center.

User Interfaces

If the smooth execution of system functions is desired, interfaces between operators and computers must be designed properly. The guidelines and standards for user-computer interface design are relatively new, and less stable than designers typically prefer. The status of these standards and guidelines will present the most significant challenge to the control center configuration effort.[(1)]

Many troublesome human factors problems existing in operational control centers are derived from poor user interface design. One common problem is the use of command line interfaces that require operators to memorize commands that have little, if any, inherent meaning. Another common interface problem can be attributed to "error traps" — procedures that carry an unacceptable risk of user errors. Some of these errors may have negligible effects, while others may be devastating to the performance of the system. The steps involved in designing acceptable user interfaces include the following:[(1)]

- Develop an interface concept. This concept should be based upon a knowledge of the types of interfaces available, and their strengths and weaknesses. The types of tasks to be performed through user interfaces should be considered and should be what drives the design process, rather than technology.

- Develop criteria to govern the design and evaluation of the interface. These criteria include design requirements, dialog strategies, and training requirements. The criteria should also be verified by experienced operators, traffic engineers, and others who have experience in interface design.

- Develop a "look and feel" of the user interface and conduct initial testing of the interface, using simulations of various levels of realism. (The level of realism associated with a given simulation is also called *fidelity*.) This type of simulation activity provides an excellent opportunity to incorporate *rapid prototyping*. Rapidprototyping involves using special software tools to develop and evaluate interface prototypes. Rapid prototyping techniques offer speed, flexibility, and realism to the design effort.

- Develop user interface for full implementation.

- Conduct user acceptance testing of the interface. User expectations and perceptions do not always agree with those of the developers. Rigorous evaluation procedures must be employed during acceptance testing. Preliminary tests of training plans, user aides, and user documentation should also occur.

- Incorporate the user interface into the control center design. Design consistency and suitability should be assessed. Final development of a training plan, a training implementation plan, and user documentation should also be completed.

EVALUATION

As different elements of the control center are installed, they need to be evaluated to ensure that they meet generally accepted principles of human factors engineering. Human factors testing and evaluation should not be a one-shot, pass-or-fail activity conducted near the end of the design or implementation phase. Instead, human factors testing and evaluation should occur throughout the design and implementation process. The most important principle to follow in testing and evaluating the human factors elements of the design is to *test early and often*.[(1)]

Testing should be conducted by someone who has experience in conducting human factors evaluations. Through human factors evaluations, system operators can be assured of the following:[1]

- The design of the control center will meet accepted standards of human factors engineering and will be tailored to the specific requirements of the system.
- Mistakes and problems in the design of the control center will be detected and corrected early, without compromising the budget or schedule.
- Operators will be more easily trained.

Human factors testing and evaluation should be both formative and summative. Formative evaluations result in an iterative process where various levels of design are evaluated and modifications to the design are made on the basis of the results of the testing. Summative evaluations produce a formal pass/fail judgement of design features. The *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) provides more detailed information on how to conduct these evaluations.[1]

In conducting human factors evaluations of control center design, obtaining opinions from the following individuals is recommended:[1]

- The control center operators themselves.
- The operators of control centers in other cities.
- The managers and supervisors of the control center.
- Representatives from other agencies who will be operating in the control center or have experience with control centers (i.e., fire/police dispatchers, air traffic controllers, etc.)
- Independent human factors specialists.

10.3 TECHNIQUES AND TECHNOLOGIES

PHYSICAL DESIGN

The size of control centers varies considerably, depending on the design objectives and functions performed by the system. A functional analysis is needed as part of designing the control center. Factors that affect the design of the system include the following:

- The hours and days of operation.
- The types of information displays that will be used in the center.
- The types of monitoring and control strategies in the system.
- The desirability of interagency staffing.
- The need for media and public access to the control center.
- Whether the control center will function as a communications or dispatching center.
- Whether the control center will also function as an emergency operations center.

The size of traffic control centers varies widely throughout the United States. Some control centers, such as TransGuide in San

Antonio, Texas, and Transtar in Houston, Texas, occupy as much as 4,800 m^2 (52,000 ft^2); however, many more successful control centers occupy less space. For example, the control center in Minneapolis, Minnesota occupies only approximately 950 m^2 (10,000 ft^2). Generally, most traffic control centers are between 1,600 m^2 (18,000 ft^2) to 2,300 m^2 (25,000 ft^2).

A typical traffic control center has the following work areas within the building: (6)

- Operations room.
- Computer and peripheral area.
- Communications area.
- A gallery for viewing and training.
- A conference room.
- System support offices.
- A break room.
- A media room.

An example of a typical floor plan for a control center is shown in figure 10-6.

The operations room is the hub of the control center. It houses the operators' workstations and display boards/video terminals used to display information about conditions in the network to the operators. The size of the operations room is dictated by the number of operator workstations that will ultimately be in the control center, and the type and location of the information displays.

The computer/peripheral area houses the computers needed to run the freeway operations center. The size of the computer room depends upon system design decisions regarding how much computer capability will be based at the control center as compared with that installed at hub locations in the field. Often these rooms require strict environmental controls (i.e., heating and air-conditioning). Many locations also have strict access control for this area. Figure 10-7 is an example of a typical computer/peripheral area in a freeway management control center.

The communications area can be a stand-alone area or can be combined with the computer/peripheral area. The communications area is the terminus for data entering and exiting the control center from the field. It also serves as the distribution point for transmitting data to the rest of the system (i.e., the computer and video control systems).

Many locations like to provide a gallery or viewing area of the operations room. From this area, tours of the control center can be conducted without interrupting the operations in the control center. This area can also be used as a training center where trainees can monitor the operators without disturbing them.

Many control centers also have an area set aside for the media (see figure 10-8). Some control centers use the gallary area to service this function, but others have set aside a separate area as a media area. From this area, the media can watch what is going on in the operations center without interrupting the operations. Often, these areas have several telephones and video terminals that are available for use by the media during incidents or emergencies.

One unique feature of the Houston TranStar System is a media cabinet located in the foyer of the building. As shown in figure 10-9, the cabinet contains power, video, and audio jack that can be used by the media

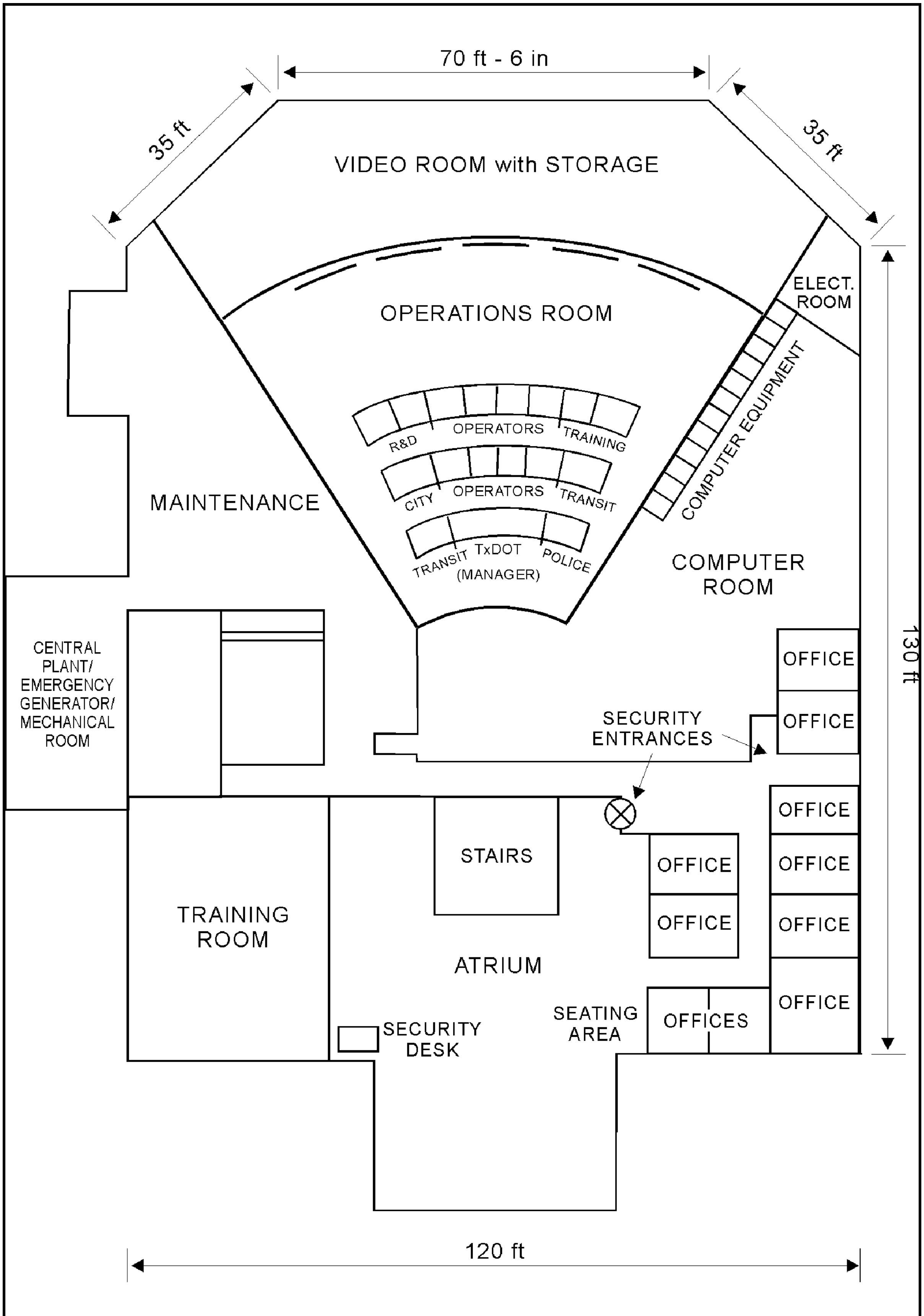

Figure 10-6. Floor Plan of the TransGuide Control Center in San Antonio, TX.

Figure 10-7. Example of a Computer/Peripheral Area in a Control Center.

Figure 10-8. Example of Media / War Room in a Freeway Management Center.

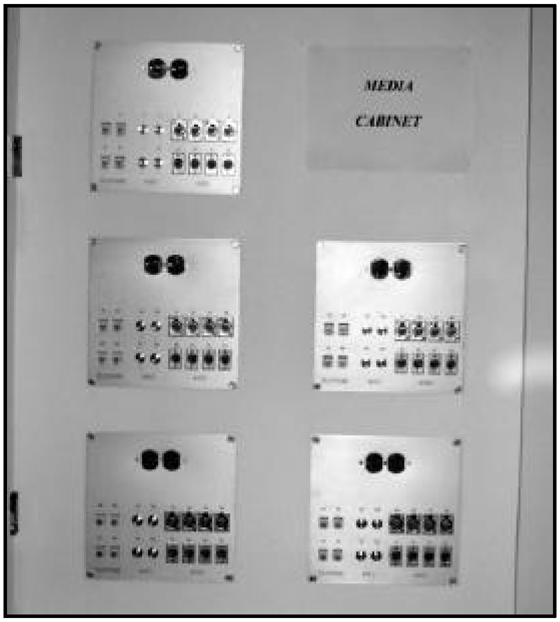

Figure 10-9. Media Cabinet in Houston TranStar Center.

when conducting interviews or reporting on traffic situations. Cables run from the cabinet in the foyer to a cabinet located in the parking lot, where similar connectors are provided for the crews to tie into their respective vans.

Besides these common areas, office space should be provided to those working in the control center. The number of office spaces, again, depends upon what functions will be carried out in the control center. Generally, office space is required for the operations supervisors, the system support staff, the maintenance supervisors, and the engineering and administrative staffs.

Some agencies have included space for their system maintenance personnel at their control centers. If maintenance operations will be based at the control center as well, the space provided at the control center is based on the number of electrical maintenance personnel that will be stationed there. In addition, if the control center is also expected to serve as an Emergency Operation Center (EOC), then additional space is needed for such items as dormitories, a large kitchen, and showers. Some locales may have mandated structural requirements for an EOC that are more stringent than for regular commercial office space.

Lighting

Lighting is an important consideration in the design of a control center. Viewing a large situation map with LED signals or a bank of CCTV monitors, for example, is not compatible with high levels of general illumination. On the other hand, many operators' tasks cannot be performed in low levels of illumination. The lighting scheme and choice of luminaries must be viewed as an integrated whole, and not designed piecemeal. [(1)]

The greatest challenge in designing the lighting in the control center revolves around the need to provide dim general illumination and higher levels of local illumination. Usually, a low level of illumination is provided in the operations room because of the nature of the tasks and displays used. Most centers provide supplemental lighting at each operator console. Some general recommendations related to lighting in control centers are as follows:[(1)]

- Indirect lighting should be employed to provide overall illumination for the control room.

- Canister fixtures should be employed to provide supplementary illumination over work areas.

- Adjustable fixtures should be used in work areas where more intense illumination is required.

For more detailed recommendations on lighting issues, the reader is referred to the

Human Factors Handbook for Advanced Traffic Management Center Design (First Edition).[(1)]

Acoustics

Communications between operators can be critical, especially in emergencies. Common sources of noise in a control center include the following:

- Alarms.
- Radio/telephone communications.
- Operator conversations.
- Data processing equipment.

Overall, the noise level in a control center should not be high enough to interfere with normal speech between operators. The objective in designing for noise is to balance the different sound sources so that local speech is unaffected, but is sufficient to mask intrusive noise from adjacent spaces. Some general recommendations for reducing the impact of noise in the control center include the following:[(1)]

- Identify possible noise sources (including machines, telephones frequently in use, loudspeakers, and radios with speakers) during the design phase and eliminate them.
- If noise sources cannot be eliminated, consider strategies for reducing noise level, including textured or sound-deadening wall and ceiling materials.
- Consider placing noisy functions that are not tied to normal operator activity in a separate room or in an area enclosed by acoustic partitions.

The *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) should be consulted for more detailed recommendations and specifications for accounting for noise in control centers.[(1)]

Heating and Cooling

Operator comfort and performance can be affected by temperature and air quality. In designing a control center, designers must be concerned about two issues related to the thermal environment of the control center: the general heating, ventilating, and air conditioning (HVAC) standard and the effects of local thermal conditions related to special equipment such as computers and video display units. Sometimes, special rooms in the control center, such as the computer/peripheral room or the communications area, may require separate heating and cooling standards. The *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) summarizes the heating and cooling standards applicable to control centers. General standards that should be considered in the design of the heating and cooling system for control centers include the following:[(1)]

- Actual ventilation should be ensured by introducing fresh air into any personnel enclosure.
- Within permanent structures, effective temperature shall be maintained at not less than 18°C (65°F), and not greater than 29.5°C (85°F).
- Approximately 45 percent relative humidity should be provided at 21°C (70°F). The humidity should decrease with rising temperatures, but should remain above 15 percent to prevent irritation and drying of body tissues.

- The temperature of the air at floor level and at head level should not differ by more than 5.5°C (10°F).

- The exhausting of air from instrumentation (video display units, system units, etc.) should be so accomplished as to avoid discomfort to users and others close to the equipment.

- Units should be designed so that forced-air exhausts are not directed toward the operating position, or toward other workers in their work positions.

- External surfaces that can be touched during operation shall have a surface temperature that does not exceed 50° C (122°F). Surfaces intended to be touched during normal operation should not exceed 35°C (95°F).

- Heat build-up from equipment under the work surface (around the operator's knees and legs) greater than 3°C (5.5°F) above ambient should be avoided.

INFORMATION DISPLAYS

A dominant feature in nearly every control center is a large information display board or screen. These devices are used to provide a broad overview of the status of the system to both operators and visitors in the control center. Three different kinds of information displays are generally used in control centers: static wall maps, projection television screens, and video walls. [7]

Static Wall Maps

Static wall maps were used extensively in systems designed in the 1960s and 1970s. These types of displays provide the geographic layout of the roadway system and show the location of the system's resources, such as detector stations, signals, signs, and cameras. Tiny light bulbs or light-emitting diodes (LEDs) connected to sensors in the field are used to display information about the status of the system. In some freeway management centers, different colored lights are used to depict various traffic flow conditions (e.g., green for free flow, yellow for moderately congested, red for congestions, and flashing red for incident location). Since these displays are generally large painted maps, making modifications to these displays as the infrastructure changes is difficult and costly. Figure 10-10 shows a typical static wall map used in a freeway management center.

Projection Television Systems

Projection television systems have also been used to display traffic information in control centers. The primary advantage of this type of system over static wall maps is that they are extremely flexible as to what can be displayed to the operator. Besides showing status information on computer-generated maps, operators can also display live video from CCTV cameras and television images on the screen. Because the images are usually generated by computer, the operator can zoom to various levels of detail on the display. The primary disadvantage of projection television, however, is that the resolution can sometimes make the image become blurry. Furthermore, because of its sensitive optics, it frequently requires realignment and adjustments. Figure 10-11 shows an example of a control center with a projection television map display.

Video Walls

Video walls are being used almost exclusively in new freeway management control centers. A video wall is a matrix of television monitors used as a single display. Each individual monitor can be used to

Figure 10-10. Example of Static Wall Map.

Figure 10-11. Example of a Projection Television Display.

display a single image or can be used to compose part of a larger display. By using a video wall, the operators in the control center have the flexibility of customizing the presentation of the information as conditions warrant.

Design Guidelines and Recommendations

The following guidelines and recommendations are provided to help in designing visual displays in control centers:(1)

- Avoid too much detail on large maps or status boards.
- Limit the number of colors for maps, target symbols, alphanumeric headings, etc.
- If moving objects are displayed on a map, keep the number at a minimum and display only those that move slowly.
- If the display area must have a low ambient illumination in order for individual operator displays to be used effectively, use white or luminescent markings against a dark background for maps as status boards to help operators maintain dark adaptation.
- If color-coded object information is to be used on a large map display, use only a neutral color, such as gray, for the map background; this allows the color targets to have maximum effect (contrast).
- When front projectors are to be used to project information on a large map display, ensure that the projectors are positioned so that they are not readily visible (i.e., causing obstructions and glare) to the operating personnel.
- Determine and provide the properly sized alphanumeric characters and/or symbols on the large-screen displays for the maximum viewing distances at which each set of characters and symbols must be read.
- Consider using unambiguous coding techniques to help operators in discriminating between old and new data.
- Orient maps with north to the top.
- Color codes should agree with commonly accepted practices:
  - *Flashing Red*: Emergency.
  - *Red*: Alert.
  - *Yellow*: Caution, recheck.
  - *Green*: Safe, go ahead.
  - *White*: Used when no right or wrong entry or condition exists.
  - *Blue*: Can be used to denote advisory, but use should be avoided.

OPERATOR WORKSTATION DESIGN

Considerable changes in workstation design have occurred as freeway management systems have evolved over the last three decades. In the past, most control centers were designed with multiple workstations, each with a specific function. For example, one workstation controlled the video surveillance system, another controlled the variable message signs, another controlled the ramp metering system, etc. This type of design required the operators to move between a series of workstations to implement a control strategy in a specific situation. Today, most control consoles are being designed so that a single operator can operate all of the subsystems from a single workstation. This generally results in better operational control over the system; however, in some situations, two or more operators may be competing for control of the same camera or monitor. Methods of setting priorities whereby multiple functions can be performed at a single workstation need to be established in a control center.

The design of individual workstations in a control center varies depending upon the functions to be performed by the operators. All workstations should be designed to anthropological standards. The placement of video display monitors and input devices (e.g., keyboards, mouse, trackballs, switches, etc.) should also conform to recognized standards and guidelines. Many centers have poor ergonomic designs that contribute to operator stress and discomfort. Common ergonomic design problems include the following:[(7)]

- Monitors placed above operators' seated line of sight.
- Operators having to look over consoles, monitors, and other equipment to view monitors on the wall.
- Inadequate or improper labeling of control features.
- Console heights not adjustable to extremely short or extremely tall operators.

Glare is one of the most common problems with video display units incorporated into workstations. Glare is generally caused by either lighting sources at the workstation or at other nearby video display units. Glare problems can be eliminated by the following means:[(7)]

- Provide glare shields between video display units and light sources.
- Cover light sources, including windows.
- Use task lighting.

The *Human Factors Handbook for Advanced Traffic Management Center Design* (First Edition) provides detailed standards and recommendations that should be followed in the design of operator workstations.[(1)]

COMMUNICATIONS SYSTEMS

In general, system designers need to be concerned with three types of communications systems when designing a freeway management system:

- The type of communications system that links the field devices with the control center and permits the transfer of data and commands. This type of system generally requires a high speed, high capacity type of transmission medium.
- The type of communications system that links the computer systems inside the control center that are responsible for processing information and commands, generating displays and reports, and interfacing with the control center operators. Most freeway management systems in operation today use local area networks (LANs) to connect their computer and display equipment in the control center.
- The type of communications system that permits operators in the control center to converse with other personnel (and also the public) by voice.

Because of the costs and criticality of the first type of communications system, it is covered in **Module 9**.

Local Area Networks

The term Local Area Network (LAN) is commonly used to describe the type of communications system that links the digital computers internal to the control center. By definition, an LAN is any telecommunications system that serves a limited geographic area (typically a single building or campus). The term "network" refers to the fact that multiple users are interconnected.[(8)]

No single LAN design is ideal for use in a control center. The design of the LAN needs to support the functions and the types of data exchanges in the control center. The simplest type of LAN permits the exchange of information between computers and computer-like devices (such as word processors, operator workstations, database managers, etc.). More complex forms of LANs are required to support the transmission of video and audio information besides data.

Components

While the complexity of the LAN varies depending on the type of data being transmitted, every LAN has the following basic components:[(8)]

- User workstations.
- Supporting processing equipment.
- Peripheral equipment.

The user workstations are the most visible component of the LAN. In control center applications, workstations may consist of conventional PC computers, intelligent workstations, or terminals. All these devices have the following common functions:[(8)]

- Display output to users, usually using a device such as a video display monitor.
- Receive data from users entered from a keyboard, mouse, or other input device.
- Interface with the communications medium, a function that includes formatting and transmitting data at the appropriate time and rates.
- Processes data, depending upon the LAN design, the capabilities of the workstation, and the type of software used.

Supporting processors, known as servers, are connected to the LAN to execute functions that cannot be provided by individual workstations. Generally, servers are used for the following applications:[(8)]

- Execute large computer programs that exceed workstation capacities.
- Provide centralized data storage and retrieval functions (file servers).
- Interface with external communication facilities (communications servers).
- Interface with peripheral devices.

The capacity of the supporting processors can vary from that of a PC to that of a large mainframe computer. The number and type of supporting processors depend on several factors including the following:[(8)]

- The design of the LAN.
- The number of users sharing the supporting processors.
- The functions being performed by each processor.

In most control centers, a variety of peripheral devices are supported on the LAN, including the following:[8]

- Printers.
- Plotters.
- Telex.
- Fax machines.
- Modems.
- Optical character readers.
- Scanners.

In some systems, the LAN is also used to support video and voice transmissions via connections to television equipment and the telephone system.[8]

In larger LANs, a special processor, known as the network control station, is often used to monitor the communications traffic on the LAN continuously, and to accumulate statistics on workstation usage, transmission quality, and network configuration.[8]

Planning for an LAN

Quite often, LANs are selected more on the basis of vendor recommendations than on technical or application requirements; however, when planning an LAN system, the first consideration should be the selection of the type of system or topology that is most appropriate for the application requirements. Generally, three types of topology (i.e., physical shape) are commonly used in designing LANs: a star topology, a bus topology, and a ring topology. Figure 10-12 illustrates each of these topologies. Advantages and disadvantages of each topology are summarized in table 10-3.

For simple system requirements, such as a few PCs and a file server, an Ethernet type of system may be quite appropriate. However, for large numbers of PCs with large data-transfer volumes, a token ring system is more likely to be the best selection. A rule-of-thumb is to use a baseband LAN for small office systems requirements and a token ring for large or host computer-oriented (mini/mainframe) systems.

Connections between LAN nodes can be established over twisted-pair cable, thin coaxial cable, standard coaxial cable, or optical fiber. Each of these alternatives has increasing capacities. Twisted-pair (telephone) cable is smaller and cheaper than other communications media, but is subject to electrical and radio interference. Coaxial can carry higher frequencies and data rates than twisted-pair but is more difficult to manipulate physically. Optical fiber is popular because of its small cable diameter, protection against electromagnetic or radio interference, low attenuation, and large bandwidth, but is generally more expensive to install than the other media. Factors that influence the selection and implementation of communications media used in the LAN include the following:[8]

- The amount of data being transferred between devices (i.e., capacity levels).
- The potential for external interference.
- The physical distance between devices.
- The potential for future expansion.

The ability to diagnose and predict its own failure is an important factor in designing an LAN. Simple layouts and well-established procedures should facilitate quick repair.[8] In addition, system planners should anticipate expansion needs in the design of the system. The internal design of the

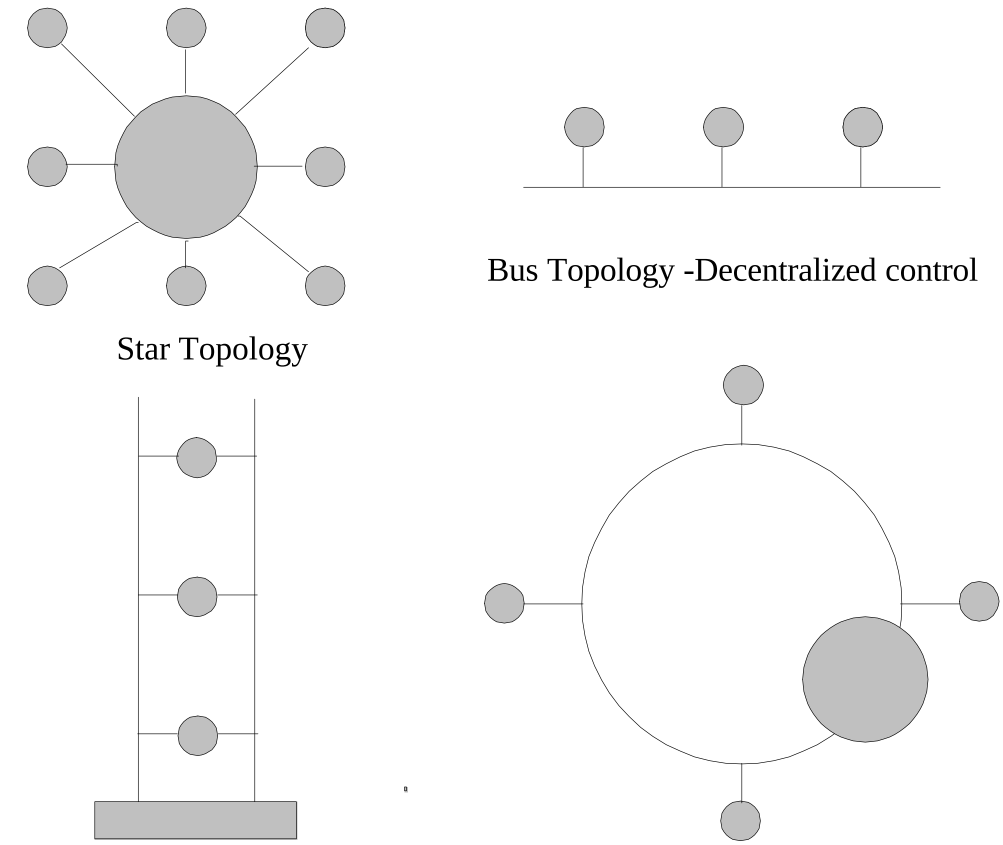

Figure 10-12. Examples of Popular LAN Topologies. [8]

building should incorporate adequate routing ducts and conduits to hold all future growth needs. In addition, access rooms should be provided to ease the job of adding and maintaining an LAN.[8]

Voice Communications

Systems within the control center are also needed that allow operators to talk with individuals outside the control center. The types of voice communication systems needed in a control center depend primarily upon the functions to be performed by the system, existing communications systems, local availability, and agency preference. Common types of voice communications systems included in the control centers include the following:

- Intercom.
- Direct line telephone connects.
- Switching telephone systems.
- Radio.
- Cellular telephones.

Figure 10-13 shows some of the voice communications devices used by operators at a control center.

Voice communications are commonly being used in control centers for the following purposes:

Table 10-3. Advantages and Disadvantages of Common LAN Topologies

Topology Type	Attributes	Advantages	Disadvantages
Star	• Communication protocols. generally controlled by central processor. • Polling techniques used to initiate data transfers. • Used by popular computer operating systems (e.g., UNIX and OS/2).	• Permits purchase of lower-cost user workstations.	• All workstations disabled in event of central computer failure. • System expansion costly.
Bus	• Topology on with both the Ethernet and token bus protocols based. • Individual workstations initiate data transfers.	• Network growth can be readily accommodated.	• Each processor must provide the capacity required to execute the user's application software. • Generally results in more expensive workstations.
Ring	• Each node receives "token" transfer data. • A token is a digital code that allows workstation access to the network. • Each node transfers data in turn.	• "Tokens" can be passed in either direction around the ring.	• Limited exclusively to token passing techniques.

Figure 10-13. Typical Communications Devices Used by Operators in a Control Center.

- Communications with incident response teams (including fire, police, emergency medical service providers, hazardous material teams, etc.).
- Control of remote and portable equipment (e.g., highway advisory radios, and variable message signs).
- Communications with operations and maintenance field personnel.
- Communications with motorist call boxes.
- Transmission of dispatch information, data, and calls.
- Communications with management and administrative staff, both internally and with outside agencies.

STAFFING

No rigid rules exist for determining the number of operators in a control center. The number of operators in a control center primarily depends on the functions that are being performed, the number of facilities covered, and the operating objectives and philosophy of the center. Table 10-4 shows the ultimate staffing requirement of a traffic operations center in Orange County. The primary function of this traffic control center is to detect and clear incidents from the freeway at all hours of the day. It also supports those individuals involved in the continued planning and operation of the system, and houses the staff responsible for developing operational strategies for special events, providing lane closure recommendations for construction contracts, and responding to major traffic incidents. It also houses maintenance dispatching

Table 10-4. Staffing Plan for Orange County Traffic Operations Center. [9]

Function	Number	Hours	Grade
CALTRANS			
TOC System Manager	1	0700-1600 M-F	Senior Engineer
Assistant Manager	1	1000-1900 M-F	Associate Engineer
Receptionist/Clerical	1	0800-1700 M-F	Receptionist
Area Traffic Engineer	5	0700-1600 M-F	Assistant Engineer
Area Traffic Technician	10	0700-1600 M-F	Engineering Technician
TOC System Operators	9	3 Shifts, 7 Days/Week	Engineering Technician
Software Support Programmer	1	0700-1600 M-F	Assistant Engineer
Electronic Maintenance Specialist	1	0700-1600 M-F	Electrical Leadworker
Maintenance Dispatch Supervisor	1	0700-1600 M-F	Maintenance Supervisor
Maintenance Dispatcher	6	3 Shifts, 7 Days/Week	Maintenance Man II
Assistant Maintenance Dispatcher	2	2 Shifts, M-F	Student Assistant
CALIFORNIA HIGHWAY PATROL			
System Coordination Officer	1	0700-1600 M-F	Lieutenant
Duty Officer	6	3 Shifts, 7 Days/Week	Traffic Officer
Media Information Officer	2	2 Shifts, M-F	Media Information Officer

functions for all of the Orange County Caltrans District offices.[9]

Generally, the types of personnel needed in the control center of a freeway management system include the following:[10]

- Electronic/maintenance technicians.
- Control center technicians.
- Communications specialists/operators.
- Software programmers.
- Computer system operators.
- Operations supervisor or director.

Generally, those centers whose functions include significant interaction with police officers in the field should consider including a police liaison officer on their staffs. A police liaison officer fosters stronger interagency cooperation and can aid in dispatching appropriate police responses to incident scenes.

Qualifications

Overall, the level of qualifications for control center operators should be directly related to the design of, and functional allocation within, the center. If the operators' functions are repetitive, predictable, and non-critical, operators with low qualifications can be used; however, if unique problems are frequent, rapid reactions are required, and/or criticality is high, operators need to have higher levels of training and expertise. As a rule, operators must possess good verbal skills, a degree of computer literacy, and good reasoning skills. Some agencies also require operators to have a good working knowledge of the freeway system and some dispatching experience.(7)

The qualifications for control center operators also vary from center to center. For example, some locations employ part-time students as operators. These students are under the supervision of a manager or a senior operator. Some control centers use operators taken from the agencies' technical staff of traffic engineers or computer scientists. Often, these operators have other assigned technical duties, or may be given special projects to work on along with their duties in the control center. A few centers require their operators to have college engineering or technical degrees. Operators should possess the following characteristics no matter how much education and experience they have:(10)

- Ability to make good judgment calls quickly and accurately.
- Ability to handle stressful situations.
- Good oral and written communication skills.
- Good understanding of the transportation language.
- Good technical skills and good interpersonal skills in dealing with nontechnical personnel.
- Ability and willingness to follow standard operating procedures.
- Initiative to learn more about the operations of the other functions in the control center.
- Willingness to provide suggestions/ideas to promote a more efficient operation.
- Computer literacy.

Training

The training of operators is critical to the success of a freeway management system. Operators need to be provided with three levels of training: technical, operational, and managerial. Both formal and informal training is needed before the system becomes installed, as the system goes on-line, and after the system has been operating for some time.(10)

How much training is required by operators in a control center depends on the functions to be performed and the level of technical competence of the operations staff. Technical training is required in a variety of areas associated with system operations and maintenance, including diagnostic procedures for all hardware as well as for new upgrade procedures.

The basic level of training needed by system operators includes the following:(7)

- General principles, operating philosophies, and concepts of freeway management.
- An overview of the system, including the system schematics, field subsystems, communications, central subsystems, and proposed or planned system functions to be added.
- Operation and interpretation of system software and displays.
- Basic radio and communications codes and procedures.
- Standard operating procedures.
- Communicating with other agencies such as fire, police, etc.

At most control centers, new operators generally receive one-on-one, on-the-job training with an existing operator.

Besides basic training, operators need to be provided with continuous advanced training. This advanced training can be adaptable to specific issues and needs of the operations and maintenance staff. Areas in which advanced training may be provided include the following:[7,10]

- Emergency response procedures.
- Hazardous material spills procedures.
- Major accident and disaster clearance procedures.
- Roadside fire response.
- Multijurisdictional extended pursuits.
- Release of information to the media.

Methods of providing advanced training include the following:[7]

- Lectures or short-courses.
- Videotape.
- Simulated events or table top exercises.
- Computer simulators.
- Site visits to other control centers.

Sufficient training should also be provided when a new element or application is added to an existing system. This is usually accomplished through contract specifications with training line items.[10] In preparing contract specifications for training, the following should be specified:[11]

- The maximum number of persons to attend each formal training session.
- The minimum number of days for each training program. (Defining what a day is may also be important.)
- Who will develop and supply all the necessary manuals, displays, class notes, visual aids, and other instructional materials for the training program.
- Outlines of lectures and demonstrations, and samples of all training materials. These materials should be submitted to the agency for review some specified time before their proposed use. Agency approval should be specified before the training courses can be scheduled.
- Where training is to be conducted (e.g., at a local site designated by the agency or at the contractor’s facility). If the training is to be provided at the contractor’s facility, the specifications also need to define who is responsible

for paying the transportation and subsistence costs of the agency personnel.

- All training should be conducted during normal business hours of the agency and the training site.

Staffing Sources — Agency versus Outsourcing

Being able to attract and maintain qualified control center personnel can be difficult for many agencies. Agencies have two basic options for staffing their control center: with personnel from with the agency, or by outsourcing. A pure agency staff has the advantage that managers and team leaders have a single personnel management system to deal with, and team cohesiveness is easier to establish and maintain. Outsourcing involves hiring private personnel to perform some or all of the functions in the control center. The primary advantage of outsourcing is the immediate availability of highly-qualified personnel. Seasonal and special events can be adequately staffed with limited training and start-up time. In addition, private employment agencies are not subject to the civil service regulations and policies that public agencies must follow. Private agencies can be more competitive and can pay the market salary rates that make it easier to attract and retain qualified people. To some degree, many agencies already employ outsourcing techniques to perform some functions in the control center (such as computer maintenance, software development, etc.). Those types of positions that can potentially be outsourced include the following:(12)

- Field and electronic technicians with communications or electronics experience.
- Team managers or leaders from a variety of backgrounds.
- Control center and communications technicians with knowledge, experience and training from other private sector hardware and software systems.
- System programmers and computer systems analysts with knowledge and familiarity of control algorithms.

SECURITY

Security surrounding control centers largely depends on the nature of the center and its objectives. Because of the vast differences in the purposes and capabilities of these centers, the appropriate levels of security to protect them vary widely, as do the perceptions of security risk. Many original freeway management control centers around the country were developed strictly as a traffic control measure and, as such, their operators did not see any particular threats to the facility. This stemmed from a perception that there would be little intrinsic value in attempting to attack or otherwise break into such a facility. In contrast, many facilities currently being brought on-line incorporate police, transit, emergency management, and traffic operations. These facilities are perceived to represent a much more likely target for computer hackers, theft of data, and even potential terrorist activities.(13)

Several generic security measures can be taken to limit physical access to facilities.(14,15) A recent article in an architectural magazine notes that "effective security is an interplay of three elements: natural and architectural barriers, including anything from landscaping strategies that discourage access, to the number, location, size, and type of doors and windows; human security, including the protection provided by guards and other personnel; and electronic security, provided by any one of the array of systems now available."[15]

Obviously, location of the facility will play a central role in determining what security measures are appropriate. Here again, the needs of staff should be considered in selecting what countermeasures are employed.[14] Communication systems, power supplies, access points, physical integrity of the building, and several other issues are all directly affected by security considerations. In addition, what countermeasures can be used is affected by building codes regarding access and egress during emergencies such as fires. Yet another layer of regulatory codes is associated with the Americans with Disabilities Act, which can affect aspects ranging from physical security barriers to systems that must accommodate both the blind and deaf.[15] Security systems also must be designed so that they are not too obtrusive, intrusive, or otherwise intimidating to employees.

Computers in the control center are also a source of security concern for many operating agencies. According to one source, the majority of all computer security losses have been attributed to errors or omissions. Major sources of other computer security losses include dishonest and disgruntled employees, and external threats such as disasters. Only a small percentage of security losses were credited to outside sources, such as hackers.[16] The point was thus made that "the two most heavily publicized types of security problems, hackers and viruses, are among the least serious threats to most systems." The threat from viruses (on a percentage basis) was also apparently small. As much as 80 percent of all computer-related damage was estimated to be caused internally. Nevertheless, because of the publicity surrounding hackers and viruses, an undue amount of attention is often focused on protecting against external threats.[16]

The extent of the risk to computer systems will vary greatly from agency to agency. The determination of how much security is necessary reverts to the need for risk assessment. Multiple layers of firewalls and other security measures may be warranted in some systems. Several publications are available that offer further detailed exploration of computer security measures that can be implemented.[16,18,19,20]

AUTOMATION

The acceptable level of automation varies from site to site. In some locations, the long-term goal for their systems is to be fully automated while, at other locations, the goal is for the operator to continue to be a critical element in the operation of the system. Each philosophy has significant implications with regard to the overall design of the control center.

The role of the operator in a system can be defined in terms of whether a human or a machine makes the decisions (i.e., closes the loop) in a task or process. The role of the operator in the decision-making process can be placed into four categories:[1]

- Direct performer.
- Manual controller.
- Supervisory controller.
- Executive controller.

Under direct performer control, the human operator performs all the functions of the system. In manual control, the machine components are heavily involved in the decision-making process as sensors and effectors, but the actual 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 decision. With executive control, the machine is totally responsible for performing all functions of the system—the operator is only there to keep the machine operating.

A continuum of operator roles exists that defines how much automation is needed to accomplish 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. As shown in figure 10-14, the continuum can be divided into four major regions; each region defines a generic operator role in relation to automation. Because it is a continuum, how much automation occurs varies within each region.

How much automation is acceptable in a control center varies from center to center, depending upon the experience of the operators, the operational goals and philosophy of the agency, and the sophistication of the system. In many locations, routine functions in the control center can be automated. For example, different control centers use different methods for generating messages for display on variable message signs, including the following:

- Messages are entered manually.
- Messages are entered manually with computer assent.
- The operator chooses from selection of canned messages.
- The computer determines a response plan with the assistance of an operator.
- The computer determines and carries out a response plan.

With the current state of technology, it is recommended the operator always remain "in the loop." Automation systems should be designed to help and support the operators. Operators should be fully aware of what information the system software has, what the automated systems is doing, why it is doing it, and what it is going to do next. At a minimum, the operator should be able to switch off the automated system to prevent future problems or to correct improper decisions.

If automated systems are to be used, the level of automation should be gradually increased throughout implementation. 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. As failures are eliminated, the role of the operator in the decision-making process can be reduced.

JOINT OPERATIONS

Joint operation can be structured through the following: [4]

- Sharing physical resources that are common to each agency's operation, but operating each system or agency component individually.
- Operating individual or multiple systems under one designated management structure where operational control is centralized.

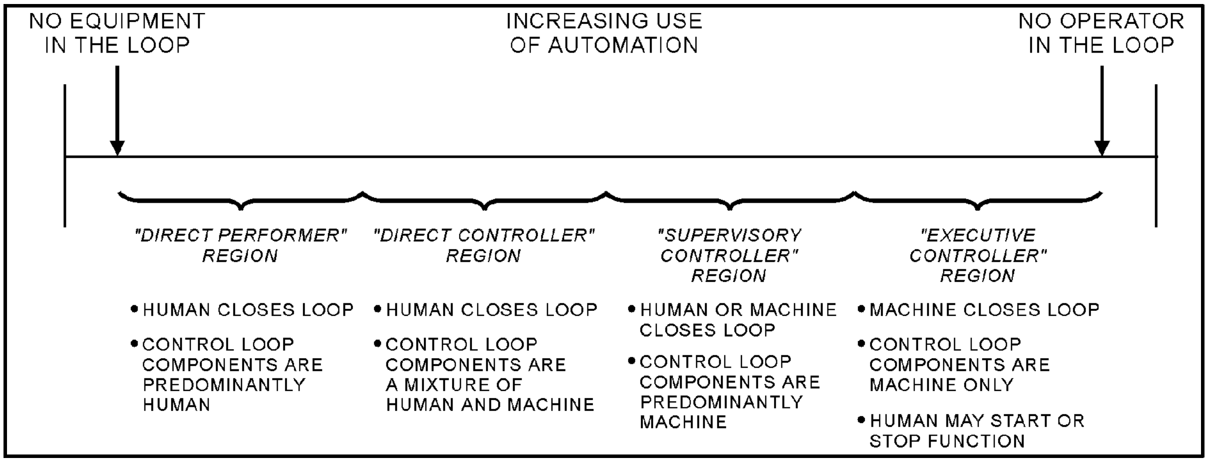

Figure 10-14. Continuum of Operator Roles in Relation to Automation.[7]

- Delegating day-to-day operations to another agency or group (including a private entity).

The ability to engage in joint operations is not an easy accomplishment and usually occurs because of ongoing relationship building. A variety of strategies can be undertaken to foster cooperative joint operations. No one individual technique or action is appropriate for all areas; instead, each community must assess its own unique situation. Strategies that can be employed to foster cooperative and joint operations in a control center include the following: [4]

- Ensure that each agency is represented in the initial stages of the design and program development of the control center.
- Emphasize how projects and programs can affect/address needs and problems of each agency throughout the development process. Look for ways to widen the focus of the initial goals of the system to help other agencies improve their operations.
- Approach joint operations with an open attitude about how overall results can be enhanced by sharing resources.
- To facilitate sharing and build trust among agencies, start joint operations with a relatively small and noncritical task. Building confidence and trust around these smaller elements will facilitate the accomplishment of larger tasks in the future.
- Develop an open-ended and flexible system architecture such that new systems and changes in hardware and operating procedures can be accommodated easily.
- Add functions and responsibilities under joint operations at a manageable rate.
- Develop standard operating procedures for how the devices in the system can be used by each agency in the control room. These operating procedures should be scenario-based and describe the roles and responsibilities of each agency in the scenario.
- Cross-train the staff from each agency so that they can do the jobs of the other agencies' staffs, and so that each operator has an understanding of the roles, responsibilities and limitations of each agency in the control center and

can serve as a backup or substitute in crises.

- Provide a mechanism for positively, reviewing and debriefing each others' operations with the idea of improving the overall operations and capabilities of the system.

10.4 LESSONS LEARNED

SYSTEM CAPABILITIES

It is important to consider system balance when deploying a freeway management system. System balance is achieved when all of the elements of the system are operating at their optimum, designed operating levels. A system becomes unbalanced when one of its elements is forced to operate beyond its capabilities. System operators should not be expected to do more to manage traffic than what the system was designed to do. Information should not be distributed and strategies should not be employed that are beyond the capabilities of the system to monitor and carry out. Erroneous information, and inappropriate and/or inadequate strategies erode public and political support for the system.

OPERATIONS MANUAL

Even though Federally funded projects require an Implementation Plan prior to actual system implementation, preparing an Implementation plan is a good professional practice, regardless of the funding source of the project. The plan defines system objectives, deployment elements to achieve those objectives, a general operations plan of how the elements will work together, a staffing plan for operations and maintenance of the system, and a commitment of resources for operation and maintenance of the system. The Operations Manual will define in more detail the actual day-to-day operations in the control center. It is essential that the manual be prepared in advance of system turn-on and used in the training of operators. In addition to the control console operation (the physical operation and adjustment of hardware and software), the Operations Manual must provide consistent and appropriate responses to similar traffic situations. Consistency can be provided by developing response plans for different levels of incidents, congestion, and traffic situations. The response plans should indicate what actions should be taken by elements of the system for a given traffic situation. Response plans should be well documented and placed in an Operations Manual. The Operations Manual also identifies who is responsible for carrying out specific actions. Figure 10-15 outlines the basic areas and topics to be included in the Operations Manual.

EFFECTIVE USE OF SYSTEM OPERATORS

Operators can be valuable in assessing the quality of operations, and in identifying potential operational and design changes in a system. The system should be designed to support operators and their task of maintaining traffic flow. Because they deal with traffic situations on a daily basis, they are often in a position to know what works, what does not work, and what needs to be done to improve the system. They can provide valuable insight into not only what additional hardware and functions are needed at the center, but also ways to improve the effectiveness and efficiency of the overall operation of the system.

In existing practice, the skills level of the individuals staffing and operating freeway management centers varies widely from system to system. Some agencies use

General Information About the TMC
- Mission and functions of the TMC
- Relationship of the TMC to other transportation agencies
- Organizational relationship of the TMC within the agency responsible for administration
- Diagrams depicting the physical layout of the TMC

Policies and Procedures on Internal Operations and Maintenance of the TMC
- General information on items such as address, main telephone number, fax number, e-mail, etc.
- Hours of operations
- Contact procedures in the case of emergencies involving the TMC
- Telephone procedures
- Personnel
  - Organizational chart
  - Description of duties for each position
  - Training (required classes and training manuals)
  - Rules of conduct
- Equipment
  - Authorized use
  - Maintenance
- Facility management
  - Security procedures and authorized access
  - Backup power
  - Custodial services
- Software
  - Backup procedures
- Media
  - Access to center
  - Media guidelines
- General public, transportation professionals, and VIP's
  - Access to center
  - Conduct of tours
- Disaster recovery plan

Policies and Procedures on Traffic Management
- Incidents (accidents, stalled vehicles, spilled loads, etc.)
  - Identification (vehicle detection, 911 calls, traffic reporters, etc.)
  - Verification (CCTV cameras, police, or DOT personnel)
  - Response plans (ramp metering, traffic signals, VMS, HAR)
  - Documentation of incidents
- Congestion
  - Monitoring
  - Response plans
- Planned events (including roadway closures and maintenance)
  - Obtaining necessary information on planned events
  - Response plans
- Field equipment malfunctions
  - Dispatching of repair crews
  - Documentation
- Interjurisdicational coordination
  - Other TMCs
  - Transit agencies
  - Other agencies (highway patrol, police, fire, etc.)
- Information distribution
  - Media
  - Value-added packages of transportation information
  - General public

Figure 10-15. Recommended Topics to be Covered in Operations Manual. [21]

students as operators, others use maintenance personnel, and still others use engineers. The key to operation of a successful freeway management center is to have highly qualified and motivated individuals who are both knowledgeable about traffic operations and technically competent.

SYSTEM MAINTENANCE

System maintenance is often overlooked by agencies. The performance of any operational traffic control system, whether a traffic signal system or a freeway management system, depends on the commitment of the operating agency to provide effective maintenance for the system. Agencies should not underestimate the budgetary or staffing requirements to properly maintain the control center and the system as a whole. Agencies must recognize that it takes highly skilled individuals to maintain today's complex systems. Public agencies should be aware of the costs associated with attracting, training, and retaining individuals with the requisite skills.

All personnel needed to operate and maintain the system should be placed under the management of the same individual in the agency's administrative hierarchy. The individual having the administrative responsibility for the control center should report to the same individual who has overall authority for traffic operations and maintenance functions of the agency. This individual may be the Head of Traffic Operations in larger agencies, the Head of Traffic Operations and Maintenance in medium-sized agencies, and the Head of Transportation in smaller agencies. This administrative structure will aid in accomplishing the following:

- Achieving a balance between funds to operate and maintain the system.
- Effectively addressing conflicts between operations and maintenance personnel.
- Developing a high level of technical expertise in operating and maintenance personnel.
- Facilitating interaction and opening lines of communications between operations and maintenance personnel.
- Facilitating interagency and intraagency communication and sharing of data and information.

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