**U.S. Department
of Transportation**

**Federal Highway
Administration**

Preliminary Human Factors Guidelines for Traffic Management Centers

FOREWORD

Traffic management centers are increasing in number and are receiving significant upgrades to respond to growing congestion in the roadway system. This growth in traffic management activity entails the installation of more and different types of traffic sensor and control systems. The integration of these systems leads to greater dependence on automation and intelligent systems to monitor and process large quantities of data, to assist decision making and to control traffic. In turn, this growing reliance on automation raises human factors issues on how traffic management operators share tasks with automation and what kind of environment is necessary for their work to be effectively completed.

This document provides human factors guidelines and other information to bear on these issues. For instance, chapters are provided for job design, the user-computer interface, workspace, controls and displays. Sections are also provided on the systems engineering design process. As traffic management centers coordinate with each other to devise new strategies and to meet regional traffic demands, new issues and new perspectives on the role of the human in traffic management will evolve. It is anticipated that these guidelines will form a basis for further examination of future operator requirements and thus continue to support effective user-system design.

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16. Abstract

This document provides human factors guidance for designers, owners, operators, and planners engaged in the development and operation of traffic management centers. Specific guidance addresses several dimensions of the work environment that can affect operator and system performance. These dimensions include the operator's work space, the equipment that operators use, and the design of their jobs. Additional guidance is provided for the user-centered design process. Supporting this guidance are several sections on operator capabilities. Several chapters address equipment design and selection. These include the user-computer interface, controls, displays, and job aids. The chapter on job design addresses shift work, team work, simultaneous tasks and workload, and the role of operators designing jobs.

This document is intended for application in planning new TMC's and for planning modifications to existing TMC's. In addition to guidance in the design of new equipment, workstations, and software, the document supports planned modification of equipment and the selection of off-the-shelf equipment. The guidelines also support specification development. At the beginning of this project, there was little human factors research specific to traffic management centers. Therefore, much of the guidance contained herein is composed of human factors material from non-TMC specific sources that are, nonetheless, relevant to traffic management centers. Recent research from this project has been incorporated into the guidelines. TMC specific guidelines cover areas such as incident detection and the management of variable message signs. An earlier version of this document was released under the title: "Human Factors Handbook for Advanced Traffic Management System Design."

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LIST OF ACRONYMS AND ABBREVIATIONS

ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
ATMS	Advanced Traffic Management System
BIT	Built in Test
CAD	Computer-Aided Design
CCTV	Closed Circuit Television
CIE	Commission Internationale de l'Eclairage
CMS	Changeable Message Signs
CRT	Cathode Ray Tube
CUI	Computer User Interface
DERP	Design Eye Reference Point
DM	Display Message
DOD	Department of Defense
DOT	Department of Transportation
GOMS	Goals, Operators, Methods, Selection Rules
GUI	Graphical User Interface
HAR	Highway Advisory Radio
HFS	Human Factors Society, now Human Factors and Ergonomics Society
HFT&E	Human Factors Test and Evaluation
HVAC	Heating, Ventilation and Air-conditioning
IDLS	Incident Detection and Locating Systems
IES	Illuminating Engineering Society
ISO	International Standards Organization
ITS	Intelligent Transportation Systems
LCD	Liquid Crystal Display

LED	Light-Emitting Diode
MOT	Method of Test
NASA	National Aeronautics and Space Administration
NBA	National Basketball Association
O-D	Origin-Destination
OSD	Operational Sequence Diagram
PA	Public Address System or Speaker
RFP	Request for Proposals
SIL	Speech Interference Level
SUT	System Under Test
TMC	Traffic Management Center
VDU	Video Display Unit
VDT	Video Display Terminal
VMS	Variable Message Sign

CHAPTER 1: HUMAN FACTORS AND THE TMC

CONTENTS

1.1　The Advanced Traffic Management System

The Advanced Traffic Management System (ATMS) will play a pivotal role in intelligent transportation systems (ITS) by efficient, real-time management of the traffic system. ATMS roles include adaptive signal control, road access control, rapid incident response, adaptive traffic rerouting, and communication with drivers through in-vehicle and external communication media. The ATMS is the instrument of effective traffic control in a given ITS service area and the Traffic Management Center (TMC) is the "brain" of that system.

In order to design such a complex, major system effectively, it is important first to document the mission and objectives of that system. This is often best accomplished through detailed discussions with potential managers and users of the new system. Based on discussions with a large number of TMC managers, designers, and vendors, we have defined an "ideal" TMC mission as:

> **Facilitate the safe movement of persons and goods, with minimum delay, throughout the region of influence.** [46]

To support this mission, the group defined the overall functional objectives of an ideal TMC in the following terms: [46]

1. **Maximize roadway throughput.** This will be accomplished by distributing the traffic load over time and space to control congestion and other traffic delays. It will also require successfully meeting objectives 2 - 5.

2. **Minimize impact of roadway incidents.** The ATMS will accomplish this in two ways: by *reducing the probability* of incidents (accidents, stalls, debris) and by *reducing travel delay* associated with incidents that do occur.

3. **Assist in providing emergency services.** The TMC will assist in providing emergency services by incident detection and verification, incident notification, coordination of multiple responses, and modification of other elements of the ATMS to improve emergency response. This may include emergencies near the roadway (e.g., structural fires), as well as on the roadway.

4. **Contribute to the regulation of demand.** Maintenance activities, and major incidents may temporarily reduce the capacity of roadway segments. Special events may generate traffic levels that greatly exceed normal roadway capacity. The TMC may reduce the resulting congestion and travel delay by influencing demand. Using the numerous available information channels, the TMC can encourage drivers to reroute trips, reschedule trips, or use alternative modes of transportation.

5. **Create and maintain public confidence.** Underlying all these objectives is the unavoidable need to maintain public confidence in the traffic control system. The TMC must be viewed by the public as a source of accurate and usable information. System

errors that produce incorrect or untimely information lead directly to a lack of compliance.

ITS technology that supports ATMS TMC design will include — as a minimum — larger numbers of more capable sensors, automation of routine procedures, computerized decision-making aids, and more effective means of influencing traffic flow and driver decisions. There will be demand for higher technology in all areas including a powerful drive toward *as much automation as possible*.

During the coming decades, ATMS TMC's will emerge through one of two processes: Evolution of existing, lower technology centers through gradual modification of existing equipment and procedures, or design and construction of TMC's from the ground up. Each approach has its advantages and disadvantages.

Most cities now have existing, older centers for signal control, maintenance and other lower-technology functions. A few have pioneering TMC's, designed in the 1970's and 1980's and ready to consider modernization and increased automation. Modernization might mean implementing new signal controller software, a more extensive network of closed circuit television (CCTV) cameras, or the integration of freeway management with surface street control networks.

The design process for *upgrading* existing systems will be more challenging in some respects than that for *replacing* them. Physical limitations of the existing facilities (e.g., space and equipment interfaces) will complicate efforts at modernization. The example below describes a typical modernization problem.

CASE STUDY: MORE CAPABILITY SHOULD NOT IMPLY MORE MONITORS AND KEYBOARDS

The signal control center in the major city was pleased with their years of experience using signal control software and hardware from Vendor A. It drove the signal timing on half the city's major intersections. It also drove the displays on all the graphics monitors on the TMC console as well as the color-coded lights on the big-board map display. Managers decided to start the move toward ITS technology by doubling the number of instrumented intersections in the network. The contract was awarded to Vendor B who promised full software compatibility with that of Vendor A. Only after installation was it discovered that the "B" sensors and controllers could not be made to communicate with the "A" monitors and map display. Information on intersections in the "B" system had to be computed and displayed on a separate computer placed against the side wall of the control room and out of the operators' normal view, severely limiting its use. While the software incompatibility would not seem to be a human factors problem, its primary symptoms, increased workload requirements, certainly are.

Whether remodeling existing facilities or building a new TMC, a fully successful program requires designers to *recognize the central role of the human element in the total system*. One major theme of this document is that user-centered design is a wise alternative to design

processes that are chiefly technology-driven. However, knowledge of the process of user-centered design is not as firmly established as traditional alternatives. Therefore, before moving directly to the application of the guidelines contained in this document, the design team should have a thorough understanding of how the human operator is incorporated into the design process.

1.2   Human Factors Engineering in TMC Design

The success of ATMS operations ultimately depends on how the human operator interacts with the system devices. The human operator is a critical component whose capabilities and limitations must be integrated into the design and operation of the TMC. Therefore, an important opportunity for overall system improvement comes from user-centered design, i.e., design specifically to support human performance. This document contains numerous examples gathered during the period of research that provided the basis for the work; many examples illustrate the cost of ignoring or misapplying human factors principles; others show significant successes in their application.

1.2.1   What is human factors engineering?

Human factors engineering can be defined as collecting data on the physical and mental characteristics, capabilities, limitations, and propensities of people and using this information to design and evaluate tools, workplaces, and other things that people use with the goal of increasing their efficiency, comfort, and safety. More simply, it is making the job *fit* the operator.

History and range of application of human factors engineering. Human factors engineering became firmly established as a separate discipline during the Second World War. During that time, the proliferation of highly complex systems (most particularly aviation systems) stretched human capacities to their limits in so many areas, and with such urgency, that a new category of researchers and practitioners came into being.

Human factors practices and standards have become a major consideration in many design areas, particularly those in which the human/system interface is critical to overall system effectiveness, safety, and convenience. Human factors research and recommendations address such issues as airplane cockpit displays and controls, military system design, nuclear power plant regulation and evaluation, and consumer usability issues ranging from instructions for videocassette recorders to the layout of automobile dashboards.

1.2.2   Scope of human factors in TMC design.

The principles and methods of human factors engineering should be applied to TMC design in a broad range of areas. The sections below list areas in which the design team should possess knowledge and expertise. If knowledge in any of these areas is lacking in the resident design

staff, consideration should be given to adding a qualified human factors design consultant to the team. Each of these areas is the subject of a specific chapter, as summarized in Section 1.3 and Figure 1-1.

- **Designing to human requirements.** The design team must be able to apply the methods and practices of human design to the TMC at the appropriate points in the design process. The concept of iterative, user-centered design is central to meeting human requirements. This process stresses tools and procedures (task analysis, flow charting, operational sequence analysis, function allocation, link analysis, rapid prototyping, mockups and simulation, and test and evaluation) and their systematic application at the appropriate points in the design process.

- **Analyzing functions, tasks, and human/machine systems.** The design team must analyze the functional requirements of the TMC in a way that focuses on the user, on how functions are allocated to human and machine, on how human tasks are analyzed and described, and on how to plan the TMC to enhance human performance.

- **Designing to reduce human error.** The design team should have a practical knowledge of human error. Mistakes appearing in the human part of the system often have their origins in design flaws. These can have a significant impact on TMC operations, and they comprise the least understood aspect of design for most managers and engineers.

- **Designing to support human performance.** Constraints to human performance should be formally considered by design teams that include a human factors engineer. Design decisions may profoundly influence the probability of operators making correct decisions and maintaining appropriate human control over the system. Most active monitoring and intervention by the operator in the TMC involves cognitive (mental) functioning. The design team should understand the nature of arousal, fatigue, memory, attention, and decision making and their interaction with design aspects of the TMC.

- **Applying the principles of job design** To create a smoothly functioning TMC, the design team must know and apply the methods and considerations for job design. Effective job design reduces errors and their consequences, provides motivation to operators, paces work appropriately, and divides work evenly across teams that operate together.

- **Applying the principles of anthropometry.** Anthropometry (the measurement of human operators' physical characteristics) is a science that often is invisible until deficiencies appear. Problems that result from ignoring anthropometry might include uncomfortable, poorly-designed work chairs; inadequate leg and knee space at work stations; displays that cannot be seen because of poor line-of-sight from operator positions; work-related injuries and conditions (e.g., repetitive stress disorders such as carpal tunnel syndrome, fatigue, lower back pain) that accompany poor physical design of furniture and accessories.

- **Applying the principles and standards for displays and controls.** The human/system elements of the TMC are closely concerned with displays and controls. Poorly designed displays induce errors (because information is difficult to read and interpret), fatigue, and inefficient system response to changing traffic conditions. Poorly designed controls affect operator errors, communication, accuracy of output, and operator confidence.

- **Applying the principles and standards for workplace design.** The design team must apply the knowledge of anthropometry, displays and controls, and other considerations to the physical design of the TMC workplace. Illumination, physical arrangement, furniture selection, temperature, noise levels, and work stations are important factors.

- **Applying the principles and standards of user interface with information systems.** As TMC's evolve, computers will become increasingly important. The user interface, information displays on monitors and input devices such as keyboards, can be designed in accordance with numerous existing standards. The design team must be able to select the appropriate interface type and/or specify the characteristics of the information systems that will channel and display information in the TMC. Poor interfaces promote errors, delay effective traffic control actions, and create frustration that reduces the operator's confidence in the technology of the center.

- **Applying the principles and standards of user aids.** The design team must be able to provide the required job aids for the operator. These include user manuals, online help, quick reference guides, and mnemonic devices designed to promote accuracy, reduce the probability of error, and make the operators confident of their ability to intervene appropriately when human decisions and actions are required.

- **Applying the principles and standards of data presentation.** The presentation of data is critical in helping the operator understand the status of the systems, the state of traffic flow, and the range of appropriate actions. The design team must be able to apply principles of data presentation, data fusion, and clarity and economy of display.

1.2.3   User-centered design avoids costly mistakes

All too frequently, the design of facilities such as TMC's begins with an initial assessment of *what the available technology can do*. Sales calls and literature from vendors, visits to existing TMC's, and exhibits at trade shows provide exciting glimpses of the state-of-the-art in ITS technology. Sometimes the results of this assessment lead to very early procurement decisions for the new TMC's central system components. Only late in the process are the actual performance requirements and operator tasks for this specific TMC considered in detail. In the end, the human operator is expected to pull everything together and make the system work.

Sometimes the attraction of new technology is so strong that designers allow it to drive the design process. Frequently, for example, there is a tendency to see automation as the ultimate design goal of ATMS evolution. Unfortunately, this view is not supported by experience, and can cause operational problems when it is allowed to bring undue influence on design goals.

In one operational ATMS, for example, an expert designed in an automation scheme in which the support system would determine the "best" pattern of changeable signs to present to motorists; and the operator would review the automatic decisions and could change them after they were implemented. After the system was fielded, it was found that the system often could not distinguish between roadway maintenance equipment working in a closed lane and wrong-way drivers in the traffic lanes. The error resulted in automatic closure of a large area of freeway. This problem arose from a faulty *allocation of functions* to a higher than feasible level of automation. This common design flaw was allowed to develop because the emphasis was on the technology rather than on the total system. Ultimately, the design was changed to give the support system initial responsibility to detect an anomaly but to require operator consent before a drastic traffic management tactic was implemented.

Technology-based approaches to design may cause very significant problems in TMC development:

> ! **Systems are specified before requirements are understood.** Many of the examples cited in this document result directly from specifying components before understanding what they are supposed to do as part of the total system. In the example below, designers over-emphasized technological possibilities and under-emphasized identifying system requirements.

A Case Study in Technology-Oriented Design

Procurement officials for the new ATMS had reviewed the state-of-the-art in TMC systems and were preparing a draft request for proposals. The team had been particularly impressed with a video wall they had seen in a (yet unopened) TMC that could integrate, perhaps, two dozen monitors to provide a single, large picture. The team felt that important uses might be found for such a display and it was, therefore, specified as a central feature of the control room. Later, the team discovered that, by concentrating on technology rather than requirements and functions, they had neglected to define TMC information output methods for controlling congestion. The team expressed hope, however, that a local radio station would agree to carry their congestion reports until additional funds could be found for a VMS network. No analysis had been done on the number of operators needed to staff the center, operator selection criteria, operator jobs, or the equipment needed to do those specific jobs.

> ! **Early design errors are difficult and costly to correct.** A common and very fundamental design flaw that plagues TMC's is the tendency to specify the dimensions of work stations without considering where information is to be displayed in other parts of the control room. In more than one TMC now operating, personnel at work stations are unable to see critical displays such as the banks of CCTV monitors and "big board"

displays that show real-time traffic conditions *because console tops and other clutter are in the way*. In almost every case observed, the work consoles were well designed from a human factors point of view for an environment in which they could be self-contained.

- ! **The human component of the system is ignored.** Even when many functions are automated, the human role is crucial. A technology-centered design process is insensitive to these cases. Designers must keep in mind the range of situations that cannot yet be left to automation. These include:

  - T **Failures in the automated system logic** due to unforeseen circumstances (for example, the support system that interpreted maintenance activity in a closed lane as a wrong-way driver and closed the freeway).

  - T **Circumstances that cannot be detected by sensor systems** but demand response (as in an airplane crash adjacent to the freeway that required freeway closure to all but emergency vehicles).

  - T **Automation malfunctions** that require full or partial degradation of the TMC to a manual mode due to software "bugs" or even a complete computer "crash." This is a frequent problem with automated systems, and requires planning to allow the system to "fail gracefully" rather than force a serious loss of function while operators recognize the problem and assume manual control.

- ! **Human error is ignored.** Human error is a factor often ignored in technology-oriented design. It is important to note that even computer systems that provide reliable and accurate information can promote system errors if they are difficult for humans to use. Researchers found almost uniformly that engineers involved in the design or management of advanced TMC's tend to define error in *machine terms* — as faulty system output. While human error was recognized as a factor in some TMC operations, there was little idea of how to plan for its reduction in the design process.

- ! **The TMC does not support the exercise of human judgment.** In many cases, the critical factor in responding to a crisis is the judgment of the operators. If the design of the TMC ignores the efficiency of operator actions, or makes such actions too time-consuming or complicated, the total system may fail to respond appropriately when it is needed most. In technology-centered design, this problem is often unrecognized until it appears under operational conditions.

- ! **The TMC architecture does not match the traffic management problems.** Another common problem is the temptation to acquire high-technology solutions for which problems are scarce. For example, a small TMC that monitors a short or relatively uncomplicated road network will gain little by installation of a dynamic "big board." Such displays are most useful if multiple operators or supervisors coordinate to make decisions based on patterns too complicated to visualize without a display.

1.2.4   Human factors and user-centered design

In spite of the drive toward full automation, the operator will remain "in the loop" and a key player in the total system until such time as automated systems can sense, interpret, and control all the myriad of variables in the environment that influence traffic flow. [2] While routine operations such as posting congestion warnings can proceed now on the basis of automation, the worth of a TMC will often rest on the ability of the operator to intervene successfully in response to special requirements such as a major incident. This ability will rest on whether the total system has been designed with the user's needs in the foreground. Here are the major elements of user-centered design:

!   **The design focus is on the operator, not the designer.** This is easy to illustrate. Consider the revolution in documentation for computer software. In the 1970's and 1980's, the "user" of an application, whether a word processing system or a graphics program, was ill-defined. User manuals, where they existed at all, were difficult to use, crammed with jargon and abstruse computer concepts. Usually, the writer wrote from the perspective of the *designer* rather than from the viewpoint of the user who would actually have to decipher the instructions before using the programs. The reason was that software developers are often too close to the underlying processes of writing programs to see the world as the user sees it.

Development of user-centered interfaces and user-friendly documentation emerged as a tool for developing a competitive edge. Many manuals for popular contemporary applications are very carefully executed and are the result of user-centered design. If they were not, the customers would tend to buy another application.

The TMC is faced with a different competitive environment, but one just as vital. Efficient operation of traffic management depends on operator effectiveness as well as technology, and most of all on that part of the system in which the human and machine components must operate together. The TMC's primary "customer" is the driving public, and a TMC designed without the operator in mind will create the same sort of response in the driver as poor documentation creates in the computer user.

!   **The selection and acquisition of configuration items is based on validated functional requirements.** A "validated requirement" is a functional capability (e.g., identify sensor locations at which occupancy exceeds 30 percent during a running 2 min. period) that has been formally stated and objectively evaluated. There are many kinds of "unvalidated" requirements, the most common being traditional practices and presumptions that are carried over from one design evolution to the next.

!   **The process is iterative.** Systems are best developed through an *iterative* process, in which design is tested and validated in a series of stages. This is particularly important in a system like the TMC, where design iterations will often uncover problems — and opportunities — that are not apparent until they are viewed in the context of the total

system. However much some designers might like to consider human factors engineering to be the rigorous application of common sense, the fact is that common sense is always clearest in hindsight. Iterative design allows for the shortest and least painful hindsight.

! **The process extends throughout the TMC life cycle.** The fact that a new TMC has been built and put into operation does not suggest that it is "complete." As TMC managers and operators are aware, changing traffic conditions, amended responsibilities, improved technology and lessons learned have a way of obliging the TMC to evolve. User-centered design should continue throughout the life of the TMC.

ANOTHER CASE STUDY IN TMC DESIGN

User-centered design, despite its obvious advantages, has not been the rule in control room development in general, or in the TMC in particular. A discouraging example of this unevenness is documented in descriptions of a European traffic signal facility of some complexity. During the data collection phase of this program, observers visited a new "ground up" facility and the older system it was to replace. The older center had evolved through a user-centered approach, with many excellent design features and procedures put in place by the operators or at the operators' request. The new center, however, showed little evidence of retaining these user-designed features and procedures in its development. In the analysts' view, important lessons were lost. [75]

Advantages of user-centered design. While user-centered design techniques may seem complex and costly in time and effort compared to the simpler approach of buying a package and entrusting its integration and ultimate satisfactory operation to a vendor, experience amply demonstrates that the time and effort are well spent. User-centered design offers very clear advantages like those listed below:

! **Task and function allocation are based on total system.** Technology-based approaches focus on the purchase of the most *sophisticated* systems, not the most *appropriate* ones. A TMC produced by designers who have not given appropriate attention to the system as a whole — which means, in most cases, applying appropriate emphasis to human factors issues — will not perform as desired. The user-centered approach will be more likely to identify the problems and opportunities that surface when the interactions of system components are viewed as a whole.

! **System deficiencies are identified early in the process.** As a general rule, the later in the development process that a problem is identified, the greater the cost (in dollars and delay) required to solve it. Iterative user-centered design reduces the likelihood of a problem going unrecognized beyond the point in design at which it could be easily corrected. Without this focus, the work that should have been done early in the process will have to be done later and at added cost in resources, frustration, and loss of confidence in the system.

! **Best use made of human resources.** As we discuss at length in later chapters, some functions are best left to automation, while others are best allocated to the human in the loop. When the traffic system is stressed, the human contribution transcends routine monitoring and becomes crucial to traffic management. To leave the operator as the weak link in the system is to invite disaster. User-centered design is intended to counter this problem.

1.3   Human Factors Guideline Contents

This document contains the following kinds of information:

! **Expository information and background.** Each chapter includes information that provides for an understanding of specific guidelines. Some may *seem* overly complex or academic, others may *seem* to be recitations of "common sense." The more complex sections address background that cannot be ignored without a demonstrated risk of misapplying a guideline (The examples that remain were often the result of intense discussions by the writers, editors, and reviewers).

! **Guidelines and reference materials.** Most of the chapters provide a number of specific design guidelines that can be used to identify important design issues and to assist in making design decisions. Many of the guidelines are accompanied by explanatory information to provide their rationale and to support their application.

! **Glossary of terms.** Unfamiliar terms are defined as required when they first appear. However, because it is unlikely that a user will read the document from cover to cover, we have included a glossary of terms to allow reference when a technical word or phrase is encountered.

! **Other available references.** Following the last chapter, and cited in the text as required, there are references to information sources. These references may provide insights to topics that have not been explored in sufficient detail for satisfactory application to a particular problem.

The document is organized in thirteen chapters, each addressing a distinct topic area. As summarized in Figure 1-1, the information content of the chapters includes the following:

Chapter 2 provides a step-by-step summary of the user-centered TMC design process. It starts with defining the mission and functions of a proposed TMC, proceeds through the workplace and job design, and ends with methods of test and evaluation to evaluate alternative solutions and to ensure that the desired performance is attained.

Chapter 3 provides more detail on the initial analysis process used to define system functions, operator roles in those functions, and specific operator tasks.

Chapters 4, 5, and 7 summarize mental and physical characteristics, capabilities, and limitations of human operators that should be taken into account during detailed design of the TMC and the jobs to be performed in it.

Chapter 6 describes how TMC jobs (e.g., task assignments and work schedules) should be designed to take these human characteristics, capabilities and limitations into account.

Finally, Chapters 8 - 13 provide details of human factors design guidelines and recommendations for the TMC environment and equipment. These may be used in designing TMC configuration items (e.g., procedure manuals or custom visual display software) or in evaluating vendor proposed items (e.g., computer monitors or operator seating).

Human Factors Guidelines for Traffic Management Centers

System and Task Analysis	Human Error and Performance	Equipment Design and Ergonomics	Human Design for Information Systems	End Matter
1 Human Factors and the TMC	4 Human Error	7 Anthropometry and Design	11 User Interface	References
2 The Human and the System	5 Human Performance	8 Display Devices	12 User Aiding	Glossary of Terms
3 Analyzing a Task	6 Job Design	9 Input Devices and Controls	13 Presenting Data	Index
		10 The Workspace		

Figure 1-1. Organization of document.

1.4   The Audience and the Scope

One of the most important decisions made in the development of this document was the definition of the user. There are many existing models for possible guideline styles already in existence and serving a variety of audiences. Some are intended for use as references by human factors engineers, some as evaluation tools for inspectors, some as guidelines for system specification. Some emphasize legal requirements, some provide wording for specification of system attributes, and some are virtually encyclopedias of human factors knowledge. None of these models proved entirely satisfactory for the TMC design environment because the intended audiences were not appropriate.

1.4.1   Intended for the TMC design team

No single person will design a TMC. The composition of a design team will vary, but will generally be drawn from these sources:

- **!** State and local DOT engineers developing procurement specifications.
- **!** General contractors responsible for designing and building a new TMC or renovating an older one.
- **!** TMC hardware and software developers and vendors.
- **!** TMC managers and engineers designing TMC upgrades.
- **!** TMC operators who serve as subject matter experts.
- **!** Human factors engineers who are members of the design team.

1.4.2   Assumes limited team knowledge of human factors

We presume that most members of the TMC design team will have only sketchy knowledge of the benefits, processes, and practices in human factors. Most users will have a strong background in other engineering fields such as civil engineering, traffic engineering, architecture, and computer science. However, it is strongly recommended that a qualified human factors engineer be included on the design team.

1.4.3   Intended for use with minimal reliance on other sources

Our surveys of existing TMC's suggest that human factors references generally applicable to control room and related designs are neither present nor readily available to TMC design teams. This document is intended to provide stand-alone support wherever possible.

1.4.4   Intended for existing and evolving TMC's

New TMC's are under development and many existing TMC's are in the process of evolving into ATMS-level facilities. This document is intended to serve the needs of all levels of development: legacy TMC's, migrating TMC's, and ATMS TMC's:

- ❗ **Legacy.** TMC's include facilities that are equipped and configured in the style of the 1970's and 1980's — essentially, first generation TMC's with relatively low automation, limited scope of operations, aging systems, and no immediate plans for extensive modernization. This document can be used by these facilities to get the most out of their existing resources while waiting for the next developmental step.

- ❗ **Migrating.** TMC's are those presently in the process of modernization from earlier missions, standards, and equipment toward the goal of ATMS capability. The guidelines in this document provide material for modifying equipment and procedures with frequent reference to the experiences of TMC's in the migratory process. Many current TMC's were built for *surface street* operations. New ATMS facilities will combine streets, highways, and intermodal ITS functions. This document will assist those TMC designers that are expanding their activities to cover new functions.

- ❗ **The ATMS.** TMC is still evolving and developing. Widely accepted standards and architectural conventions for the ATMS facility have not yet solidified, and it is likely that the experiences of design teams that use the first edition of this document will be among the richest sources for the learning processes that will inform developers of later editions as well as the next accepted definition of an Advanced Traffic Management System. A selection of lessons learned is included in the document so that the development of later facilities will avoid rediscovery of others' mistakes and successes.

1.5   How the Guidelines were Prepared

Preparation of this work required the efforts of a number of experienced human factors engineers and traffic management experts. It will help the user of this document in understanding why it is organized and written in the present form if we review the process that guided its development.

1.5.1   Definition of requirements

To help define the TMC designer's needs for human factors guidelines, the requirements analysis included an extensive survey of a number of information sources. It should be emphasized that the design of the guidelines document was user-centered in its philosophy and process. To define the user requirements, we:

! **Visited existing TMC's.** Members of the team inspected sites in the United States, Canada and Europe, conducting interviews on TMC design methods and operations, collecting lessons learned, and observing operations.

! **Surveyed existing human factors guidelines.** The resources included works on human factors engineering such as textbooks, the *Human Factors Design Handbook*, Department of Defense handbooks and Military Standards, National Aeronautics and Space Administration (NASA) and International Standards Organization (ISO) standards, nuclear regulations, and private sector guidelines.

! **Conducted formal surveys of human factors information needs.** This collection included questionnaires and formal personal interviews with managers and operators at multiple sites.

! **Coordinated with a user group of TMC managers.** Early in the design process, we designated a user working group composed of managers and engineers from selected representative sites. This group has met and corresponded regularly, and has reviewed the document in its various drafts, providing a user perspective.

1.5.2   Sources of information and guidelines

The principal sources that provide the guidelines and background information to meet these defined requirements for this document include:

! **TMC experience and practice.** This information was gathered during the requirements analysis phase (and continues to be generated). Many of the common guidelines for human factors engineers are eloquently stated in these practical insights, and have been added as guidelines where they expand or clarify more generally-accepted standards and rules of thumb.

! **Lessons learned during design and operation.** The wise designer learns from the mistakes and successes of others. The requirements analysis yielded a wealth of examples of practices and design aids that will be helpful to any TMC design team.

! **Observations from site visits to TMC's.** Human factors engineers often detect lessons and opportunities that the TMC managers and operators would miss. TMC staff members become accustomed to minor annoyances and problem workarounds. Frequently they are unable to attribute an identified problem to its ultimate source. Outside observers prepared to evaluate activities and facilities from a human factors perspective often identify important human factors issues and design deficits that insiders never notice.

- ! **Research in a TMC simulator.** A series of human factors experiments was conducted in a high-fidelity simulator of a generic advanced traffic management center. The simulator provided up to four operator workstations, CCTV monitors and controls, a large-screen projection display, graphics computer monitors and keyboards providing access to various automated support systems, voice communication systems, and simulated cellular telephone calls. Experiments covered design questions that surfaced during visits to existing TMC's and discussions with their operators and managers.

- ! **Existing references.** Many of the guidelines are adapted from human factors references in wide use. TMC control rooms share many common features with other facilities that have similar roles (e.g., air traffic control centers, military command posts, nuclear plant control rooms). Some human factors guidelines are virtually universal in their application. In addition, we surveyed the current literature available in textbooks, corporate guidelines (e.g., work station standards used by International Business Machines), and the journals of scientific research in the field.

1.6   How to Use the Guidelines

This document is organized for systematic reference and use. While design guidelines serve as the foundation of the document, a simple list of guidelines can lead to misapplication of the information and suggestions unless the designer understands the rationale and technical context. This book is much more than a compendium of guidelines. To make this a useable document, guidelines are accompanied by didactic material intended to provide context, rationale, and implementation guidance.

Also, the usefulness of the document will be significantly increased if it is employed with the guidance and review of a human factors engineer, at least at critical points in the design process (See Chapter 2 for suggestions on the critical points of user-centered design). It *does* provide the information necessary to guide designers to the key issues, and to assure that designs make the best use of human resources and avoid common mistakes. But it is best used as an adjunct to professional knowledge.

Most, but not all, chapters contain specific design guidelines. These design guidelines are embedded in the explanatory text but are easy to identify because they appear in a distinct typeface and are marked by a reference number. Guidelines are referenced by the chapter in which they are cited and by their numeric sequence in that chapter. Guideline 8/25, for example, is the 25th listed guideline in Chapter 8 (Display Devices).

There are three general categories of guidelines in this document, *principles, recommendations, and observations*. These guideline classes are based on their origin, their criticality to operation, and their status in general regulatory and human factors practice.

! **Principles.** These are taken, often verbatim, from widely used and accepted standards — military handbooks and standards, NASA Standards, Nuclear Regulations, and commonly used texts and general handbooks of human factors engineering. Some of these standards, at least in their original context, have what amounts to the force of law behind them — particularly those in such crucial areas as nuclear and occupational safety and health. In all cases they represent *common approved practice*.

8/34   Warning Light Visibility   (Principle; 125)

Warning lights should be visible from the widest possible viewing angle.
Warning or alert lights should not be recessed in panels; a recessed light will be hard to see except from directly in front of the display.

This is a simple statement of a commonly-accepted principle for the design of panel displays that include warning lights. If the light is recessed, it may be visible only to an observer seated directly to the front of the display. Since warning lights must be easily noticed to be effective, it makes sense to design them so they are visible from a wide area. This practice is reflected in a number of sources; the wording used here is taken from, *Human Factors Design Handbook*, by Woodson, Tillman and Tillman (Second Edition, 1992). [125] It is also found in one form or another in MIL-STD 1472D, *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities* and other handbooks, standards, and regulations. [38]

In this guideline, as in most, explanatory text has been added to increase the guideline's usefulness. The added discussion is identifiable because it is not rendered in boldface like the guideline itself, but *is* in a distinct sans-serif typeface.

! **Recommendations based on research.** As a relatively new discipline, the body of knowledge in human factors engineering is rapidly changing and expanding. There are countless cases in which peer-reviewed and published research results suggest new design recommendations and guidelines. This is particularly true in such areas as information systems and their associated human/system interface. In such cases, the most reliable published research and other peer-reviewed recommendations were gathered and crafted into appropriate guidelines for the TMC.

This was not an easy process. Many published experimental results had not been available long enough for replication and validation. In fact, such guidelines were added *only* when they addressed an important design issue that was not covered by more seasoned standards.

This example from Chapter 11, illustrates a reference to recent research:

11/50 Selection of Verbs   **(Recommendation; 51)**

Select action verbs as command names.
For example, "save" is considered a better command name than "file" for specifying the action of retaining work for later use. One reason for this is that "file" is both a noun and a verb and users typically think of the noun first. "Save" is less ambiguous.

The parenthetical (Recommendation) on the guideline title indicates that this is a provisional guideline based on recent research and that it has not undergone the rigorous review and testing required to make it a principle.

! Suggested practices based on observation and TMC experience/ lessons learned. Quite a few very topical guidelines emerged from the site visits and interviews; many were too good to pass up even if they are not derived directly from experimental data.

This guideline, from Chapter 8, is of the "observation" variety:

8/1   Amount of Detail on Display   **(Observation, 125)**

Avoid excessive detail on the large map or status board.
Leave the detail to operator displays. Packing in detail usually requires reduction in size of individual characters and symbols, which are hard to discriminate in a TMC control room environment. This is particularly true for video-projection displays, which at present have an inherently limited resolution.

This particular point came from a widely used reference (125 — *Human factors Design Handbook*) as well as from our observations of display formats in several TMC's. However, it is so general that it is not usable as a guideline without other, more specific, information (in this case, precise principles for character size and readability, which are referenced). The principal difficulty is that "too much detail" is hard to define as a general rule; it depends on the level of training and experience of the operator, the style and purpose of the display, the task loading, and other variables. The explanatory text is added in this case to place this rather vague design principle in the context of the TMC "big board."

1.7   A TMC Design Scenario

An overview of the process by which a fictional TMC might be developed is used in this section to provide an example of the requirements oriented, user-centered design process. In this overview, important points at which involvement by human factors engineering specialists should be used are indicated. The reader is also referred to the specific sections of the document in which methods used by the human factors engineering consultants are found.

The following sections describe one specific design scenario for a city with unique traffic problems, unique objectives, and unique evaluation criteria. Other ATMS applications and objectives may easily lead to different design approaches and decisions.

1.7.1   Defining the Environment

Bayside is a fictitious small city of a million or so population in the Midwest. An interstate highway runs north-south through the city just west of the prospering downtown area. A major, divided state highway crosses Bayside west to east runs just south of the downtown and terminates at the lakefront. A large university in the center of town, southwest of the interchange between the interstate and the divided state route, is a major traffic generator, especially during special sports events and concerts. A second traffic generator is a beach resort area and amusement park on the eastern edge of the city that attracts both local and vacation traffic. A regional airport 19.3 km (12 mi) north of the city center is not a major factor in the traffic flow.

The layout of arterial streets and highways is basically a grid with on-off ramps to the interstate and divided state route approximately every mile. Morning rush traffic creates congestion in the southbound interstate lanes and the eastbound divided state route lanes as commuters approach the downtown and university areas. Evening rush hours are reversed with northbound and westbound congestion. Rush hours experience an average of five minor incidents (one lane blocked) and one major incident (two or more lanes blocked).

Major events at the university create substantial congestion around parking lots, surface streets and frequently spilling back onto the interstate. Fine summer weekends frequently produce backups as much as 4.8 km (3 mi) long on the divided state route as it nears the lake shore area.

Weather is a significant factor in traffic flow. During the summer, frequent heavy thunderstorms create accidents and congestion. During the winter, fog, ice, and snow are common and create incidents and congestion. Inclement weather can easily triple the number of incidents experienced.

City and state transportation officials have determined that certain elements of an advanced traffic management system would likely be effective in reducing some of the traffic problems. A combination of sensors, communication devices, and control devices, all operating through an advanced traffic management center is envisioned.

Numerous steps are required in the design of the ATMS. The steps in a requirements-oriented, user-centered design process are detailed in Chapter 2. The process described generally follows the flow of activities shown in Figure 2-1. Some of these activities can be performed by the traffic engineer, civil engineer, or architect without need for human factors engineering guidance; in other steps, employment of a human factors engineer can pay long-term dividends.

It should be noted that this design process is an iterative process of design, review, testing, and refinement at each step. The earlier in the design process that corrections and adjustments are identified and made, the smaller the cost in money and time to make the changes.

1.7.2   Advanced Traffic Management System Mission Analysis

The initial step in the mission analysis is to document the system objectives and requirements. The objectives of the Bayside ATMS are defined in terms of solving identified traffic management problems. System requirements then are defined to describe, without defining specific hardware, the steps by which the objectives should be met. These can be defined by local traffic engineers or by traffic engineering consultants. Expertise in human factors engineering is not a prerequisite for this step.

System objectives for Bayside, based on a listing of typical traffic management problem scenarios, would include, but not necessarily be limited to the following:

- ! Minimize inbound rush hour congestion.
- ! Minimize outbound rush hour congestion.
- ! Reduce the impact of incidents on traffic flow.
- ! Reduce effects of summer thunderstorms on congestion and incidents.
- ! Reduce effects of snow and ice on congestion and incidents.
- ! Reduce congestion related to inbound and outbound university stadium special   events traffic.
- ! Reduce congestion related to inbound beach traffic.
- ! Coordinate maintenance of ATMS infrastructure.

For each of these objectives, requirements for information collection, information processing, response selection, and decision execution are then derived. For Bayside's identified objectives, these might include:

Minimize inbound rush hour congestion.

- **!** Measure traffic speed and volume.
- **!** Detect traffic congestion.
- **!** Predict traffic congestion.
- **!** Evaluate traffic situation.
- **!** Evaluate management strategies.
- **!** Select appropriate strategy.
- **!** Execute selected strategy.

Minimize outbound rush hour congestion.

- **!** Measure traffic speed and volume.
- **!** Detect traffic congestion.
- **!** Predict traffic congestion.
- **!** Evaluate traffic situation.
- **!** Evaluate management strategies.
- **!** Select appropriate strategy.
- **!** Execute selected strategy.

Reduce the impact of incidents on traffic flow.

- **!** Detect incidents.
- **!** Evaluate need for intervention.
- **!** Alert drivers to congestion ahead.
- **!** Encourage drivers to divert.
- **!** Encourage drivers to change lanes.
- **!** Encourage drivers to delay travel.
- **!** Coordinate with emergency responders.

Reduce effects of summer thunderstorms on congestion and incidents.

- **!** Detect boundaries and movement of thunderstorm cells.
- **!** Evaluate potential traffic effects of storm.
- **!** Evaluate need for intervention.
- **!** Alert drivers to weather ahead.
- **!** Encourage drivers to divert.
- **!** Encourage drivers to delay travel.

Reduce effects of snow and ice on congestion and incidents.

- **!** Detect snow/ice on roadway.
- **!** Evaluate need for intervention.
- **!** Coordinate plowing/sanding/salting.
- **!** Alert drivers to road conditions ahead.

- **!** Encourage drivers to divert.
- **!** Encourage drivers to delay travel.

Reduce congestion related to inbound and outbound university special events traffic.

- **!** Obtain schedule of special events.
- **!** Plan responses to special event contingencies.
- **!** Check status of surface streets in area.
- **!** Evaluate need for intervention.
- **!** Coordinate traffic with onsite personnel.
- **!** Recommend parking locations to drivers.
- **!** Recommend exit routes to drivers.
- **!** Control traffic on major exit routes.

Reduce congestion related to inbound beach traffic.

- **!** Measure traffic speed and volume.
- **!** Evaluate need for intervention.
- **!** Select intervention strategies.
- **!** Encourage drivers to divert.
- **!** Control traffic on major arterials.

Coordinate maintenance of ATMS infrastructure.

- **!** Become aware of maintenance need.
- **!** Track maintenance resources.
- **!** Determine response to maintenance need.
- **!** Execute response to maintenance need.

1.7.3   Develop a Preliminary Design Concept

The next major step in Bayside's TMC design process is to develop and refine a preliminary design concept for the ATMS. This process identifies candidate approaches for meeting all of the operational requirements developed under the mission analysis, explores tradeoffs between the approaches, and determines how the approaches can be combined into a well-integrated ATMS.

In the ATMS design and development process, there are numerous points at which the project might be handed off to a contractor team. This is one such point. The preliminary design concept can be developed by local and state engineers, by contractor teams during the Request for Proposals process, or as an engineering contract.

The advantage of obtaining significant contractor and vendor inputs at this relatively early point is that a more innovative design concept may result. New, more effective technologies and approaches for meeting the identified requirements may be offered by the vendors. The disadvantage is that some control over the design concept may be lost. Engineers for the Bayside ATMS decided to develop the preliminary design concept in-house but to include a number of independent outside consultants on the design team. These consultants included a human factors engineering company recommended by a human factors researcher from a nearby university.

An important step, that is often skipped, is the appointment of an independent design review team (Section 2.2.2). This team should consist of a group of consultants who have no other relationship to the project. The review team should meet frequently (at least monthly) with the design team to consider design decisions from an outside perspective. Bayside selected managers of two TMC's in the region, and an architect, a traffic engineer, and a human factors engineer from the local university.

In the preliminary design concept, each operational requirement must be defined in detail including:

- Operational scenarios that generate this requirement.
- Prerequisite functions for meeting the operational requirement.
- Candidate technologies and approaches.
- Advantages, disadvantages, costs and benefits for each approach.
- Potential levels of automation for each approach.
- Operator roles and requirements for the selected approach.
- Projected operator tasks and workloads.

As an example, one operational requirement that appears in several objectives and scenarios is that of "Measure Traffic Speed and Volume." There are numerous ways that this can be done including cellular phone calls from probe vehicles, reports of observers, loop detectors in the pavement, closed circuit television cameras, image processing camera systems, acoustic signal processing and radar — to name but a few. Table 1-1 lists several potential information sensors that would be considered and describes the four potential levels of automation for each approach (described in Section 2.2.3) for collecting on-site traffic flow information and sending it back to the TMC.

Table 1-1. Candidate technologies and operator roles for the function *measure traffic speed and volume***.**

Information Source	Operator Role			
	Direct Performer	**Manual Control**	**Supervisory Control**	**Executive Control**
Probe Vehicle	Verbal speed and density reports by phone or radio to TMC.	Speed and density keyed into computer and radioed to TMC.	Speed and density automatically determined. Driver can edit or append data before it is sent to TMC.	Speed and density automatically measured and sent to TMC.
On-Site Observer	Verbal speed and density reports by phone or radio to TMC.	Speed and density keyed into computer and radioed to TMC.	—	—
Closed-Circuit Television	—	Operator views a number of CCTV monitors to obtain a general awareness of the traffic density.	Image processing system counts passing vehicles and displays numbers at each site. Operator may correct the numbers if they appear incorrect.	Image processing system counts passing vehicles at each site and displays the count.
Inductive Loops	—	Operator views raw data from sensors and keys it into the traffic flow data base.	Operator reviews raw data from sensors and consents to its transfer into the traffic flow data base.	Data from the loop detectors is sent directly to the traffic flow data base.
Image Processing	—	Operator views raw data from sensors and keys it into the traffic flow data base.	Operator reviews raw data from sensors and consents to its transfer into the traffic flow data base.	Data from the loop detectors is sent directly to the traffic flow data base.

In this step, expertise in traffic management technology, and in human factors engineering is crucial in identifying and evaluating potential machine and operator roles. Some potential approaches may require computer technologies that are not yet sufficiently reliable. Automated speech understanding of incoming cellular phone calls is one example. Other candidate approaches may require operator performance that is near or beyond the capabilities of the expected operators. Detecting errors in large quantities of alphanumeric data is an example. Such problems need to be identified as early as possible in the design process.

Section 2.2.3 describes several approaches that might be used by the design team's human factors engineers to define the roles of computers and operators in the partially automated system. These include using the classic "Fitts List" approach, evaluation matrices, time-line analyses, operator role assessment, and formal tradeoff studies.

After evaluating each of the alternatives, Bayside selected a fully automated image processing system, with cameras placed every half mile. Trade studies indicated that this approach provides data that is not quite as accurate as an inductive loop detector but that the cost of installation, including the inconvenience of closing lanes and cutting pavement for loop detectors, outweighed the insignificant reduction in accuracy of the image processors. The automated system will collect data on the speed and density of traffic in each lane and transmit the summarized data to the TMC. The operators' role will be to check the veracity of abnormal appearing data points.

After this evaluation process is repeated for every defined operational requirement, a complete list of proposed machine and human functions will be made available to the design team. This list is then reviewed for inconsistencies and completeness by the design team and then the design review team and revised as needed.

The human functions and automated machine functions may then be plotted by the human factors engineer in an information flow chart or a more formal operational sequence diagram (OSD). Figure 2-11 provides a high-level OSD for monitoring traffic. The OSD identifies information and decisions needed to meet the operational requirement, and ensures that these have been accounted for in the selected functions and function allocation. Usually, the design team and design review team will require several iterations of this step before all of the "holes" in the requirements are identified and filled.

1.7.4   Perform Operator Task Analysis

After the tentative selection of technologies and operator roles has been completed and approved, the next step for the human factors engineers is to carefully define the tasks that the operators will be required to perform. The goal is to create a document describing and analyzing every action the operators will take and every decision they will make during a range

of plausible scenarios including normal traffic, congested traffic, special events, various kinds of incidents, and various kinds of inclement weather.

Task analyses generally include conducting detailed interviews with identified subject matter experts. In order to conduct these interviews for the Bayside TMC, human factors engineers would interview experienced TMC managers and operators from another location with similar problems, operational requirements, and goals.

Procedures that might be used by the human factors engineers for the task analysis are detailed in Sections 2.2.4 - 2.2.6. Some guidelines are provided in Section 3.2.5.

For each task in the Bayside TMC, information or estimates are documented for the areas summarized in Table 1-2. [30]

The task analysis document will be used to help define:

- **!** The number of operators needed (and accordingly, the number and size of workstations, and the size of the control room needed to house them.
- **!** The kinds of skills and knowledge people need to serve as operators.
- **!** The design requirements for user-system interfaces.
- **!** The content of operator training courses.
- **!** The content of job aids.

1.7.5   Design Jobs

The operators' job design brings together all the defined operator tasks for a given job classification. The task analysis and job design steps, therefore, are closely related; changes in job design will require the analyst and designer to revisit and modify the task analysis.

Job design combines pencil-and-paper analysis with performance evaluation of live human operators performing the identified Bayside scenarios.

The *number of operators* needed for each shift is largely defined by the expected peaks of workload during the shift. Time line analyses can be performed on the identified scenarios to estimate peak workloads and find points at which several simultaneous operator tasks may be needed.

To answer some design questions, the scenario tasks may be simulated on a prototype computer interface or TMC workstation mockup. Human subjects typical of those likely to serve as operators will perform simulations of the defined jobs. The operator's level of workload and frustration at points in the scenarios can be determined by a questionnaires. If the

workload appears to be too high, the task must be redesigned or the staff size increased. If it appears too low, additional duties may be assigned during slow periods.

Table 1-2. Data obtained in task analyses.

Information Requirements

        What information is required?

        What information is available?

        How do operators evaluate the information?

        How do operators decide what response is made?

        What errors in information handling and decision making are likely?

Action Requirements

        What action do operators take?

        What movements are required by the action?

        How often must the action be taken?

        How precise must the action be?

        How quickly must the action be taken?

        What response errors are likely?

        What feedback do the operators get about their action?

Workspace Requirements

        How much workspace is required by the action?

        How much workspace is available for the action?

        What configuration items (e.g., monitors, keyboards) are needed?

        What job aids are needed?

Staffing Requirements

        How many operators are required?

        How will the operators interact?

Training Requirements

        What is the required level of skill and knowledge?

        What is the expected entry level of skill and knowledge?

        What skill and knowledge must be trained?

Environmental considerations

        What is the nature of the work environment?

The Bayside design staff determined that, during peak traffic hours and special events, four operators would be required for effective traffic management. During mid-day and evening hours, a staff of one or two would be sufficient.

In this design step, operator performance and errors are also explored. Operator performance is largely a function of operator interface design, motivation, and workload. Likely sources of operator error or increased workload are noted from the task analysis and from studies with the control room model. Ways of addressing these with the job design are explored. For those that can't be addressed directly, the potential problems are noted for future exploration when workstation and user-system interface design is done.

1.7.6   Design the Environment

Designing the environment is largely the responsibility of an architect who is experienced in the design of control centers like the TMC. The TMC environment that includes lighting, acoustics, and air quality, has an effect on the performance and motivation of operators and there are established standards and building codes that address these effects.

TMC designers are making ever greater use of computer aided design (CAD) software to assist in designing the environment. A three-dimensional CAD software package allows the architect and designer to change a simple flat floorplan into a rotatable, three dimensional image to allow viewing the control center from a number of different positions and angles.

The layout of the workstations in the center is also an important environmental factor. A link analysis, based on the task analysis data, can be used to approximate the optimal design for the control room layout. In addition, centers frequently provide their existing operators, or consultants, with cardboard or foam models of the candidate building layout. The operators are allowed to experiment with alternate layouts and provide inputs to the design process based on their preferences.

It is also important for designers to explore lessons learned during design and operation of similar facilities. Bayside design team leaders visited a number of newer TMC's to explore their technology, design, and lessons learned. The following is among the lessons they learned in their discussions.

The Bayside design team wanted to provide such an observation balcony but decided to address this "fishbowl" problem by locating the operators workstations directly under the balcony and providing repeater displays in the observation area.

1.7.7   Design the Workstation

The workstation design is based heavily on the operator task analysis and job design. Workstations (including auxiliary equipment such as facsimile machines, copiers, and wall-mounted displays) must be designed to support every defined task that is part of the operators' job. Again, link analysis can be used to optimize locations of the workstation elements and minimize the need to walk between machines, reach long distances for knobs, or view displays outside the normal visual field (e.g., behind the operator). Computer-aided design and rapid prototyping are also effective in designing and evaluating the workstation layout.

Bayside invited vendors of workstation consoles, chairs and other furniture, information displays, communication systems, and office equipment to submit recommendations for workstation equipment. They discovered that nearly every item was described as "ergonomic." These claims were presented to the human factors engineers on the design staff for evaluation. They concluded that only a few of the items were well designed from an ergonomic viewpoint (i.e., they met recognized principles).

1.7.8   Design and Specify Controls and Displays

Design of the user-system interface also is based largely on the results of the task and job design analyses. The user-system interface design includes the specific controls and information displays the operator uses to interact with the system.

For off-the-shelf configuration items (e.g., facsimile machines) design of the controls and displays are established by the manufacturer. Thus, adequacy of the controls, displays, and operating procedures should be part of the trade studies under which the specific brand and model are selected. Initial inspection and evaluation by human factors engineers became part of the basis

for Bayside's procurement decision for these items. For critical items, initial testing of candidate machines to evaluate operators' performance, learning rate, and error rate while performing a sample of identified tasks may be indicated.

Most of the operators' information in the Bayside TMC will be derived from computer monitors and closed-circuit television monitors. The task analysis provides a detailed listing of the information needed by the operator but does not specify the format in which it will be presented. Figure 11-1 provides a summary of the process selected by Bayside for designing controls and display screens. Some guidelines for control and screen design are contained in Chapters 9, 11, and 13. The most important steps, though, involved continued testing and refinement of the candidate interfaces using workstation mockups and rapid prototyping of display screens. The tests used actual operators and subjects with the same demographics (e.g., age, education, intelligence) as the anticipated operators performing tasks in the previously defined Bayside traffic scenarios.

The key to the successful Bayside TMC design project was the continuous and repetitive testing and refinement of candidate design options. The philosophies and procedures of section 2.3 were used from the beginning by designers who made decisions based on small experiments using CAD and rapid prototyping systems, models and mockups. All design decisions were examined by the independent design review team. The result was an ATMS and a TMC that were able to meet the originally defined objectives with a high level of operator morale and performance.

1.8   What Now?

After completing Chapter 1, the following steps are recommended before beginning to use the document in the design process.

> ! **Take time to become familiar with the organization of the document and the sequence of the chapters and topics.** There is no set sequence in which subjects will be treated in the design of a TMC. A good understanding of the document's arrangement will be adequate to support general design discussions.

> ! **Take time to read and understand Chapter 2 (*Principles and Methods of Human Design*), then use other sections as required.** The process of user-centered design, and how this document supports user-centered design, is considered in detail in the next chapter. Chapter 2 also shows how the succeeding chapters can best be used.

CHAPTER 2: PRINCIPLES AND METHODS OF USER-CENTERED DESIGN

CONTENTS

2.1 User-Centered Design Considers the End User

The term *user-centered design* refers to a design philosophy in which the user is viewed as a critical system component whose characteristics, capabilities and limitations need to be defined and considered during TMC requirements analysis and design. The fundamental principle of user-centered design can be stated as follows: *Involve the user at the earliest stages of design and continue this involvement throughout the design and test/acceptance process.*

Contrary to this philosophy, TMC design programs frequently adhere to a *technology-centered design* approach in which procurement of advanced hardware and software is the focus. Issues concerning human users — in particular, *how* these users will interact with the technology — may not be considered until after the system is designed.

The goal of this chapter is to introduce TMC designers to the process and techniques of user-centered design. In this chapter a series of activities and decisions that comprise this

design approach are summarized. This introductory material is presented for general guidance and should be applied with the support of an experienced human factors specialist.

Figure 2-1 shows the general sequence of activities associated with user-centered design. These processes are described in Section 2.2. Guidelines for each of these activities are contained in the referenced chapters.

The process, though, is not as linear as the design activity list suggests, and most activities are iterative (done repeatedly). Iterative design enables system elements and procedures to be defined, refined, and evaluated in a series of cycles. As each critical element is added to the system design, the design team will, whenever possible, evaluate its adequacy and its impact on the remainder of the system. Test and evaluation methods appropriate for the TMC are presented in Section 2.3.

Software design packages (e.g., rapid prototyping tools and computer- aided design (CAD) tools), along with traditional modeling and simulation techniques, can improve the cost effectiveness and timeliness of iterative design approaches.

2.2 The User-Centered Design Process Consists of a Series of Steps

In this section, the steps to be applied in any user-centered design process are described. Eleven major steps are included in this process:

- **!** Conduct a mission analysis.
- **!** Prepare a design concept.
- **!** Conduct function analysis and allocation procedures.
- **!** Conduct an operator task analysis.
- **!** Identify sources of human operator error.
- **!** Identify human performance constraints.
- **!** Design jobs.
- **!** Design the work environment.
- **!** Design and specify workstations.
- **!** Design and specify controls and displays.
- **!** Design and specify user interfaces.

The description of each design step includes four elements: (1) reasons for completing the step, (2) information that will support the step's completion, (3) procedures for completing the step, and (4) methods and tools that will assist designers in completing the step.

DESIGN ACTIVITY	CHAPTER											
	2	3	4	5	6	7	8	9	10	11	12	13
MISSION ANALYSIS	■											
SCENARIO DEVELOPMENT	■											
DESIGN CONCEPT DEVELOPMENT & REVISION	■											
FUNCTION ANALYSIS		■										
FUNCTION (ROLE) ALLOCATION	■											
TASK ANALYSIS	■	■										
HUMAN PERFORMANCE CONSTRAINTS				■								
ERROR ANALYSIS / CONTROL	■		■	■	■							
TESTING & EVALUATION	■											
JOB DESIGN / TASK ALLOCATION					■							
HUMAN MOTIVATION					■							
WORK LOAD ANALYSIS		■			■							
SCHEDULE DESIGN					■							
WORKPLACE DESIGN						■	■	■	■			
WORK ENVIRONMENT									■			
WORKSTATION FURNITURE						■			■			
DISPLAYS							■					
CONTROLS								■				
USER-COMPUTER INTERFACE										■		■
USER AIDS											■	

Figure 2-1. Activities in the user-centered design of a TMC: chapter reference (Matrix indicates primary distribution of design activities among chapters).

The sequential aspect of system design "steps" can be misunderstood and over-applied. The steps to be described in this section have no rigid ordering scheme nor are they independent. A function allocation strategy, for example, may depend on the level of engineering expertise required of operators (a job design issue). Job design, however, depends on the function allocation process. Consequently, a reasonable approach is to perform both steps in parallel.

Consider the problem of arranging wall displays (e.g., closed circuit television monitors,

dynamic map displays) within a TMC. The arrangement for such displays will depend on the arrangement and configuration of operator workstations. Workstation operators will require visual access to wall displays. (Console height, for example, must not interfere with display visibility.) Workstation configuration depends on the nature of operator tasks, and the nature of operator tasks helps to determine the best arrangement of workstation controls and displays. Characteristics of workstation displays interact with illumination levels, and illumination levels impact the design of wall displays.

This does not suggest that designers ignore a sequential ordering of design steps. Instead, designers are reminded that no step can be considered in isolation. In performing iterative, user-centered design, the most dangerous error is to view the set of design steps as a series of checklist items, where completion of a given step implies that it can be "checked off" and forgotten.

2.2.1   Conduct a mission analysis

The first step is to identify the operational capabilities required of the new or modernized TMC. This is the most essential single activity in the design process. Fundamental errors at this point, most frequently underestimates of total system requirements, can negatively impact an otherwise organized design effort.

Why should designers conduct a TMC mission analysis? Any design effort should begin with an intended destination – the functional mission of the design product. Many designers, however, can remember design programs that ignored this rule and consequently terminated in a minimally useful product. In some cases, destinations change because of decisions reached by authorities external to the design team. In other cases, real-world conditions change. New technologies that show obvious application and promise in traffic management may be developed. Project funding may be reduced. Mission requirements may be extended as a result of changes in philosophy or traffic burden.

A more serious error in establishing the TMC mission can result from what is otherwise considered to be a strength of any well-founded design team: real-world traffic management experience. Too much experience, and too little critical evaluation of that experience, may (perhaps inadvertently) bias designers against new ideas. Basing a new design on previous successes is a reasonable approach only when earlier design contexts match the existing design context. By applying ideas and principles that have worked before, designers may actually perpetuate inappropriate design solutions.

In establishing a realistic TMC mission, the design team must consider traffic management conditions that will arise during the entire life-cycle of the proposed TMC, not only on existing conditions, or on those that have occurred previously. By establishing such a mission statement, designers will, in effect, *anticipate* future TMC responsibilities, and thus visualize a TMC that can adjust to changes in real-world conditions.

Several sources of information support development of the TMC mission statement. Projected traffic management needs for the United States are currently being examined, and a

picture of the future is gradually coming into focus. The emerging emphasis is summarized in the *Strategic Plan for Intelligent Transportation Systems in the United States*, *Federal ITS Program Plan* and in other reports published periodically by the US DOT and ITS America.

Procedures for analyzing the TMC's mission are available. A procedure for defining the TMC mission is presented in Figure 2-2. An assessment of outside sources of experience and information is critical to this approach. This includes relevant research literature, practices at other TMC's (given that these TMC's have missions similar to the one being defined) and — in particular — recent experience with newer design strategies and technology. Reasons for proceeding in this manner are summarized below:

! Using only local experience can needlessly limit a TMC's mission definition. By relying solely upon local experience, designers run the risk of inadvertently perpetuating design concepts and practices merely because they are familiar. A conservative bias of this type can cause the design team to miss opportunities to enhance the mission definition of the TMC.

! Site visits are preferable to remote data collection methods (e.g., surveys, telephone interviews). By *directly observing* the effects of innovative design approaches, designers can obtain an intuitive understanding of such design approaches. Additionally, the benefits of implementing innovative design techniques are readily apparent.

! Formal working groups that represent TMC and human factors communities will provide a more extensive range of TMC mission knowledge than working groups that represent only designers and architects.

! Scenarios and mission profiles (described below) encourage designers to assess the TMC's mission within the context of potentially occurring traffic management events. They also provide a mechanism for assessing possible deficiencies in software tools that are currently being marketed to the traffic management community.

The numbers to the upper right of activities are unique identifiers. For example 2-2.2 refers to figure 2-2 and the 2nd activity.
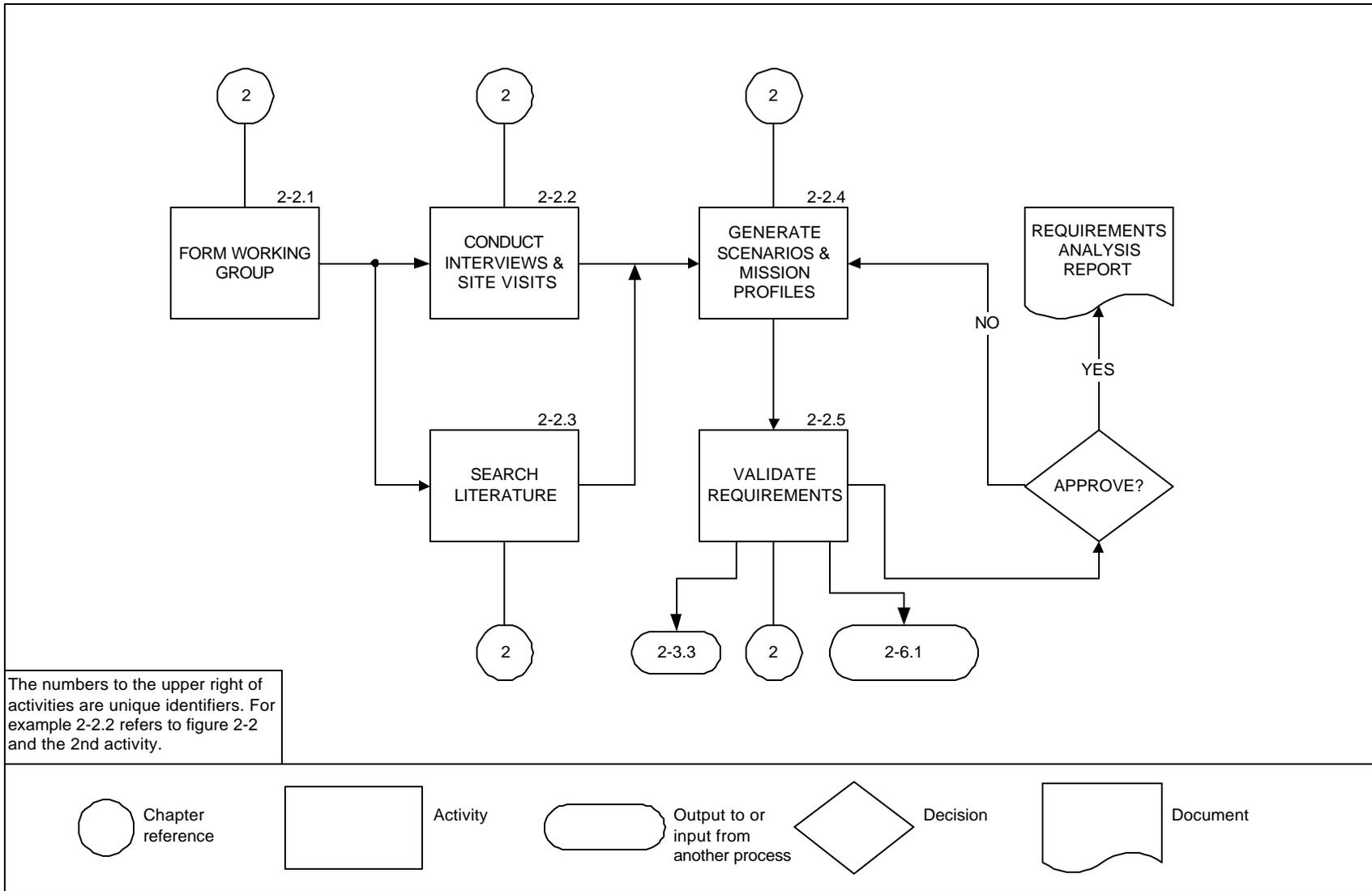
Figure 2-2. Recommended procedure for TMC requirements analysis.

Methods and tools for completing a TMC mission analysis are available. Years of practice have established a number of approaches that are useful in the conduct of mission requirements analyses. The two most effective — mission profile development and scenario development — are applicable to the ATMS TMC.

! **Mission profile development.** A *mission profile* is a detailed description of normal system operations that occur during a given system activity or over a given period of time. Each TMC will have a slightly different mission profile because of unique traffic conditions and TMC goals. The profile developed at this stage of system development will be somewhat tentative since the mission definition will be refined iteratively. The mission profile is a useful precursor to a task analysis, function allocation procedure, and task allocation procedure. It also contributes to job design, selection, and training activities.

The profile consists of a list of functions to be performed by the total TMC system. The list includes simultaneously-performed activities (e.g., automated tasks performed by system hardware, operator assessments, operator decisions). Activities are described at a fairly high level and no attempt is made to define the roles of operators or automated systems in performing them. This technique provides an organized, high-level framework of system requirements that will support subsequent, detailed design analysis.

! **Scenario development.** Descriptions of specific *scenarios* — non-routine but typical situations that would challenge the capabilities of the TMC — are sometimes useful in providing an understanding of the TMC's mission. Scenarios might describe freeway incidents, conditions surrounding major traffic stressors (e.g., large athletic events, inclement weather), or strategic planning episodes (e.g., hurricane evacuation). Reference (46) includes several examples of TMC scenarios.

2.2.2   Prepare a design concept

The remaining 10 steps of user-centered design address the development of a TMC configuration. This configuration is based on the mission analysis introduced in Section 2.2.1 and described in Chapter 3. Once the mission requirements have been considered, the design team should create a preliminary design concept for the ATMS TMC. Initial design ideas represent a "strawman" concept that will change over time, but the "strawman" will provide a working structure for the design team.

While creating a design concept might seem premature at such an early stage in the design process, having a "strawman" TMC will help designers organize ideas and information that develop and arrive from multiple sources. As work toward the final design concept proceeds incrementally, the preliminary concept will provide a framework for initial assessment, and — more importantly — impose a structure that prevents design ideas from being evaluated *independently of the total system, in particular, the user*. The final design may have little in

common with the original concept, but experience suggests that modifying an existing plan, rather than correcting a design that has been implemented, is an effective use of design time.

Several sources of information can help in developing an initial design concept. The preliminary design concept will be developed from a number of models and existing structures. These include professional experience, experiences in other TMC's, experiences in other control room environments, and human factors engineering.

- **❗ Professional experience.** The design team should place a high value on the judgment of experienced traffic managers. The experience of individual members of the design team should also be considered. The main advantage of relying upon previous design experiences is a more efficient use of design time (i.e., avoiding the unnecessary rediscovery of standard (as well as poor) design practices). One disadvantage of relying only upon previous experience is an inevitable bias toward known design approaches.

- **❗ Experiences in other TMC's.** Site visits and literature reviews can provide fresh perspectives. New perspectives are especially important during transitions from traditional TMC's to ATMS-level TMC's. Existing TMC's represent a range of developmental stages. They have also had many opportunities to experience successes and failures. An active exchange of ideas will, at the very least, expose the design team to lessons learned from other TMC design efforts.

- **❗ Experiences in other control room environments.** TMC's and other types of control rooms have many characteristics in common. Air traffic control centers, military command and control centers, and broadcast studios, for example, perform activities that are similar to those of the TMC. In addition, technologies found in other control room environments will also be found in the TMC. Reference (73) provides descriptions of TMC elements and conditions at comparable facilities.

- **❗ Human factors engineering.** The design team should include human factors engineers. At a minimum, human factors engineers should review progress and be asked to make recommendations at critical points in the design process. If formal test and evaluation is being considered, a human factors review is essential. The testing and evaluation of designs that include roles for human operators should be planned by human factors specialists.

Procedures for preparing a TMC design concept are available. The procedure represented in Figure 2-3 — while it may seem cumbersome to execute so early in the design program — provides important advantages. The parallel efforts of a design team and a review panel will supply independent reviews of the concept *before* extensive development has been completed. The design team is subject to the inherent tendency of any small, independent team. Members of such groups typically bring ideas that may go unchallenged — even if *individual* members recognize their error — because of problems in human interactions. A review panel, however, evaluates from a perspective that is *outside* the closed environment of the design

team. This perspective will help in alleviating a number of prejudices.

! **Establish the design team.** This team need not include the same individuals who defined the TMC mission, although an overlap is likely. The actual composition of the team will be driven by the requirements of the TMC. Design requirements for a new TMC facility will differ from those for an existing facility that is to be modified so that it can meet new demands and incorporate newly-developed technologies. The application of user-centered design implies that end users (e.g., experienced TMC operators and managers) will be included on the design team.

Again, it is recommended that a qualified human factors engineer be included. Such experts are available on a consulting basis. In addition, many universities offer programs in human factors engineering. These programs may reside in engineering departments (typically industrial engineering) or in psychology departments.

! **Establish a review panel.** Because the role of the review panel is to offer an *outside* perspective, it should work independently of the design team. Members of the review panel should *not* participate as members of the design team. The review panel might include traffic managers from other TMC's, experts from other operational areas requiring control room facilities, academic researchers, professionals from government and industry, and traffic engineers.

! **Develop the draft preliminary concept.** The initial concept is a preliminary design. This preliminary concept may not be recognizable in the final TMC, but it provides a flexible foundation around which the design effort evolves. What agencies will reside in the TMC? With whom will they communicate? What ATMS resources will be located on the roadways and how might they be monitored/controlled? The concept may be composed of sketches, design guidelines, design objectives, and elements of a strategic plan. The strategic plan should guide the program management effort from beginning to end: schedules, resources, task dependencies, and critical paths.

! **Validate the draft preliminary concept.** At this point, the review panel should examine the draft preliminary concept and strategic plan. As indicated earlier, the review panel will provide a fresh perspective, and it may identify inappropriate assumptions made by the design team.

! **Prepare the preliminary concept.** The preliminary design concept should include concept sketches and line drawings, preliminary estimates of staffing and automation requirements, and key design challenges identified by the design team and review panel.

The numbers to the upper right of activities are unique identifiers. For example 2-2.2 refers to figure 2-2 and the 2nd activity.
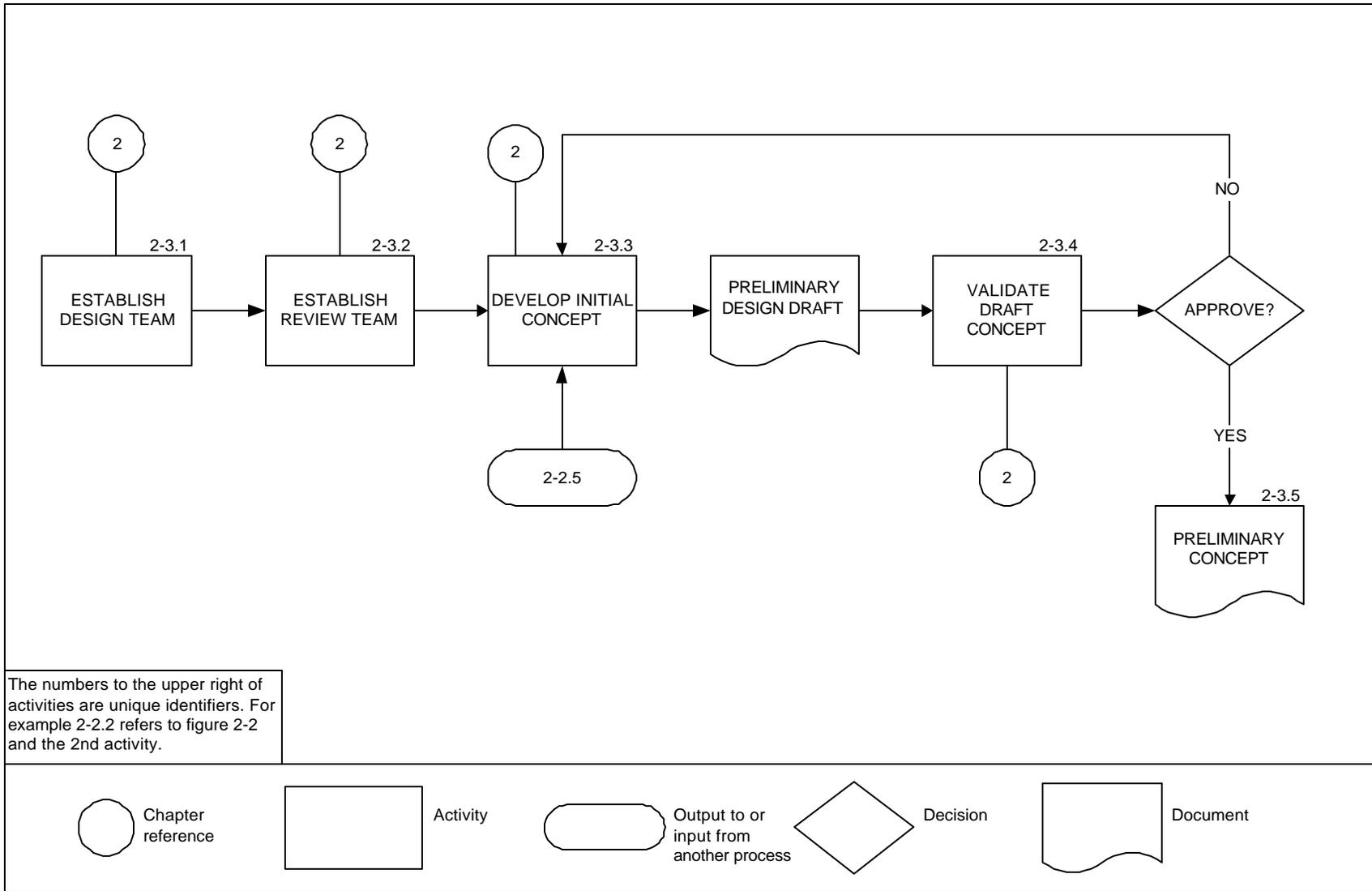
Figure 2-3. Recommended procedure for establishing TMC design concept.

Methods and tools for preparing a design concept are available. A variety of possible techniques to support the preparation of a preliminary design concept are available. They include brainstorming, the Delphi method, questionnaires and interviews, and site visits.

> ❗ **Brainstorming.** This technique — typically used early in the process — progresses from a relatively unstructured distribution of ideas to a more detailed evaluation and prioritization of ideas. Brainstorming helps to evoke ideas, identify possible problems and opportunities, and forge the design team. Recently a more structured approach has been introduced under the general label "groupware." This approach uses elements of brainstorming, the Delphi method (described below), and other group decision aids. It differs from traditional methods in that it is a computer-mediated approach.
>
> The advantages of this groupware approach include relative anonymity of participants (who interact through workstations), the ability to conduct sessions on a long distance basis (given an appropriate electronic networking capability), and the availability of a verbatim record of ideas. It also allows an activity report to be produced immediately after the conclusion of a session. Immediate availability of such a report will help participants continue off-line discussion. While the technique is not inexpensive, it can facilitate an efficient use of design time.

> ❗ **Delphi method.** The Delphi method is more formal than brainstorming, and it forces a fusion of ideas. A group composed of subject matter experts is asked to respond anonymously to questions from a group leader. The Delphi method forces a consensus among members of the group. Since responses are not attributed to specific participants, status or personal persuasiveness is less likely to impose undue influence. (77)

> ❗ **Questionnaires and interviews.** Questionnaires and interviews allow a relatively efficient polling of subject matter experts from (1) other TMC's, (2) the research and industry communities, and (3) control room environments similar to that of the TMC.

Designers should recognize that questionnaire development requires considerable skill and experience. Flawed questionnaires may cause errors or deficiencies in TMC design to be perpetuated. It is suggested that the design team seek assistance from individuals who have expertise in questionnaire preparation. The possible expense in consulting fees will most likely be offset by the collection of more useful information. Reference (47) includes an example of a questionnaire that was successful in obtaining information on TMC requirements.

> ❗ **Site visits.** No questionnaire or telephone interview will yield as much information as a visit to another TMC or control facility. In the preparation of this document, the authors visited nearly a dozen traffic management centers in North America and Europe. *No designer is so educated in the opportunities for TMC improvement that he or she cannot discover something new.*

Note that rules for conducting on-site interviews are the same as those for long distance

(questionnaire-type) interviews. The interviewer must ask the "right" questions. In order to compose such a list of questions, the interviewer must carefully prepare, edit, and test an interview "script."

2.2.3   Conduct function analysis and allocation procedures

Function allocation is the assignment of system functions to machine components, human operators, or to a combination of human and machine components. Details of the function allocation process are presented in Chapter 3.

The first stage of the TMC design effort is a thorough analysis of TMC functionality. In others words, the design team considers what the TMC will actually do (function analysis). User-centered design implies consideration of the human operator as an integral part of the TMC.

Why should designers analyze and allocate functions? The process of designating who (human operator) or what (machine) will perform a given function is as old as human factors engineering. This process is formally referred to as *function allocation*. Appropriate function allocation is the cornerstone of effective TMC operation, and the design team should devote a significant amount of effort to the function allocation process.

One goal of ATMS development has been increasing levels of automation. But automation must not be applied blindly. During any function allocation process, designers must have access to a reliable approach for assigning an *appropriate* level of automation to a given TMC function. The most appropriate roles for human and machine components must be determined. Figure 2-4 defines a continuum of human operator roles such that at one end of the continuum, a function is allocated solely to a human operator, and at the opposite end, a function is allocated solely to a machine. Between the extremes, function execution is shared by human operators and machines.

The continuum of roles is divided into four regions, in which each region corresponds to one of four operator roles. Each region implies a level of automation. Operator roles are direct performer (no automation), manual controller (operator performs decision-making activities), supervisory controller (operator has the ability to override a machine-made decision), and executive controller (operator enables or disables execution of a fully-automated function).

The term *controller*, associated with three of the four operator roles, implies that operators control machine components. The fourth role, associated with the term *performer*, implies that operators directly perform a function, rather than merely control or supervise machine components. The most advanced TMC's (currently in the planning stages) will operate at a level that is somewhat to the right of the continuum's center. Current technology does not permit a TMC to operate under complete executive control (i.e., where all functions are completely automated).

NO EQUIPMENT
IN THE LOOP → INCREASING USE OF
AUTOMATION → NO OPERATOR
IN THE LOOP

"DIRECT PERFORMER" REGION	"MANUAL CONTROLLER" REGION	"SUPERVISORY CONTROLLER" REGION	"EXECUTIVE CONTROLLER" REGION
• HUMAN CLOSES LOOP • CONTROL LOOP COMPONENTS PREDOMINANTLY HUMAN	• HUMAN CLOSES LOOP • CONTROL LOOP COMPONENTS ARE A MIXTURE OF HUMAN AND MACHINE	• HUMAN OR MACHINE CLOSES LOOP • CONTROL LOOP COMPONENTS ARE PREDOMINANTLY MACHINE	• MACHINE CLOSES LOOP • CONTROL LOOP COMPONENTS ARE MACHINE ONLY • HUMAN MAY START OR STOP FUNCTION

Figure 2-4. Hypothesical continuum of hamun operator roles (after Folds, et al., 1993)

Operator roles are defined more precisely by considering the manner in which information is processed within a function. Figure 2-5 represents the information processing behavior that might occur as TMC functions are executed. Each function is defined in terms of four stages of information processing: input, processing, response selection, and output. At the input stage, information is received from an external source by a *sensor*. At the processing stage, received information is manipulated by a *processor*. At the response selection stage, a *controller* decides what control actions are to be performed. At the output stage, an *actuator* executes control actions.

Several sources of information support completion of the function allocation process.
No hard and fast rules govern TMC function allocation (or for that matter, function allocation in any other control facility). Chapter 3 provides a detailed discussion of the function allocation process, as well as task analysis topics. Other potential sources of information are questionnaire/interview results, design team experience, and review panel experience. Research documented in human factors journals, *ITS Journal*, and proceedings from ITS conferences may be helpful. Reference (47) includes a thorough discussion of ATMS function allocation.

Procedures for completing the function allocation process are available. Figure 2-6 depicts a typical procedure for allocating system functions.

- **Define the function.** Each function must first be defined *operationally* — that is, in terms of the system activity to be performed (e.g., *post travel advisories on information outlets*, *monitor compliance with current advisories*). Operational definitions reduce ambiguity and overlap and are necessary preparations for subsequent operator task analysis activities.

- **Apply allocation criteria and guidelines.** Each function should be examined in terms of accepted function allocation *criteria*. Examples of such criteria are provided in the Fitts List in Table 2-1, and in Section 3.2.2 (Guidelines 3/1 to 3/15). These criteria and guidelines allow the design team to complete a "first pass" function allocation, during which functions obviously suited to the human operator and those obviously appropriate for total automation can be identified.

Experience suggests, however, that many functions will fall into neither category. Instead, each of these functions fall into a questionable area (e.g., manual controller and supervisory controller regions), where no single rule of thumb is convincing enough to provide an answer. In such cases, further assessment is required.
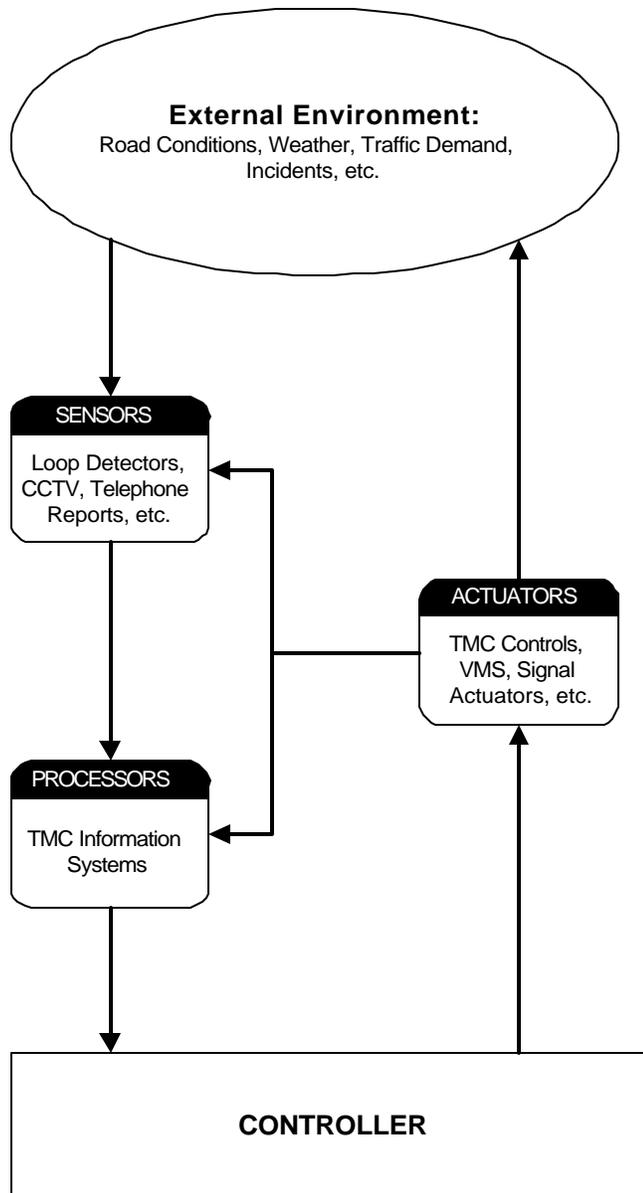
Figure 2-5. Generic control loop that shows interaction of highway and total system (after Folds et al., 1993).
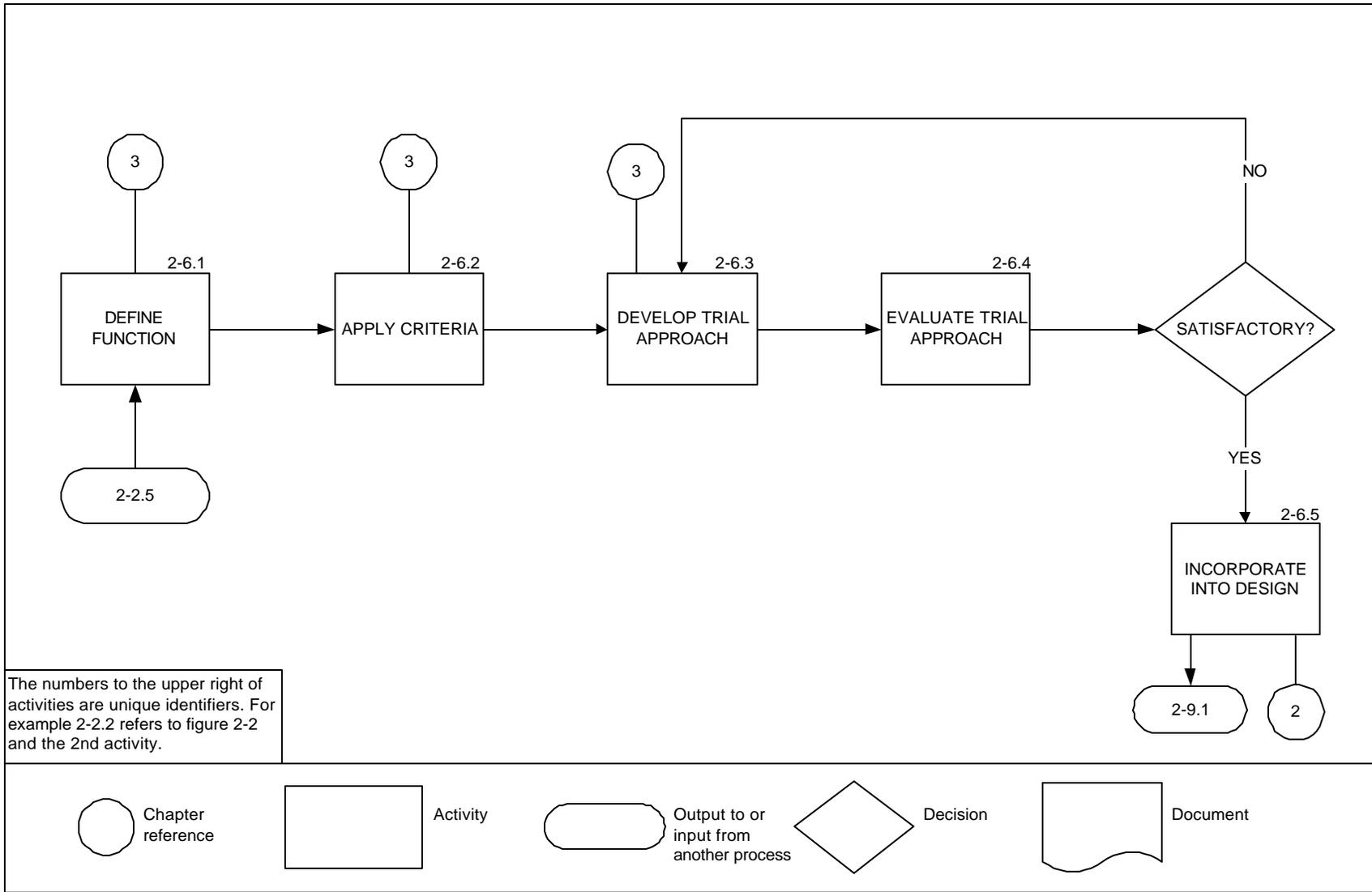
Figure 2-6. Recommended procedure for allocating TMC functions.

Table 2-1. Fitts List (after DOD-HDBK-763).

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
Store large amounts of information for long periods – and recall relevant facts at appropriate moment	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 (e.g., infrared, radio waves)
Reacting to unexpected low-probability events	Doing many different things at the same time
Applying originality in closing problems	Exerting large amounts of force smoothly and precisely
Profiting from experience and altering course of action	Insensitivity to extraneous factors
Performing fine manipulation, especially where misalignment appears unexpectedly	Repeating operations very rapidly, continuously, and precisely
Continuing to perform when overloaded	Operating in environments that are hostile to man or beyond human tolerance
Reasoning inductively	Deductive processes

! **Develop a trial solution.** Experience gained from previous (perhaps analogous) function allocation activities will suggest possible allocation solutions.

! **Evaluate the trial solution.** In most cases, this evaluation is implicit. In some cases, however, more formal testing may be required. Formal testing will provide some assurance that the proposed allocation is the most appropriate one. Testing and evaluation may indicate that a function has been allocated incorrectly. Under these conditions, the error can be corrected (iterative design). Simulators, mockups, or

computer-based prototypes may be used as evaluation tools.

- **‼ Incorporate the selected allocation in the evolving design.** Once the design team has allocated a given system function, the result should be incorporated into the design. Recognize that this result is *not final* merely because an "answer" has been obtained. The allocation for a particular function may prove unworkable when viewed in the context of the whole system and the other functions with which it must be integrated. Again, iterative design is the best approach, even if an apparent "answer" must be redesigned.

Methods and tools for allocating functions are available. A number of methods have proven to be useful in the function allocation process. While detailed descriptions of such methods are offered in Chapter 3, we include brief descriptions and examples here.

- **‼ Trade analysis.** Trade (or tradeoff) analysis is generally performed once functions have been defined and analyzed via functional flow diagrams and/or decision/action diagrams. [40] (See Section 2.2.4.) Results obtained from various techniques (described below) are to be compared.

- **‼ Fitts list.** Table 2-1 depicts the well-known "Fitts List" (named for its developer, Paul Fitts). Figure 2-7 provides two lists: one list identifying those activities best performed by humans and another list identifying those activities best performed by machines. This particular assignment of activities to human or machine has become an accepted standard. Function allocation results derived from a Fitts List analysis can be assessed with two methods (both described below): operator role assessment and/or evaluation matrix.

- **‼ Operator role assessment.** With this method, designers consider each function and assign the most appropriate operator role (direct performer, manual controller, supervisory controller, executive controller) to that function. In applying this method, designers first assess the appropriateness of assigning either of the two extreme operator roles (direct performer or executive controller) to the system functions. One of these two roles is considered appropriate if (1) its assignment to a function will satisfy that function's performance requirements and (2) a significant increase in capabilities will *not* be expected by the assignment of a different operator role to that function. If a direct performer role satisfies performance requirements and no significant performance gains are expected by the assignment of some other role, then it should be assigned to the function under consideration. Similarly, if a function's performance requirements are satisfied by an executive controller role and no significant performance gains are expected from some other role, an executive controller role should be assigned.

Designers must then consider any remaining functions (i.e., those for which direct performer or executive controller roles are inappropriate). For these functions, the appropriateness of manual controller and supervisory controller roles is assessed. Once again, appropriateness is evaluated in terms of the satisfactory achievement of performance requirements and the

expectation that significant performance gains cannot be achieved through another role assignment.

Once designers reach a consensus on operator role assignments, they consider the four stages of information processing associated with each function. Each information processing stage (i.e., input, processing, response selection, or output) is assigned one of four levels of operator involvement. These operator involvement levels are defined as:

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

Recognize that this method is time-intensive (when a large number of functions must be assessed) and somewhat subjective. However, it is particularly effective when the design team has experience in similar or analogous function allocation exercises.

- ❗ **Evaluation matrix.** With an evaluation matrix (Figure 2-7), designers rate a function according to its suitability for "operator execution of the function," "machine execution of the function," or "human-machine execution of the function." Each function receives a weighted score. The score suggests how the function should be allocated: "to the operator", "to the machine", "to a human-machine combination". These allocation categories are traditional, [40] but designers may also use the operator roles suggested in Reference (47): direct performer, manual controller, supervisory controller, executive controller. Operator roles have the advantage of considering *degrees of shared responsibility.* Traditional function allocation tends to place much emphasis on "either/or" decisions. In addition, the function allocations in Reference (47) are specific to TMC's and integrate additional insights gained from interviews, questionnaires, and TMC site visits.

- ❗ **Time line analysis.** A time line analysis (Figure 2-8) allows designers to identify the dynamics of functions and determine critical tasks (i.e., tasks that impose unrealistic time demands on unassisted operators — too many activities in too short a time). A time line analysis also identifies times at which incompatible tasks must be performed (e.g., requiring the TMC operator to be in two places at once, requiring the TMC operator to enter complicated command sequences while communicating with emergency services). Problems like these contribute to errors. A collection of simultaneous, time-constrained operator tasks is often a potential source of error. The time line will identify any time conflicts clearly and suggest when a function's level of automation should be increased. The time line analysis depicted in Figure 2-8 is relatively simple. A more detailed diagnostic time line is described in Chapter 6. Note also that as the system evolves, early time lines may become obsolete.
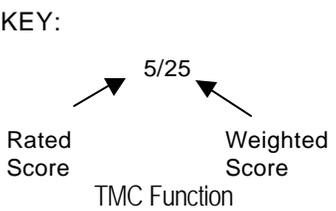
TMC Function	Inherent Operator Capabilities						Inherent Equipment Capabilities						Total Score		Proposed Allocation			
																	Machine	
KEY: (Rated Score / Weighted Score = 5/25)	Perceiving patterns and generaling (x5)	Recalling relevant facts (x3)	Exercising judgement (x5)	Reacting to low-probability events (x4)	Originality in problem solving (x2)		Monitoring (x2)	Routine, repetitive task	Quick response to control signal (x3)	Storing and recalling information (x4)	Complex and rapid computation (x4)		Operator	Machine	Operator	Both	Equipment	Software
1. Detect Vehicle Locations	1/5	1/3	1/5	1/4	1/2		5/25	5/25	5/25	5/25	5/25		12	45			X	X
2. Detect Vehicle Speeds	1/5	1/3	1/5	1/4	1/2		5/25	5/25	5/25	5/25	5/25		10	45			X	X
3. Detect Vehicle Types	1/5	1/3	1/5	1/4	5/10		5/25	5/25	5/25	5/25	5/25		15	35			X	X
4. Sense Roadway Surface Conditions	2/10	2/3	4/25	4/16	5/10		5/25	5/25	5/25	5/25	5/25		26	35		X		
5. Receive Built-In Test Reports	1/5	1/3	1/5	1/4	1/2		5/25	5/25	5/25	5/25	5/25		10	50			X	X
6. Receive Ad Hoc Component Status Reports	5/25	5/15	4/10	5/20	5/10		5/25	5/25	5/25	5/25	5/25		25	35		X		
7. Monitor Incident Clearance	2/10	2/6	2/10	2/6	1/50		5/25	5/25	5/25	5/25	5/25		25	45		X		

Figure 2-7. Recommended procedure for allocating TMC functions

TIME LINE SHEET 1.0 - 2.0	FUNCTION: INTERPRET TRAFFIC FLOW AND EFFECT CHANGES	OPERATOR

NO.	TASKS	TIME (MINUTES) 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1.1	RECEIVE UPDATED REAL-TIME TRAFFIC FLOW DATA FROM COMPUTER	
1.2	SCAN VDU	
1.3	ACTIVATE DATA SCREEN CHANGES	
1.4	INTERPRET VDU DISPLAY	
1.5	DISCRIMINATE ABNORMAL FLOW PATTERNS	
2.1	IDENTIFY TRAFFIC CONCERN	
2.2	NOTIFY POLICE, EMERGENCY, etc.	
2.3	ESTIMATE POTENTIAL IMPACT OF CONGESTION	
2.4	EFFECT ROUTING PLAN OPTIONS	
2.5	ENTER INCIDENT DATA	

Figure 2-8. Sample timeline (after DOD-HDBK-763).

2.2.4   Conduct an operator task analysis

An operator task analysis defines the activities operators will be required to perform. The task analysis and two other steps in the user-centered design process, specifically, identifying sources of human operator error (Section 2.2.5) and identifying human performance constraints (Section 2.2.6), are typically performed in parallel.

Why should designers conduct an operator task analysis? A thorough task analysis forms the basis for the TMC staffing plan, the required equipment, the user-system interfaces, and the operator training program. The task analysis helps the designers ensure that critical activities and communication links are not neglected during the design process. The authors, though, found that *only one of the 20 facilities they surveyed had conducted a formal task analysis*.

Task analyses are performed most efficiently during the design effort. Unfortunately, they are often performed after the TMC is in operation. The latter approach is not recommended. The primary cost of conducting a task analysis during design is the analysts' time. The costs of delaying a task analysis until after the TMC is running also include operational deficiencies and design errors. Changing procedures and configurations while the TMC is managing traffic is difficult, costly, and usually requires compromises, rather than clear solutions.

Several sources of information support the conduct of task analyses. Task analysis is discussed in detail in Chapter 3. Related discussions that focus on error analysis, human performance constraints, and job design are presented in Chapters 4, 5 and 6, respectively. Other resources include *Human Engineering Procedures Guide*, *Human Factors Design Handbook*, *Human Error*, and *Engineering Psychology and Human Performance*.[41, 125, 98, 122] Theoretical and practical issues surrounding operator workload, as well as workload assessment techniques, can be found in *Operator Workload: Comprehensive Review and Evaluation of Operator Workload Methodologies*.[117]

Procedures for conducting a task analysis are available. In Figure 2-9, a recommended sequence of activities to be completed during a task analysis is shown. These activities begin with an initial task definition and conclude with incorporation of the task structure into the TMC design. The initial task definition typically follows function allocation. Figure 2-9 includes activities associated with error analysis (Section 2.2.5) and job design (Section 2.2.7). These two activities are identified in conjunction with the task analysis activity because (1) results from all three activities are interdependent, and (2) all three activities are conducted (to some extent) concurrently.
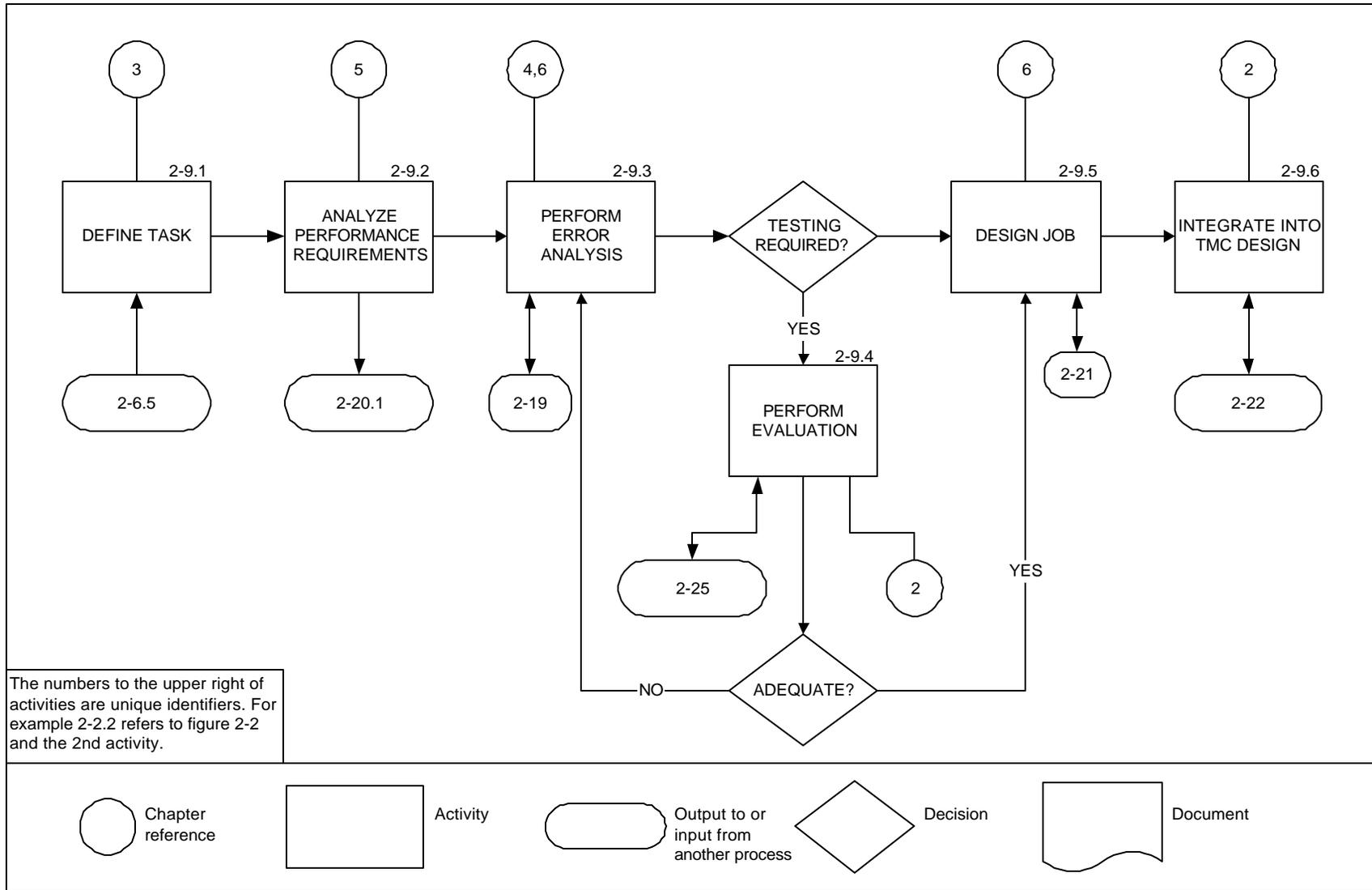
Figure 2-9. Recommended procedure for task analysis.

! **Task definition.** A task definition provides the initial (operational) description of the operator tasks required for execution of a given system function. The level of operator involvement required for function execution (and thus the nature of tasks to be performed) is specified in accordance with the function allocation results. Highly automated functions, for example, will require more machine involvement and less direct human operator involvement. Consequently, an operator will have less responsibility for *direct* execution of the function, and tasks that require the operator to *monitor* machine activities, *verify* machine computations, and *approve* machine recommendations will be typical. Some tasks may be modified (e.g., allocated to automation) during subsequent design iterations. In some cases, additional tasks may be incorporated into the design. Discrete tasks can be grouped into *work modules* (Chapter 3) for easier integration into job descriptions.

! **Performance analysis.** The design team must consider all tasks with respect to human performance requirements. Human operators will have a number of limitations, and such limitations must be recognized. Guidelines for conducting performance analyses are offered in Chapter 5.

! **Error and workload analysis.** Operator error and workload should be considered throughout the design process, particularly when the likelihood of unacceptably high operator error and workload are discovered. When considering operator error, the design team should review operator tasks and identify those for which the potential for error is high. In some instances a reallocation of the associated function may be necessary. Guidelines for reducing operator error are found in Chapters 4, 5, and 6. Any negative effects of operator workload will contribute to error rates and degrade overall system performance. Workload is addressed in Chapters 3, 5, and 6.

! **Evaluation.** Evaluating the design of a new or complex task is important to ensure that the task can be effectively performed as designed. Such evaluations may be elaborate (employing mockups or simulators), or they may be less formal (relying on the design team's observations of operator task performance).

Methods and tools for analyzing tasks are available. Task analysis is a routine component of human factors analyses, and many techniques are available. This section offers the methods most applicable to TMC design. Note that the list of tools offered here is not comprehensive. More detailed discussions of these and other methods can be found in DOD-HDBK-763, *Human Engineering Procedures Guide*. [40]

! **Functional flow diagram.** This method translates a sequence of activities into a block diagram. The diagram represents sequences of occurrence for activities, as well as ordered relationships among activities. In a task level flow diagram, each block represents a single task of some uniform level of complexity or importance. An example is provided in Figure 2-10 panel a. Here, a sequence of traffic monitoring activities is analyzed. Logical operators (OR and AND) indicate when a single activity is performed in sequence and when multiple activities are performed simultaneously. Logical

operators are not universally applied to simple flow diagrams.

A variant of the simple functional flow diagram is the decision/action diagram. This type of diagram identifies required activities, depicts key decision points, and outlines the flow of activities that must occur once a decision is made. An example is provided in Figure 2-10 panel b. In this example, the decisions and events surrounding the traffic access control are analyzed.

! **Operational sequence diagram.** An operational sequence diagram (OSD) is employed when (1) more complex interactions of operator, computer, sensor, and actuator inputs/outputs must be documented, and (2) a new task, for which designers have no previous experience or analysis results, is under consideration. The OSD yields a more detailed analysis than does the functional flow diagram. Consequently, it is a more difficult tool to learn and implement. On the other hand, the need to develop an OSD for every TMC task is unlikely. The OSD provided in Figure 2-11 represents the sequence of activities described by the flow chart of Figure 2-10, panel a.

! **Task description.** Task descriptions represent one of the more traditional analysis methods and have been used for a number of years. A task description is derived from results of the function allocation. It provides a breakdown of tasks into subtasks and is particularly useful in assessing function allocation results, developing training programs, and supporting manpower and procurement activities. [40] An example of a partial task description is provided in Table 3-2.

! **Workload analysis.** Because workload is operator-specific, it is difficult to measure and define. Figure 2-12 identifies elements that contribute to workload. These elements, referred to as *determinants* of operator workload, may be external (i.e., related to task design, job design, and environmental conditions). However, others may be internal (i.e., related to human skills and limitations). The methods most readily available to the design team are of two types: subjective scales and observation/experimentation.

a. Functional Flow Chart

Monitor Traffic Conditions → OR → Receive Updated Traffic Data → AND → Scan Video Display → OR → Interpret Video Display → Discriminate Abnormal Patterns

Activate Data Screen Changes → OR

b. Decision / Action Diagram

Observe network Conditions → Check Maintenance Database and Weather Forecast → Continue with "Normal" Access control? → Yes → Perform Advance Planning Activities, Review incident Performance Data from Previous Rush Hour, Perform Administrative Work

No → Cancel "Normal" Access Control

Figure 2-10. Sample functional flowchart and decision/action diagram.
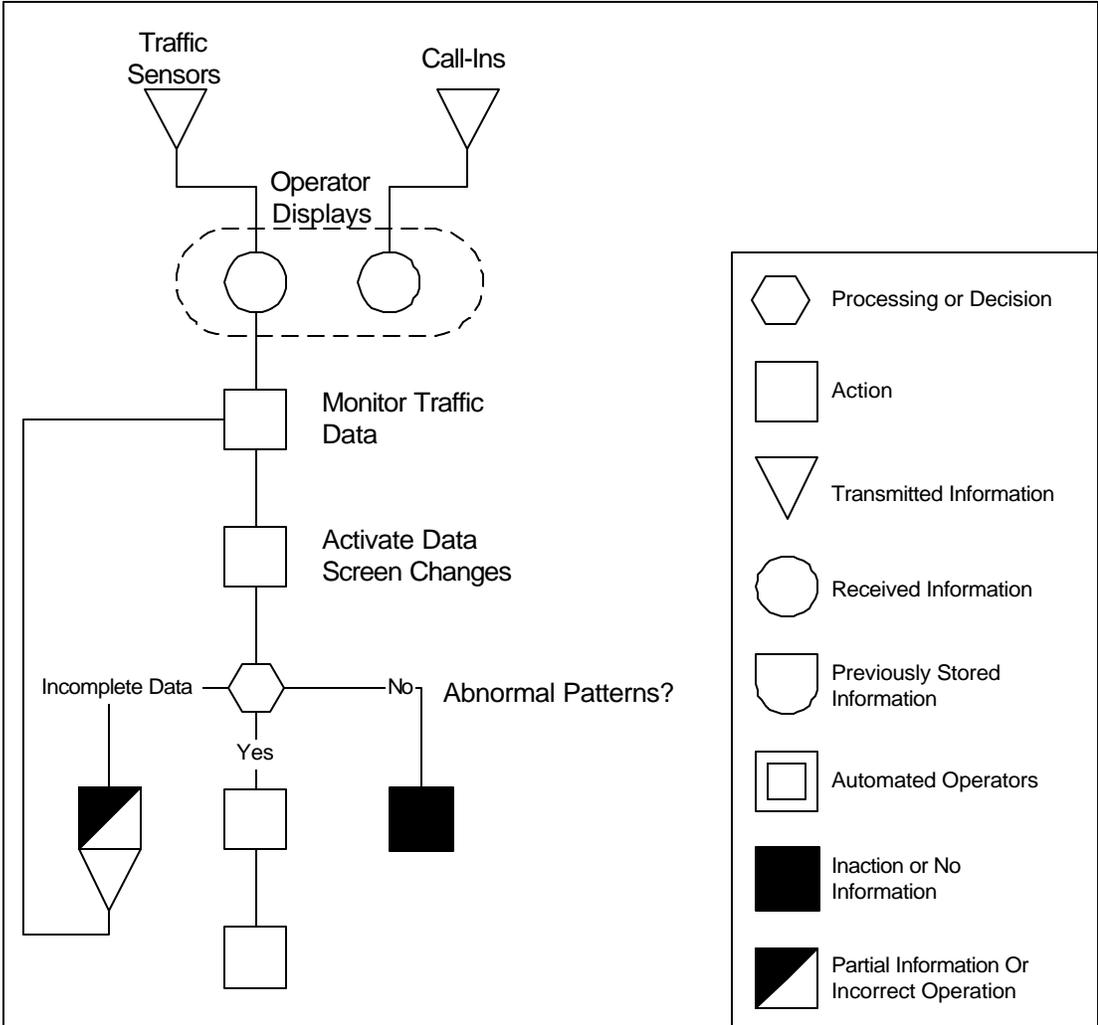
Figure 2-11. Sample operational sequence diagram.
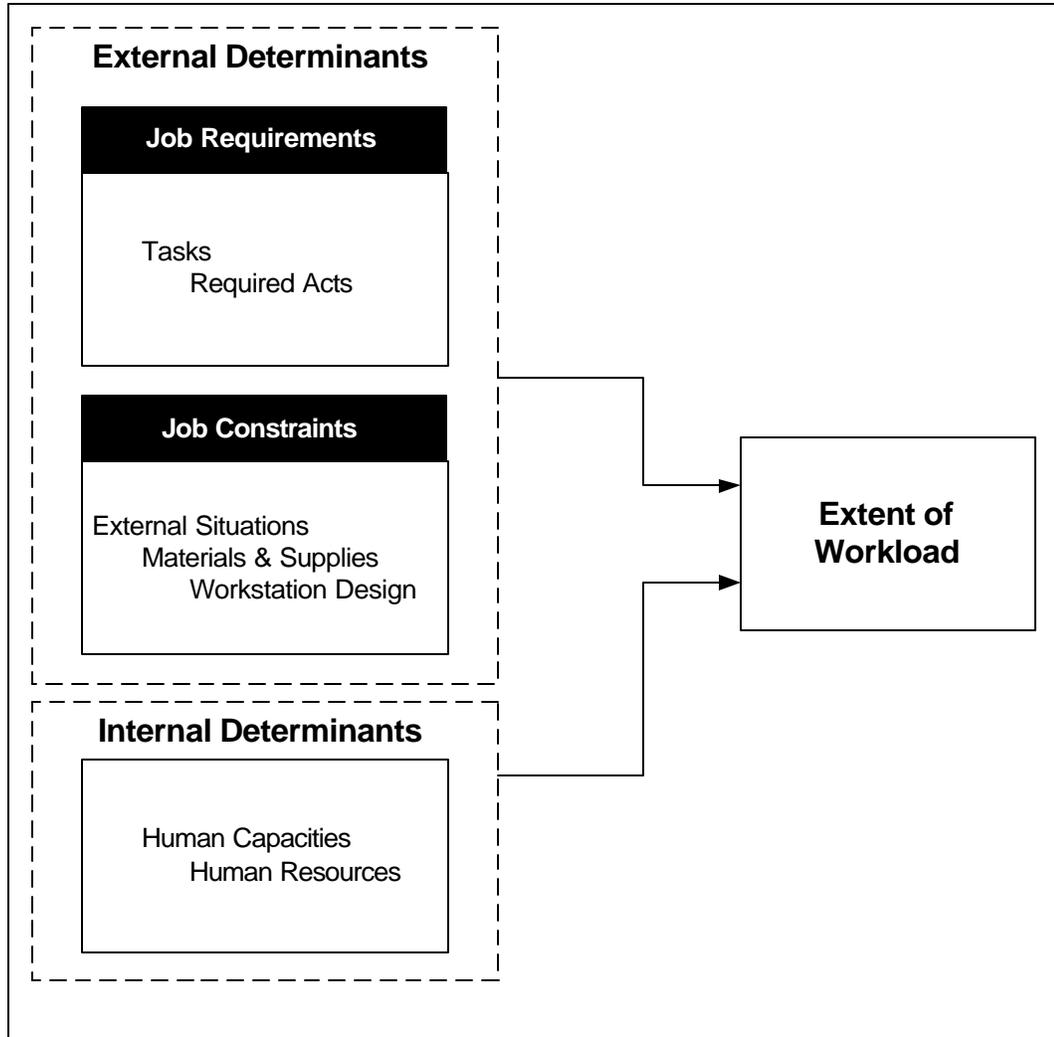
Figure 2-12. Determinants of operator workload (after ARI Technical Report 850, 1989).

Among the subjective scales frequently used are the NASA Bipolar Rating Scale (Figure 2-13) and the Modified Cooper-Harper Scale (Figure 2-15). The workload index derived from the NASA Bipolar Rating Scale is obtained through subjective ratings of task difficulty. These ratings are provided by experienced operators. For a given task, the operator first rates the task according to the nine dimensions:

- **!** Overall Workload.
- **!** Task Difficulty.
- **!** Time Pressure.
- **!** Performance.
- **!** Mental/Sensory Effort.
- **!** Physical Effort.
- **!** Frustration Level.
- **!** Stress Level.
- **!** Fatigue.

The rating assigned to each dimension reflects a subjective assessment of the degree to which that particular dimension affected task performance. The operator then classifies the task according to activity type (skill-based, rule-based, or knowledge-based). This assessment of activity type reflects the level of complex cognitive processing required for task performance. The most complex cognitive processing skills are required for knowledge-based activities. [117] (See Figure 2-13.)

The *Modified Cooper-Harper Scale* provides a means for rating operator demand level. The rating is derived from the algorithm described in Figure 2-14. [117] During informal interviews with experienced operators, designers might use this method to estimate initial task workload ratings. This method is used most readily on tasks for which operators have experience. If the task is new to the TMC design, testing and simulation may be required in order to assign this rating. (This technique can be used to generate the task difficulty ratings used to analyze tasks according to tasks and work modules — Section 3.2.)

Work profiles (Figure 2-15 and Section 6.4) allow the design team to identify possible conditions under which TMC operators must execute too many activities simultaneously. [40] In this way, they are similar to time line analyses. This approach considers accumulated sequential task demands.

Dimension	Anchors	Description of Dimension
Overall Workload	Low, High	The total workload associated with the task considering all sources and components
Task Difficulty	Low, High	Whether the task was easy, demanding, simple or complex, exacting or forgiving
Time Pressure	None, Rushed	The amount of pressure you felt due to the rate at which task elements occurred. Was the task slow and leisurely or rapid and frantic?
Performance	Perfect, Failure	How successful do you think you were in doing what we asked you to do and how satisfied you were with what you accomplished?
Mental/Sensory Effort	None, Impossible	The amount of mental and / or perceptual activity that was required (e.g., , thinking, deciding, calculating, remembering, looking, searching (etc.)
Physical Effort	None, Impossible	The amount of physical activity that was required (e.g., pushing, pulling, turning, controlling, activating, etc.)
Frustration Level	Fulfilled, Exasperated	How insecure, discouraged, irritated, and annoyed versus secure, gratified, content, and complacent you felt
Stress Level	Relaxed, Tense	How anxious, worried, uptight and harassed or calm, tranquil, placid and relaxed you felt.
Fatigue	Exhausted, Alert	How tired, weary, worn out, and exhausted or fresh, vigorous, and energetic you felt
Activity Type	Skill Based, Rule Based, Knowledge Based	The degree to which the task required mindless reaction to well-learned routines or required the application of known rules or required problem solving and decision making

Figure 2-13. NASA Bipolar Scale (after ARI Technical Report 851, 1989).

DIFFICULTY LEVEL	OPERATOR DEMAND LEVEL	RATING
Very Easy, High Desirable	Operator mental effort is minimal and desired performance is easily attainable	1
Easy, Desirable	Operator mental effort is low and desired performance easily attainable	2
Fair, Mild Difficulty	Acceptable operator mental effort is required to mainta adequate system performance	3

Minor But Annoying Difficulty	Moderately high operator mental effort is required to maintain adequate system performance	4
Moderately Objectionable Difficulty	High operator mental effort is required to maintain adequate system performance	5
Very Objectionable but Tolerable Difficulty	Maximum operator mental effort is required to bring errors to moderate level	6

Major Difficulty	Maximum operator mental effort is required to bring errors to moderate level	7
Major Difficulty	Maximum operator mental effort is required to avoid large or numerous errors	8
Major Difficulty	Intense operator mental effort is required to accomplis task, but frequent or numerous errors persist	9

Impossible	Task cannot be accomplished reliably	10

Yes

Is mental workload acceptable? — No → Mental Workload is High and Should be Reduced

Yes

Are errors small and inconsequential? — No → Major Deficiencies: System Redesign Strongly Recommended

Yes

Even if errors are large or infrequent, can task be accomplished most of the time? — No → Major Deficiencies: System Redesign Mandatory

Operator Decisions

Figure 2-14. Modified Cooper-Harper scale for assessing workload (after Wierwille and Casae, 1993).

Figure 2-15. Sample workload profile.

In the example of Figure 2-15, the demands placed on each operator are represented in terms of a percentage of available workload capacity. The example analyzes a scenario in which a driver enters a freeway and begins to travel in the wrong direction — a condition likely to secure the attention of the TMC. The shaded area shows a critical period in which the demands placed on Operator 1 are rather high. Since the demands placed on Operator 2 and Operator 3 are somewhat lower, the design team might consider a change of task procedure in which one of these two operators notifies the supervisor of this particular event.

While this type of analysis may seem excessively detailed and time-consuming, it need not be performed on all tasks and work modules. Experience and function allocation results will help to identify functions that may place unrealistic demands on TMC operators. We suggest that at this point in the design process, designers should focus only on the most extreme workload conditions. Note that because the design process is iterative, any design changes will invariably create new workload patterns.

! **Correlation matrix.** In evaluating the adequacy of a TMC's physical layout, designers can develop correlation matrices and perform link analyses in conjunction with one another. The physical layout is considered in terms of the TMC's operational requirements. These analyses may be very broad — as in the arrangement of workstations, printers, displays, etc. — or very narrowly focused on individual displays and controls. [40]

The correlation matrix identifies principal locations at which transactions occur — human and machine — and the relative frequency with which each system component interacts with each of the other components. Observation is the best means of obtaining these data (perhaps during simulations conducted throughout the design process). The result is a matrix similar to the mileage chart on a highway map. The example matrix shown in Table 2-2 (representing transactions occurring in the TMC control room of Figure 2-17) indicates the number of interactions — between three operators (Stations 1-3), the shift supervisor, the radio room, and a line printer — that occur during a given shift. Each intersection represents the number of interactions that occur during this period of time. The operator at Station 1, for example, interacted with the operator at Station 2 a total of 14 times, and only operator 1 interacted with the supervisor (7 times). These results serve as input to a link analysis. Figure 2-16 provides an example of an alternative method for displaying link analysis results.

Table 2-2. Sample correlation matrix (see Figure 2-17 for adjacency diagram).

	Station 1	Station 2	Station 3	Radio Room	Printer	Supervisor
Station 1	—	—	—	—	—	—
Station 2	14	—	—	—	—	—
Station 3	6	17	—	—	—	—
Radio Room	1	3	9	—	—	—
Printer	0	4	0	0	—	—
Supervisor	7	0	0	3	2	—
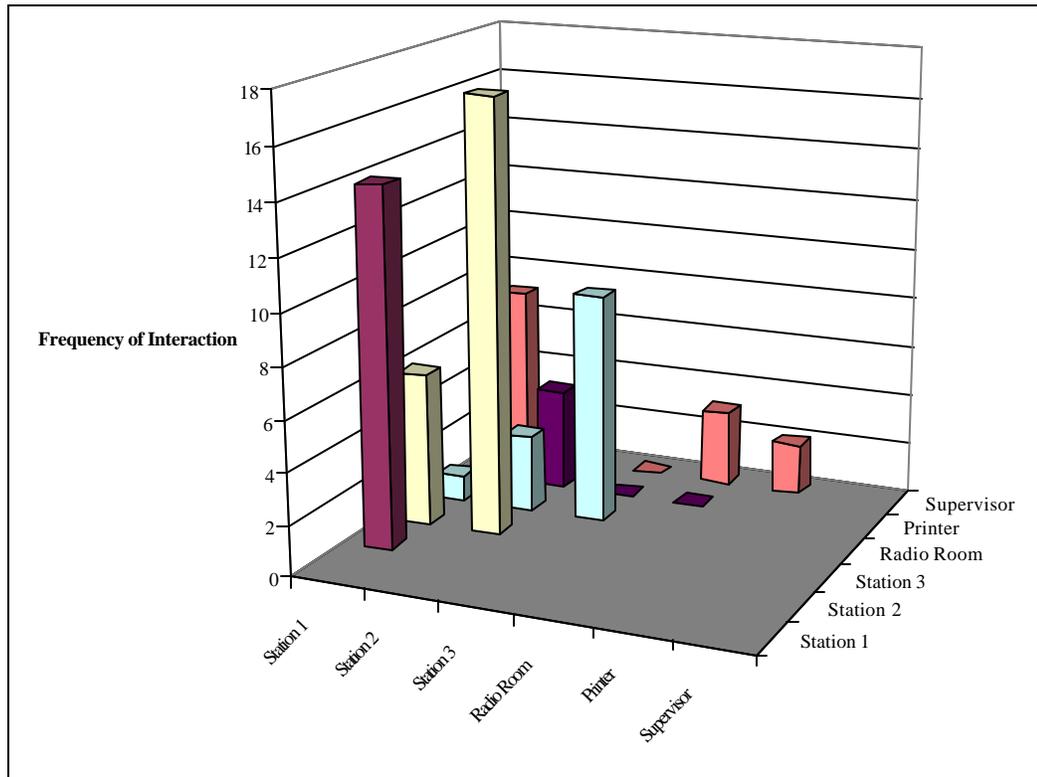
Figure 2-16. Method of displaying link analysis results.

- **Link analysis**. Figure 2-17 shows a TMC control room schematic on which the results from the correlation matrix of Table 2-2 are reflected. Figure 2-17 is sometimes referred to as an *adjacency diagram*. Here, critical physical links are drawn. Frequent interactions between two control room components are reflected by heavy lines, and less frequent interactions are indicated by narrower lines.

Given the adjacency diagram, designers can identify a poorly conceived control room layout — where the arrangement of control room components does not accommodate actual link requirements. Suppose, for example, the left-to-right ordering of workstations was 2, 1, and 3. The operator at Station 2 would be obliged to talk across operator 1 to operator 3 on the order of 17 times during a typical shift. A finer analysis is shown in Figure 2-18, where the same approach has been applied to evaluate the layout of workstation controls and displays according to their sequence of use. As discussed in Chapter 10, link analysis may assist in workstation specification. More detailed discussions of link analysis are found in References (40) and (122).
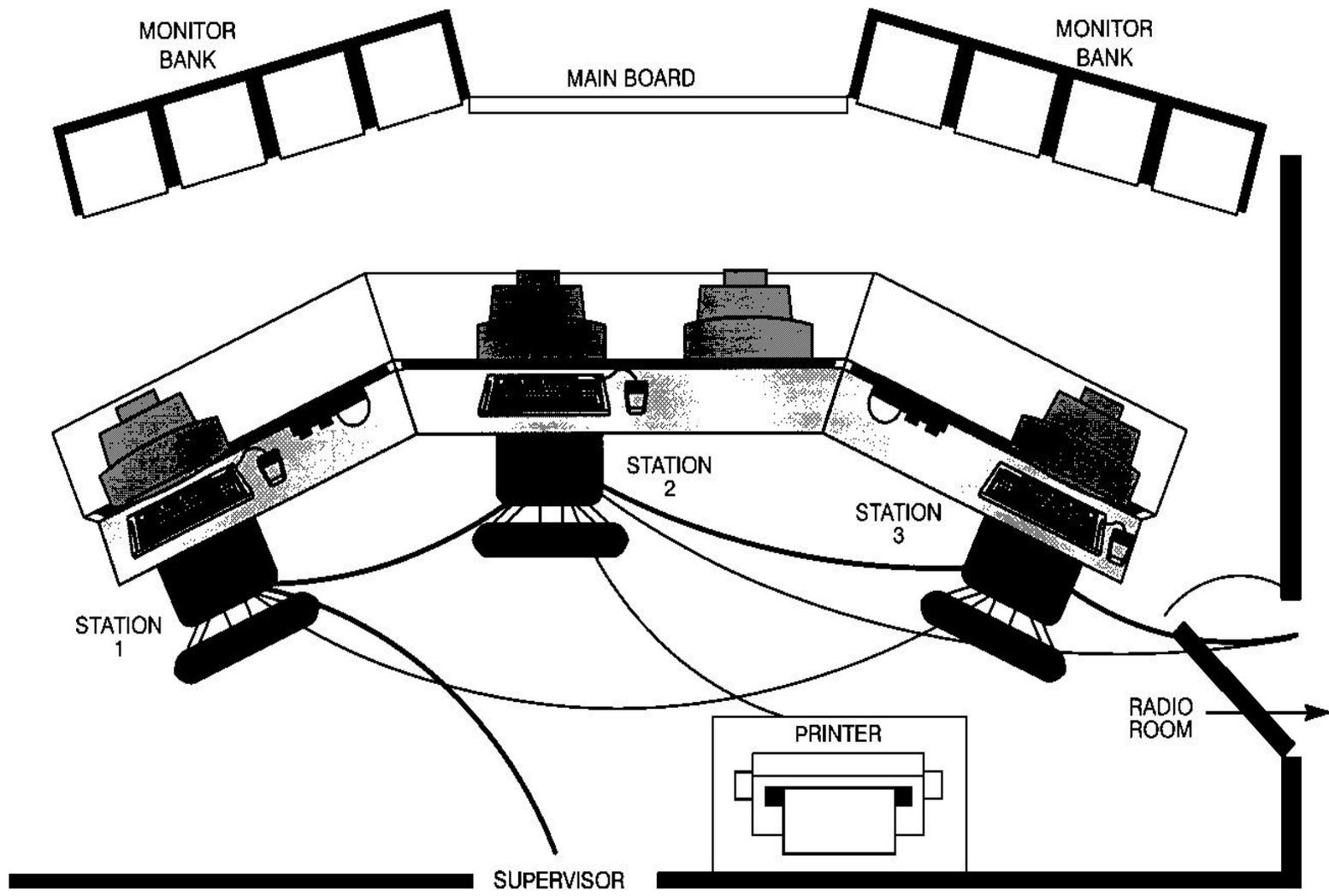
Figure 2-17. Sample link analysis (adjacency diagram) for TMC control room.
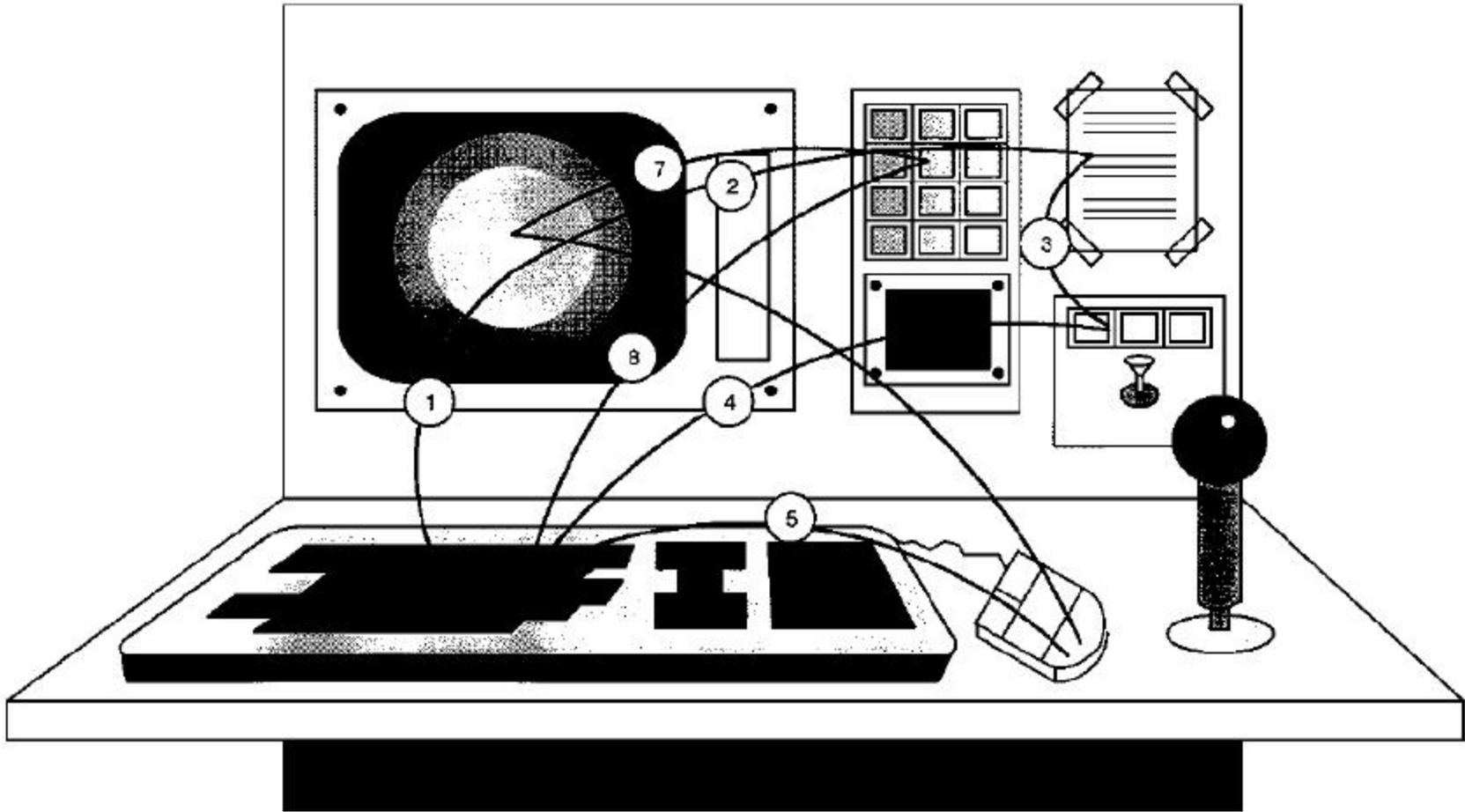
Figure 2-18. Sample link analysis for a workstation.

2.2.5   Identify sources of human operator error

Unfortunately, operator errors will always occur, no matter how carefully designers try to guard against them. Designing a system to accommodate operator errors has three goals: (1) identifying the operator tasks for which errors are the most likely to occur and cause system performance problems, (2) designing the system such that error likelihoods are reduced, and (3) designing the system such that negative effects of any errors that do occur are reduced.

Why should designers identify sources of error? Within any TMC, two sources of error exist: human and machine. As noted in Chapter 4, while most TMC designs have addressed the problems of machine error (e.g., faulty output), many have ignored human error. Because human behavior is inconsistent, human errors are more difficult to resolve than are machine errors. In addition, the causes of human error, as well as approaches for reducing and alleviating error, are not familiar to hardware and software developers. Predicting and addressing human error is a specialty of human factors engineers.

Several sources of information address human error. A discussion of human error and general guidelines for preventing and reducing human error are provided in Chapter 4. Chapter 5 focuses on the interactions between operators, tasks, and the environment that impact the likelihood of errors. Errors specific to human-computer interaction are discussed in Chapter 11. More detailed treatments of human error are found in References (7), (89), (98), and (122).

Procedures for identifying sources of error are available. Figure 2-19 provides a typical sequence of error analysis activities (Note that this procedure is an elaboration of activity 2-9.3 in Figure 2-9). Perform an error analysis whenever the design team's judgment calls for it — generally when some procedure seems to carry a high risk of error or unusually severe error consequences.

Previous design experience may help in estimating human error likelihoods. If a given task has already become accepted within TMC environments (i.e., it is currently being performed in an existing TMC), or if a clearly analogous task is available as a model, designers can — through interviews and observation — develop reasonable estimates. If no task is available to serve as a model, a simulation may be required.
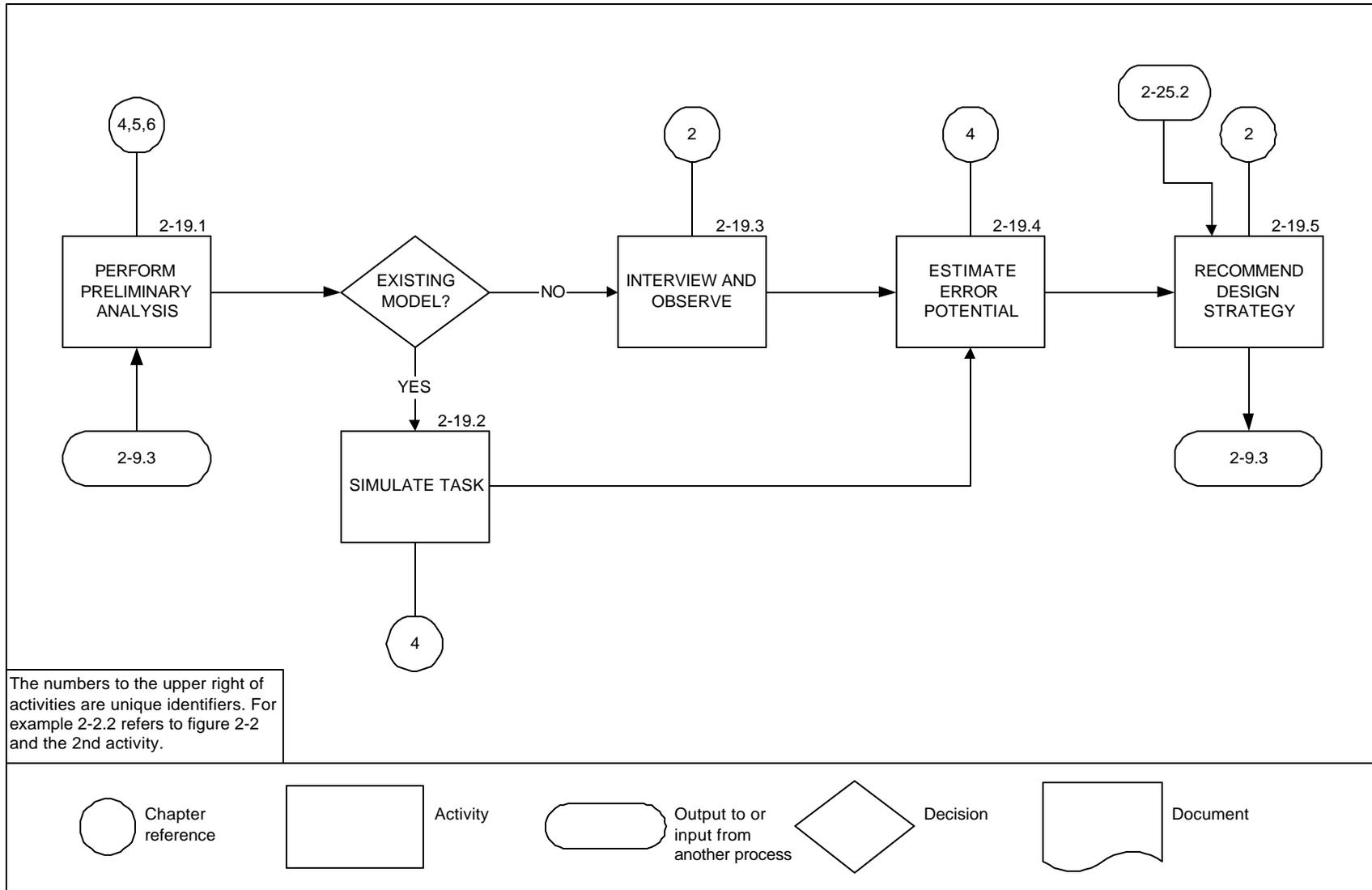
Figure 2-19. Recommended procedures for error analysis.

Note that a simulation under these circumstances should conform to the "rules of the road" prescribed for test and evaluation (Section 2.3.1).

After observation or simulation, the design team will be in a position to (1) estimate the likelihood of an error under the present design concept and (2) assess the consequences of such an error. These assessments may suggest a change in design strategy, requiring another iteration in task and job design. Similarly, an OSD may indicate points at which multiple inputs and outputs may increase error potential *and* error cost.

Methods and tools for analyzing human error are available. Many tools used in other areas of task analysis and subsystem design can be applied to human error analyses. Workload profiles, for example, will indicate conditions under which operator task demands are high. Errors are more likely under such conditions. Note also that high task demands may occur when critical conditions prevail in the TMC. During moments such as these, the cost of an operator error may be unacceptably high.

In identifying errors that result from design decisions, designers can apply a range of simulation techniques (e.g., rapid prototyping, mockups, or — when they are available — full-task or part-task simulators) throughout the design process. These techniques are discussed in more detail in subsequent steps. Recognize that even if these techniques seem extravagant, the cost of a poor design may well outweigh the temporary complication of several design iterations.

2.2.6   Identify human performance constraints

Two identical computer systems will share almost identical performance characteristics. On the other hand, the performance characteristics of two human operators will likely differ in many ways. The performance of a single operator will vary according to the time of day, task demands, and other internal and external influences (e.g., individual skills and knowledge, or perhaps personal problems). Designers must consider these variations. When the demands of any given moment challenge human limitations, the human element can become the TMC's weak link. On the other hand, when a TMC is designed to accommodate human limitations, the human can be the key factor in averting disaster.

Why should designers identify human performance constraints? Unsuccessful operator-in-the-loop system designs are often the result of insufficient attention to human capabilities and limitations. In some instances, designers are unfamiliar with human performance constraints. In other instances, designers rely too heavily upon the assumption that increasing automation will reduce the likelihood of human error. In fact, this kind of assumption can cause problems. The design team might be led to believe that a design requiring the operator to behave solely as an executive controller (Section 2.2.3 and Figure 2-4) will reduce operator errors. Under this design philosophy, human errors may actually increase. Monitoring activities (typically associated with executive controller roles) performed over extended periods of time tend to promote boredom and fatigue. A number of accidents and disasters can be traced to task environments in which the crew had little to do but monitor system status.

The ATMS-level TMC operator should remain aware of the traffic and system status and be ready to respond. The benefit in maintaining the presence of a human component in the TMC is realized when the demands of a traffic crisis exceed an automated system's ability to respond appropriately. The relationships between human and automated components, as well as the design that incorporates both components, must be based on an understanding of the capabilities and limitations of the human operator and how system design affects the system's capabilities and limitations.

Several sources of information address human performance constraints. Chapter 5 introduces the topic of human performance constraints. However, a thorough treatment of this topic is far beyond the scope of any design guideline document. *At this stage of the user-centered design process, including a human factors engineer as a permanent member of the design team is strongly recommended.*

An important consideration is that of compliance with the provisions of the Americans with Disabilities Act (ADA). A certain segment of the design process requires (1) the identification of task performance standards that may exclude persons with certain disabilities, and (2) the design of tasks to include disabled persons wherever practical. Reference (118) describes the ADA guidelines.

Procedures for analyzing human performance constraints are available. Figure 2-20 outlines a procedure for analyzing human performance requirements and constraints. The order in which activities 2-20.2 to 2-20.6 occur is arbitrary. In fact, since these activities tend to interact, they are considered in parallel. Human performance is an extraordinarily complex subject, and predicting human performance is never precise.

Special attention should be given to each significant task — where "significant" refers to a task that depends on some human action or decision for its successful implementation. Most operator tasks require some degree of attention and vigilance (e.g., monitoring of system status). When the ability to detect unusual (perhaps critical) conditions is essential to successful task performance, alarm and display characteristics must be considered carefully. If the operator *must* detect a critical condition, the indicator for that condition *must* be detectable under operating conditions. It *must* accommodate human sensory limitations, environmental conditions, and other performance constraints.

When human performance constraints have been analyzed, preliminary results should be integrated into the evolving system design. As always, however, as the design evolves, they are subject to modification.
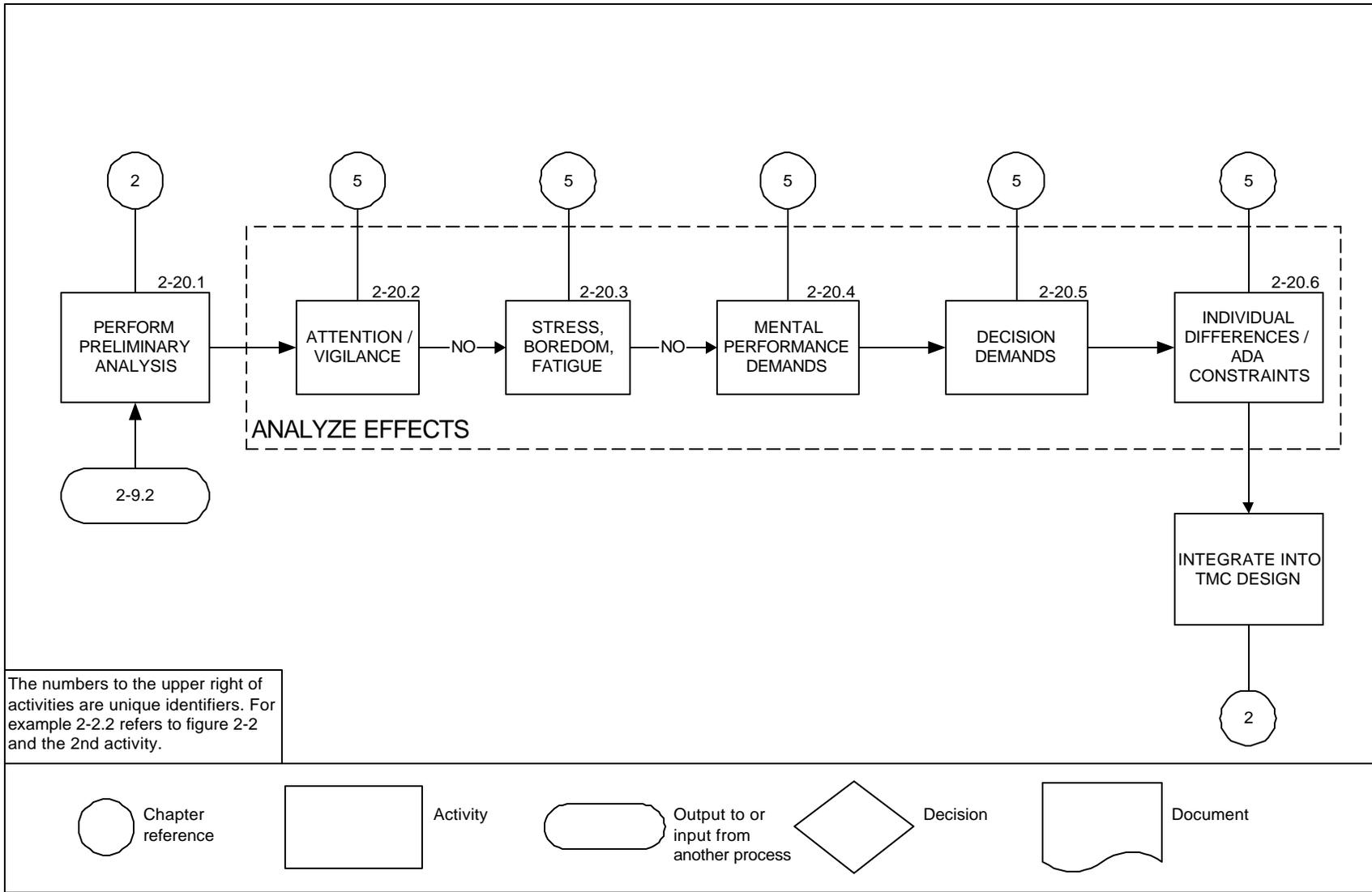
Figure 2-20. Recommended procedures for human performance analysis.

Methods and tools for analyzing human performance constraints are available. An important resource for predicting operator performance in a new design is the knowledge of operator performance of similar tasks in existing systems. Previous experience is extremely important in predicting human performance. If previous design experience is unavailable, telephone calls to other TMC's and/or to other similar control room facilities may be useful. Even anecdotal evidence may improve a design.

Workload and error analyses identify points at which human performance will be challenged. Important situations to examine may be scenarios in which crises erupt with little warning or preparation (e.g., rush hour incidents). In such cases, a critical problem may be the operator's ability to recall procedures implemented only in emergencies. Since emergencies will — we hope — be relatively infrequent, respective procedures may not be as reliably encoded in memory as routine actions performed during every shift. Design features such as user aids and decision aids (described in Chapters 6 and 12) may be required.

Simulation and other test and evaluation techniques will help in identifying performance problems overlooked in earlier design iterations. This is one reason formal testing is *never* an extravagance in system design.

2.2.7   Design jobs

A *job* is a collection of tasks assigned to a single employee category. Within this context, it refers to a coherent set of activities for which a single TMC operator is responsible. During the job design process, interaction among two or more operators is considered. This design phase typically follows the initial function allocation and task analysis, and once the final TMC design begins to stabilize, job design begins in earnest.

Why should designers conduct a job design analysis? A thorough initial task analysis documents a list of tasks that must be performed by *someone* in the TMC. The job design assigns these tasks to specific individual operators. No matter how well documented the task analysis, the effect of performing a set of tasks under operational conditions is never entirely clear until all tasks are assigned to identifiable personnel and tested. An understanding of personnel qualifications, training issues, work schedules, motivation, and teamwork requirements is required.

Frequently, the analysis is performed informally and it continues to be revised as problems appear while personnel are actually performing tasks. This approach is not recommended. Attention to job design issues during the design phase will save confusion when the TMC is operational.

Several sources of information support the job design analysis. Chapter 6 discusses job design issues in detail. References (36), (56), (108), and (122) provide additional background material. Referring to a diverse set of resource material is extremely important for most design teams, particularly those composed of hardware and software designers, traffic engineers, and

architects. Job design is a complex process and should be viewed as a legitimate step in the user-centered design process.

Procedures for conducting a job design analysis are available. Figure 2-21 identifies a sequence of activities typically associated with job design. Job design should begin with the development of a prototype. Observing operators during their performance of existing similar jobs (a "walk-through" technique) can support prototype development. A number of issues that might not have been evident — or effectively answerable — during the analysis of discrete tasks can be addressed during the job design phase. These issues are discussed below.

- ! **Sources of error associated with the job.** Such errors might appear only after task analysis because they arise from operator-operator interactions and operator-TMC interactions. Communications problems between operators and other personnel, as well as training issues, may become evident at this step in the design process.

- ! **Motivation and task design.** Within the context of job design, high motivation is supported by job diversity, task significance, operator autonomy, and performance feedback. In this sense, motivation does not refer to compensation, reinforcement, work environment, or other such factors that are independent of the *nature* of the tasks assigned to a given job. These factors are sometimes referred to as *hygiene factors*.

- ! **Job-related workload.** Unlike the workload problems analyzed in task design, the workload problems considered here are those that derive from the number and pacing of tasks during normal — and non-normal — TMC operation. These problems are reflected in the demands of work schedules, fluctuations in traffic levels, and the division of work across TMC operators.

- ! **Work schedules and task allocation.** By studying the nature of jobs assigned to TMC operators and the manner in which these jobs change as work demands change, designers can distribute workload more evenly.

- ! **Design for optimal job performance.** This job design activity reflects the *integration* of other design efforts (e.g., configuring controls and displays, workspace layout, satisfying environmental standards, and requiring ergonomically-designed furniture) that are intended to enhance job performance. Procedures and guidelines for assuring optimal job performance are offered in Chapters 7 through 13.

- ! **Design for individual differences.** This effort reconciles TMC job design with the characteristics of individuals who will operate the TMC. Here, the consideration of any established job standards and compliance with the ADA are appropriate.
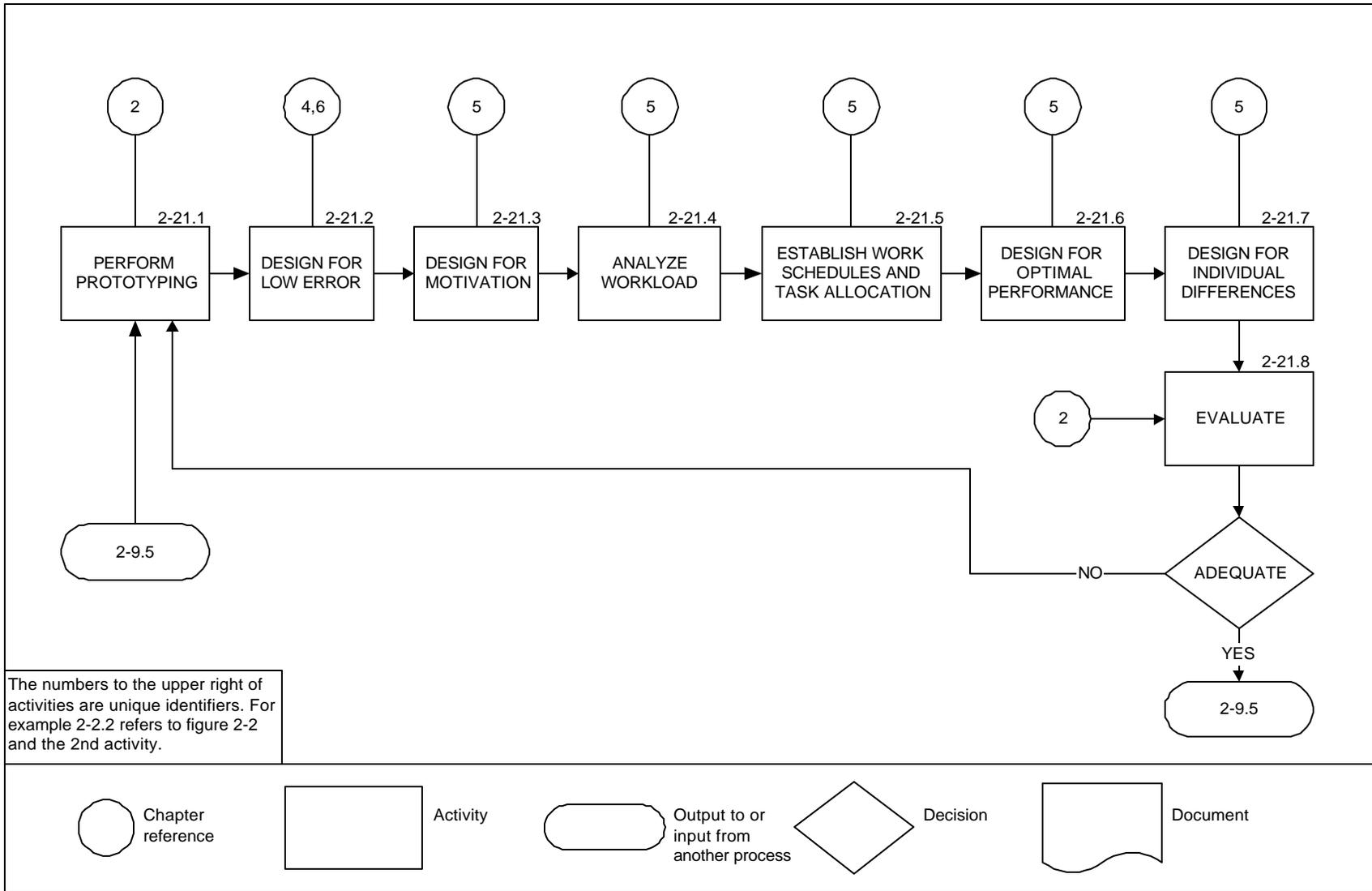
Figure 2-21. Recommended procedures for job design.

Methods and tools for completing a job design analysis are available. Many of the techniques used in analyzing operator tasks, identifying sources of human error, and analyzing human performance constraints are also applicable to the job design step. Note, however, that because job design occurs relatively late in the design process, its respective tools are more likely to require observation, testing, and evaluation of prototype activities. Job design problems often have such complex antecedents that their importance will not emerge until the design team begins assessing job performance under realistic conditions.

2.2.8 Design the physical environment

The TMC's physical environment consists of design elements that allow the system — both human and machine components — to function effectively. Included are the following types of environments: atmospheric (heating, ventilation, and air conditioning), visual (primary and supplementary lighting), acoustic (background noise and interior acoustical properties allowing operators to communicate), and the physical design of the workspace (access, dimensions, and fixtures). Some features of the physical environment are mandated by public law (e.g., access for the disabled). Other features are based on established design practice (e.g., lighting standards for designated work areas).

Interactions among environmental factors. Environmental design guidelines are influenced by human factors concerns. Illumination levels within the TMC control room, for example, must be sufficient to support all visual tasks. On the other hand, they must not interfere with operators' abilities to view video displays (e.g., glare). Illuminated fire exit signs are essential, but poor placement can cause distracting reflections on display screens. Again, designers should consider environmental design issues in conjunction with other human factors design issues.

Procedures for designing the TMC's physical environment are available. Procedures for designing the TMC physical environment are summarized on Figure 2-22. Designers should begin with a prototype of the TMC's physical environment, perhaps no more than a conceptual floor plan. Using common standards, the team can begin to establish certain environmental requirements: general lighting (supplemental lighting will be added later) and acoustic requirements (where TMC jobs have been considered), characteristics of visual and auditory displays being developed in parallel, and air quality requirements.

While considering initial environmental requirements and the development of displays and workstations, the design team should begin to assess how the workspace will be used. This activity may be carried out by the design team alone, particularly at first, but will eventually require involvement from the architects and engineers who will prepare and execute the final plans. Finally, the initial results of environmental design should be incorporated into the existing TMC design and revised as the system evolves.

The numbers to the upper right of activities are unique identifiers. For example 2-2.2 refers to figure 2-2 and the 2nd activity.

Flowchart:

1 → 2-9.6 → **PERFORM PROTOTYPING** (2-22.1)

8,10 → 2-24.4 → **ESTABLISH LIGHTING REQUIREMENTS** (2-22.2)

10 → 2-24.4 → **ESTABLISH ACOUSTIC REQUIREMENTS** (2-22.3)

2 → 2-24.4 → **ESTABLISH HVAC REQUIRMENTS** (2-22.4)

10 → 2-23.4 → **ARRANGE WORKSPACE** (2-22.5) → 2-23.1

2 → **EVALUATE** (2-22.6) → **ADEQUATE** decision

ADEQUATE — NO → back to ESTABLISH LIGHTING REQUIREMENTS

ADEQUATE — YES → **INTEGRATE INTO SYSTEM** (2-22.7) ← 2 → 2-9.6

Legend:
- Chapter reference (octagon/circle)
- Activity (rectangle)
- Output to or input from another process (rounded)
- Decision (diamond)
- Document

Figure 2-22. Recommended procedures for work space design.

Methods and tools for designing the TMC's physical environment are available. The design team has access to several methods that support design of the TMC's physical environment. These methods are discussed in the following paragraphs.

- ! **Site visits.** Some of the best ideas will come from visits to other TMC's. The benefits of a particular design concept can be seen most readily on a firsthand basis, although drawn plans and photographs may be helpful. Observation of effective designs in ATMS-level TMC development can prevent unnecessary "reinventions of the wheel."

- ! **Models.** Sometimes an inexpensive physical model made of foam, balsa, or cardboard will help in visualizing the final geometry of the TMC and in isolating potential problems. Models may be no more complicated than line drawings, but in some instances three-dimensional models supplemented by careful scale replicas of major pieces of furniture and fixtures may be in order.

- ! **Computer-aided design (CAD).** An alternative (or supplement) to physical modeling is computer-aided design (CAD). CAD tools offer flexibility. The drawings they produce can be modified quickly, and (when produced by an experienced CAD user) are less time-consuming to create than a physical model. Modern CAD packages can provide extremely realistic views of the emerging design. Visual interference problems can be detected. CAD images can even be combined with animation to provide a "walking tour" through the future TMC.

- ! **Link analysis.** Broad-area link analysis (adjacency diagrams — see Figure 2-17) can be applied at this point to assure that operator workstations and other key TMC components are located appropriately.

2.2.9 Design and specify workstations

At the time the design team is considering how the TMC workspace will be used, it should begin designing and specifying TMC workstations. When workstations are to be configured from commercial off-the-shelf components, this task will require catalog searches and negotiations with vendors. In some instances — when, for example, the control room is too small to hold separate workstations — customized fixtures (i.e., designed specifically for the TMC under development) may be required. The *layout* of workstations and other furniture and fixtures should be specified as part of the overall workspace design (Section 2.2.8). Designing workstations for comfort and suitability is a separate issue, and one that is supported with a number of experience-based guidelines.

Why should designers consider workstation design and workstation specification?
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 referred to as *ergonomics*. The strong movement toward ergonomic suitability has created many sources that support proper workstation design. Designers should note, however, that "ergonomic" has become one of the most misused words in the English language. Vendors apply the term to any item that looks modernistic or is adjustable. An experienced ergonomist or human factors engineer should be consulted before a large investment is made in nominally ergonomic workstation elements.

Several sources of information support TMC workstation design and specification. Guidelines supporting workstation design are plentiful and easily understood. The Department of Defense's human factors literature includes detailed standards in MIL-HDBK-1472D. [38] A more usable reference for TMC design teams is *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations* ANSI/HFS 100-1988. [4] These standards are also covered in *Human Factors Design Handbook* by Woodson, Tillman and Tillman. [125] Workstation standards and guidelines are provided in this document (Chapter 10 — Section 10.4). In many cases, the information contained in Chapter 10 will provide the detail required by a TMC design team. The other references are available for supplemental study, or as sources for special information.

Procedures for designing and specifying TMC workstations are available. Figure 2-23 recommends a strategy for designing workstations. Note that this design step is performed in conjunction with development of the workspace plan and the design of displays and controls.

An important consideration in any user-centered design effort is the population from which users will be selected. In most circumstances, designers will specify a wide range of physical characteristics (e.g., a "5th to 95th percentile" population). Designers might also consider the special requirements of disabled operators. Note that the final design *must accommodate the range of operators that is expected to be hired*. A workstation that excludes operators who fall within established population constraints may be difficult or impossible to modify after it has been placed in an operational TMC.

A *prototype* is developed from the design work completed in Section 2.2.8 (design of the TMC's physical environment). Most likely, it will be a line drawing or floor plan for the entire TMC, showing proposed workstation locations. The *preliminary design* (2-23.3 of Figure 2-23) specifies workstation dimensions and configurations. At this stage, designers must consider workstations on their own merits.

!   Are workstations ergonomically adequate for the designated operator population?

!   Do workstations provide adequate workspace for the completion of TMC activities?

2

2-23.6

INTEGRATE INTO SYSTEM

2-24.4

2-25.6

2

7

10

2

2

2-22.5

2-22.5

2-25

YES

2-23.1

2-23.2

2-23.3

2-23.4

2-23.5

DEVELOP PROTOTYPE

DEFINE POPULATION

DEVELOP PRELIMINARY DESIGN

INTEGRATE WITH TMC WORKSPACE

EVALUATION

ADEQUATE

2-24.2

NO

The numbers to the upper right of activities are unique identifiers. For example 2-2.2 refers to figure 2-2 and the 2nd activity.

Chapter reference

Activity

Output to or input from another process

Decision

Document

Figure 2-23. Recommended procedures for work station design.

Integration considers workstations within the context of the total system.

- **!** Can operators see large-screen displays and map displays?
- **!** Can operators communicate effectively with one other?
- **!** Can normal movements between workstations and movements into and out of the control room be accommodated?

The issues surrounding these questions may seem too obvious to require emphasis. However, one of the most common configuration problems in existing TMC's is the use of workstation consoles that are so tall they block a seated operator's view of the bottom row of CCTV monitors.

Methods and tools for designing and specifying TMC workstations are available.
Workstation design is precise. A number of existing tools and specific guidelines can support this design effort. An experienced human factors engineer can complete the workstation design effort efficiently. The following techniques will help to refine the process.

- **!** **Drawings.** Preliminary sketches, ranging in detail from pencil drawings to CAD specifications, can initially guide the design effort. They will help the design team maintain its focus on vital operational considerations. All too often designers become involved in details of the design — when at this step, design objectives should be their focus.

- **!** **Computer-aided design (CAD).** Current CAD systems allow designers to create precise three-dimensional representations of TMC workstations. Wireframe human operators reflecting specific populations can also be represented. Specifying a "95th percentile American male," for example, will allow designers to verify knee clearances and reach envelopes easily. Adjustments to the workstation configuration can also be made easily. CAD methods allow the integration of all physical points of reference within the TMC. Architecture and engineering consulting firms are equipped with sophisticated CAD systems. More economical CAD services may be available through a university.

- **!** **Link analysis.** Detailed link analyses (Figure 2-17) can be performed here. Results obtained from the task analysis should be used. A link analysis will help identify possible problems in control and display placement. Installation of a telephone keypad to the left of a central video display, for example, may require a right-handed operator to reach across the video display, or use the non-preferred hand. If accuracy in keypad entry is critical, this design solution may be inappropriate. A supplementary display may distract the operator's attention from important system status displays. In one TMC the authors visited, the required position of a mouse pad conflicted with the desirable location for a ring binder that contained operating procedures. A link analysis will identify problems such as these. CAD and/or rapid prototyping techniques will facilitate the testing of alternative design solutions.

! **Reach envelopes.** Workstations must accommodate an operator's physical range of motion. Frequently-used controls must be seen and manipulated easily. A poorly placed video monitor, for example, may force the operator into an uncomfortable posture and contribute to work-related medical problems. Satisfying standard reach envelopes (Chapter 7) can greatly reduce the likelihood of such design deficiencies. Commercially-available templates may help in developing preliminary design drawings.

! **Mockups.** In some instances, full-scale foam core mockups may be extremely helpful — especially for innovative designs that have not been implemented elsewhere. In assessing a controls and display layout, designers can "mockup" controls and displays in cardboard or balsa and attach them to a workstation mockup. Trained operators, in assessing the workstation mockup, can identify design problems that would otherwise remain undetected.

2.2.10 Design and specify controls and displays

Integral to any TMC workstation are the means by which operators enter and receive information. Controls allow TMC operators to guide certain traffic parameters (e.g., traffic flow) within the limits of the TMC's mission. Displays provide status information.

Why should designers consider the design and specification of TMC controls/displays? Poorly designed controls and displays can have a profound effect on TMC operations and operators (e.g., cognitive information processing deficiencies, faulty situation assessments and decisions, inaccurate data and command entry, occupational stress, and the general loss of operating efficiency).

Dim, low-contrast, or glare-prone video displays can cause eyestrain and errors. Illegible maps or displays, the improper use of color coding, HVAC background noise that interferes with required conversations between operators create problems in information flow. Correcting a poor design (once it has been implemented in hardware and software) is often inconvenient, disruptive, and costly.

Several sources of information that support the design and specification of TMC controls/displays are available. Chapters 8 and 9 provide background information and general guidelines for the design of controls and displays. Additional information can be found in the *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations* (ANSI/HFS 100-1988), prepared by the Human Factors Society; [4] *Human Engineering Guidelines for Management Information Systems* (MIL-HDBK-761A), a Department of Defense standard; [40] *Human Factors of Workstations with Visual Displays*, prepared by IBM; [67] and *Human Factors Design Handbook*, authored by Woodson, Tillman and Tillman. [125]

Procedures for designing and specifying TMC controls/displays are available. Activities associated with the design and specification of controls and displays are actually a subprocess of the workstation design effort (Figure 2-24). Controls and displays are considered separately

because of the established body of knowledge and standards associated with them.

TMC controls and displays should be defined 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. Results of the 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 of Chapters 8 and 9 will help in specifying display quality. 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. If headsets are required, comfort, as well as sound quality, are important considerations.

Control and display design 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 TMC. A high-resolution, wide-screen map display may look impressive when mounted on the top of an operator's console, but it is ineffective if operators are located such they cannot appreciate the map's details.

Methods and tools for designing and specifying TMC controls/displays are available.
The challenge in designing and specifying TMC controls and displays is integrating designs and specifications into the complete TMC. The procedures outlined in Sections 2.2.8 and 2.2.9 can also be applied at this step in the user-centered design process. Determining appropriate standards for control and display design requires a rather straightforward application of the guidelines presented in Chapters 8 and 9. Some knowledge of the fundamentals of display technology and human sensory processes is helpful.

2-9

2-23.3

2-25.3

8

2

2

2-24.1

ESTABLISH
INFORMATION
REQUIREMENTS

2-24.2

SELECT
CONTROL AND
DISPLAY TYPES

2-24.3

APPLY
STANDARDS

2-24.4

INTEGRATE INTO
SYSTEM

2-23.3

3

2-25.3

2-22.2

2-22.3

2-22.4

The numbers to the upper right of
activities are unique identifiers. For
example 2-2.2 refers to figure 2-2
and the 2nd activity.

Chapter
reference

Activity

Output to or
input from
another process

Decision

Document

Figure 2-24. Recommended procedures for control and display design. (Note: evaluation and revision of controls and displays is included in work station and workplace design.)

2.2.11 Design and specify user interfaces

TMC operations require human and machine activities to be performed in concert. 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 current status of these standards and guidelines will present the most significant challenge to the TMC configuration effort.

Why should designers specify and design the TMC's user interfaces? Many of the most troublesome human factors problems that exist in operational TMC's are derived from poor user interface design. One common problem is the continued use of command line interfaces that require operators to memorize commands that have little, if any, inherent meaning.

Another common TMC 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 some may be critical to TMC performance.

Several sources of information support the design and specification of the TMC's user interfaces. Chapters 11, 12, and 13 provide background information and guidelines specific to interface design. References that provide more detailed information include Schneiderman's *Designing the User Interface: Strategies for Effective Human-Computer Interaction*; [102] *Guidelines for Designing User Interface Software*, by Smith and Mosier; [108] and MIL-HDBK-761A, *Human Engineering Guidelines for Management Information Systems.* [40]

Procedures for designing and specifying the TMC's user interfaces are available. Figure 2-25 recommends a sequence of activities for developing user interfaces. The procedure is similar to procedures used in developing system hardware. The difference is in the presence of *two* evaluation cycles — one for developmental iterations (during which the interface design evolves) and one for user acceptance testing (during which the interface's suitability in an operational environment is verified).

As in other subtasks, the first activity is to develop an interface concept. This concept should be based upon a knowledge of the types of interfaces available, as well as their strengths and weaknesses (Section 11.9). Tasks to be performed (developed in the task analysis step) should also be considered. The interface concept should be task driven rather than technology driven.

Initial testing can be conducted via simulations of various levels of realism. (The level of realism associated with a given simulation is also referred to as *fidelity*.) This type of simulation activity provides an excellent opportunity to incorporate *rapid prototyping* (described below). At this point, the objective is to develop a "look and feel" of the user interface.
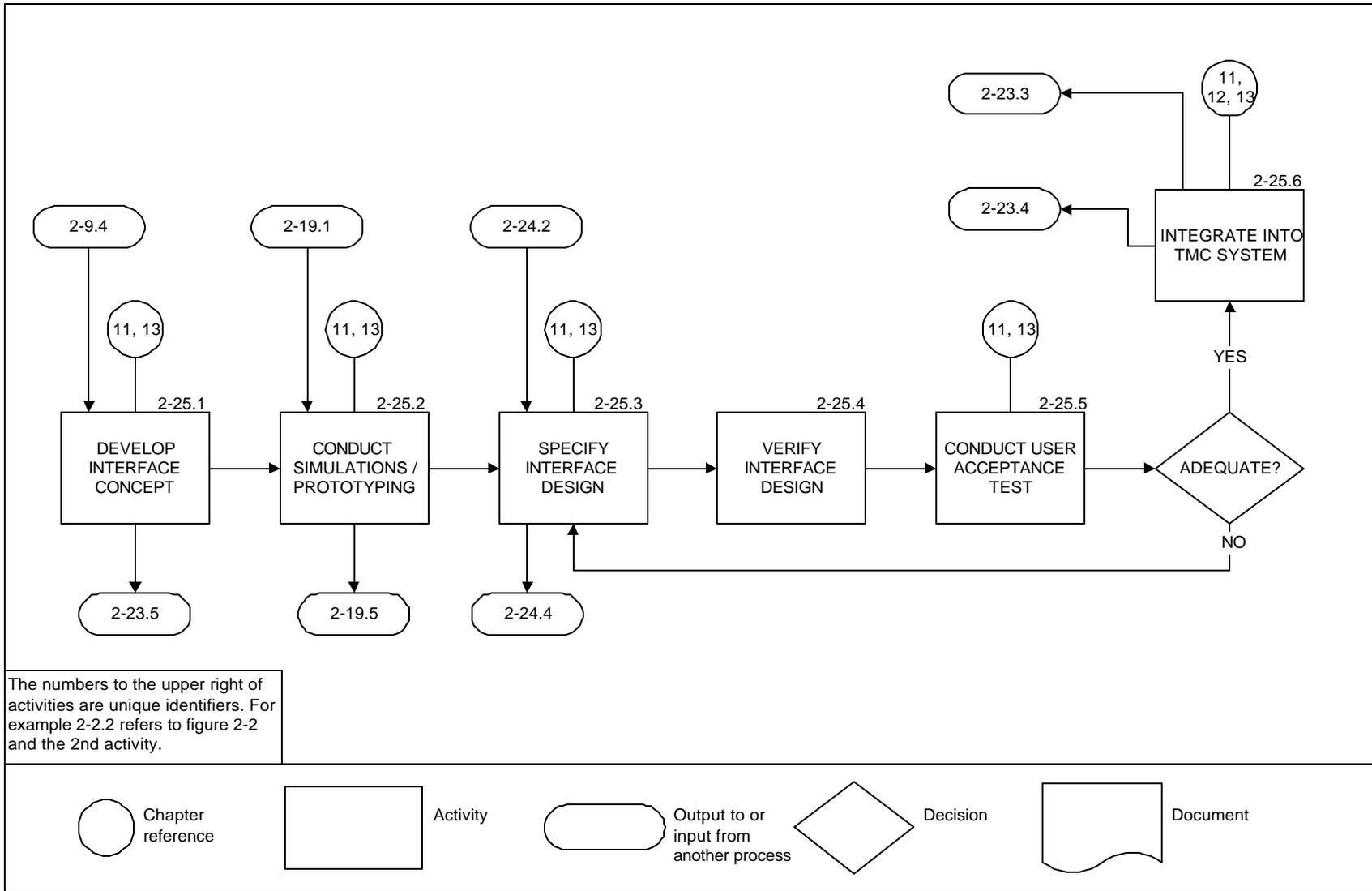
Figure 2-25. Recommended procedures for user interface design.

Designers should then develop design criteria: display requirements, dialog strategies, and training requirements. These criteria should be verified externally — by experienced operators, traffic engineers, and others who have experience in interface design. An external review of the design criteria is important for the same reason a review panel was used in evaluating the TMC mission statement and design concept (Sections 2.2.1 and 2.2.3). *The design team can develop "tunnel vision" and overlook problems that others who have had no role in the developmental process will readily identify.* At this point, designers can begin considering data presentation issues (e.g., data fusion — Section 13.6).

User acceptance testing is a strict requirement and many software developers have learned to appreciate this process. User expectations and perceptions do not always agree with those of the developer. Rigorous evaluation procedures must be employed during acceptance testing (Sections 2.3 and 11.3-11.5). A preliminary test of training plans, user aids, and user documentation (Chapter 12) should also be conducted.

Finally, user interfaces should be incorporated into the TMC design. In this manner, design consistency and suitability can be assessed. Final development of the training plan, the training implementation plan, and user documentation should be completed.

Methods and tools for designing and specifying the TMC's user interfaces are available. Some interface design tools are shared with other steps in the user-centered design process, and some are unique. The methods recommended in this docment are not the only ones available, but they represent the authors' best estimate of the tools most readily available and usable for typical TMC design teams.

- **Function allocation and task analysis.** These steps, performed early in the design process, provide the foundation for interface design. *The interface is driven by operator task requirements.*

- **Questionnaires and "thinking aloud" analyses.** These methods (Section 11.2.3) are helpful in evaluating interface consistency. A questionnaire is usually distributed during a structured interview, where an interface designer (perhaps a human factors engineer) queries an experienced operator on aspects of a given interface design. Questionnaire responses can identify deficiencies in the logic that underlies interaction procedures. The "thinking aloud" method allows the designer to observe the thought process that develops while the operator navigates the interface. Questionnaires and thinking aloud analyses are best used in conjunction with one another.

- **Concept sorting.** Concept sorting (Section 11.3.1) is useful in assessing the characteristics of expected users. The technique addresses the distinctions in novice, intermediate, and expert users — distinctions that must be addressed during the interface design effort, in formulating the training plan, and in creating user documentation.

- **User modeling.** User models (Section 11.3.2) describe the sequence of mental and

physical operations a user must perform in order to complete a task. One technique useful in generating this kind of information is the GOMS (Goals, Operators, Methods, Selection Rules) approach. The GOMS approach is essentially a task analysis. In some instances task analysis results can be readily converted to a GOMS format (Section 11.4.1). GOMS models provide a qualitative assessment of user-interface interaction tasks. The cognitive complexity model (Section 11.4.2 and Figure 11-4) provides a quantitative assessment of such tasks.

! **Surveys and observation.** These methods are especially useful in assessing user acceptance (Section 11.5.3). However, in applying these methods, designers should refer to test and evaluation principles (Section 2.3).

! **Workload analysis.** This type of analysis (Chapters 4, 5, and 6) can be applied to human-computer interface tasks as a means of determining interface design effectiveness. Observation and experimentation, in conjunction with subjective assessments (Section 2.2.4) can also be used effectively.

! **Rapid prototyping.** Rapid prototyping is a commonly used interface evaluation technique. Special software tools allow the development of interface prototypes. The most sophisticated tools allow potential users to interact with design prototypes. Given a sophisticated rapid prototyping tool, designers can provide preliminary test and evaluation environments, as well as create interface designs. Rapid prototyping techniques offer speed, flexibility, and realism to the design effort.

2.3   Principles and Methods of Test and Evaluation

Human factors test and evaluation principles (HFT&E) are necessary to ensure that the design of your TMC meets the generally accepted principles of human factors engineering, plus the special human factors requirements associated with a specific TMC. HFT&E provides a way to measure the human factors aspects of TMC design and to evaluate those measurements against specific design criteria.

In addition to formal HFT&E, design of the TMC may require numerous small experiments. These may help designers choose between two different monitor sizes, select the control characteristics of the mouse or joystick controllers, test operator roles in an automated VMS system, or address other issues of this nature. Such small experiments should generally follow the HFT&E process although procedures and documentation may be less formal.

2.3.1   Overview of human factors test and evaluation

This section describes the principles and methods for HFT&E. It covers *why* you should test, *when* you should test, *what* you should test, *how* you should test, and what you should do with the results.

HFT&E is most effective when it is a continuing *process* that accompanies user-centered design, rather than a one-shot, pass-or-fail activity conducted near the end of TMC design or implementation. Thus, the most important principle of HFT&E is *test early and often.*

HFT&E is the process that tests and evaluates the design of the operator interfaces in the TMC. Thus, it should be conducted at each stage of design. Different methods and procedures are used at different stages of design. Therefore, the same set of tests are not conducted over and over again.

It will be rather difficult to plan and conduct a program of HFT&E without the services of someone who has experience in HFT&E. Qualified consultants can be found at many consulting firms (especially those that specialize in human factors) and in industrial engineering or psychology departments at some universities. One word of caution, though: Human factors is a broad field, with many sub-specialties, and many human factors specialists have little experience in conducting HFT&E. If available human factors support personnel (either in-house or contractors or consultants) are not experienced at HFT&E, the following section provides limited guidance.

Properly conducted, HFT&E will result in the following benefits:

!   The end product, the user interfaces in your TMC, will meet accepted standards of human factors engineering *and* will be tailored to specific TMC requirements.

!   Mistakes and problems in the design of the user interfaces will be detected and corrected early without compromising your budget or schedule.

!   It will be easier to train operators because the interfaces they use will be easier to learn and easier to use on the job.

On the other hand, omitting or under-emphasizing HFT&E results in an increased risk that:

!   The user interfaces will have flaws that were not discovered in time to fix them without impacting schedule and budget.

!   More resources must be devoted to training operators to work around the design problems in their user interfaces.

!   The user interfaces will *not* meet general standards of human factors engineering, much less the specific requirements of your TMC, unless more money and time are spent to get the problems fixed.

There are two primary types of HFT&E, *formative* and *summative.* Formative HFT&E is an integral part of user-centered design. It occurs throughout the design process and is called *formative* because it helps form the design of the user interface. Summative HFT&E is a formal evaluation of a design and is structured to produce pass/fail judgements on design features. It is

called summative because it renders a summary judgement on design features.

2.3.2   Formative human factors test and evaluation

Formative HFT&E is the part of HFT&E that makes the strongest contribution to a good design. It gets real users involved in the design process early on, and keeps them involved throughout the design process. And, it keeps the designer (whether in-house or a contractor) from going off and working in a vacuum without a good understanding of the requirements of the users.

Formative HFT&E is done as a cooperative joint venture with the designer. The users and other subject matter experts who participate in formative HFT&E serve as part of the design team, though they play a different role than the programmers who actually design and develop the user interfaces.

Of course, users and subject matter experts must be involved throughout the user-centered design process. They should support mission analysis and task analysis. They should be the focus of activity in formative HFT&E.

In addition to involving users and subject matter experts, formative HFT&E should also include evaluations performed by human factors professionals. These evaluations will be similar to those performed in summative HFT&E, described in the next section.

It is very important to begin formative HFT&E in the early stages of design, before too many design decisions are made. Formative HFT&E should continue, iteratively, until the final design of the operator interfaces is established. Each iteration should address progressively more detailed issues (unless a second iteration is needed on a particular problem discovered in a previous iteration).

Formative HFT&E should be conducted for a broad range of issues, including the overall layout of the facility and the selection of major configuration items (e.g., communications system, large screen displays), as well as detailed issues such as the terminology to be used in particular menus on the computer display.

In the early stages of design, the formative HFT&E should address issues related to the overall layout of the facility and the selection of major configuration items. As the design process proceeds, formative HFT&E can focus on more detailed design issues.

Formative HFT&E should be led by someone familiar with the design at each stage. Each session should be conducted with a specified agenda, that is, a predetermined set of decisions or issues to be considered by the evaluators.

A fundamental principle of formative HFT&E is that it should be an *evaluation* session, not a design session. Don't expect participants to design the interfaces themselves. The designers should offer a design, or a small number of design options, for evaluation. *Sitting around a*

conference table asking the users to describe "what they want" does not qualify as a formative HFT&E session!

A formative HFT&E session should feature members of the design team and a *focus group* made up of representative users of the system under design. Remember that users may include supervisors and support personnel as well as the primary users: the TMC operators. In forming a focus group for a TMC, consider including the following types of individuals in the focus group:

TMC Operators: Operators in the current TMC should definitely participate if they are to be the operators of the system under design.

TMC Operators from other cities. In a city where a new TMC is being built and there are no existing TMC operators, consider enlisting some operators from another city's TMC to participate in formative HFT&E. Also, if there is a neighboring TMC close enough so that operators will have to coordinate with each other, it will be a good idea to get operators from that TMC to participate in the focus group.

TMC Managers and Supervisors. It is often beneficial for TMC managers and supervisors to participate in the focus groups. The major drawback is that an overbearing manager may suppress the creativity of the focus group. Other members of the group may not feel free to disagree with the boss, and the process may degenerate into a group that listens while one person expresses an opinion. *The leader of the focus group should structure the activities to prevent this from happening.*

Representatives from other agencies. Given the involvement of the TMC in incident management, it may be productive to involve representatives from other agencies, such as police, in some of the formative HFT&E sessions.

Independent human factors specialists. If there is a problem in getting enough participants from the categories above, or if the expertise of the available participants is too limited in the relevant subject areas, consider including an independent human factors specialist in the focus group. This individual should have no other link to the project (in particular, no involvement in the design).

The size of the focus group may vary from session to session, but in general the number of participants for this type of HFT&E should be small, say, 5 to 10 participants. Fewer than four may not provide enough breadth of experience nor diversity of opinion. More than 10 or 12 participants tends to create a large, impersonal group that will devolve into two or three participants who do most of the talking, while the others mostly remain silent. *It is better to assemble a small number of the correct individuals than a larger number of individuals who are tangentially related to the project.*

Desirable characteristics of a formative HFT&E session:

! The session should be led by a member of the design team who is familiar with the design and the design issues to be addressed in the session. It is preferable for this individual to be experienced at conducting formative HFT&E sessions. The leader should be skilled at keeping the evaluation session on track, at framing the issues and questions appropriately, and at channeling disagreement within the group into a constructive dialog rather than a competitive contest.

! The session should have a specified agenda — specific design features for the focus group to review and design issues to address.

! Each agenda item should be a specific design issue, and there should be at least one design option offered for evaluation. For some agenda items, there may be two or perhaps three design options offered for evaluation. Avoid large numbers of design options. Also avoid raising a design issue without offering a design option — that is, don't give the focus group a blank sheet of paper and ask them to do the design.

! For each agenda item, the group should reach a consensus on a decision. The decision could be to endorse the design (or one design option) offered for evaluation, to endorse a modification of that design, or to withhold any endorsement until the design team does more work for consideration in a follow-up session (or simply the next formative HFT&E session).

! In the process of considering the agenda items, the group may uncover additional issues for consideration. Some of these may be simple, and may be resolved on the spot. Others, however, may require the design team to take comments of the focus group under advisement, go and do more study and/or design work, and report back to the group in a follow-up session.

! After the first formative evaluation session, each subsequent session should devote some time to reviewing the activities of previous sessions, and reporting the status of action items from those sessions. This will help provide context to the reviewers, and will help prevent the group from revisiting closed issues.

The results of a formative HFT&E session should be documented. The formality of the documentation can vary according to the needs of the project. A simple way to document results is to keep minutes of the meeting. One drawback to simply keeping minutes is that they may not fully document the group's consensus (or lack thereof) on a particular issue. The documentation should include a complete account of the disposal of each agenda item, whether it resulted in endorsement, endorsement of a modification, or a deferral until later. Document any modified designs (whether endorsed or simply taken for consideration) with appropriate drawings and text descriptions.

Expect suggestions to arise during the evaluation session. Participants will offer ideas for design alternatives, or for new features not previously considered. Each suggestion should be taken seriously, and should be taken under consideration by the design team. For suggestions that arise during the meeting, assign action items to appropriate members of the design team. At the next formative evaluation session (or through some other appropriate means of follow-up), report the status or outcome of the suggestion. Be sure that the originator of the suggestion is promptly informed. Once the formative evaluation process is complete, it is usually worthwhile to compile a cumulative documentation of the formative evaluation sessions.

2.3.3   Summative human factors test and evaluation

Summative HFT&E is an evaluation process that renders pass/fail (or acceptable/ unacceptable) judgements on the design of the user interfaces in a TMC. It is sometimes called acceptance testing. It can be structured so that it produces a single pass/fail judgement on the overall design of the user interfaces. Usually, however, it will be more constructive to render pass/fail judgements on various design features (or subsystems) individually.

Summative HFT&E is conducted in its final form after the design is complete, but before the design is accepted. Much of the summative HFT&E can be conducted beforehand, and should be if at all possible. Given that summative HFT&E will render a pass/fail judgement on design features it should be conducted as soon as possible.

For design features that are to be evaluated by inspection, begin by inspecting the documentation of the intended design. Problems may be discovered at that point that can be corrected before implementation is finalized. If there is a mockup or working prototype of the

system design, preliminary evaluations can also be conducted in these facilities. However, the final summative HFT&E must be conducted on the actual system in its (presumably) final form.

Summative HFT&E should render an evaluation on aspects of the operator interfaces and work environment that can be measured and compared to established criteria. Some of these measurements can be performed by inspection or by use of standard ergonomics instrumentation (e.g., sound pressure levels as measured by a sound meter). Obtaining other measurements may require use of operators performing real or simulated tasks using the system or a prototype.

Thus, summative HFT&E involves two primary types of activities:

! Evaluations performed by human factors professionals, using an evaluation checklist or other criteria. Examples of this type of activity include measuring levels of light or sound, counting the number of keystrokes or mouse clicks required to perform critical tasks, and verifying that function key definitions have been implemented as specified.

! Performance-based testing in which representative operators perform real or simulated tasks, and their performance is measured and assessed against established criteria.

Typical features that can be evaluated in summative HFT&E, and how they can be measured, are illustrated below.

Lighting levels   Use a photometer to measure general illumination and task lighting at specific points of operation. If measurements of specific wavelengths (colors) are needed, a spectral photometer must be used.

Sound levels   Use a sound level meter to measure general ambient noise levels, and the levels of sounds emitted by particular devices (such as alarms, bells, loudspeakers). Use a sound spectrum analyzer to measure the level of sound in specific frequency bands.

Adjustment ranges   Adjustment ranges of chairs, tables, display mounts, and similar structures can be measured using rulers to measure distance, and protractors to measure angles.

Distances   Distances, such as viewing distances and reach distances, can be measured using a tape measure and should be anchored to an established reference point, such as the Design Eye Reference Point (DERP).

Viewing angles   Viewing angles can be measured using a protractor anchored to a DERP.

Control actions   The number of control actions (e.g., mouse clicks, keystrokes, button presses) required to perform some task may be measured by inspection

or demonstration.

Task time	The time required to complete critical tasks may be measured by having representative operators perform the task and measuring the elapsed time from a specified starting point to a point that defines completion of the task. It is preferable to use multiple operators performing multiple repetitions (or variations) of each task.
Accuracy/errors	Accuracy in performing critical tasks may be measured by comparing actual performance to a standard or criterion for defining correct performance. Depending on the task, errors may be measured on the same scale as accuracy, or may be measured as discrete events to be counted and categorized.
Subjective opinion	Subjective opinion, such as the suitability of an interface to meet the requirements of the tasks it supports, may be measured by exposing qualified raters to a demonstration (preferably hands-on) of the interface, and then having them rate their opinions using one or more Likert-type scales. For example, a scale might be constructed so that 1 = very unsatisfactory and 7 = very satisfactory. Such a scale might be used to measure an overall subjective opinion as to whether a given design feature is satisfactory for its stated purpose.

Here's what the human factors team should do in planning and conducting the summative evaluation:

Develop and document a Method of Test (MOT). The first activity for the HFT&E team is to develop and document the methods they will use in performing the summative evaluation. This activity requires that every aspect of the evaluation be thought through and planned in advance. The focal point of this activity is the production of a draft Method of Test (MOT) document. Figure 2-26 provides an outline of an appropriate MOT document.

The draft MOT should be reviewed by program management and by other affected parties. For example, the HFT&E may be conducted as part of a larger acceptance test program. If so, the overall manager of the test program should be given the opportunity to review and comment on the MOT for the human factors part of the test. The HFT&E portion may require resources that are not required by any other testing activity, and it is important that these requirements be identified and understood by individuals who will be responsible for providing them.

After feedback is received from reviewers of the draft MOT, a final MOT document should be prepared. In a large HFT&E program, there might be several iterations of the draft before a final version is produced. In a small effort, the final MOT could be produced on the second iteration with very little change from the draft version.

Specify candidate test objectives. Each objective should be worded so that an action is

described, such as *determine, describe, measure, verify, identify.* Objectives are based on established design standards, lists of guidelines and recommendations such as this document, performance requirements identified during function and task analyses, and other defensible requirements. Each objective should address a single aspect of design. Do not combine multiple aspects into a single test objective, that is, where it is conceivable that one aspect could be passed and another failed. An example of this problem might be: *Verify that all menus may be reached from any other menu with a maximum of three control actions and that the previous menu can always be accessed with one control action.* Even though you can obviously test both aspects simultaneously, they should be presented as separate test objectives and the subjective utility test should be judged separately on them.

Title:

1.0   Introduction

1.1 Background – explain the context of the evaluation, who is performing the evaluation and for whom, whose design is being evaluated, etc. This will provide the necessary context for a reader who is not directly involved in the project to understand what is going on.

1.2 System Under Test – describe the system under test (SUT) at a high level, and refer to any detailed descriptions that are available.

1.3 Test Objectives – present the specific test objectives to be accomplished by the summative HFT&E. No elaboration is needed at this point.

1.4 Summary of Test Sessions – summarize the test sessions that will be conducted, in terms of number and duration, schedule (if known, use exact dates, otherwise use relative dates).

2.0   Method

2.1 Objective 1:_____.

2.1.1   Purpose – explain the purpose of the test objective.

2.1.2   Procedure – explain how the objective will be accomplished in terms of what procedures will be followed, how many repetitions, and any other descriptions that are appropriate.

2.1.3   Criteria – state the criteria that will be used to render a pass/fail judgement.

2.1.4   Resource Requirements – state the requirements for hardware, software, supporting materials, and personnel (including subjects) associated with this test objective.

2.1.5   Data Requirements – describe and define the raw data that you must measure during the test in order to accomplish the objective.

2.1.6   Data Reduction – describe the techniques you will use to screen, aggregate, transform, or otherwise reduce the raw data to create the derived data that you will use in analysis. If no data reduction is required by this test objective, state that fact.

2.1.7   Data Analysis -- describe the techniques you will use to analyze data and render a judgement of whether the SUT passes or fails the criteria associated with this test objective. Include a specification of inferential statistics that will be calculated, if any.

2.1.8   Technical Risks – describe the factors that threaten the likelihood that you will be able to accomplish the test objective. (Note – this does not mean whether the SUT will pass the test. Rather, it means whether you will be able to render a judgement.) Identify and describe actions you will take to reduce the technical risks.

2.2 Objective 2: _____ [continue until 2.N for N test objectives]

3.0   Summary of Resource and Data Requirements

3.1 Resource Requirements – accumulate the resource requirements from each test objective in Section 2 into an overall summary. Identify each piece of equipment, each software item, all supporting material, all personnel requirements. For each item, indicate how many are required and for what length of time. In preparing this summary, the common resources that will serve multiple test objectives will be apparent.

3.2 Data Requirements – accumulate the data requirements from each test objective in Section 2 into an overall summary.

4.0   Summary of Schedule – provide a summary of the schedule including relationship to any other project milestones. Include an indication of when the various personnel, equipment, and material resources are required.

Figure 2-26. Outline for method of test.

If the standard applies to multiple entities, however, consider combining them into one test objective. For example, if you adopt a standard that all menus should be accessible by no more than three keystrokes or mouse clicks from any other menu, an appropriate test objective would be to *Verify that all menus may be reached from any other menu with a maximum of three control actions.* In this example, the test objective is based on an adopted standard that applies to all menus. Thus, if the system is to pass it must be true for all menus.

Develop a technical approach for each test objective. Decide what methods will be used to accomplish each test objective. Identify the resources (equipment, software, personnel, facilities) that will be required to accomplish the test objective.

Combine procedures from individual test objectives into test procedures that can serve multiple test objectives. For example, you could have subjects rate the comfort of their new communications headsets after performing some tasks in which they wear and use the headsets.

Identify and recruit Subjects. One of the most crucial decisions to be made in acceptance testing for the TMC is the identification of the subject population, the people who will act as TMC operators in tests. These subjects should be as similar as possible to the people who will actually serve as operators when the TMC is in operation. Some TMC's require their operators to have college technical degrees; others require little more than a high school education. Test performance may vary widely depending on the qualifications of the subjects. One recommended approach for a new TMC is to integrate the HFT&E schedule with the recruitment and training schedule so that the future operators, themselves, will be available as the test subjects.

One major mistake often made by design teams is to use their members as subjects. The knowledge that these people have developed during the design process should disqualify them from being test subjects in all but the earliest pilot testing.

Conduct a pre-test/pilot-test/dry run of the summative tests. The method of test should be conducted in a preliminary form (the results are not official). The purpose of the preliminary test should be to ensure that the actual test can be conducted as planned. Methods, including instructions to subjects, should be validated. Instrumentation should be checked out, and the measurements obtained from instrumentation should be verified. Potential problems and their solutions should be identified.

It should be expected that the preliminary test will reveal aspects of the test method that need to be revised. Do not expect the tests to work perfectly as planned the first time!

Adjust the test plan as needed in accordance with findings from the preliminary test and comments from reviewers. Fine-tuning and minor modifications may be implemented without need for additional preliminary testing. Major problems, however, warrant additional preliminary testing before subjecting the system under test to its formal summative HFT&E.

Conduct the summative HFT&E. When conducting performance testing, the goal is to

provide conditions as similar to actual operating conditions as feasible and to keep those conditions constant throughout testing. Do not allow visitors, telephone calls, or other distractions during testing. Try to keep temperature, lighting, and noise levels constant. Make sure participants are trained until their performance is stable (no significant test-to-test improvement) for those tasks where stable performance is a prerequisite for proper evaluation.

Some experimental data may be collected automatically using the TMC computers to record data such as response times, operator control actions, and other such indices. In general, though, most data will be recorded by human observers with pencil, clipboard, stopwatch, and other such tools. Humans should be considered imperfect as data recorders. It is recommended that, at least initially, two such observers record the data independently. If it is found that there is a very high degree of agreement between the two individuals' data sets, it may then be possible to reduce data collection to one observer.

At the conclusion of data collection, data may be analyzed in two ways, descriptive and inferential, as defined in the MOT document. For most pass-fail tests of a single system, descriptive statistics will provide all of the data required. These might include:

- **!** The percentage of Subjects that could initialize the system without assistance.
- **!** The mean (average) response time to a computer message.
- **!** The mean number of joystick movements.

For tests to select between two or more alternatives (monitor brands, screen layouts), inferential statistics will be required. Such questions might include:

- **!** Is screen layout A more intuitive than layout B as measured by the number of subjects who could initialize the system without assistance?
- **!** Is screen layout A more legible than B as measured by the number of probe vehicle icons found by subjects within 10 seconds?
- **!** Is headset A more comfortable than headset B based on comfort ratings?

Various statistical methods are appropriate, depending on the nature of the data and the way that it was collected. For some statistics, for example, it is important that the data be distributed as if it came from a normal, *bell-shaped* curve. For other statistical methods, such assumptions are not necessary. The HFT&E consultant should play a major role in designing tests from the standpoint of meeting these statistical requirements.

Document the results. The results of the summative HFT&E should be reported, formally, to program management. The documentation should review the context of the evaluation, present the test objectives, describe the methods used to accomplish the test objectives, and present the results. The results should be organized by test objective. For each objective, present a "pass" or "fail" judgement. If the systems fails to meet the criteria for any test objective, present design or management recommendations for remedial actions.

CHAPTER 3: ALLOCATING FUNCTIONS AND ANALYZING TASKS

CONTENTS

3.1   Approaching Function Allocation and Task Analysis

The TMC is a complex and interdependent system of humans and machines. Proper functioning depends upon the designer recognizing the roles of humans and machines from the beginning of the design process. Some tasks such as traffic sensing with loop detectors will be performed entirely by automation. Others, like voice communication, may rely entirely on human actions and decisions. But a fair share of the most critical tasks will be accomplished through a human/system interface, with the operators and computers contributing their own inputs and outputs, according to the task at hand.

Design of systems for effective human use requires design approaches that are unfamiliar to many engineers. Numerous otherwise well-designed systems have failed to meet their designers' expectations because the designers initially defined requirements in terms of *machine* capabilities, overlooking the requirements of the users. Design for effective human use requires the same systematic approach used in the design of functional hardware and software components. The analysis and design process is complicated by the variability and complexity of human behavior and performance, but without such analysis the system may not perform satisfactorily.

User-centered design is different from traditional design philosophies because of its emphasis on analyzing the operation of the TMC in terms of *functions and tasks* required for traffic management rather than initially specifying machines and then training human operators to operate them. Proper task analysis focuses on outcomes of the system, and suggests ways to integrate the human and automated components of the system.

The techniques described in this chapter allow the designer to understand what TMC operators and other personnel do in the execution of their jobs. In this activity, the designers subdivide

TMC operational requirements and functions into a series of well-defined activities. Thorough task analysis includes determination of inputs, decisions, outputs, consequences, and opportunities for automation for each identified task.

Design analyses, as organized for this handbook, comprise several related activities. These include function allocation and traditional task analysis, described in this chapter; error analysis and the identification of human performance constraints, covered in Chapters 4 and 5; and the design of jobs, discussed in Chapter 6.

These analyses typically employ the inputs of a panel of experts. A properly organized analysis team includes experienced traffic engineers, managers, and operators along with systems analysts, system integrators, architects, and engineers, including human factors engineers.

It is important in the TMC design process that the analysis and design team *include members who are not intimately familiar with the existing system and procedures.* If the task is the development of a new TMC that replaces an older one, limiting guidance sources to traffic engineers and managers of the old facility will tend to make the new design derivative of the old one and ineffective practices may be preserved. Familiarity with old designs and procedures may blind designers to better ideas.

3.2 Performing Function Allocation and Task Analysis

The process of identifying, defining, and analyzing functions and tasks is organized into five interdependent operations:

- **!** **Objectives definition.** The step in which the top-level objectives of the specific TMC are documented. One TMC may have special event parking optimization as a major objective; another might manage traffic only on the freeways. Each TMC may have different sets of objectives and priorities.

- **!** **Function definition.** The step in which all actions or functions necessary to carry out a specific TMC objective is defined and described in detail. These actions can include one or more of the following to achieve the objective: information collection, communication, processing, decision making, decision implementation, planning, data storage, and administrative support.. These functions are defined independently of how they are performed (i.e., by human or by machine).

- **!** **Function allocation.** The step in the design of human/machine systems in which system functions are assigned to the operator, to automated machine processes, or to a combination of human and machine processes.

- **!** **Human performance analysis.** The identification of specific task criteria (task completion speed, accuracy, and/or other parameters such as skill acquisition) to be achieved by the operator based on system function requirements.

- **Task analysis.** The systematic breakdown of a task into its elements includes a detailed task description of both manual and mental activities, task and element durations, task frequency, task allocation, task complexity, environmental conditions, necessary clothing and equipment, and other unique factors involved in, or required for one or more humans to perform a given task.

3.2.1   Objectives definition

The determination of system *objectives* is driven by the established mission of the TMC. For example, a list of basic system objectives that should be used to guide the design of a generic "ideal" traffic management system was defined by structured interviews with a group of traffic management experts who were nominated by their peers as visionaries. These objectives include: [47]

- Maximize the effective capacity of existing roadways.

- Minimize the impact of roadway incidents (accidents, stalls, fallen debris, etc.) on travel times without compromising public safety.

- Assist in the provision of emergency services.

- Contribute to the regulation of demand.

- Maintain public confidence in the traffic management system.

3.2.2   Function definition

Function definition proceeds from the specifications, requirements and constraints identified and validated in the first design stages (Sections 2.2.1 and 2.2.2). At this point, *functions* are identified and constructed as broad statements of work to be performed by the system as a whole in order to meet its mission objective(s). The function list should include every operation and activity required to meet these objectives. Note that, at this point, we have not yet defined whether activities will be performed by humans, by automated equipment, or jointly by a human using a computer. Table 3.1 lists 104 generic TMC functions derived by one organized analysis team.

Table 2-1. Generic TMC functions.

INPUT	THROUGHPUT
Detect vehicle locations	Assess current load
Detect vehicle speeds	Anticipate near term traffic conditions
Sense roadway surface conditions	Select best traffic control option
Receive BIT reports	Determine need for incident detection support
Receive ad hoc component status reports	Track special vehicles
Sense visibility conditions	Predict traffic conditions given current options
Verify incident data	Determine remedial maintenance needs
Monitor incident clearance	Assess predicted traffic conditions given options
Receive traffic volume reports	Assess traffic management effectiveness
Receive probe vehicle reports	Determine software upgrade needs
Receive ad hoc travel time reports	Determine hardware upgrade needs
Receive ad hoc roadway condition reports	Determine personnel upgrade needs
Receive O-D data	Determine preventive maintenance needs
Receive commercial rail traffic data	Identify anomalies in traffic patterns
Receive ad hoc commercial rail traffic reports	Determine source of anomalies
Receive weather service data	Predict multimodal demand given current options
Receive ad hoc weather reports	Determine ATMS responsibilities
Receive interagency incident reports	Determine need for incident services
Receive ad hoc incident reports	Determine appropriate ATMS response
Receive ad hoc incident response reports	Assess multimodal capacity
Receive interagency response data	Identify demand regulation options
Receive interagency emergency response data	Predict multimodal demand
Receive ad hoc emergency response reports	Assess predicted multimodal demand
Receive interagency data from alternative transportation modes	Monitor compliance with ATMS advisories
Receive interagency special event reports	Monitor compliance with other advisories
Receive ad hoc special event reports	Assess survey data

Table 2-1. Generic TMC functions (continued).

INPUT (Continued)	THROUGHPUT (Continued)
Receive public comments	Assess ad hoc public comments
Receive requests for public relations activities	Plan public confidence enhancements
Receive requests for historical data	**SUPPORT**
Receive requests for simulation studies	Store electronic network data
OUTPUT	Retrieve electronic network data
Control railroad/bridge crossings	Store electronic incident data
Post route advisories on information outlets	Retrieve electronic incident data
Provide route advisories to other users	Retrieve hard copy of incident reports
Post speed advisories on information outlets	Perform data base management
Provide speed advisories to other users	Provide traffic management training
Post travel advisories on information outlets	Provide maintainer training
Provide travel advisories to other users	Provide incident management training
Post mode selection data on information outlets	Provide special events training
Provide mode selection data to other users	Develop strategic traffic management plans
Transmit electronic maintenance requests	Develop special event traffic contingency plans
Issue special maintenance requests	Develop traffic management contingency plans
Issue upgrade requests	Receive directives
Transmit electronic incident service requests	Develop policies
Issue special incident service requests	Specify procedures
Issue requests for information	Implement policy and procedures
Issue requests for on-site traffic control	Perform fiscal planning
Transmit electronic incident reports	Perform budget tracking
Issue special incident reports	Perform evaluations
Transmit electronic incident management reports	Perform personnel selection
Provide historical traffic data	Maintain personnel records
Provide simulation reports and recommendations	Maintain communication w/incident responders
Provide public relations information	Coordinate multi-agency incident response
	Coordinate multi-agency emergency reasons
	Coordinate multi-agency transportation planing

3.2.3   Function allocation

After the functions are defined, there are a variety of proven frameworks available to system designers for performing the design steps of function allocation and task analysis. Sections 2.2.3 and 2.2.4 include discussions of how these activities fit into the larger process of design. The section that follows will provide an understanding of the process and a selection of guidelines.

Function allocation is often the first point in the design process where critical decisions must be made about the role of the operator. Section 2.2.3 includes a discussion of procedures, methods, and tools for function allocation.

The most common misconception that complicates function allocation is the *either-or illusion*. Many designers presume that there is one set of functions that should be handled by machine and another by humans. In fact, many of the most critical functions in TMC operations are best handled by the *integrated* efforts of human and machine. Identifying these partly automated tasks will probably require more study and insight than other elements of task analysis; but failing to identify them and assign proper interface strategies could cause problems when the TMC is in operation.

Allocating functions to one side or the other of the human/system interface relies on several general principles derived from the Fitts List (See Figure 2-7). The following guidelines summarize issues to consider when deciding how to allocate functions among humans and machines. The first guideline recommends when to consider automation of tasks that exceed human limitations. The second guideline recommends where the skills of human operators should be empowered to encourage beneficial achievements.

3/1 Human Limitations and Automation   **(Recommendation; 125)**

- ! **Environmental Constraints.** Allocate a function to the *machine* when environmental constraints limit human performance. For example, observation cameras on elevated mounts in all weather; use of human observers in such a function would be neither cost effective nor humane.

- ! **Sensory Ability Limits.** Allocate a function to the *machine* when human operators are not afforded adequate sensory input. Traffic sensors respond to events not easily monitored by humans. For example, events such as changes in level of traffic moving past a point on the highway are outside the sensory range of a TMC operator.

- ! **Speed/Accuracy Requirements.** Allocate a function to the *machine* when requirements for speed and accuracy exceed human capacities. Monitoring streams of code on a video display that represent raw sensor status, for example, is a task much better suited to the machine.

- ❗ **High Information Volume.** Allocate a function to the *machine* when information arrives in such speed and volume that human processing capacity is overloaded. This addresses the human limitations for processing and acting on input. Swarms of discrete impulses in raw form from traffic sensors at multiple sites are likely to overwhelm human input capacity. The information system must process and display the data so that important elements of information are called to the operator's attention.

- ❗ **Excessive Memory Requirement.** Allocate a function to the *machine* when information is produced in such large quantities that human memory capacity is exceeded. Cumulative traffic sensor counts and signal conditions are of such complexity that they will quickly overwhelm the human capacity for encoding them. A critical machine function in such cases becomes *data fusion* (Chapter 13), which presents data in a processed form that makes it accessible for analytical assessments in which the human has the advantage.

- ❗ **System Performance Monitoring.** Allocate a function to the *machine* when continuous performance surveillance is required. Humans are relatively poor "self-monitors." Unlike humans, machines do not become bored, distracted, or fatigued.

- ❗ **Precise or Repetitive Tasks.** Assign to the machine tasks that require extremely precise manipulations, continuous and repetitive steps, and lengthy or laborious calculations.

3/2 Human Empowerment   (Recommendation; 125)

- ❗ **Response to Unusual Events.** Allocate a function to the *human* when the interpretation of, and response to, unusual or unexpected events is required. If a traffic situation cannot be fully identified and classified using automated algorithms, then human interpretation and more complex decision making is required. The machine may respond with a potentially incorrect set of actions or simply fail to act.

- ❗ **System Effectiveness.** Choose an allocation approach that maximizes total system effectiveness. Avoid decisions based solely on the ease or difficulty of automation; system performance in the long run is more important. If a graphical user interface (GUI) will have to be designed for your application at a higher initial cost than a package with a less usable interface, consider the effect on the *total system*.

- ❗ **Operator Workload.** Couple humans with machines in such a way that the humans are not compelled to work at peak limits all or most of the time. Imagine the frustration of having to work on an assembly line that moves

slightly faster than the sustained ability of the human workers to accommodate its pace.

! **Human Motivation.** Couple humans with machines in such a way that the humans can recognize or feel that their contribution is meaningful and important. Operator abilities are not well used in a job that merely requires serving a machine.

! **Information Flow.** Couple humans with machines in such a way that information flow and information processing are natural. Learning time is reduced and human performance will be improved by natural and intuitive user-computer interfaces. An obvious example is the design of computer interfaces so that they make sense to the *operator* rather than to the programmer. Provide information in the operator's natural language; pay attention to display stereotypes (e.g., red color indicates a problem or hazard); ensure meaningful icons on the graphical interface by testing candidate icons on the target population.

! **Operator Intervention.** Design the human/system interface on the presumption that the human might at some point have to take control. The nominal mode may be automatic, but there will inevitably be cases for which the system will need human capabilities for judgment and initiative, and for perceiving things the machine cannot recognize. Design the system to allow the operator to perform all of the computer's functions manually, if required.

! **Automation and the Operator.** Use the hardware and software to aid the operator; do not use the operator to complement a predetermined hardware/software concept. *Let requirements, not elegant technology, drive design decisions.*

3.2.4 Human performance

The analysis of the performance that will be required of the operator, and the performance that can be expected of the operator, are key factors in function allocation and task analysis. This step, therefore, must be tightly coupled with the function allocation and task analysis steps. Chapter 5 is dedicated to this step, and Section 2.2.6 places these activities in the larger TMC design context.

Critical factors. As functions are allocated to elements of the system, compare expected operator abilities with the human performance requirements. Bailey suggests that the critical factors are: [7]

! Human error.
! Processing time.
! Training time required to reach minimum skills.

! Job satisfaction.

Sources of performance data. Much of the problem in defining human performance require-ments lies in identifying sources of performance data. There is a variety of such sources:

! **Studies in the laboratory and, in particular, studies using task simulation.** [18] This is an attractive option when the mission of a TMC has changed significantly, and new systems and procedures are being considered. Facilities that can simulate most TMC tasks have been developed. As laboratory simulations come into use, they will allow the assembly of performance data bases for use by designers and provide a test bed for innovation.

! **Operational data.** [18] These data can be derived from studies at existing TMC's, and should include both observation and analysis of routine operations and structured exercises, such as discussions with TMC personnel, from which objective performance data are drawn.

! **Subjective data.** [18] The term "subjective" often connotes offhand experience, clouded by narrow viewpoint and personal bias. In fact, it is a rich source of insight when collected and properly assessed. Information for this handbook, for example, was drawn from structured surveys and interviews and from discussion in focus groups composed of subject matter experts and experienced traffic engineers.

Figure 3-1 shows the relationships among these data sources. These sources are excellent for prediction, evaluation, and specification of human performance. Knowing the measured human *capabilities* permits the introduction of such data into system design, and this information can also be applied to performance standards for selection and training. At the design level, they provide designers with material for determining the allowable human performance limits in the total system.

An important source of performance data is available in existing TMC's. The collective experience of trained operators and supervisors can provide many of the most useful insights. Such observations may be of more use than incidental performance information stored in data banks for similar organizations (e.g., nuclear power plant control rooms and air traffic control centers).
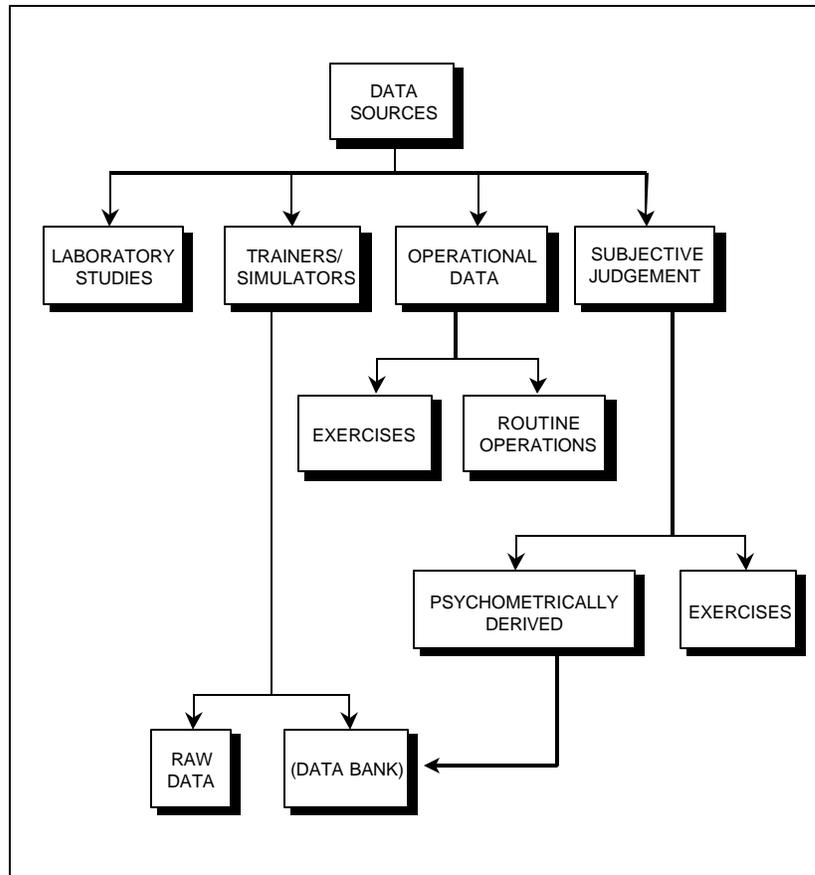
Figure 3-1. Human performance data and sources (after Boff & Lincoln, 1988).

The designer and the human factors practitioner must be cautious in the use of existing performance data. These data should be examined for limitations and these limitations should be taken into account when considering their value for use in the TMC design: [18]

!   Data from laboratory studies are sometimes of comparatively little value for application to system design because they are limited to controlled and artificial conditions. The problem here is one of *external validity*, the degree to which laboratory results can be generalized to the real world (See Section 2.3.2.). Data from laboratory studies are generated under controlled conditions that emphasize *internal validity*, the degree to which the experiment measures the desired effect (for a discussion of what this means to the design team in its own testing efforts, see Section 2.3.2). This is not to say that such data are useless; in fact, they often form the basis for studies in more realistic settings.

!   The amount of empirical data formatted into data banks and derived from formal psychometric processes is limited. Some of this information is in the form of "expert opinion," sometimes gathered using formal psychometric methods, but most often

simply included as recorded. It is difficult to know the comparative validity or each source, and how readily it can be applied to the TMC.

! Few quantitative performance standards exist**.** There are several reasons for this, among them (a) it is difficult and burdensome to specify detailed performance standards, (b) employees do not generally like to work to precise quantitative standards and supervisors do not wish to be bound by them, and (c) unless the standards are developed by qualified people, their reliability is suspect.

3.2.5   Task analysis

Task analysis can be divided into four main stages:

Stage 1:   Determine the system structure.
Stage 2:   Identify the tasks that make up system functions.
Stage 3:   Organize tasks into a flowchart.
Stage 4:   Identify work modules.

How to determine the system structure. The objective of this step is to determine the distribution of task complexity and match it to jobs. A TMC manager, usually a trained traffic engineer, can handle tasks of rather high complexity requiring a relatively large and diverse body of knowledge, skills and abilities; collectively called "experience." A task for a supervisor or technician may be defined at a high level of experience. Entry-level personnel, on the other hand, may be more effective in tasks that are lower level — that is, requiring less experience.

In general, personnel with little experience can perform in almost any environment if the tasks can be designed at a low enough level. Often, the advanced TMC is so complex that it is impractical to set task levels very low. It requires higher levels of experience because of this complexity.

The sites visited during preparation of this handbook showed a wide variation in manning philosophies. One site allowed only engineers as operators; another required only a high school diploma and average verbal communication skills. This represented two distinct tasking philosophies, and it was apparent that the nature of the tasks had evolved in each case to *fit the capabilities of the operators*.

Determination of task levels should be based not only on the technical capabilities of the hardware and software subsystems, but also on the people who will be operating them. For one thing, personnel with very high technical skills may not be available or affordable. Even if enough operators with high technical skills fill the important positions, there will be lower-level employees who want to advance in the system and find themselves blocked by the imposition of higher-level task structures. There is a distinct advantage to building a system in which knowledge and skills increase in a way that allows personnel to move to more demanding jobs without leaving the TMC system.

Identifying tasks. There are at least six indispensable activities for task identification: [7]

- ! Determining existing knowledge and skills.
- ! Deriving skill level categories.
- ! Identifying inputs and outputs.
- ! Deriving lower level activities.
- ! Ensuring that the activities are mutually exclusive and exhaustive.
- ! Matching activity complexities with previously determined skill levels.

The process of task analysis requires a thorough familiarity of the working environment and the work force involved. The factors that make up "complexity" are not easily derived without a knowledge of what operators will be doing, including the activities associated with infrequent incidents that require intricate responses and decisions under stress. Most task analyses need not be exhaustive, particularly if ample experience exists within the community designing and implementing the TMC. The following considerations should support your task analysis:

The task should be defined in terms of duration. This requires the designer to consider (a) the time in which the task must be performed (system requirement) and (b) the anticipated time for the operator to perform the task (performance requirement). A comparison of (a) and (b) that yields a discrepancy in duration is a warning flag — of particular importance if the function in question is essential to the TMC mission. If there is no way that operator performance can be made to meet system requirements, then the task must be modified — either by automating activities or by redesigning the way the task is to be accomplished.

The task should be defined in terms of criticality (error consequences).
This assessment of criticality is derived from potential errors, the effect of each potential error on system operation, and the relative criticality of each of the errors. Error analysis is discussed at Section 2.2.5 and in Chapters 4 and 11.

The task should be defined in terms of the difficulty of attaining correct performance (error likelihood). Errors in the TMC can have dire consequences. Faulty entry to a signal control system, for example, could inadvertently set all lights blinking red (most such systems are designed to prevent accidental creation of dangerous, as opposed to annoying, consequences). Errors are more likely in difficult tasks, and designers generally focus on tasks that are identified as both critical and difficult. Certain characteristics are generally associated with difficult or error-prone tasks:

- ! The input which initiates the task requires precise discriminations or fine motor responses. For example, a GUI that uses a large number of complex icons that are not easily discriminated, or are too closely spaced to be reliably selected by the pointing device, produces an increased likelihood of errors.

- ! The operator's response to the initiating inputs must be performed so quickly that he or she has problems keeping up with the initiating inputs. Interfaces that post changes in status too fast for timely response can cause problems for operators; they may keep up

for a time, but errors then become cumulative as small mistakes build up and destroy efficient "pacing."

! The accuracy demanded of the operator is excessive.

! The task must be coordinated precisely with other tasks performed by other personnel.

! The environment in which the task is performed tends to degrade task performance. For example, a control room in which radio operators and other TMC personnel are working together without acoustic shielding may be excessively noisy, particularly at critical moments (as during the reaction to a serious incident, with a combination of police reports, emergency communications, and other noise sources).

! Information from multiple sources (e.g., several displays) must be coordinated by the operator in order to make a decision. Rapid assessment of an incident via CCTV images, for example, is complicated by the fact that the operator must translate map information (from large display or from screen mapping displays) to a monitor view, then integrate the information. Since it is easy to make an error in estimating the direction a camera is pointing, an operator may commit a fundamental error such as identifying an accident in the northbound lane as one in the southbound lane.

! There is little information available on the basis of which a decision must be made or an action taken.

! Short-term memory requirements for task performance are excessive. While immeasurable amounts of information can be stored long-term in the human brain for later retrieval, short-term capacity is limited (See Section 5.4) in capacity and duration.

Task difficulty and workload. Task difficulty may also be defined in terms of *workload*. In a control room situation, the principal variable is *mental workload*. Unfortunately, mental workload is very difficult to measure. More detailed discussions on workload are found in Chapters 5, 6, and 7 and methods and tools are explained at Section 2.2.6; but as a general way of understanding the concept we use the model proposed by Wickens. [122] Figure 3-2 shows the relationship between demands of the system with respect to a given task and the capacity of the human operator to service these demands. The degree to which the operator meets performance requirements ("primary task performance") will drop off when available resources are exceeded by demands.
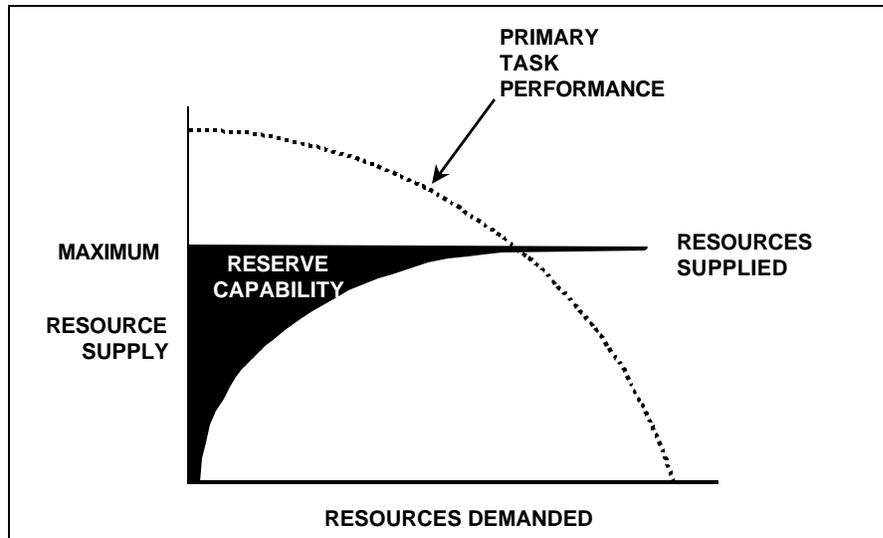
Figure 3-2. Human resources and task performance (after Wickens, 1984).

In essence, system demands may be defined as (a) within the capacity of the operator or (b) beyond the capacity of the operator. In the first case, the operator will maintain a residual capacity ("reserve capacity"), as any human in the system *should* do in an operational setting. In the second case, there is no reserve capacity. The quality of task performance will steadily decline as demands grow beyond capacity while morale and operator health also can be adversely affected. In system design, there are ways to address these factors.

It is extremely desirable to define workload during this phase of the design process. This will provide information needed to plan the allocation of functions to humans, hardware, and software, and the allocation of tasks among operators. The simplest approach is to equate the workload with the *number of tasks* that must be performed at a given time. A time line analysis is useful here, and the method is described in Section 6.6.

It is also possible to conduct an analysis that estimates workload based on rated *task difficulty*. However, we caution that workload and task difficulty are not equivalent, and such estimates are likely to be approximate at best. Even experiments under tightly controlled conditions may yield ambiguous assessments of workload, and in some cases experience may be the best guideline.

A sample of a partial task analysis is shown in Table 3-2. Activity is organized in this example as *functions*, which are high level descriptions of the TMC's mission. Each function contains one or more *tasks*, which are components of operator performance that support a work module, but are independent in that they result in an identifiable outcome ("enter incident data"). The tasks must 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.

In the example, Task 2.3 ("Estimate congestion's potential impact") is clearly a *high-level task*, requiring not only extensive training in the interpretation of system information, but also quite a lot of experience in the nature of traffic incidents. It is not likely that a new or inexperienced operator could perform this function effectively. Task 1.3 ("Activate data screen changes"), on the other hand, is a fairly low-level task, requiring only knowledge of the computer interface and a minimum level of manual dexterity. Task 2.2 ("Emergency notification") lies somewhere in between; it is a fairly complex function, but one that requires only a knowledge of standard procedures.

Note that errors may occur in high-level *or* low-level tasks. The source of the error (manipulation of a mouse at the lower end, incorrect assessment of complex interactions at the higher end) may differ, but probabilities of error may not be entirely contingent on task "difficulty."

Figure 3-3 shows a rough analysis of task and subtask complexity for the examples in the table. Measures of task complexity can be derived from expert opinion of TMC operators or designers, from existing performance/error data, or from experiments. In general, high complexity represents either a high level of expertise or adequate experience and training to integrate a variety of lesser activities into an integrated, synthesized plan. This can be used to provide input for workload profiles, (Section 2.2.4. and Figure 2-15.)

Organizing tasks. In Figure 3-4, the function of dealing with a traffic incident is illustrated, at a fairly high level, in an operational flow diagram. This example incorporates an entire work module — in this case, a critical operational procedure. We should note, however, that this function does not necessarily describe the tasks of one operator. An incident requiring all these activities will probably involve several team members in the control room, automated equipment, and the active cooperation of outside agencies such as state police, emergency services, and information officers.

The tasks that comprise this function are shown as squares ("actions"); information that feeds into the execution of tasks (traffic sensors, CCTV images, communications from other sources, e.g., state police) or is transmitted out of the TMC (communications and system commands) is shown as inverted triangles; existing reference information (e.g., TMC operating procedures) is represented by a shield. Decisions (hexagons), if not automated, constitute tasks as well. In this case, all decisions are made by operators (i.e., not automated). Note, however, that automated system output to operator displays is critical to many of the operator functions.

Table 2-2. Example initial task analysis.

Tasks will differ in a variety of ways across individual TMC's, because of variations in mission, staffing and philosophy. This sample first-pass selection shows specified activities performed by typical operators in representative situations.

Function	Task	Subtask	Characteristic Error
1. **Monitor** traffic conditions.	1.1 **Receive** updated real-time traffic flow data from computer.		
	1.2 **Scan** the video display.	1.2.1 **Scan** for congested areas.	
		1.2.2 **Scan** for congestion.	
		1.2.3 **Scan** for potential alternate routes.	
	1.3 **Activate** data screen changes	1.3.1 **Select** menu items with mouse.	Choose wrong icon.
		1.3.2 **Enter** codes via keyboard.	Enter incorrect code.
	1.4 **Interpret** graphs, maps, and text on video display.		
	1.5 **Discriminate** ab-normal flow patterns from normal flow patterns.		

Table 3-2. Example initial task analysis (continued).

Function	Task	Subtask	Characteristic Error
2. **Analyze** traffic incidents and **implement** plan to relieve non-recurring conflict situations.	2.1 **Identify** traffic concern.	2.1.1 **Detect** information suggestive of incident.	
		2.1.2 **Locate** site of incident.	
		2.1.3 **Categorize** incident type.	
	2.2 **Notify** police, emergency, fire, and medical teams as the situation requires.	2.2.1 **Manipulate** controls.	
		2.2.2 **Communicate** through headset or telephone.	Enter incorrect number or frequency.
	2.3 **Estimate** congestion's potential impact.	2.3.1 **Estimate** duration of congestion.	
		2.3.2 **Estimate** accident clearance duration.	
		2.3.3 **Predict** effect on traffic pattern.	
	2.4 **Effect** routing plan options.	2.4.1 **Identify** alternate routes.	
		2.4.2 **Predict** effect of each alternative on traffic flow.	
		2.4.3 **Compare** alternate routing plans.	
		2.4.4 **Select** alternate routing plan.	
	2.5 **Enter** incident data.	2.5.1 **Select** from menu.	
		2.5.2 **Enter** data	
		2.5.3 **Transmit** information to other operators.	
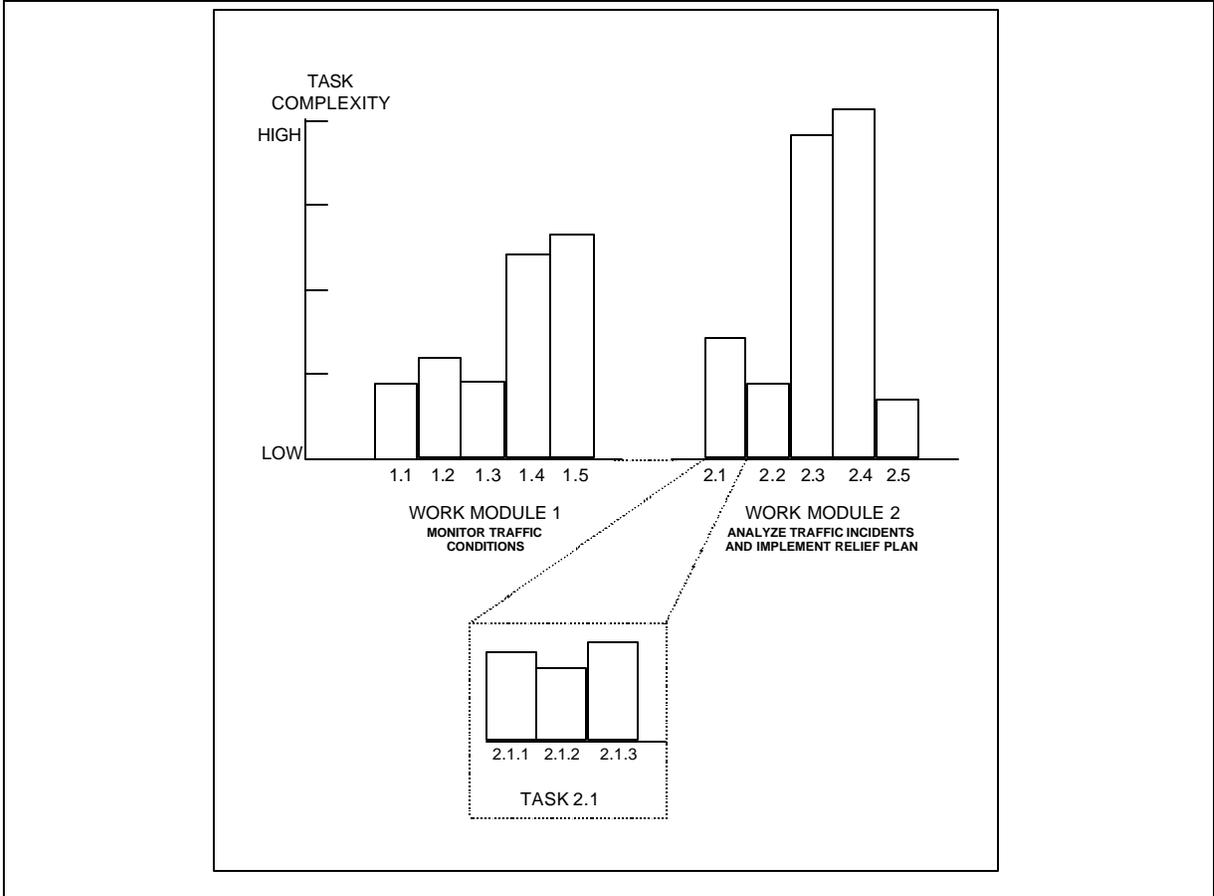
Figure 3-3. Assessment of work complexity of activities, tasks and work modules.

Figure 3-5 shows the last task in the work module sequence which consists of closing out the incident by entering information into a data base that stores such information for later retrieval and analysis. This diagram shows the series of subtasks undertaken by a single operator. The loop that describes a visual check for correctness of information entered into the system indicates a possible error source that could be influenced by the level of training and experience of the operator, the complexity, reliability, and volume of the information to be entered, and the interface design.

Operational Sequence Diagram

Traffic Sensor

Other Traffic Information

TMC Operating Procedures

Operator Displays

DECLARE EMERGENCY?

Operator receives information from traffic sensors and other sources of a possible incident

Traffic sensors, CCTV, etc.

No Action Required

YES

Declare Emergency

Operator evaluates information, consults operating procedures, decides that (1) an emergency exists, (2) further information is required before action is taken, or (3) no emergency exists.

Select Procedures

Traffic sensors, CCTV, etc.

Notify Police

Dispatch Response Vehicle

Query System

Based on standard operating procedures and the situation, the operator takes actions necessary to deal with the emergency

YES

Further Action Required?

Operator monitors the situation and revises control activities as required until the situation is resolved.

Symbol	Meaning
⬡	Processing or Decision
▢	Action
▽	Transmitted Information
◯	Received Information
⬭	Previously Stored Information
▢	Automated Operators
■	Inaction or No Information
◤	Partial Information Or Incorrect Operation

Figure 3-4. Operational sequence diagram.

Task Flowchart

This flowchart example shows a task in which the operator enters a traffic incident into the traffic records database. The operator selects the appropriate icon, consults the standard operating procedure (if necessary), enters the incident data, verifies the correctness of the information, selects "Transmit", and exits the procedure.

TMC Operating Procedures

Select Icon

Enter Incident Information

Display Incident Information

Information Correctly Entered?

No

Yes

Select Transmit

To Database

Exit Procedure

⬡	Process and/or Decide
☐	Action
▽	Transmit Information
◯	Receive Information
⌂	Previously Stored Information
☐	Automated Operators
■	Inaction or No Information
◪	Partial Information Or Incorrect Operation

Figure 3-5. Task flowchart.

CHAPTER 4: HUMAN ERROR

CONTENTS

4.1 Human Error is Important to System Designers

You are driving on a suburban freeway during the morning rush hour, and see a changeable message sign that informs you that there is an "accident ahead; left lane blocked." You and other drivers attempt to move into the right lanes, but you never encounter the accident or blockage. You are inconvenienced, and traffic is significantly slowed. TMC operator errors, like failing to turn off the VMS warning message after the accident has cleared, can have serious effects on ATMS effectiveness and credibility.

Human error is a normal characteristic of human behavior. It occurs in many forms and in all environments. It is not always easily understood or prevented. Human factors research and experience have provided useful principles for classifying errors and for reducing their probability and consequences through system design.

This chapter presents an introduction to the types of errors humans are likely to make, and

provides some general principles and guidelines for designing error-tolerant systems. Other chapters in this handbook address specific design strategies to reduce the frequency and effects of errors.

4.1.1 Dealing with error systematically

This chapter deals with the *science* of human error. Designers should use this part of the handbook to gain an understanding of the *types* of errors likely to be encountered in the TMC and the general guidance for reducing error probability. Specific examples of operator errors in the TMC and error-reducing design guidelines are found in this and other handbook chapters.

Typically, the term "human error" refers to a wide variety of events that share two defining characteristics — *a human took an action (or neglected to take an action) and the outcome was unacceptable*. This chapter further defines human error, and addresses methods to analyze and classify errors.

The potential for error exists in any system of which humans are a part. People don't perform with the same uniformity as machines. The boundaries between acceptable and unacceptable performance are often unclear. Actions that seemed correct when they were performed may be judged to be erroneous after the undesirable outcomes are known.

The likelihood of human error can be strongly influenced by the design of the machines people use. Operators make fewer errors if systems are designed in accordance with sound human factors principles. One of a system designer's goals should be to ensure compatibility between operators and machines. Thus, system designers should have a basic understanding of error and of the system design features that influence the probability or consequences of errors.

4.1.2 A definition of error

Most lay definitions of error include the concept of an incorrect action, which is inappropriate, mistimed, misplaced, poorly chosen, or poorly executed. James Reason, a psychologist who has studied human error and its relationship to complex systems, offers the following definition, which will be used in this chapter:

> Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency. [98]

Human behavior is immensely variable. We have the capability to assess a situation we have never encountered before, draw conclusions about it, and respond to it in an adaptive manner. This capability draws on the unique cognitive abilities of the human species, and has been essential to our survival and to our accomplishments. But it also means that our conclusions will

sometimes be erroneous, our responses not the most appropriate (or not perfectly executed), and our timing imperfect.

Chapter 6 (*Job Design*), and Chapter 11 (*The User-Computer Interface*), will present in some detail the specific methods which can be used to factor the possibility of human error into a design. The current discussion concentrates on recognizing various types of errors. This should help the reader understand the ways in which humans behave when interacting with complex systems. This understanding is a foundation for user-centered system design. This chapter also contains suggested methods for documenting and analyzing errors. Finally, this chapter presents a brief explanation of the principles of designing systems to reduce error and its consequences, with general guidelines for error-reducing and error-tolerant design.

4.2 The Types of Errors

It is easier to understand the nature of errors and their relationship to system design if we can categorize errors by type and identify their important features. Several classification schemes have been proposed to categorize human errors. Two of these will be discussed here. They have been chosen because they provide foundations for guiding the design of human-machine systems. The first (in Section 4.2.1) examines intended and unintended actions, and the resulting errors of intention and of execution. The second (in Section 4.3.1) concentrates on decision making errors when incomplete or uncertain information must be used. Each has consequences for system design.

4.2.1 Errors are related to the operator's type of behavior

Operator behavior can be assigned to three levels, depending upon the level of mental processing controlling the behaviors. [96] This model of operator behavior assumes that the operator has had considerable time to learn his or her job. An example would be an experienced driver operating a standard transmission vehicle.

The first level, *skill-based behavior*, includes those actions which have become "automatic." In the driving example, this would include actions such as depressing the clutch and moving the gearshift lever to shift gears — actions performed with little or no conscious attention or thought. This type of behavior is most commonly used in routine action sequences when the situation is familiar.

The second level, *rule-based behavior*, occurs when one is consciously attempting to reach a goal or to solve a problem. It refers to behaviors where the operator uses a rule, an "if-then" statement, to decide upon the appropriate action. In the driving analogy, the driver might have been given directions to head east at an intersection to find his or her goal, and may invoke the rule, "If I am facing north, east is to my right" to decide which way to turn. A rule is available to

guide the behavior, but the behavior is not automatic.

The third level of operator behavior, *knowledge-based behavior*, is most familiar in a problem-solving or troubleshooting setting. In this case, the learned or available rules or routines are not sufficient to specify what to do next, and the operator must rely on his knowledge and understanding of the system to select an appropriate action. The driver in this case might find himself plotting a new route to avoid construction, or trying to determine the cause of a strange noise under the hood.

The chief differences among these three levels are in the conscious attention given to the actions, the awareness of a challenge or problem to be solved, and, finally, the types of error associated with each.

During the first level of operator behavior, skill-based behavior, operators may be thinking about another task or may even be daydreaming. Typical errors during skill-based behavior are slips and lapses.

Slips are the execution failures, in which an action sequence continues to the wrong conclusion. For example, an operator catches himself entering the wrong sequence into a variable message sign.

Slips show up most frequently in skilled behavior. We don't make so many slips in things we are still learning. In part, slips result from a lack of attention. On the whole, people can consciously attend to only one primary thing at a time. But we often do many things at once. We can do more than one thing at a time only if most of the actions are done automatically, subconsciously, with little or no need for conscious attention. [98]

Lapses are the memory (storage) failures, as when an operator forgets the appropriate sequence for a command entry or becomes distracted and forgets to perform an important procedural step as in the following example:

AN OMITTED KEYSTROKE

Preparing for the major special event, the TMC operator spent about 30 minutes manually fine-tuning the signal timing plans for intersections in a large part of the downtown area. Suddenly, all of this work was erased when a preprogrammed time-of-day timing plan took effect. The operator had forgotten to input the keyboard command that would have disabled the automatic change.

Rule-based and knowledge-based behavior, because they require more attention, are more likely to result in the kind of errors known as *mistakes.* Mistakes are the errors that occur when operators misconstrue a situation or select the wrong solution to a problem.

Mistakes may be defined as deficiencies or failures in the judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan. [98]

If the driver turns on his lights when he intends to turn on the windshield wipers, this is a slip. The intention is correct, but the execution is wrong. If the north-facing driver decides that to go east he should turn left when in fact he should turn right, it is a mistake. He is using an invalid decision rule.

Reason further differentiates rule-based mistakes from knowledge-based ones. Rule-based mistakes follow from the wrong choice of rule, or from incorrect application of a rule or procedure, which in turn may be caused by a misinterpretation of the problem situation or by other causes. Rule-based mistakes are somewhat easier to predict and to diagnose than are knowledge-based mistakes. More important, it is easier to minimize them through appropriate design.

Knowledge-based mistakes, on the other hand, are quite unpredictable, since they are based on the individual's unique mental model of the system and his or her reasoning process. An example of a rule-based mistake for our driver was given above: if in fact he was *not* facing north when he applied the "east is on my right" rule, he would take a wrong turn. A knowledge-based mistake would occur if he did not know the rule, and acted on an incorrect recollection of the neighborhood geography.

4.2.2 Design implications of error types

Why is it useful for a system designer to understand theories of human error? The theories make some predictions and observations which are worthy of attention. These have design implications that will be summarized in this chapter and discussed more fully in Chapters 6 and 11.

Most people can remember slips they have made (e.g., putting objects in the wrong place, absent-mindedly taking the wrong freeway exit, dialing the wrong phone number). Often, slips occur when familiar action sequences are interrupted or confused with each other. One starts out to do one thing and ends up doing another, inappropriate to the original intention.

A familiar error example is a skipped step in a procedure. The implications of such errors can range from the trivial to the catastrophic; from a letter mailed a day late to an airliner touching down on the runway with its landing gear up. In between would be such errors as forgetting to end the automatic rotation of changeable message signs, or a message advertising upcoming radio traffic reports at the close of rush hour. In system operations, a common design solution used to prevent errors of omission is the use of formal procedures and checklists. Many such aids can be automated, with the software programmed to prompt for the next step in a

procedure or to query the operator if the most likely next step is omitted. The familiar message "FILE CHANGES NOT SAVED; EXIT ANYWAY?" is an example of this strategy. In a traffic management center, one might choose to include automated reminders — for example, to ensure that all procedures needed at the end of morning rush have been performed.

Unfortunately, mistakes are typically less easily detected than slips. In a mistake, the action supports the intention and may proceed smoothly. The intention seems reasonable, given the interpretation of the problem situation. Thus, a mistake is not usually detected until it has an undesired effect; we do not realize that we should have turned right until we are lost. At the Three Mile Island nuclear plant, a valve display was interpreted as showing that that valve was closed (when fact it was stuck open). The resulting actions taken by the control room crew were not discovered to be inappropriate until a sequence of wrong actions had been performed.

It is necessary to find ways to cause operators to stop and confirm their judgments before taking irreversible actions. It is helpful to provide checklists and to build in reminders to aid in the application of rules and procedures. Designers can display warnings, require confirmation, and require additional steps before allowing completion of actions that can have serious consequences.

Systems should provide clear, accurate, and timely feedback on the consequences of operator actions. The Three Mile Island indicator for the stuck valve showed only that the valve had been *commanded* to close; it did not show the valve's actual status. Thus, the operators did not have accurate feedback (but thought they did) and continued to presume that the valve had closed when it had not.

Complex, system-level issues often arise when such errors are carefully analyzed. Crew coordination or task allocation issues can be involved; job design may not have been sufficiently attentive to ensuring that everyone involved knows who is responsible for a particular task or step. Controls may not have been designed to support operators' adherence to procedures. Rigorous analysis, as discussed later in this chapter, may also reveal that the task or workplace was designed in such a way that the omitted action was difficult or inconvenient to perform at the proper time, or that the step did not fit smoothly into the task flow, or that the operator was expected to attend to too many tasks at a given time.

4.3 Consequences of Error in Decision Making

A major category of decisions involves situations in which the operator must decide whether a condition exists or does not exist. In many cases, information received in the TMC control room will be fragmentary or ambiguous; sensor count and CCTV image may, for example, seem to conflict. Other information may be "noisy" — that is, cluttered with nonessential background noise or extraneous data.

4.3.1 Signal Detection Theory and decision errors

Signal Detection Theory contends that in a detection and verification situation there often is background noise that can interfere with the detection of a signal. The observer must decide whether the signal (the event being awaited) did or did not occur. A roadway incident, for example, may be indicated by an unusual level of congestion detected by loop detectors or viewed on a CCTV camera. The operator who detects an unusual level of congestion must determine whether an emergency incident response is needed. Heavy congestion without an incident may, then, be considered as noise in the incident detection process; heavy congestion caused by an incident may be considered a signal.

Visually, noise on a monitor is any element that does not carry pertinent information (e.g., cluttered, crowded graphics on a display). Note that "pertinent information" means information necessary to the task at hand. A cluttered display may have a number of visual targets and images that provide information pertinent to any number of things. However, if they are not useful to the decision at hand, by definition they become noise.

When the observer is to distinguish signals from noise, four possible outcomes exist. When the operator makes the decision that a signal did or did not occur, the outcomes are as follows:

> **!**   Stating that a signal is present when a signal *is* present is a HIT.

> **!**   Stating a signal is present when a signal *is not* present is a FALSE ALARM or TYPE I error.

!   Stating a signal is not present when a signal *is* present is a MISS or TYPE II error.

!   Stating a signal is not present when a signal *is not* present is a CORRECT REJECTION.

The observer takes action based on two conditions -- the physical detectability or sensitivity of the signal itself and of the observer's own *decision criteria*. These measures are based on the probability of hits and the probability of false alarms. [18] For example, if the noise level is low and the signal is conspicuous (as in the case of an auditory warning in a quiet control room) detectability will be high. If the noise level is high and the signal is inconspicuous, the probability of detecting the signal will be lower. Thus, factors that alter sensitivity include signal strength as well as event rate.

The decision criterion is a ratio that defines the degree of bias toward responding positively to signals (decide that a signal is present). The decision criterion is an individual operator's decision bias at a given time that may influence him or her to respond more often with "yes" or "no" under similar conditions. [18] Factors that influence the setting of the decision criterion include probability of signal occurrence, instructions to adopt a risky or a conservative criterion, and the perceived costs and advantages associated with hits and false alarms. The driving factor here is that the decision criterion can change depending on the individual acting as monitor and the circumstances.

A new operator, for example, may be inclined to discount an ambiguous signal through inexperience or, conversely, respond to all ambiguous situations as signals. Trained and experienced operators are less likely to do either, since they have a finer sense of the nature and likelihood of the signal.

4.3.2 Errors and consequences

In the operational environment of the TMC, a MISS — stating that a signal is not present when it is — could have serious consequences. That is, if an incident has occurred and a traffic monitor failed to recognize the occurrence, appropriate response would be delayed and gridlock, injuries or other disruption could result. If, on the other hand, a traffic monitor stated an incident had occurred when actually there was no incident (FALSE ALARM), unnecessary responses on the part of the TMC would occur. One risk involved here would be the "boy who cried wolf" syndrome. That is, if learning that an incident did not occur but the TMC activated warnings and detours anyway, the general public's trust in the system may be reduced and unnecessary expenses may be incurred.

This problem is made worse by machine output — particularly a faulty sensor, such as loop detector — that has a high rate of false alarms. Site visits and interviews by the authors indicated that such a condition is not rare in existing TMC's, and tends to reduce the operator's

confidence in incident detection algorithms. In this very real case, a *machine error* resulting in a high number of false alarms (in effect, a machine *Type I error*) could logically contribute directly to a human *Type II error* (missing or not reporting a signal).

Table 4-1 shows potential consequences of each possible condition.

Table 4-1. Consequences of decisions.

STIMULUS

RESPONSE	Signal IS NOT present	Signal IS present
Yes	TMC actions disrupt normal operations for no reason.	TMC responds correctly.
No	TMC responds correctly	TMC fails to respond to an incident.

Table 4-1 is called a *Payoff Matrix*. In each cell, the decision consequences are summarized. Designers should weigh the relative seriousness of misses and false alarms when specifying the design of displays (See Chapter 8), interface provisions such as warnings (Chapter 11) and the design of tasks and jobs (Chapters 3 and 6).

The point to remember here is that there is a relationship between the probability of a miss and the probability of a false alarm. With an automated incident detection system, for example, decreasing the number of false alarms entails increasing the number of misses or the time required to detect an incident. Many TMC designers "tune" the detection algorithms to reduce false alarms but recent research has shown that a better approach is to reduce misses and detection time, allow false alarms to occur but provide an easy way to recognize and dispose of them.

4.4   Analysis of Human Error

Given an understanding of the types of errors possible, we can begin to consider methods for analyzing human error. A number of methods for analyzing error are available, including questionnaire studies, laboratory and simulator studies, case studies, and the critical incident technique. Questionnaire studies allow users to answer questions about errors that occur in their respective user environments. Laboratory and simulator studies allow analysts to investigate

human error in a controlled environment. Case studies provide a way for analysts to conduct detailed investigations of specific instances in which errors were noted. With the critical incident technique, problems that led or might have led to a crisis are analyzed.

Detailed descriptions of two of these methods, questionnaire studies and the critical incident technique, are presented. These methods are particularly well-suited to operational TMC's. Readers who are interested in learning more about laboratory studies, simulator studies, or case studies are referred to Boff and Lincoln. [18]

4.4.1 Questionnaire studies

Self-report questionnaires represent another means of obtaining data associated with everyday errors. Typically, such a questionnaire will present respondents with descriptions/examples of various errors (slips, lapses, mistakes) and ask them to indicate the frequency with which they have committed such errors. While questionnaire responses are susceptible to bias, analysts can use them to investigate:

- **!** How frequently errors occur and individual differences in error proneness.

- **!** The relationship between various error types.

- **!** The instances under which errors of a given type have occurred as a means to identify error causes.

In general, responses to questionnaire items involving different severity of error reflect positive correlations. In other words, individuals who admit to frequently making one type of error (lapses, for example) also tend to admit their susceptibility to other types of errors. [18]

Questionnaire studies have also discovered that whatever is responsible for determining an individual's proneness to slips and lapses also appears to contribute to stress vulnerability. In other words, certain styles of cognitive management can lead to both erroneous behavior and ineffective stress management.

4.4.2 Critical incident technique

Accident and near-accident data can be analyzed with an approach known as the critical incident technique. The method was originally developed during World War II to identify reasons for failures in flight training methods and for failure in bombing missions. This particular technique, used within the context of accident analysis, is an adaptation of a method that has also been applied to job analysis, the analysis of performance requirements, proficiency testing, and training needs assessment. In applying the critical incident technique, an analyst interviews users of a given system. Each user is asked to consider the given system (e.g., a piece of

equipment, a group of instruments, a computer system) and describe an error he or she has made while interacting with the system. The underlying assumption of the technique is that given a large number of reported errors, the analyst can identify *critical* design problems (i.e., those that led to or might have led to a crisis or accident).

In general a critical incident is specified in terms of three types of information: the background or context in which the incident occurred, an observable behavior that occurred as a result of the incident, and a description of the consequences of that behavior. This provides a format for documenting critical incidents. Note that in the term *critical incident*, the word *incident* refers to an event that has generated specific problems. It does not, in general, refer to a *traffic* incident.

Consider a hypothetical TMC in which operators have a well-documented history of misinterpreting computer-based sensor displays. The scenario below provides an example of a critical incident that might have occurred as a result of display interpretation problems. After reading about the events surrounding this incident, one might easily arrive at a conclusion of "operator error." After all, the operator misinterpreted displayed information.

> It was at the end of a busy shift. A blinking red spot appeared on the primary map display on my monitor indicating a possible accident on the freeway at Maple Street. To verify the incident, I keyed in the five digit code to call up the nearest camera. A minor fender-bender appeared on my CCTV monitor so I sent a message to the upstream VMS sign to warn of the blocked right lane. It turned out that I'd called up the wrong camera and there actually was no accident at Maple. The red light that I thought I saw had actually been an orange light used to show possible stuck-on loops. I felt kind of embarrassed but that's not the first time this kind of mistake has happened.

Recognize how the design of the human-computer interface may have contributed to the operator's errors. (Recall the operators' repeated problems with this sensor display.) The sensor display may have been cluttered or poorly color coded such that it did not facilitate the operator's assessment of existing traffic conditions. In any event, given a well-designed interface, the operator might have interpreted information correctly and thus avoided the error (unnecessarily modifying the VMS message). Another possible inadequacy of the human-system interface was revealed when the operator, in trying to confirm sensor data, examined the wrong CCTV view. The operator did not recognize that he was observing conditions on the wrong freeway. In this case, video labeling may have been ambiguous, difficult to read, or perhaps missing. Furthermore, the five-digit code for camera control may have created memory problems.

The critical incident method enables analysts to determine the types of incidents that recur and the events that lead up to errors. It also allows analysts to examine human behavior, to identify behaviors that lead to errors and to associate an outcome (and outcome severity) with that behavior. Factors that contribute to errors can also be determined.

Typically, in the critical incident method, a large number (perhaps several dozen) of reports are obtained and sorted into groups of similar events according to the configuration item involved, the type of error, or some other factor. A large number of similar errors related to a specific task, display, or decision indicates a need to examine that job aspect in greater detail to see whether there is a need for redesign.

In reviewing any data collected via the critical incident technique, one should note the limitations of the data: selective recall of incidents is a function of time (i.e., certain types of incidents are quickly forgotten), the total number of incidents varies over time, and the types of incidents reported depend upon the individual responsible for reporting them.

4.5   Design for Error Reduction

Error analysis is one of several processes which can support the design and/or evaluation of an operator tool, procedure or other item designed for a task. When an error is observed, it is easy to assume that the operator was not fully attending to the task or does not understand the task and needs more training. While these interpretations may be true in some cases, one must also consider that the tool has a design deficiency. Whether an error is observed through casual observation or in a more thorough, formal evaluation, analysis of that error can be used to determine whether modifications are in order. Such modifications may be applicable to procedures, job design, training or equipment. The following guidelines apply to error analysis:

4/1 Error Identification   (Observation)

Include operators in the error identification process.
There are several approaches that can be employed in the identification of error origins. These approaches are more effective if used in combination. One method may employ a checklist of possible equipment design deficiencies. Some of the guidelines in this handbook could be reformatted for such a checklist. Another method would use an engineer or analyst to perform a detailed analysis of the steps involved in the relevant procedure to isolate the conditions which led to the error.

The method emphasized here collects data from the person or persons who made the error, and/or other individuals who perform that task in the same context. The rationale for this method assumes that operators are attempting to do their job well, but have encountered a situation which was difficult to anticipate. In other words, the situation is sufficiently subtle or complex that the operator does not or can not know that an error prone situation exists. In this situation, the analysis can become complex because the operator often does not know what caused the error.

Nevertheless, the operator usually possesses intimate knowledge about the circumstances surrounding the error which can lead to the identification. One way to gain insight into such a situation is to observe the operator performing the task and document those behaviors for analysis. In addition, the operator may be interviewed. Effective interviewing skills can elicit useful information from an operator. For instance, the interviewer should be receptive to operator suggestions for solutions. While it may be apparent to the interviewer that the offered solution does not address all of the necessary elements to provide a workable solution, the suggestion can still provide an invaluable insight toward a clear definition of the problem. If error analysis proceeds without operator input, it will often be difficult to understand the full context of the error.

4/2 Ranking of Errors (Observation)

Prioritize errors using well defined criteria to establish which errors should first receive attention.
A thorough error evaluation can result in the documentation of numerous errors. It is seldom necessary, however, to eliminate all sources of operator error. It *is* important that the documented errors be examined for their significance. Errors should be prioritized early in the process to determine which errors should receive more attention. Prioritization criteria may include a combination of the following:

- **!** Error Consequences: An explicit analysis of the error may indicate, for example, that the significance of an error may be trivial, or that it may have serious economic effect, or be life threatening.

- **!** Error likelihood: Some errors may occur frequently (e.g., an operator cannot find an item in a computer menu because of an awkward menu nesting structure) while other errors seldom occur (e.g., an awkwardly written procedure is occasionally misinterpreted). Note that a normally low error probability can increase when the operator is under time pressure or another stressor.

- **!** Cost Analysis: An error that has a small effect and a high cost to remove may not be worth the effort. On the other hand, an error that affects safety deserves serious attention independent of a cost analysis.

- **!** Error Reversibility: Some errors (e.g, an error that is signaled by an audible and visible alarm) may be corrected before a problem occurs. An error that directs vehicles to take the wrong exit may take

longer to correct. This error can be corrected, but only after a number of vehicles have taken the wrong route.

4/3 Operator Tool Design   **(Observation)**

Design controls and procedures to make correct responses easier than incorrect ones.
System design can influence the probability of errors, and it can also determine the consequences of errors that do occur. For example, the probability of error can be reduced by designs which make incorrect responses difficult to perform: guards for switches, interlocks, and lockouts are examples of design features used for this purpose. The consequences of errors can be minimized by design features that recognize input with serious consequences and prompt the user to reconsider them before their execution. The familiar query used in many word processing file management routines, "Delete all marked files?" is an example. Another method of reducing error probability is to identify and increase the discriminability of control (or display) elements which can be confused with each other.

4/4 Procedures, Job Aids and Operator Error   **(Observation)**

Provide and encourage use of clearly written, standard operating procedures for crucial, complex or rarely performed procedures.
Identify which operator tasks are important; i.e., must be performed accurately in a timely fashion. Error control for these tasks may benefit from a written procedure based on a step-by-step analysis. Include active operator input when writing these procedures to promote usability of the procedure and/or job aids.

4/5 Design Evaluation (Observation)

Evaluate a modified design with usability testing which incorporates the operator.
When an operator tool is modified to improve performance, it should be evaluated to ensure that the new design performs according to documented expectations and criteria. A new design should be evaluated with one or more operators preferably using several important scenarios. This is particularly important when the new design replaces a previous design associated with significant error. Another reason for testing a new design is to ensure that the design does not introduce a new, different type of error. Just because the design has changed does not automatically mean that all error will be resolved.

4/6 Provide Decision Support Tools (Observation)

Design and provide decision supports for complex, critical, or infrequently made decisions.
Paper or computer-based decision trees, for example, for maintenance troubleshooting or for managing unusual incidents may make the job less error-prone.

CHAPTER 5: HUMAN PERFORMANCE

CONTENTS

5.1   Human Performance

One of the major goals of the ITS philosophy is to bring increasing levels of automation into the TMC. On first consideration, it seems obvious that increased automation of sensing, data processing, decision making, and communication and control functions should reduce the operator's workload, reduce operator errors, and improve TMC performance. But automation brings with it a whole new set of human factors problems. Operators must use complex hardware and software systems with functions they do not fully understand, and with

user/system interfaces that may seem far less natural than the lower technology systems with which they are familiar.

While high levels of automation may be the ultimate goal, our studies have shown that the human will remain an indispensable element in the TMC during the foreseeable future. Thus, the expected performance of the human operator is as important as the expected performance of the sensors, computers, and other hardware/software systems in designing the TMC. This chapter summarizes some of the important human performance characteristics and limitations that should be understood by designers of TMC's and TMC systems.

5.1.1   Human response to TMC demands

One of the primary jobs of the TMC operator is responding to traffic anomalies such as incidents, equipment malfunctions, and roadway congestion. In order for ATMS operators to respond to a traffic anomaly, the problem first must be detected and appropriately categorized. Alternative responses to the anomaly must be identified and weighed. Then appropriate response tactics must be selected and implemented.

Detecting and verifying roadway incidents will remain largely the responsibility of operators in the TMC. Incident detection requires focusing attention on various information displays, including automated incident detection systems, and correlating the information obtained. Vital tasks include monitoring numeric, graphic, and closed-circuit television displays to determine whether traffic speeds and volumes are at abnormal levels. In addition, observers scan the video monitors to find incidents and evaluate their severity. Operators may also listen to radio and telephone communications for reports of traffic incidents and other alerts. Whether using automated or manually operated systems, operators must continuously evaluate the need for their intervention, determine intervention priorities and tactics, and then carry out actions to control or influence traffic flow.

Although technologically advanced equipment will aid in the ATMS's monitoring, memory, and decision making tasks, humans will still play a large role. When humans perform attention demanding tasks, mistakes will naturally occur. As ATMS automation increases, the range of human tasks will narrow to mostly include those in which the nature, amount, and relative ambiguity of information exceed the capability of the system to take automated action. This will, in fact, increase, rather than decrease, the criticality of the human role.

5.1.2   Performance concerns

Human performance issues in the TMC can be categorized into four primary areas:

> **!**   **Attention, monitoring, and vigilance.** As operator functions become secondary to computers, there is an increased burden on the operator to perform accurate monitoring functions. Watching the state of multiple system and traffic variables may seem so routine that errors appear unlikely. In fact, the probability of errors may actually increase as the operator's role becomes more passive.

! **Stress, boredom, and fatigue.** Human input, output, situation awareness, and processing of information are affected by the pace and variability of the job. The normally low workload of the TMC operator can be expected to result in boredom and daydreaming. The sudden transition to a high workload environment during a major incident can be stressful and result in performance decrements.

! **Memory.** All human cognitive activities in the TMC require the use of memory. For example, the operator must remember the appearance and meaning of display indications. The operator must remember TMC procedures or, at least, where to find the procedural checklist. The operator must also remember past experience with a variety of traffic anomalies in order to help select an appropriate response or fine-tune a response that was inadequate.

! **Decision making performance.** The operator's most important TMC function is as a decision maker. In this chapter we consider the decision making process, its limitations and biases, and the expected human performance. Other chapters (e.g., 11, 12, and 13) address the questions of machine design and information display and their relationship to effective decision making.

5.2   Attention and Vigilance

A primary task of the TMC operator is to monitor system and traffic conditions. Performance is thus constrained by the operator's ability to maintain appropriate attention — to be aware of system and traffic status, to detect relevant changes in status, and to respond appropriately. Attention and vigilance have been the subject of extensive research, and the findings are sometimes subtle and difficult to reconcile with widespread notions of how people function. System design, however, must accommodate these sometimes complex issues.

5.2.1   Definitions

The following are definitions of terms that are necessary to the understanding of human performance during sustained attention to information displays:

! **Monitoring.** Attending to an operation or procedure to identify circumstances or events that require some action or response. This may require attending to one or more information channels.

! **Detection.** Observing that a signal or event has occurred. Usually skill based and fairly automatic, it relies on sensory inputs.

! **Search.** Rapid scanning of visual material for particular targets (icon on a map display, keyword on a paper, data point on a graph) within clutter, or a pattern.

! **Vigilance.** Maintaining overt attention to a perceptual task for prolonged time periods often with infrequent stimulus events. The challenge is to maintain a sustained level of attention for prolonged periods of time, while searching for targets that may rarely or never appear.

! **Signal.** An indication of an event that requires a response or action.

5.2.2 Selective attention

Situations or tasks that require attention can be divided into three categories: selective attention, focused attention, and divided attention. The following sections describe each of the three categories and provide guidelines and recommendations for improving performance of tasks in which these occur.

Selective attention is attention that alternates between channels of information. A TMC operator who scans a number of displays looking for a deviant reading is using selective attention. Selective attention is probably the attention type that will be most commonly identified with TMC operators. When studying selective attention tasks, two sources of stress may be evident.

! **Load stress.** Is stress imposed by an increasing *number of channels* over which information is presented.

! **Speed stress.** Is stress related to the *rate of signal presentation*.

For selective attention tasks, load stress is more important than speed stress in degrading performance. [53] When people must attend to multiple channels of information, they usually concentrate on channels in which signals occur frequently rather than those where the signals occur infrequently.

Further, due to human memory limitations, channel scanning strategies may be less than optimum. People often forget to examine a specific source when many sources are present, and people tend to check other sources more often than would be necessary if they remembered the status of the source when it was last experienced. [101] Under high stress conditions, fewer sources are attended to and the sources attended to are likely to be those perceived as the most important and salient. People tend to overlook or ignore information that is contradictory to their analysis of the situation. [86] This characteristic frequently has been called "tunnel vision" although it is in no way related to the operator's visual fields.

A limitation of selective attention is that, in some cases, we select an inappropriate aspect of the environment to process. Thus, when designing selective attention tasks, the following guidelines should be considered.

5/1 Number of Channels   **(Recommendation; 101)**

When multiple channels (displays or sensory modalities) must be monitored for signals, use as few channels as possible.
This holds true even if it means increasing the signal rate and amount of information per channel. After prioritizing the channels, examine the least important for deletion.

5/2 Channel Prioritization   **(Recommendation; 101)**

Provide information to the person as to the relative importance of the various channels so that attention can be directed more effectively.
A support system, for example, might specify specific displays or CCTV monitors that are showing anomalies.

5/3 Workload   **(Observation)**

Reduce the overall level of stress or workload on the person so that more channels will be sampled.
"Stress," in this case, refers to other demands. If more channels must be monitored, the attention resources must be increased. The most obvious way to do this is to reduce the amount of attention that must be paid to other tasks. In an emergency situation in the TMC, the operator who must do the monitoring might temporarily have other tasks given to temporary personnel so he or she can attend to the important information.

5/4 Scanning Pattern   **(Recommendation; 101)**

Train the person to effectively scan information channels and develop optimal scan patterns.
Some operators may tend to concentrate their attention on their CCTV monitors to the detriment of computer displays. An effective scan should include all of these information sources.

5/5 Channel Proximity	(Recommendation; 101)

If multiple visual channels are to be scanned, put them close together and in relative positions that reduce scanning (eye and head movement) requirements.
Chapter 2 on link analysis describes techniques for analyzing the order in which displays might best be scanned and Chapter 10 on work station design describes their placement in the console.

5/6 Auditory Channel Competition	(Recommendation; 101)

If multiple auditory channels are to be scanned, ensure they do not mask (interfere with) one another.
Select sounds that can be recognized when mixed with other auditory display sounds. See Section 8.3 on auditory signal choice.

5/7 Signal Time Separation	(Recommendation; 101)

Signals that require individual responses should be separated in time and presented at such a rate that they can be responded to individually. Avoid extremely short intervals (less than 0.5 seconds).

5.2.3 Focused attention

Focused attention involves attending to one source of information and excluding others. An example is a maintenance dispatcher who must concentrate on a single radio communication while ignoring other noise in the room. Failure of focused attention means that the individual is unable to concentrate on one source of information in the environment and tends to be distracted (e.g., a traffic operator attempting to rapidly locate a critical information element in a crowded display.) Thus, when designing the control center, the following guidelines concerning focused attention tasks should be considered.

5/8 Channel Discrimination	(Recommendation; 101)

Make the channel to which the person is to attend as distinct as possible from competing channels. Make it larger, brighter, louder, or more centrally located than the competing channels.
Use the task analysis performed during the front-end analysis process of the TMC design to define the most important channel and make sure that it "stands out" from other sounds or visual signals.

5.2.4   Divided attention

A divided attention task requires the operator to pay attention to two sources at the same time. An example is an operator performing two or more separate tasks (e.g., monitoring congestion buildup at one location and dispatching maintenance to a malfunctioning controller at another) while simultaneously paying attention to both.

Simultaneous visual signals and simultaneous auditory signals are both difficult to monitor. Such a divided attention auditory task is somewhat easier if the messages are delivered to separate ears. Divided attention is more easily accomplished if information channels use different sensory modalities, such as vision and audition. However, performance still suffers in comparison to attention focused on only one channel, whenever the task is at all difficult. [34, 111] Only when the tasks are very basic (e.g., responding to a simple signal as soon as it occurs in either of the two modalities) is performance unimpaired under divided attention conditions. [34, 80] A major limitation of both visual and auditory attentional mechanisms is that, like the movement of the eyes, attention cannot be drawn simultaneously to more than one location in the visual field at any one instant. [43] Guidelines for designing divided attention tasks include the following: [101]

5/9 Task Difficulty   **(Recommendation; 101)**

Keep difficulty level of tasks as low as possible when more than one task must be done at once.

5/10 Task Similarity   **(Recommendation; 101)**

Tasks to be performed simultaneously should be made as dissimilar as possible.
The operator, for example, should not be required simultaneously to perform multiple manual operations, multiple operations requiring listening to information, or multiple mental calculations. Combining a manual operation with a mental calculation would be more permissible.

5/11 Task Memory Requirements   **(Recommendation; 101)**

When manual tasks are timeshared with sensory or memory tasks, design work so that tasks with high memory requirements have low manual requirements.
This can be accomplished by deliberate task design or by training to make the manual functions so automatic that (like walking or driving) they require little planning or thought and so do not compete with mental demands.

5.2.5 Vigilance

Vigilance and monitoring tasks require sustained performance, the continuous execution of a task over a prolonged time period. Driving an automobile a long distance, working on one task all day, and monitoring a TMC computer screen for incidents are all examples of tasks which require sustained performance.

Though the basic tasks are simple, sustained performance can be hard to achieve. For some tasks, a person can perform well for an extended time period, but then the performance level drops. On other tasks, the performance level steadily decreases from the start of the task. Performance decrements include both loss of ability and loss of attention. Monitoring tasks — hours of boredom punctuated by moments of excitement — may comprise a large part of the TMC operator's duties. Several significant variables impact performance of these kinds of tasks.

Arousal. A significant part of maintaining overt attention is a certain degree of arousal or alertness. In vigilance tasks, people adopt certain body positions, tense specific muscle groups, and have the feeling of "concentrating." [34] People associate physiological arousal with the ability to sustain attention. However, performance does not always increase as arousal increases.

The Yerkes-Dodson Law describes the relationship between arousal and performance as an inverted U-shaped function (Figure 5-1). The upward limb is "energizing," and expands the resources available. The downward side is the consequence of a more specific effect of high arousal on the selectivity of attention or "tunneling" (narrowed attention) to different cues.
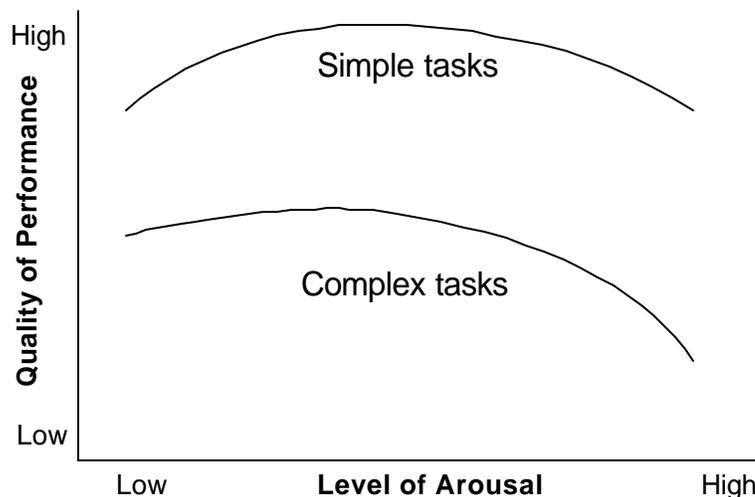
Figure 5-1. Performance as a function of arousal level for simple and complex tasks (after Gawron, 1982).

Overall performance in any task *peaks at an intermediate level of arousal*. Optimum level of arousal is higher for simple tasks than for complex tasks. In the TMC case, this has an impact

on design of tasks that will be undertaken under higher levels of arousals. Emergency procedures, for example, should be relatively simple to avoid performance decrement. In any case, physiological arousal is mainly responsible for the *overall level of vigilance,* but is basically unrelated to the decline in performance over time. [90]

Sensitivity loss. A sensitivity loss occurs with fatigue and memory load. [21] Fatigue may cause the observer to become inattentive and look away more frequently as the watch progresses. Consequently, signals are missed. Such a condition might occur during night shifts in the TMC when workload demands are light. A similar decrement may occur when the job stresses the operator's working memory (for example, a number of tasks that require reference to knowledge of operating procedures, protocols, and entry commands). [91]

Criterion shifts. In most vigilance tasks, when the hit (successful detection) rate declines, the decline is paralleled by reduction in false alarms (See Section 4.3.1.). This may indicate decreased arousal. A high number of false alarms by the human operator implies a "hair trigger" while a low number indicates a sluggish or conservative bias. As arousal decreases, vigilance performance decreases (the probability of correctly noting an event goes down). Because *physiological arousal* is basically unrelated to the decline in performance over time, arousal shifts do not explain all criterion shifts. [91]

Subjective probability and the resulting response criterion change both from training and from experience with the actual signal rate. For example, to facilitate rapid learning, a trainee is presented with a high number of targets during training. If, during the actual vigilance session, a considerably smaller number of targets appear, this creates a sizable difference between the trainee's *expectations* and reality. A significant decrement in vigilance performance (a high false alarm rate) might be expected until the criterion becomes more realistic. If training more closely corresponds to reality, initial vigilance decrement is reduced (though training may become more time consuming.)

The operator in the older TMC was provided with graphical computer displays that provided occupancy data for each of the inductive loop stations in the network. When these data (high occupancy) indicated a strong likelihood of an incident, the operator was to begin verification measures including CCTV scans and radio calls to patrol cars that might be in the area. High occupancy could also be the result of "normal" congestion or a temporary sensor malfunction.

When first given the task, the operator selected 50 percent occupancy as his criterion level at which to begin incident verification procedures downstream from the given sensor. After a few days experience it was apparent that almost all incidents were being found but that the operator had a very high workload "chasing" false alarms (especially minor congestion). Moving the criterion to 60 percent occupancy reduced the operator's workload considerably as there were many fewer false alarms; as expected, though, several small accidents went undetected.

As the new operator gained more experience, he recognized that the 60 percent occupancy criterion didn't work equally well for every sensor location. Upstream from one freeway interchange, for example, was an area of frequent accidents and many of these were missed by the TMC. The operator, therefore, decided on a criterion of 45 percent occupancy to begin verification actions at that particular location.

5.2.6   Vigilance, search, and monitoring

Many of the most critical operator functions in the TMC involve monitoring of machine output. The design of that output is described at length in Chapters 8, 9, 10, and 13. In this chapter, we examine the human side of the vigilance equation.

The following factors in the design of the monitoring task can affect human performance:

Duration of monitoring. *Monitoring performance deteriorates with time.* In monitoring situations, such as a military radar watch or observation of CCTV images in the TMC, performance deterioration usually begins after only 30 minutes. Hence, the military limits shifts involving close monitoring to that amount of time. Observations of individuals performing during long watches show that there is a continuous performance decrement followed by a brief burst of improvement when individuals realize they are reaching the end of the watch. [18]

The monitoring tasks in the TMC are somewhat more diverse, and less vulnerable to early performance decrement than in a mentally unchallenging task such as watching a single radar screen. But performance does, in fact, decline no matter how motivated the operator. Factors that influence the monitoring performance of operators are as follows:

Frequency of signals. Generally, a *moderate* frequency rate (that is, the number of times the signal occurs in a given period, not the frequency in the sense of cycles per second) gives the best performance. However, in all-or-nothing displays in which the signals to be detected are the only stimuli presented, the detection percentage of low frequency signals is lower than high

frequency signals. In the TMC, automated detection and reporting of low frequency signals should be a priority (See Chapter 8 for more detailed description of signal frequency.)

Regular occurrence of signals. Regularly occurring signals are more likely to be detected. An experienced TMC has noticed that controllers in the central city, installed by one vendor, are substantially more reliable than those in the northern periphery that were installed by another vendor. The operator will be more likely to quickly detect a failed controller in the area where a daily failure is expected than in the area where failures are rare. The higher probability of a signal occurring corresponds with a higher probability of detection. (In fact, it affects the *decision criterion* discussed in 4.3.)

Complexity and accuracy of the display. A highly cluttered background from which the signal must be detected will lead to performance decrements. For instance, noisy, hard to read displays require longer sampling durations. In the TMC, a cluttered "big board" or video map display may make small targets — a blinking pixel at an intersection indicating an unusual traffic condition, for example — hard to detect. (For design purposes, see guidelines for visual and auditory displays in Chapter 8, display "declutter" in Chapter 11, and data fusion in Chapter 13.)

Signal strength. The signal intensity and clarity affect detection performance. A long duration, high intensity signal improves performance.

Knowledge of results. Providing knowledge of results improves performance. Feedback provides a guideline for operators to adjust their behavior monitoring.

Location in space. If visual fixation is required, peripheral signals (those outside the center of vision) are often overlooked. For guidelines on visual display position, see Chapters 8 and 10. Signals expected to be in the visual periphery will be more easily detected if they are blinking or moving.

Source of signal (one source versus multi-source). Performance is superior with multi-source signals. For example, a critical traffic condition on a video map display might consist of a visual indicator (flashing symbol) and an auditory display (beeping tone), particularly if the display is noisy and the target is hard to notice, or the condition is infrequent. Peripheral sources (a flashing signal outside the direct line of vision, for example) are less likely to be detected than central sources, and might benefit from a multi-modal display.

Perceptual load/memory load. A small load leads to boredom and to a performance decrement. A large load leads to fatigue and a performance decrement. Note: successive presentations of signals cause greater memory load than simultaneous presentations.

Overall monitoring strategy chosen by observer. Given a large number of displays to view under a time constraint, the viewer will only monitor those displays that are higher priority and/or more easily viewed because of the information format. A TMC operator may, for example, be obliged to divide attention among CCTV displays, the "big board" and his

personal display (which will probably have several sub-choices of information: maps, system status, etc.) Several TMC's currently operating have multiple displays for each operator, usually due to the installation of new systems that supplement older ones that are hardware or software incompatible without *replacing* them.

Amount of practice. Generally, the more experienced the observer, the more the response is automatic and performed in an optimal manner. This is particularly critical for displays with contributions that are infrequent and irregular.

Task complexity. Two tasks requiring different modalities will suffer a lower performance decrement than those under the same modality. Two tasks of visual modality will create the worst performance. In the TMC, monitoring a visual display while attending to radio communications will result in little or no loss of vigilance; a requirement to monitor two visual displays, on the other hand, may cause loss of efficiency in either or both.

5.2.7 Designing TMC's to improve vigilance

During the design process, there are several broad, systematic efforts that can be employed to improve vigilance performance. These are summarized in the following guidelines and recommendations:

5/12 Activity and Alertness   **(Principle; 18)**

Vary operators' activity to improve alertness.
A break as short as 5 minutes can decrease the decrement if placement of the break is appropriate for the work flow. In general, TMC operators have several tasks to attend to during the shift and they will frequently vary activities on their own to maintain alertness.

5/13 Rest Break   **(Principle; 18)**

Provide an appropriate amount of time for a break.
A 5 to 10 minute break is about the right length.

5/14 Break Schedule   **(Principle; 18)**

Schedule a break at an appropriate time.
Placement of breaks interacts with their length. To reduce performance decrement, brief pauses must occur within the first 30 minutes of the task. Thus, there is a trade-off between how much effect a pause has and how much task time is used for the break.

5/15 Self-Paced Tasks   **(Recommendation)**

Use self-paced tasks to reduce boredom and fatigue.

5/16 Task Complexity   **(Observation)**

In designing work, allow for the fact that the complexity of the task should be appropriate to the expected level of alertness or arousal.
If a predicted situation, such as a traffic emergency with injuries, can logically be expected to raise the arousal level of the operator on the spot, the actions required should be as simple as practicable. Sequences of action that are easy to perform under routine conditions may be much more challenging under pressure.

5/17 Infrequent or Irregular Signals   **(Observation)**

Provide special cues such as unusually strong signals to ensure that the operator notices conditions that occur infrequently or irregularly.

5/18 Use Operator Feedback   **(Observation)**

Provide feedback on operator responses to decrease the probability of an error of commission.
For example, messages transmitted by an operator to a VMS should provide feedback to assure that the message and location are correct.

5/19 Multi-Channel Signals   **(Observation)**

When a signal must be detected with high reliability, use redundant visual and auditory signals.
An incident detected by an automated system might be signaled by both a flashing icon and a beeping sound. This technique also supports signal detection after a long period of operator inactivity.

5/20 Stress Identification (Observation)

Identify likely stressful conditions and structure tasks to reduce high stress levels.
This will usually come at a later stage, possibly during prototyping, when it is possible to observe or predict the nature of real TMC scenarios. The decrement in vigilance under stressful conditions could allow an operator to miss critical information.

5/21 Range of Operator Skill (Observation)

Consider the range of operators that will use the system, and allow for the effect of experience on performance.
This may, for example, include on-screen choices for computer interface that allow the operator to select more or less information displayed based on experience and comfort.

5/22 Perception and Memory Requirements (Observation)

Identify and eliminate possible interface requirements that force an operator to exceed the limitations of human perception and memory.
For example, entry of complicated codes from a long list of possible choices should be supported by job aids such as quick-reference cards. Excessive requirements can be identified during rapid prototyping of the interfaces and early test and evaluation.

5/23 Multiple Monitoring Tasks (Observation)

Avoid situations that may require the operator to monitor more than one task at a time in the same Channel.
Where complex monitoring tasks are necessary, use data fusion techniques to simplify the tasks.

5/24 Optimal Demand on the Operator (Observation)

The design of work should allow for optimal level of demand on the operator.
If the operators' tasks are so automated that little activity is required beyond monitoring automated systems, the operators' level of arousal may be expected to fall and the response when the traffic situation requires human intervention may be less than desirable.

5.3 Stress, Boredom, and Fatigue

Stress, boredom, and fatigue all alter the state of the body in a way that may be independent of the specific demands of the work the individual is doing.

5.3.1 Stress

Stress, the response of an individual to demands, stems from a number of sources including work, environment, and circadian rhythms. [101] Stress derives from physiological, psychological, and social factors.

Stress grows from both external and internal origins. External origins may be physical and social aspects, such as high workload, exacting demands, or uncomfortable environmental conditions. Internal sources are particular internal states. A person's concern for consequences or failure could cause him/her internally driven stress. [101]

Examples of *physical* stressors include: [63, 101]

> ! Physical exertion.
>
> ! Exposure to noise over 80 dB.
>
> ! Work environment with high or low temperatures.
>
> ! Changes in individual's circadian rhythms.
>
> ! Boredom, which can result in an aversion to continued effort.
>
> ! Information overload and vigilance.

Examples of *social* stressors are:

> ! Pressures from peers/supervisors/anxiety.
>
> ! Anxiety over an anticipated evaluation of work.
>
> ! Adapting to domestic changes.

Physical symptoms of stress are identifiable in a number of ways. These include increased blood pressure, heart rate, respiratory rate, gastrointestinal disruptions, and neurological manifestations. Psychological measures include behavioral (work rate, errors, blink rate) and attitudinal measures (boredom and other factors). [101] The effects of stress on performance vary among people.

One of the clearest conclusions about stress is that effects of stress depend on the type of job being carried out. For instance, some situations are not vulnerable to stress from high temperatures and/or shift work because they demand efficiency on performance functions that are not impaired under these conditions. [63] However, performance of many critical tasks in the TMC may be affected by stress. Loading printer paper is a mechanical task that can be carried out satisfactorily even under stressful conditions; entering a complex series of commands in response to traffic flow *is* a task vulnerable to stress.

At this point, we must again consider the effects of *individual differences*. Different people working within the same environment may have highly different reactions to the stress level. [101] Characteristics in physical, mental, attitudinal, or emotional natures may be revealed in an individual's capability to adapt to differing conditions.

5.3.2   Boredom and fatigue

Boredom and fatigue are often overlapping states. Boredom is the subjective state which arises in repetitive and monotonous environments. Boredom can become apparent within minutes of onset of a monotonous task. Boredom is the result of the requirement to maintain attention in the absence of relevant task information. [63]

Fatigue can also be the principal product of hours of continuous work. For instance, skill fatigue is fatigue stemming from performing complex tasks or tasks involving a number of simultaneous processing requirements. Skill fatigue causes an increase in the variability and timing of actions. Skill fatigue also produces changes in attention distribution. These changes vary depending on the task. [63]

Sleep disturbances also cause fatigue and stress. Total sleep loss produces considerable subjective stress. Performance effects usually appear after the operator has been working for some time, and thus, brief tasks may not be impaired. [63] In continuous work without sleep, an individual's fastest reactions are unaffected, but the slowest reactions take longer and longer to execute. In vigilance performance, both auditory and visual signals are impaired by sleep loss and are especially impaired later in the work period. [63, 123]

Moderate or small reductions in sleep time may reduce efficiency if continued over several nights. In addition, differences between no sleep and one to two hours may be important.

Circadian rhythms, and rotating shifts. Another aspect of ATMS that must be considered is rotating shifts and their affect on circadian rhythms. Simply stated, the circadian rhythm is your body's natural clock. Circadian rhythm is the biological cycle all humans experience throughout the day and the night. During this daily cycle, one's pulse rate, blood pressure and body temperature rise and fall. These changes also cause us to be more alert and effective at some times during the day than at others. Human peak activity is associated with the circadian rhythm peak that occurs between 8:00 AM and 2:00 PM. Human low activity occurs in the late evening and early morning when circadian minimums occur.

Time of day effects. Performance differences occur during the day because of the circadian rhythms. For example, human performance of calculation tasks and during sporting events may be at its best in mid-afternoon. [63] In other tasks, a performance impairment occurs in the early afternoon. [63] Performance on nearly all dimensions is poorest at approximately 3 AM. Figure 5-2 shows the distribution of performance for a 24-hour cycle.
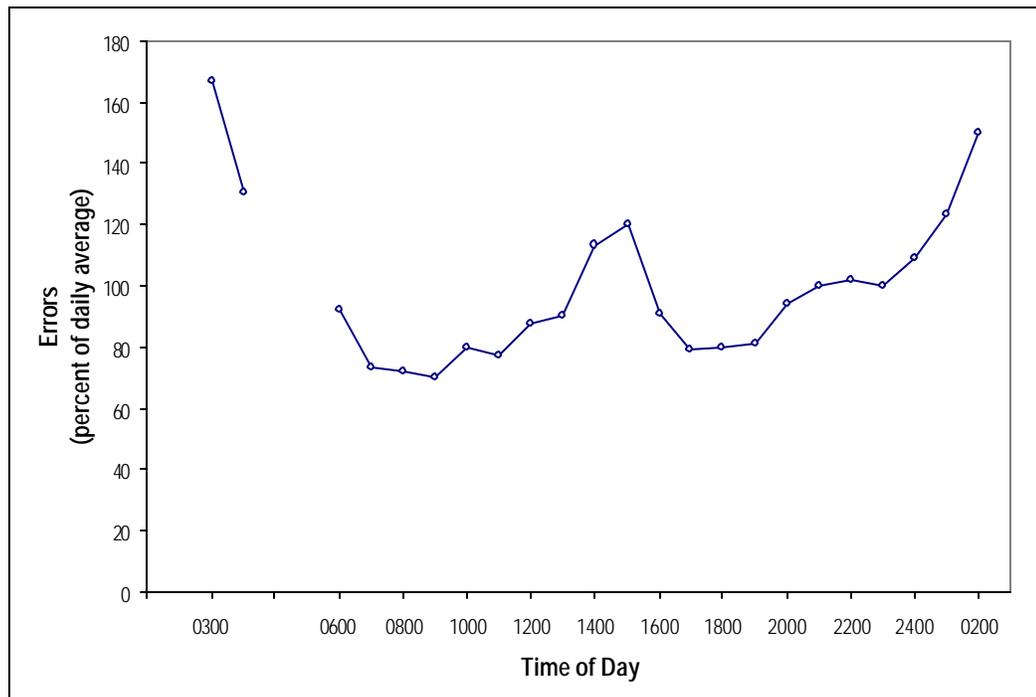
Figure 5-2. Errors in reading meters as a function of time of day (from Minors & Waterhouse, 1981).

Shift work. Circadian rhythms are crucial to consider when shift work is involved. [57] Any operation or activity that runs 24 hours each day (including some TMC's) requires shift work. For instance, air traffic controllers, nuclear power plant workers, medical personnel, production workers, and police officers all could have shift work schedules. Since motor vehicle traffic is a continuous activity, TMC designers will consider shift work. Night shift workers are near their circadian minimums when they work early morning and night shifts. [76, 82]

Individual's reactions to shift work changes are usually assessed according to subjective health-effects including sleep/wake disturbances and digestive and neurological problems including sleepiness and irritability. [57] There is considerable evidence that sleep of shift workers is disturbed by both permanent and rotating shifts. The effects are most apparent for night shifts. [63]

Shift work can cause sleepiness, gastrointestinal symptoms, and decreases in performance due to conflicts with normal circadian variation. [57] Thus, it is easy to see how rotating shift work could leave workers fatigued and error-prone.

Several factors appear to affect circadian adjustment. First, frequency of rotation affects adjustment. In slow rotation shift schedules, more circadian adjustment occurs than in rapidly rotating schedules. In addition, individual differences affect adjustment. Individuals whose body temperatures peak early in the day ("morning" people) will have more difficulty adjusting to a night shift than "evening" people whose body temperatures peak much later in the day. Age is also a factor. Beginning around age 40-50 years, people tend to have slower adjustment rates to shift changes. Physical fitness, ability to overcome drowsiness, and flexibility of sleeping habits are other individual differences to be considered in designing and assigning shift work schedules. [57]

5/25 Extended Shifts   **(Principle; 101)**

Consider more frequent breaks and closer supervision during extended shifts.

Errors and stress may result from extended work time. Extended shifts should not be considered unless unexpected traffic system stress absolutely demands it.

5/26 Night Shifts Performance   **(Recommendation; 76)**

Expect and plan for degraded performance in the 3 AM to 6 AM hours when circadian rhythms are in the low part of the cycle.

Minimize the need for careful monitoring, short-term memory, and decision making in the pre-dawn hours.

5/27 Shift Changeover   **(Observation)**

Avoid quick shift changeovers.

Allow a 30-minute shift overlap for the incoming operators to develop a "picture" of the traffic situation before outgoing operators leave the TMC. Rapidly changing shift assignments can cause performance problems.

5.4 Memory

Memory is divided into two types, *working memory* and *long-term memory*. Working, or short-term, memory is the temporary, attention-demanding storage used to retain new information (like a telephone number) until we use it (dial the number). Long-term memory is stored more-or-less permanently.

5.4.1   Working (short-term) memory

Working memory is used when we evaluate, compare, and examine different mental representations. Also, it acts as temporary storage for new information that we later place in permanent memory storage (facts, how-to-do things). The following characteristics describe the use of working memory:

Information in working memory is in two forms. *Spatial memory* contains visual images in three-dimensional form. *Verbal or Phonetic memory* contains words and sounds. A glance at the "big board" traffic map may require a comparison to verbal or spatial data on the operator's own display. Since both displays cannot be viewed at once, the operator must hold a working image of a relevant part of the big board before comparing it to the personal display.

Working memory's rapid decay rate is one of its greatest limitations. Unless information in working or short-term memory is rehearsed and encoded in long-term memory, it will decay within 15-20 seconds. *Once information has decayed from working memory, it is gone; it cannot be retrieved.* The fastest decay occurs when a near-capacity number of items are held in working memory. When this occurs, the individual cannot rehearse and transfer the information to long-term memory.

Memory capacity varies. When full attention is used, a person can store between 5 and 9 (7+/-2) items in working memory at one time. [83] An item may be an individual letter or digit *or* letters and numbers that can be combined ("chunked") into words, images, or series of numbers that make sense to the individual. Essentially, the person remembers the single chunk, such as the word, "computer," rather than remembering the 8 letters, c-o-m-p-u-t-e-r. Chunking expands working memory capacity by reducing the number of items in working memory. Displays and information can be designed to facilitate chunking.

Forgetting of material from working memory also results from active interference. Both previous information and new material interfere with material stored in working memory. For example, an individual looks up a phone number and then forgets it before it is dialed because someone asks a question during the retention interval (interference caused by new material).

Need to monitor multiple variables. When contending with multiple variables, working memory is more efficient when the variables are very different. Similarities in tasks tend to be confusing if those tasks share a common code; therefore, the codes may be easily forgotten or confused if one's attention is diverted, even briefly. Examples of codes that challenge working memory include telephone numbers, postal ZIP codes, and computer commands.

5.4.2 Long-term memory

The second type of memory is long-term memory. In computer metaphor, working memory is RAM and long-term memory is the brain's "hard disk." Long-term memory is subject to the following rules:

The long-term memory contains information in at least three forms. One form is *declarative* knowledge or *facts*. The second form is *procedural* knowledge or "how to" do something. The third is *sensations*; the sights, sounds, tastes, and odors we experience.

Decay may never occur but difficulty in retrieval and retrieval failures *will* occur. While working memory will decay and become *inaccessible* (like a file erased from a computer disk), long-term memory may become *unavailable* (like a computer file whose name has been forgotten.) A good example of this is the familiar "tip-of-the-tongue" phenomenon in which recall of a familiar name or book title remains frustratingly just out of reach.

Job/memory aids can be valuable. One apparent solution to the quick decay of information in memory is to incorporate job aids into the task. Memory aids provide a valuable service and can be filtered or physically turned off. One type of job aid, display augmentation, could provide a continuous record of the information appearing in a long lasting display. Another job aid might set a movable pointer to a previous or nominal value. A third job aid may simply record and replay radio and telephone messages.

Memory aids are not always easy solutions. A trade-off occurs; while memory aids reduce the strain on working memory, they increase display clutter. A cluttered display is more confusing and difficult to read, and the increased visual workload also causes increased error rates. Thus, keep in mind that memory aids can distract and disrupt perception. Chapter 12 (*User Aids*), discusses these challenges in detail.

Time of day affects memory. As previously noted in this Chapter, performance differences occur during the course of one's circadian rhythms and these rhythms are connected with the "time of day effects." While performance on most tasks follows body temperature rhythms and tends to increase throughout the day, long-term memory performance appears to be best in the morning. For immediate recall, short-term memory performance is also better in the morning than later in the day.

5.4.3 Designing TMC's to support memory

Research and experience have shown that there are numerous strategies that can be used to support performance on memory tasks in the workplace. Some of these are summarized below:

5/28 Consider Memory Requirements   (Observation)

Design tasks to respect the limits of working memory.
If the items are important, put them on paper - or on the monitor. Forcing an operator to remember long numeric strings, for example, can quickly tax working memory; similarly, memorizing one string and then a second string will tend to drive the first out of memory. Performance testing with prototypes will help identify problem areas.

5/29 Long Term Memory   (Observation)

Support long-term memory with techniques that promote recall, including:

- ! **job aids.**
- ! **mnemonics.**
- ! **recall cues on displays.**

5/30 Similar Sounds   (Observation)

Avoid codes with large strings of similar sounding chunks.
A series of commands to be keyed in to the system that are similar in sound may interfere with one another. Verbal information is rehearsed and temporarily stored by its "sound," even if the sound is generated in subvocal speech.

5/31 Memory for Long Series of Items   (Recommendation)

Support memory for a long series of items by providing a mix of numeric and alphabetical items.
Years ago, telephone numbers were of mixed content — verbal and numeric. As telephone systems "improved," the verbal part gradually disappeared; Woodlawn 2-1636 became 962-1636 and recall became more difficult.

After task analysis has revealed what information will be stored in working memory, ensure that intervals before, during, and after storage are free of any unnecessary activity that uses the same code (spatial/verbal).

If someone is trying to keep a telephone number or numerical location code in working memory, having to listen to a string of unrelated numbers will not be a welcome interruption. In interfaces, operators will frequently have to keep some information (such as a location code, variable message, or telephone number) "in mind" — that is, in working memory — for a short period of time. Tasks should be designed to avoid forcing the operator to attend to conflicting information of the same coding type.

5.5 Decision Making Constraints and Biases

Many of the active interventions by human operators in the TMC will involve making decisions. These decisions may be complex, based on limited information, and have uncertain outcomes. These are the kinds of decisions for which the human is better suited than a computer or an artificial intelligence system.

5.5.1 Requirements for decision making: The General Decision Model

Decision making is a complex cognitive process by which people identify and evaluate alternatives and select a course of action. The general process in decision making is illustrated by Figure 5-3. A decision maker samples cues/information sources from the environment. Some uncertainty comes with the information. Upon sampling and integrating information, the decision maker attempts to formulate a hypothesis about the true state of the world and use it as a basis for further selections (this can be a diagnosis *or* a prediction/forecast). This process utilizes both working memory (compare, evaluate hypothesis) and long-term memory (plausible hypotheses are stored in long- term memory). The initial diagnosis may be followed by a further search for cues confirming or rejecting the hypothesis. Next, a choice of action is taken. Choice usually involves the evaluation of *risk*. Then, feedback begins.

The outcome of the decision may affect the next round of sampled cues. Knowledge of the outcome, whether successful or not, can influence future decisions through learning or through modifications of current plans. Feedback reinforces or discounts the rule/process used to make the decisions. If feedback shows a decision to be correct when the rule used was wrong, it will be reinforced, and thus more difficult to "unlearn" later. Delayed feedback may cause many factors of the decision to be forgotten/distorted. [122]
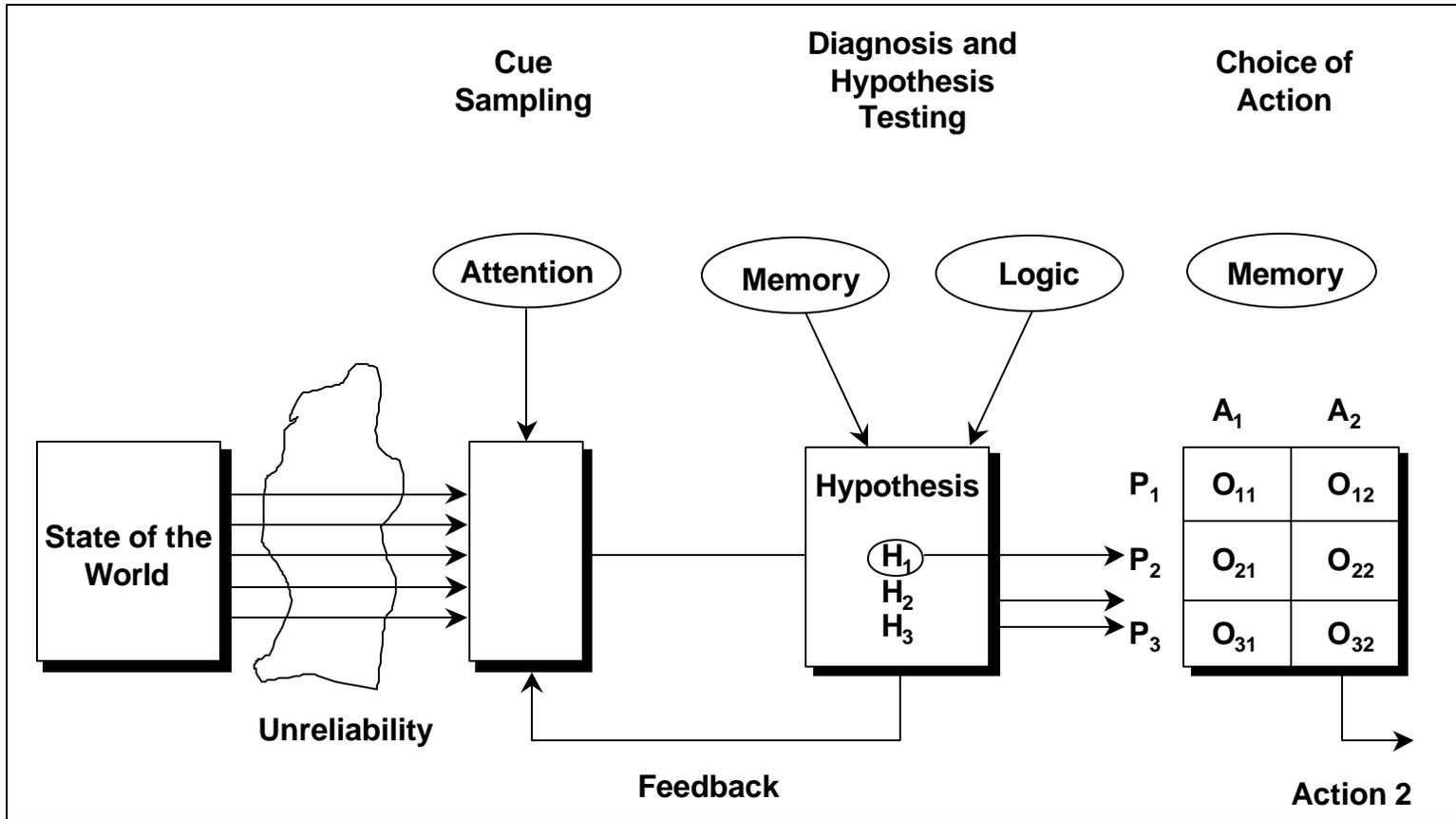
Figure 5-3. The general decision making process.

5.5.2 Humans as decision makers

There are inherent biases in the way people seek information, estimate probabilities, and attach values to outcomes. These biases may produce irrational behavior. People do not always act according to objective probabilities of gain and loss. [101, 122] Consider how each of the following decision biases might affect a TMC operator's assessment of a developing traffic crisis:

! People give undue weight to information *first* received and less weight to information received *later*.

! People are generally *conservative* and do not extract the optimal amount of information from the sources.

! Subjective odds favoring one alternative over another are neither assessed to be as extreme nor given as much confidence as they should be. This is another example of a human *conservative bias*.

! As information is gathered, people become more *confident* in their decisions, but not necessarily more *accurate*. In addition, the accumulation of too much information for the operator to handle can cause a loss of confidence.

! People have the tendency to seek far more information than they can absorb.

! People treat all information as if it were equally reliable.

! Humans appear to have a limited ability to entertain more than a few (3-4) hypotheses at a time.

! Humans tend to focus only on a few critical attributes at a time and consider only two to four possible choices that are ranked highest on those few critical attributes.

! People tend to seek information that *confirms their choice of action* and to avoid information or tests whose outcome would disconfirm their choice.

! A potential loss is viewed as having greater consequence and, therefore exerts a greater influence over the decision making behavior than does a gain of the same amount.

An example of the complications of human decision making comes from an evaluation of an Army command center. Tactical commanders had been demanding that electronic media provide them with ever more and more knowledge about the enemy situation and probable intentions, on the presumption that more information would yield more certainty.

In a carefully designed experiment, researchers at West Point tested this idea. The result: more information *does* provide more certainty — up to a point. When *too much* information was provided, the Subjects (all of whom were experienced commanders) felt *less* confident that they had any accurate idea what was happening. In fact, they were increasingly unable to integrate multiple sources of information into a mental picture that meant anything.

Follow-up testing disclosed that the problem could be solved in part by *data fusion* (See Section 13.10). The lesson: when a human is part of the system, an important task of the automated subsystems is to present information to operators in a way that supports accurate decisions.

5.5.3   Use of decision aids

Decision making is influenced by many factors. Engineering psychologists have looked at such factors and been able to identify *some* of the circumstances under which decisions are likely to be degraded. This knowledge allows us to propose decision aids that tend to offset biases.

By understanding human capabilities and limitations, designers can develop better methods for presenting and preprocessing information to improve decision quality. For instance, we might program a computer to keep track of hypotheses, aggregate probabilities, and select the best information sources.

Advantages of decision aids [122]

> ! Tend to minimize the influence of individual differences, emotional states, and misperceptions of probabilities.
>
> ! May force structuring of problem as opposed to haphazard guesswork.
>
> ! May force consideration of multiple options, offsetting common decision bias.
>
> ! May force quantitative weighing of options (trade-offs).

Disadvantages Of Decision Aids. Decision aids are not always the best answer. If improperly designed or applied, a decision aid: [122]

> **!** May discount valuable user intuitions.
>
> **!** May be ignored if it is seen as inaccurate.
>
> **!** May not be adaptable to unusual circumstances.
>
> **!** May increase time for decision making (this could also be an advantage in some situations).
>
> **!** May be exceedingly difficult to evaluate.

When designing decision aids, observe the following guidelines:

5/33 Diagnostic Information Access   **(Recommendation; 122)**

Present all diagnostic information concerning all alternatives for simultaneous consideration.
This creates challenges for display design that are considered in Chapter 11 and especially in Chapter 13.

5/34 Information Prioritization   **(Recommendation; 122)**

Design the system aid to filter and present those information sources that contain information on the important attributes.
Data may be presented so that sources that are most reliable and most diagnostic (that is, most likely to provide information useful to the decision) are highlighted. A caution should be added here: This approach implies machine-centered decisions, and the machine is not always in the best position to make a decision. See discussions on function allocation in Chapter 3.

5/35 Decision Alternatives   (Recommendation; 122)

Design the decision aid to force the operator to consider alternative hypotheses so that anchoring and recency of initial hypotheses do not dominate memory.
This guideline refers to a human bias toward the first interpretation. If decision aids are used, they should forestall the users' natural tendency to make their decisions before all required information is available.

5/36 Statistics and Decision Making   (Recommendation; 122)

Provide interpretation of statistics when used for decisions.
This is particularly important when large numbers of data points are being consolidated for presentation to help the operator make a decision. When possible, calculate and present numerical probabilities that a decision is correct.

5/37 Decision Aid Complexity   (Recommendation; 122)

Provide simple decision aids.
Test the complexity and ease of use on a sample of typical operators and adjust the complexity accordingly.

5.5.4   Confidence in decisions

Confidence and accuracy in decision making are often unrelated. Since decision quality is not usually evident at the time a decision is made, high confidence in that decision is often considered as an indication of a correct decision. The task, human characteristics, and mode of display all influence decision quality. [103]

Many computer interfaces that lead an operator to a decision use graphic displays to carry information used in the decision. Is this a help in making the right choice? There is some question whether the new graphics technology affects the accuracy-confidence relationship. [18] Results showed that overconfidence in decisions occurred when subjects used graphic displays. In simpler tasks, overconfidence is not a problem because the decision is much more likely to be correct.

5/38 Avoid Automation Overconfidence (Observation)

Avoid leading the operator to place too much confidence in display information and decision aids.
Ensure that all operators are aware of the computer limitations in their TMC. This may include the display of sensor data and decision aids. Sometimes introducing technology into a process that is difficult for humans may create the illusion of correctness simply because the machine seems to "agree" with the operator.

CHAPTER 6: JOB DESIGN

CONTENTS

6.1   The Need for Job Design

A *job*, for purposes of this handbook, is the sum of all tasks assigned to a given category of
TMC employee, and where these tasks are performed within a given working context. The
tasks and work modules described in Chapter 3 are grouped in a way that describes the
activities required of an operator. But factors other than the tasks — for example, motivation,
workload, scheduling, and task allocation across operators — can influence the design of a job.

Effective job design is vital to the performance of the TMC's mission. A well-designed job will
permit a qualified person to perform that job to documented standards without undue stress and
provides enough challenge and variety to keep the job performer engaged and motivated.
Conversely, a poorly-designed job may be boring or may overwork the performer to the point
of early burnout. In such circumstances the range of duties may not be appropriate to one
person's knowledge, skills, motivation or approach. The job performer may operate far below

his or her level of effectiveness.

Designing a job is more than writing a position description. Job design is supported by a thorough task analysis. Only after system and operator tasks are documented and analyzed can they be distributed effectively among personnel and supporting technology.

Job design for complex systems considers the hardware/software and the corresponding operators as a joint system and designs the technological and human aspects of the system as a unified whole. [35] Chapters 2 and 3 have described methods for analyzing and allocating tasks in complex systems. All of the information in those chapters is applicable to job design and should be read as preparation for the ideas discussed here.

An organization seldom has the opportunity to design a job from the ground up. More commonly, job design evolves as an organization grows and changes. This evolution may result in well-designed jobs, or it may eventually result in jobs that are irrelevant and cannot be performed effectively.

Most often, job design is explicitly addressed when a new system is introduced or a new function or mission is assigned to a work group. Transitions such as these provide opportunities to re-examine the assignment of duties to personnel and to ensure that such assignments are rational and practical within the real-world limitations of the organization. Thus, a job or group of jobs is more often re-designed than designed "from scratch." The ideas presented in this chapter can be applied either to the design of new jobs or to the re-design or adjustment of existing jobs. Even minor changes in duty assignments or schedules can have important effects, positive or negative, on job performance. Such changes should be made with attention to human factors issues.

This chapter discusses specific issues to be considered in designing (or re-designing) jobs. These issues include error, job characteristics and motivation, workload and work pacing, work schedules, task allocation, optimal performance, and individual differences. Many of these topics are discussed in detail in other chapters of this handbook, and in many cases, specific guidelines may be found in the other chapters.

TMC EXPANSION AND JOB REDESIGN

A TMC example where jobs may need to be redesigned was observed in one of the site visits made during the preparation of this handbook. A few years ago, two controllers, each responsible for a geographic region, handled communications tasks along with the additional tasks of monitoring cameras and ramp meters and setting variable message signs. As the system expanded and workload increased, it was decided that a separate information officer was needed to handle dispatching and non-broadcast radio communications. At that time, the center was staffed at peak hours by two controllers, one information officer, and a radio announcer, a radio station employee who provided regular traffic information broadcasts. The system was expanding, and the two controllers were likely to be overworked as additional cameras and ramp meters were brought on line. A resolution has not yet been enacted, yet one solution that is currently being considered is adding a third controller position. This would require considerable redesign of the physical facility, which now has two controller consoles, two banks of TV monitors, all of the infrastructure to support the two stations, and very little room for expansion. A second solution is to add a supervisor/coordinator to the team during peak periods, and/or the re-design the information officer's job to include formal coordination duties. Situations like this one require that changes in the design of jobs be given considerable thought, and be treated as *system* changes.

6.2 Job Design and Error Reduction

The principles discussed in Chapter 4, *Human Error*, may be applied to job design as well as to overall system design. In fact, system design is often inseparable from job design, since the design of human-machine systems also involves the determination of other job characteristics that go beyond the assignment and scheduling of operator tasks, the design of the interfaces that determine and constrain job performance, and the design of the physical work environment. Especially important is the way in which multiple duties and tasks are combined or integrated in the design of jobs.

6.2.1 Task Integration

Careful integration of tasks can prevent the inclusion of incompatible procedures or conflicting cues across job tasks. Integration is especially important when a job involves use of multiple subsystems designed by different teams. As noted in Chapter 2, the system design process should be a planned movement from specific subsystems to tests of the complete system.

The user-centered design process, described in earlier chapters, applies to job design, as does the recommendation to use information from analyses of current jobs in the design or redesign of new jobs. Often, careful observation of persons at work can do more than any other method to reveal sources and patterns of errors and suggest ideas for avoiding such errors.

6.2.2 Job Prototyping

Prototyping provides a "strawman" version of a job that can be used as the starting point for iterative design of the final job. Experienced operators should be given an opportunity to review and to "walk through" new duties and tasks similar to those they already perform, before the designs are finalized (see Section 2.2). They will often spot potential problems that are evident only to those who have actually performed such jobs. Operators are likely to notice conflicts among duties and tasks that may lead to high error probabilities and to work overload.

The idea of prototyping is somewhat more difficult to apply to job design than to system design, but the concept is worthwhile. Techniques such as interviews, questionnaires, and "thinking aloud" (Section 11.2.3) are used. In the case of a new TMC, for example, the design team might use experienced operators from other sites as subject matter experts, using their knowledge of analogous jobs to help form a prototype. If there is an existing facility, experienced users can provide useful input for new or modified jobs by comparing present duties to the revised mission of the upgraded TMC. This input may require some speculation, but the resulting design will be a prototype, not a finished product. Subsequent design and evaluation iterations should identify the bad guesses.

6.2.3 Operator Participation in Job Design and Testing

The reduction of errors is a major objective of systematic job design. Poor job design can be a significant source of human error. The guidelines in Chapter 4 (Section 4.5) for minimizing errors in performance apply to job design as well as to system design. Careful attention to the design and integration of individual procedures and tasks can help to avoid lapses caused by the need to divide attention among simultaneous tasks. Some special guidelines apply to the design of jobs to minimize errors and their consequences. [126]

6/1 Design and the Operator   **(Observation)**

Involve operators in the design of jobs, tasks, and procedures.
Operator involvement is a fundamental element of user-centered design (see Section 2.1.3), and applies particularly to job design because the job is specifically *about* the user.

In TMC's visited during a requirements analysis, some of the most creative ideas were associated with centers that used the experience, opinions and recommendations of in-house personnel to assist design. In these cases, a heightened sensitivity to human issues of job design, as well as an active and ongoing attempt to identify and solve job-related problems was evident. Operators' contributions must be scrutinized, however, for bias toward old, accepted methods.

6/2 Prototype Tasks and Operator Testing	**(Observation)**

After developing a preliminary design, operators should work with prototypes to help test and refine the design.
As discussed in Chapters 2 and 3, this step is often ignored because of delay and expense, and because many designers do not know how to execute a user-centered design test. Many of the example problems and failures presented as supporting material in this handbook could have been averted had prototyping of tasks been accomplished during design and development.

6/3 Prototype Instructions and Operator Testing	**(Observation)**

Test all TMC instructions to ensure that operators understand them.
Never presume that instructions will be understood or followed. To ensure clarity and completeness, always test instructions on operators and revise them to address identified shortcomings.

6/4 Errors and Operator Testing	**(Observation)**

Use operators to test user interface designs to ensure that intuitive actions will not lead to unrecoverable errors.
"Intuitive" actions that trap TMC operators fall into two categories: (a) actions that seem logical because they match some internal "map" unique to the operator, and (b) actions that fit the logic of similar or earlier tasks. Computer users who buy a new word processing package, for example, will invariably try to apply familiar conventions that guided use of the *last* package. They only fall back on the new instructions when the familiar approach fails to produce the desired result. Of particular importance are those actions that can cause serious complications in traffic control or system function (such as the scenario described in Chapter 11 in which a key entry of <1> begins setup, while an entry of <11> initiates system shutdown).

6.3   Job Characteristics and Motivation Influence Job Design

Many industrial psychologists support the theory that workers are most highly motivated and perform best when their jobs are designed to maximize a few key characteristics. According to many researchers, highly motivating jobs have a common, identifiable set of characteristics.

Design jobs so that operators will be motivated to perform them well. Provide skill variety, task identity, task significance, autonomy, and feedback. [56]

! *Skill variety* is the degree to which a job constitutes a variety of different activities, involving the use of a number of different skills and talents.

! *Task identity* is the degree to which the job requires the completion of a whole and identifiable piece of work — that is, doing a job from beginning to end with a visible outcome.

! *Task significance* is the degree to which the job has an impact on the lives or work of other people, whether in the immediate organization or in the external environment.

! *Autonomy* is the degree to which the job provides substantial freedom, independence, and discretion to the individual in scheduling the work and in determining the procedures to be used in carrying it out.

! *Feedback* is the degree to which carrying out the work activities required by the job results in individuals obtaining direct and clear information about their performance.

Not all of these characteristics can be maximized in TMC's. In vehicular traffic control, just as in air traffic control or other proceduralized jobs, operators must follow established procedures and guidelines and cannot be given as much autonomy as workers in many other jobs. These desirable characteristics should, however, be emphasized wherever possible in the allocation of tasks to jobs. For example, where possible, an individual job should be designed so the employee finishes what he or she starts and sees the results.

6.4   Workload and Work Pacing Influence Job Design

Traffic management centers operate under conditions of widely varying workloads, with rush hour and event-related peaks separated by periods of little activity. Designing jobs and staffing schedules to cope with these variations is a challenge. A few basic principles can help to ensure that performance does not decrease and employees are not burned out by the work pace.

6.4.1   Workload Optimization

Jobs involving supervisory control of automated systems are often described as "hours of intolerable boredom punctuated by a few minutes of pure hell." [123] This description has been applied to the jobs of commercial airline pilots, nuclear power plant operators, and other command/control positions. These are jobs where many of the normal functions are automated, and the human operator has two important functions. First, he or she monitors the automated operations of the system, perhaps fine tuning them from time to time — the "boredom" component. Second, when the system malfunctions, he or she must diagnose and correct the malfunction, often under severe time constraints and with the threat of serious consequences if the malfunction is not corrected — the "pure hell" component.

Supervisory control jobs require the operator to maintain up-to-date knowledge of the status of many system parameters, even though he or she may not be involved in controlling those parameters most of the time. The danger is that the operator will lose touch with the system and be unable to respond appropriately in an emergency. Visits to traffic management centers made during preparation of the handbook suggest that many of these issues surrounding supervisory control jobs may be relevant in the TMC, especially during off-peak periods when operators may become mentally detached from indicators of system performance. As more automated support systems appear in the TMC, maintaining operator awareness will become more challenging.

Good job design can be a factor in improving performance in such circumstances. When allocating functions between the human operator and automated systems, designers should sometimes (e.g., during night shifts or other low-workload periods) specify more operator involvement than the technology requires, so that the operator will remain engaged and attentive to system operations. Requiring periodic checking and logging of system status is one option, although if the work is not meaningful and is clearly "busy work," it will not engage the operator. Operators may be given discretionary power to fine tune or even override automated controls, although such discretion requires clearly understood and well-enforced limits.

6/6 Operator Awareness of System Operation   (Observation)

Design jobs so that operators are required to maintain contact with their system.
This may be possible only by forcing the operator to a higher region in the continuum of operator roles than the technology demands (see Section 2.2.3 and Figure 2-4). Such a decision may seem on the surface to be *technically* inefficient. What the design team must consider is the value of having the human functioning actively in the loop during emergency situations versus the operating efficiency of high automation during *routine* periods.

Some general workload and work pacing issues to consider in job design include overall workload, peak loading, and the pacing of work. The following paragraphs suggest some ways of dealing with these in the design of systems and jobs. Additional material on task allocation is presented in Section 6.6.

Using tools and techniques described in Section 2.2.4 and 2.2.6, examine the overall workload implied by the demands of the job prototype and the operational scenarios for the TMC (Section 2.2.1). The following guidelines apply:

6/7 Workload Level   **(Recommendation; 123)**

The overall workload should be high enough to keep the operator busy and engaged, but not high enough to induce severe stress or to subject the operator to frequent simultaneous task requirements. Research results (see reference 123) suggest that as workload increases beyond what is easily handled, operator error and stress levels increase. Consequently, periods of extremely high workload should be minimized.

Section 6.6.1 includes possible techniques for identifying workload level. Operational sequence diagrams, prototyping, work profiles, and other methods are discussed in Chapters 2 and 3. Consider this guideline along with Guideline 6/6 in planning optimum workload.

As emphasized in Chapter 2, user-centered design must view the operation of the *total system*. Since jobs do not develop fully until late in the process of system design, and are influenced by a variety of factors, integrated design is essential.

6/8 Competing Tasks   **(Observation)**

Integrate system and job design of systems as a means of preventing tasks from competing for the operator's attention.
Piecemeal design (and thus piecemeal assignment of corresponding tasks assigned to the operator), will often inadvertently cause periods of overload. Where incremental design cannot be avoided, prototyping of the new tasks in the real work environment can help to alert designers to the potential for conflicts and overloads.

6/9 Peak Load and Task Distribution   **(Observation)**

Design work and training scenarios such that tasks can be re-assigned during peak load.
Obviously, task reassignment does not work if all operators tend to be overloaded at the same time, but often one operator can take on some of another's tasks to relieve a short-term overload. The feasibility of task reassignment should be considered when systems and jobs are being designed.

Since TMC workload can vary not only within a single day, but during special conditions — for example, late afternoon before a "long" weekend, major sports and cultural events, extreme weather conditions, and disaster evacuations — there should be provision in design for additional staff. This variable staffing will usually be a short-term measure.

6/10   Variable Staffing   **(Observation)**

Consider variable staffing, with more operators working during peak or other demanding periods, as a means of reducing workload.
This method is frequently used in existing TMC's, as is the use of "on-call" workers. One center assigned only one operator to monitor operations during off-peak hours. If an incident occurred during those hours, creating a work overload, other workers left their routine tasks and assisted in the control room.

6.4.2   Work Pacing

The pacing of work is an aspect of job and system design that may have some application to the TMC environment. The major consideration here is whether the pace of the work is set by the worker, "self-paced," or by the technology, "system-paced." The typical assembly line job is an example of system pacing. The work pieces are delivered to the worker at a system-

determined rate, and he or she must work at the system's pace. Typically, workers express dissatisfaction with machine pacing of their work, but research findings are not clear on whether self pacing or system pacing leads to better performance. [125] Generally, system pacing should be avoided, if possible, if only to avoid the negative effects on worker motivation or satisfaction. Clearly, some tasks must be performed at regular intervals (e.g., traffic reports every ten minutes during rush hour), and, where this is understood to be essential to job completion, workers are typically willing to comply.

6.5   Shift Scheduling

Studies have investigated the effects of various work schedules on worker performance and well-being. Most of this research has concentrated on the effects of working shifts other than normal daytime hours, and is covered in Chapter 5 on constraints to work performance. The scheduling of shift coverage may be considered a part of job design.

Most TMC services are needed from the beginning of morning rush hour (5:30 to 6:00 AM) to the end of evening rush hour (6:30 – 7:00 PM), although some centers are staffed 24 hours per day. Typically, the workday is too long to be covered by a single team of operators, but it may not require two full 8-hour shifts. Schedule requirements can be satisfied in a number of ways, including overlapping shifts, and assignment of other duties to fill the shift time not spent as an operator. College students, for example, can serve as an excellent resource for augmenting the TMC team because their schedules are often flexible enough to allow them to sandwich their classes between two short, rush-hour shifts in the TMC. Any of these approaches may be effective, if the basic guidelines given in Chapter 5 are followed.

Assigning workers permanently to night shift work is not recommended, but rotating shifts can be difficult as well, especially if careful scheduling is ignored. The following guidelines are suggested for scheduling rotating shifts.

6/11 Forward Shift Rotation   (Recommendation)

Shift rotation should always be in a forward direction.
A "forward direction" is, for example, from day to evening to overnight.
People adapt more easily to a *longer* than normal day than to a shorter one.

6/12 Sudden Shift Rotations	**(Observation)**

Avoid quick changeovers between shifts (with less than a normal interval between successive workdays) for any worker.
Sudden shifts can cause temporary disorientation as the circadian cycle catches up. For example, a change in shift assignment from day to overnight should allow a full day of adaptation time between the old and new schedules.

6/13 Preferences for Shifts	**(Observation)**

Where possible, individual workers' preferences for early or late day shifts should be accommodated.
The differences between "morning people" and "night people" are real, and workers are most effective when they are working in harmony with their own internal rhythms.

A seemingly minor issue, but one which can have serious implications if not considered, is the need to allow for sufficient overlap between outgoing and incoming shifts. A 30 minute overlap ensures that the new shift has time to be briefed on system status and to receive information from the outgoing team.

6/14 Shift Turnover Timing	**(Observation)**

Shift turnover should be scheduled for periods of lower workload.
This allows time for transfer of information between incoming and outgoing shifts.

6.6   Task Allocation Influences Job Design

The allocation of operator tasks to individual positions or teams is a job design issue. The authors' observations of existing TMC's showed that the allocation of tasks to team members appears to be based on habits that groups develop on their own, although some specialization was observed (e.g., dedicated radio communicators). In this section, three major questions are addressed:

- !   How are the normal tasks assigned to jobs or positions (*default allocation*)?
- !   How are peak load tasks assigned (*dynamic allocation*)?
- !   How should tasks be apportioned within teams (*shared allocation*)?

6.6.1 Default Task Allocation

The most basic question in the design of any job is "what tasks should be assigned to this position?" Some of the principles to be considered in answering this question have already been discussed in Chapters 2 and 3, and the desirable overall characteristics of a job have been listed. The system analytic approach first identifies those functions which the system must perform and then decomposes these functions into tasks. The tasks are allocated to human and machine components of the system or, more frequently as information system interfaces evolve, to a combination of human and machine components. The output of this process includes a list of tasks the operators must perform, either alone or in concert with the system, and detailed task requirement information. This information may include: the *knowledge, the skills, and the abilities* required to perform the tasks; the *timing and the frequency* of each task; the *links* that define the relationships between tasks; the *characteristics of the interface* required for task performance; and the *information flow* between the operator and the automated system for each task.

The job designer (often an engineer) must then use this information, along with information about available human resources and the constraints applicable to task assignment, to determine who will perform which task(s) on a regular basis. This decision process is required not only for the addition of new tasks (when systems are changed), but also for the original tasks. The following guidelines should be considered (in addition to those in Section 6.3) in making such decisions.

6/15 Operator Workload Capacity   **(Observation)**

The total and peak workloads for any one operator should not exceed the operators' capabilities.
If peak workloads are expected to require assistance, then design of the job of the person expected to assist should include relief tasking.

6/16 Tasks Distribution Over Time   **(Observation)**

Distribute tasks over time as evenly as possible.
In a TMC, task pace is largely dependent on the demands of the traffic system. Design of individual tasks can worsen difficult situations, especially when performed concurrently with other tasks. In iterative tests and evaluations, designers should identify scenarios that are vulnerable to overload and then reduce that overload to manageable levels.

Assign multiple operators those tasks that require conflicting actions or simultaneous attention to several information sources.
Such problems may not be evident without prototyping and evaluation under realistic conditions.

Figure 6-1 shows the output of a time-line analysis for multiple tasks under consideration for assignment to a single operator, showing the distribution across time of the defined group of tasks. This generic example shows a convenient method for predicting operator overload. The list of tasks represents a word module composed of 10 tasks. Note the periods of heavy activity, particularly in the first ten minutes. Such an analysis can reveal where task overloads are likely to occur and can help prevent the designer from allocating conflicting tasks or overloading a single operator. If such information is not available from a task analysis, a designer should generate it before performing the allocation of tasks to individuals. Sources of information can include data from similar tasks currently being performed, estimates from operators, and estimates from system designers. Chapter 3 provides information on generating such task analytic information, along with references for appropriate methods which may be used.
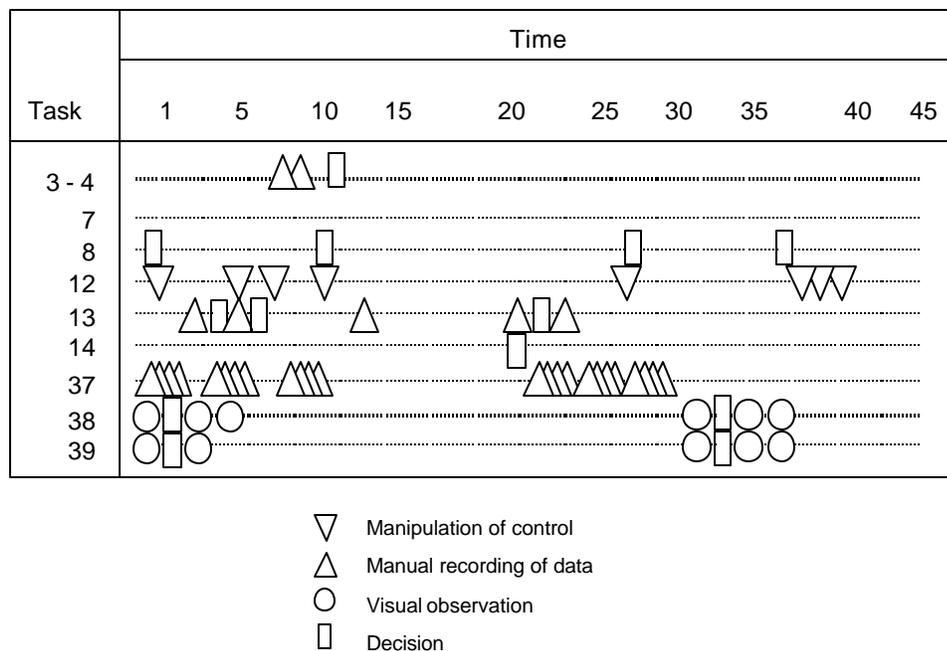
Figure 6-1. Sample time line analysis (after Woodson, Tillman & Tillman, 1992).

6.6.2 Dynamic Task Allocation

When more than one operator is on duty in a facility, a dynamic task allocation is often appropriate, where the existing conditions determine who does a particular task at a particular time. Operator A may routinely perform task A while performing other tasks, but when he or she is overloaded, Operator B may take responsibility for that task. The following guidelines, in addition to all those for normal workload allocation, are appropriate.

6/18 Operator Availability   **(Observation)**

Ensure availability of additional operators for task transfer when operator workload becomes excessive.
Analyze task requirements for all operators to project their workloads.

6/19 Task Transfer and Task Shedding   **(Observation)**

Provide rules or guidelines governing the transfer and shedding of tasks.
With these rules each operator's responsibilities are clearly defined, all tasks are assigned, and priorities for task transfer among operators and task shedding are established. Task shedding refers to allowing some low priority tasks to remain undone under defined circumstances.

6/20 Task Transfer and Operator Workstations   **(Recommendation)**

Ensure that the system hardware and interface support the transfer of tasks between operators.
If Operator B must take over Operator A's task under overload conditions and use Operator A's equipment to perform the task, problems are likely to occur if the equipment is different. An appropriate approach is to standardize the capabilities and user interfaces across all operator stations.

6/21 Cross Training   **(Observation)**

Include cross training of tasks in training plans such that a task may be performed by different operators under different conditions.
An operator whose primary duty is managing the CMS system may also need to be available for verifying and managing incidents.

Based on TMC surveys, three basic schemes were identified for division of the tasks among

operators. Perhaps the most common was division by *function* – one operator might be responsible for identifying and verifying all incidents within the area assigned to the TMC while another was responsible for communication responses to the incidents. A second scheme was by *geography* – each operator was responsible for all traffic management functions in a specific area of the city. In the third and least common scheme, there was no division of labor. Operators sought and addressed traffic management problems in the metropolitan area without regard to their location or nature.

Research has examined the differences between functional and geographic task assignments. While differences were minor, they tended to favor functional tasking. Thus, specializing in specific TMC tasks, operators responded more quickly, produced higher quality responses, and avoided more incident-related congestion.

Functional teams have one disadvantage that needs to be addressed in TMC design. Significantly more communication and coordination between team members is needed because, for example, the team member finding and verifying the incident must communicate a detailed incident report to the team member conducting the incident response. Means of facilitating this communication by voice, computer, or gesture should be taken into account in TMC job design and procedures (see Guideline 6/23).

6.6.3   Shared Task Allocation

The design of teams, team tasks, and team training has received much attention, especially in the military and the aerospace industry. [111] Most likely, the majority of TMC operator tasks are best performed by single operators, but certain tasks lend themselves to team work. In general, tasks requiring (1) simultaneous gathering, transfer or processing of information (monitoring and reporting on system parameters); (2) the following of complex procedures while observing system feedback (troubleshooting); and (3) problem-solving activities may be best performed by two or more persons. They should be designed as team tasks.

One advantage of team task performance is that the specialized skills and knowledge of each team member can contribute to the performance of a task that would be difficult for any single individual. Many aspects of the design and management of team work, including personnel selection, training, and communications, are not discussed here. The following guidelines concentrate on the design of team jobs and tasks. The guidelines assume the availability of human resources, and that appropriate human resource and operational management actions will be taken.

6/22 Support Team Communications   **(Observation)**

Provide technology and design that supports all required team communications.
Facilitate team communications by implementing workspace design principles. This includes both formal verbal and electronic communication and informal gestures and body language. Principles of workspace design are covered in Chapter 10.

6/23 Formal Task Assignments   **(Observation)**

Develop team procedures that (1) clearly assign responsibilities to particular team members or that (2) clearly state that any team member may perform given steps or tasks.
Take advantage of the specialized skills and training of each team member in assigning these responsibilities.

6/24 Team Procedure Testing   **(Observation)**

Test prototype team tasks and procedures before using them.
This approach will ensure that team tasks/procedures are feasible and are supported by the technology. In addition, it will ensure that time estimates are realistic.

6.7   Design for Best Operator Performance

As noted earlier, jobs and technology should not be designed separately, but rather should be treated as aspects of an overall operational system. Many of the human factors issues discussed elsewhere in this volume with reference to the design of technological systems and interfaces are also relevant to the design of jobs. The guidelines given serve as reminders of those factors that can influence the speed and accuracy of performance and the attitude and well-being of the operator. They are intended to remind the design team that many features grouped under other chapters influence job design.

6/25 Task Transition Time   **(Observation)**

Minimize the transition time between related sequential tasks.
Task analysis data and link analysis are useful workstation design tools for reducing idle time and transition times between tasks.

6/26 Workstation Flexibility (Observation)

Design control, display, and work area layouts to support the range of tasks an operator will perform.
The optimal layout for a single function may not be the best for the job as a whole.

6/27 Consistent Information Presentation (Observation)

Select information presentation and coding techniques to support the range of tasks the operator will perform.
Ensure that coding, nomenclature, and presentation style are consistent across tasks to the greatest extent possible.

CHAPTER 7: ANTHROPOMETRY AND DESIGN

CONTENTS

7.1 The Dimensions of People

People come in a broad range of sizes, shapes, strengths and agilities. It is a challenge for the designer to be sure that the TMC workstations and jobs are designed to physically "fit" the entire staff of operators. In order to ensure that TMC operators can see all of their displays and monitors, reach all of their controls and keyboards, and still maintain a safe and comfortable posture, designers must take the operators' physical dimensions into account.

The science of *anthropometry* measures and documents the physical dimensions of humans - both static measures such as height and dynamic measures such as strength - and applies them in the design of human/machine systems. A full understanding of anthropometry blends knowledge of a range of topics in physiology, biophysics, and biomechanics.

The samples of data and guidelines in this chapter were selected for their pertinence to TMC human factors design. They form the basis of design guidelines in Chapters 8, 9, 10 and 11 that are specifically related to control room design.

In addition, other topics — such as standards for lifting tasks — reflect the realities of the work place. Operators who normally occupy TMC work stations may be required on occasion to perform physically demanding work (for example, unloading a fresh box of printer paper or a computer monitor). The first sections of this chapter concerning structural anthropometry (the size of human bodies) contain only reference information. Specific guidelines based on anthropometry are grouped under their respective design topics in later chapters. This chapter may be used to provide human dimension data for specific design tasks. The final section on

strength and movement include guidelines on strength and functional anthropometry.

7.2   The Principles of Anthropometry

Anthropometry is literally translated as *measurement of humans.* As with all design sciences that involve measurement of physical properties, there are accepted, standardized techniques concerning who to measure, what to measure, and how to measure it. These issues are addressed in the following sections. Understanding the principles of anthropometry can forestall employee health problems, lost work time, and even litigation.

7.2.1   The target population

Dimensions of the human body vary widely. Sources of this variation include gender, nationality, and other predictable factors. Males are typically taller than females. Northern Europeans are typically taller than east Asians. Individuals in some jobs may tend to be larger or smaller than those in other jobs. But, even within a single defined group, there is significant variability. Figure 7-1 shows the distributions of standing height for American females and males.
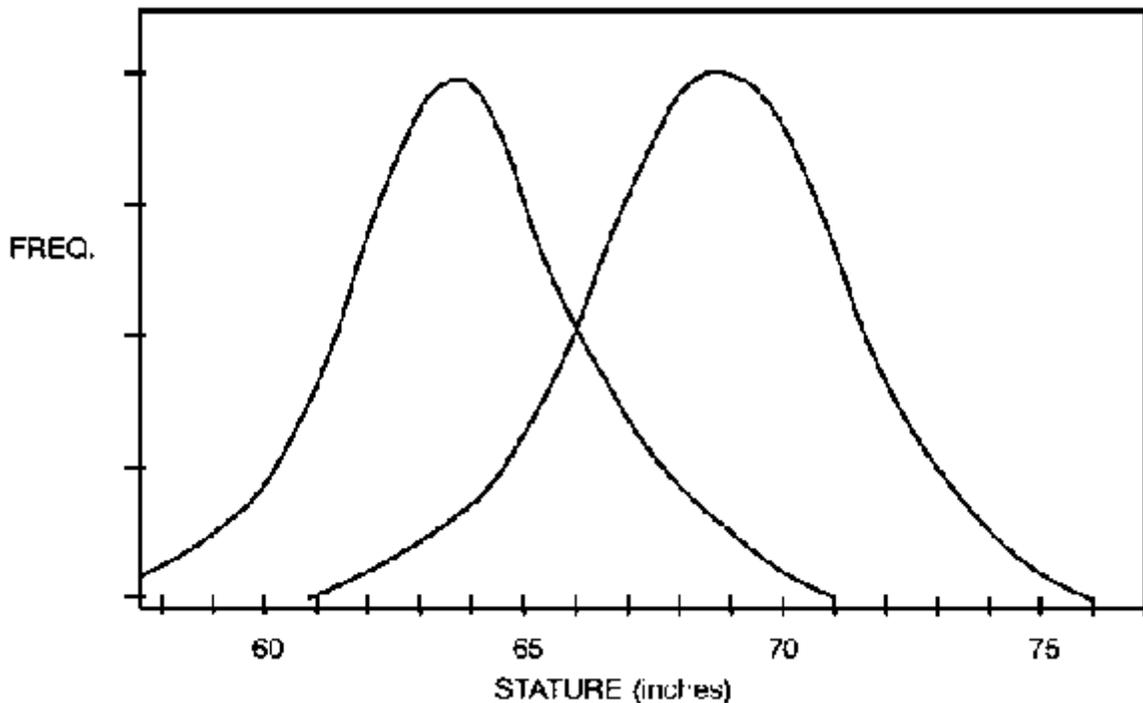
Figure 7-1. Stature distributions for American females and males.

The stature of American males ranges between approximately 155 cm and 193 cm (61 in and 76 in). This 95th percentile range does not include extremely tall or short individuals. The mean stature of American women is approximately 13 cm (5 in) less, and ranges from 142 cm to 180 cm (56 to 71 in).

Figure 7-2 illustrates the size contrast between a large American male, 191 cm (75 in), and a

small American female 142 cm (56 in). These figures represent individuals who are three standard deviations taller or shorter than the means of their respective groups. Figure 7-3 shows mean differences in stature for young males in five countries.
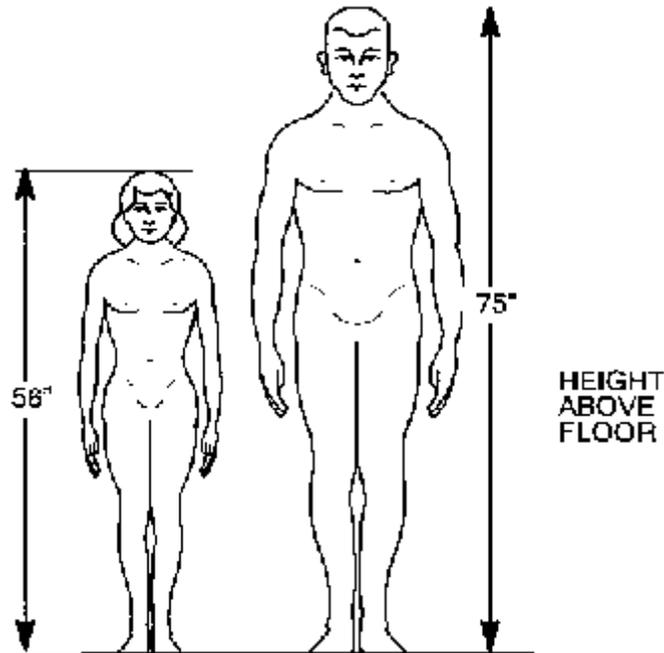
Figure 7-2. Large American male with small American female.

It is important to recognize that when we identify a population with restricted membership criteria, statistics on the size of the populations may differ from the norms of the broader populations. It should also be recognized that this difference may have design implications. A population of professional basketball players, for example, will be substantially larger than a population of jockeys. Shower fixtures in National Basketball Association locker rooms may be installed somewhat higher than in the jockeys' locker rooms.

When we specify the height of work surfaces, the height of chair seats, the reach distance and reach angle to controls, and the height of console tops, we might prefer to pick dimensions that would accommodate the entire normal range of humanity (from the smallest Asian female to the tallest Scandinavian male). This is not a practical goal, because the compromises necessary would usually result in an unwieldy design. In general, human factors engineers will make a diligent effort to identify and accommodate the largest possible fraction of the expected users, *the target population*.
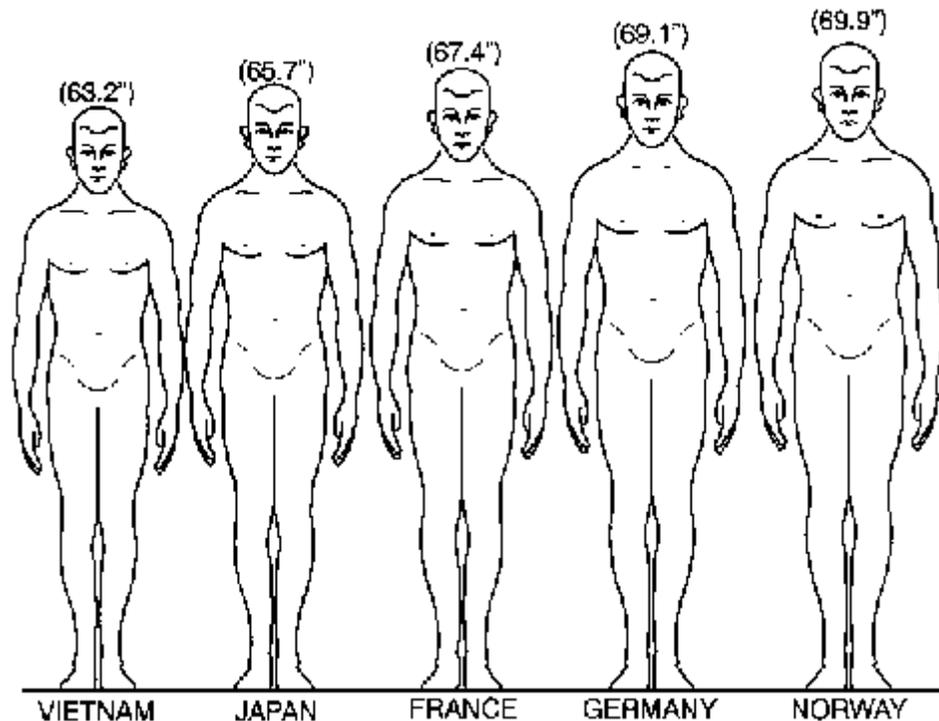
Figure 7-3. Mean heights of young males in five countries.

What target population must the TMC designer seek to fit? Since TMC operations exercise the abilities of the mind much more than those of the body, there appears to be no need to recruit individuals who are taller, shorter, longer-legged, or longer-armed than usual. If selection criteria for employment at a TMC will not be constrained by size, the design of the TMC must accommodate a target population representing the full range of American workers.

Variation is large within the selected target population, and there are extremes that may not be practically accommodated through the normal design process. Exceptionally tall, short, or obese operators may be handled by exception (that is, by making modifications to accommodate a rare employee who is at the upper or lower end of the range). The rule of thumb that is used to determine the design dimensions is to design the system to fit minimum and maximum body dimension that range from the *5th percentile to the 95th percentile of the target population*.

Thus, by design and adjustability we try to accommodate the middle ninety percent of people. But on what dimensions? Height? Weight? Reach distance? This is not a trivial question. There are many commonly used anthropometric measures (we will examine only those that have the most applicability to the TMC). These anthropometric dimensions are not as strongly correlated with each other, as would be liked from a design standpoint. A person who is average on one measure (e.g., standing height) may be well outside of the 5 to 95 percentile range on another parameter (e.g., arm length).

Thus, determining size guidelines is complicated, and designers often end up ignoring

anthropometric data and making the decision to just allow for a very wide range of physical dimensions. This can be done by selecting adjustable tools and furniture, by providing a range of sizes, or by selecting a "one-size-fits-all" design to which outliers must adapt.

Design aids are available to help the designer fit the workstation to the operator. Scale model, two-dimensional human manikins representing different body sizes have been used to check workstation designs. Many computer-aided design (CAD) tools now provide a similar capability incorporated in their software.

7.2.2   Structural anthropometry

The science of anthropometry, like any other field, has its own conventions and vocabulary. *Structural* (or *static*) anthropometry is the measure of body dimensions in a series of standard fixed postures. Included in this section are commonly used measures and data for US adults. Both the Society of Automotive Engineers (SAE) and the National Aeronautics and Space Administration (NASA) have published anthropometric data bases that are widely used for design. Not all pertinent dimensions are included in both data bases so the numbers presented here are a combination of the two.

In Chapter 10, guidelines will be provided for the design of operator workstations. The commonly used measures described in this chapter provide the foundation for many of the conventions and guidelines in Chapter 10.

Standing measures. The following measures apply to standing workers.

   ! **Standing height.** This is a measure that is sometimes used for screening candidates for special jobs. It is critical for minimum head clearances. In TMC's, it might be used in design of access to electrical cabinets or other areas where entry is not frequent and where standard doors and passages are impractical. (Figure 7-4)

STANDING HEIGHT (STATURE)

Standing height is the primary indicator by which one selects general test subjects to evaluate various designs when there is no specific aspect of the design pertaining to an individual body component. The dimension is pertinent for adjusting head clearances.

	Percentile		
	5th	50th	95th
Adults			
Males	63.6 in	68.3 in	72.8 in
Females	59.0 in	62.9 in	67.1 in

Figure 7-4. Standing height.

   ! **Eye height.** In the TMC, providing an unobstructed view of critical displays is

important. Since views may be blocked from certain points of observation by equipment racks, partitions, or other obscurations, line-of-sight information is vital. (Figure 7-5)

EYE HEIGHT (STANDING)

This dimension is pertinent to the location of visual displays and/or the sizing of visual obstructions, where a small person may have to see over the obstruction or over someone who is taller. When people stand normally (i.e., with some slump), their eye height lowers by about 1.6 in (4.1 cm) for males and by about 1.2 in (3.0 cm) for females.

	Percentile		
	5th	50th	95th
Adults:			
Males	60.8 in.	64.7 in.	68.6 in.
Females	57.3 in.	60.3 in.	65.3 in.

Figure 7-5. Standing eye height.

! **Forward reach.** Adjustment of controls on standing-height consoles, particularly where workers must reach forward (e.g., over work surfaces), requires consideration of forward reach. (Figure 7-6)

FORWARD REACH (STANDING)

This dimension is pertinent to evaluating reach conditions within the design situation. This dimension should be used in conjunction with leg-reach dimensions when the design situation calls for a seated operator to operate both hand and foot controls.

	Percentile		
	5th	50th	95th
Adults			
Males	31.9 in.	34.6 in.	37.3 in.
Females	29.7 in.	31.8 in.	34.1 in.

Figure 7-6. Standing forward reach.

! **Overhead reach.** If controls or maintenance access are overhead, this measure is critical. Woodson and associates (1992) suggest that its use should also take operators' stature into consideration since overhead arrangement that fits a shorter person may create awkwardness for taller people. [125] (Figure 7-7)

OVERHEAD REACH (STANDING)

This dimension is pertinent to locating controls that are overhead. It should be used in conjunction with stature because, although a short person must be able to reach a control, it should not be so low that it becomes an obstruction for the taller person. Use this dimension for evaluating the accessibility of objects on high shelves.

	Percentile		
	5th	50th	95th
Adults:			
Males*	82.0 in.	88.0 in.	94.0 in.
Estimated Females	73.0 in.	79.0 in.	86.0 in.

Figure 7-7. Standing overhead reach.

!   **Maximum body width.** This dimension might be considered critical in the TMC for passage of personnel through narrow spaces (e.g., clearance between console and wall). (Figure 7-8)
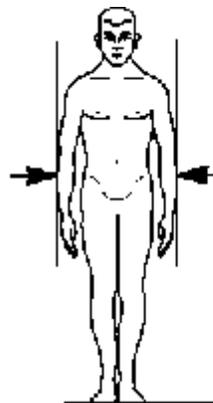
MAXIMUM BODY WIDTH

As indicated by the lack of data below, this measurement is seldom taken during typical anthropometric surveys. However, it is pertinent to lateral clearance requirements in design work. It would be useful, for instance, to evaluate lateral corridor clearance.

	Percentile		
	5th	50th	95th
Adults:			
Males*	18.8 in	20.9 in.	22.8 in.
Females*			

* Combined Air Force personnel and college students.

Figure 7-8. Maximum body width.

Sitting measures. A number of anthropometric measures are related to the operators' requirements to work in a safe and comfortable posture while seated. Most TMC workstations are designed for seated operation, although, in reality, they are used from both standing and seated positions. The following measures are commonly used in the design of seated workstations.

!   **Sitting height.** This measure is critical to a variety of functions, particularly with respect to seating and control placement, described in Chapter 10. (Figure 7-9)

SITTING HEIGHT

This dimension is pertinent to the establishment of proper overhead clearances for seated persons.

		Percentile	
	5th	50th	95th
Adults:			
Males	33.2 in.	35.7 in.	38.0 in.
Females	30.9 in.	33.4 in.	35.7 in.
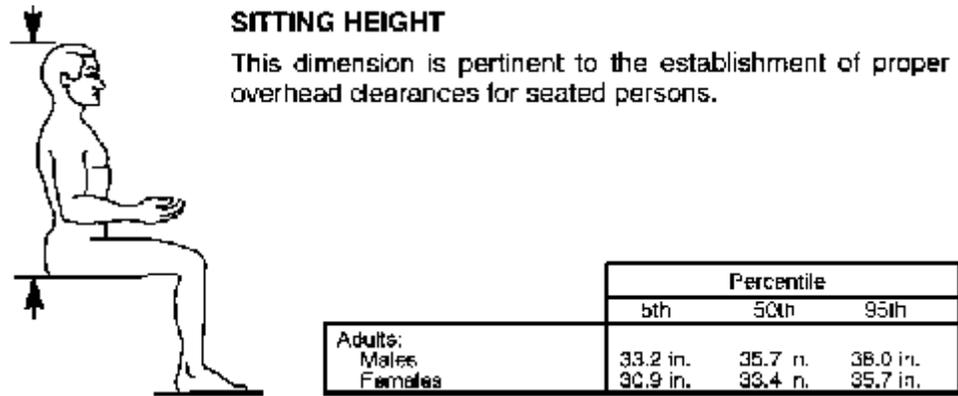
Figure 7-9. Sitting height.

❗ **Sitting eye height.** This measure is important for TMC's because it affects the placement of video displays at work stations; detailed discussion is found in Chapters 9 and 11. (Figure 7-10)

EYE HEIGHT (SITTING)

This dimension is pertinent to the design of work stations in which visual displays and/or outside viewing requires accommodation of a range of operator sizes. When people sit normally (with some slump), their eye height lowers by about 1.2 in (3.0 cm) for males and by about 1.2 in (3.0 cm).

		Percentile	
	5th	50th	95th
Adults:			
Males	28.7 in.	31.3 in.	33.5 in.
Females	27.4 in.	29.3 in.	31.0 in.

Figure 7-10. Sitting eye height.

❗ **Buttock-to-popliteal length.** The popliteal is the point at the back of the leg where the knee bends. Buttock-to-popliteal is the dimension that defines the seat pan depth of chairs. Because of the requirement for fatigue-free posture *and* accommodation of a wide range of body size, this and similar measures are essential to the design of seating. Further discussion is found in Chapter 10. (Figure 7-11)

BUTTOCK–TO–POPLITEAL LENGTH

This dimension is pertinent to seat length. Although it is desirable to provide adequate support for the larger person, it is the shorter person who will have the most problems if this dimension is ignored.

	Percentile		
	5th	50th	95th
Adults:			
Males	17.3 in.	19.5 in.	21.6 in.
Females	17.0 in.	18.9 in.	21.0 in.
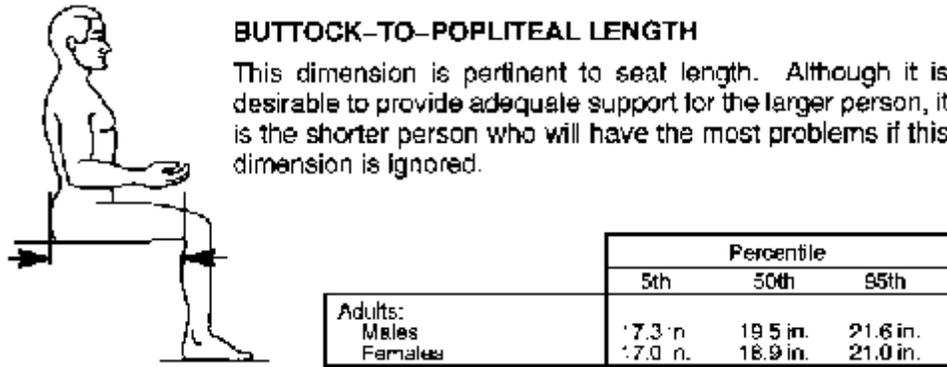
Figure 7-11. Buttock to popliteal length.

! **Midshoulder height (sitting).** This is essentially the height of the shoulder above the chair. This measure and forward reach are essential to the placement of controls, including communication devices, display adjustments, camera remote controls and other key elements of TMC work station design. (Figure 7-12)

MIDSHOULDER HEIGHT (SITTING)

This dimension is pertinent to the location of controls (i.e., most controls should not be located above the shoulder).

	Percentile		
	5th	50th	95th
Adults:			
Males	21.0 in		25.0 in
Females	18.0 in	—	25.0 in.
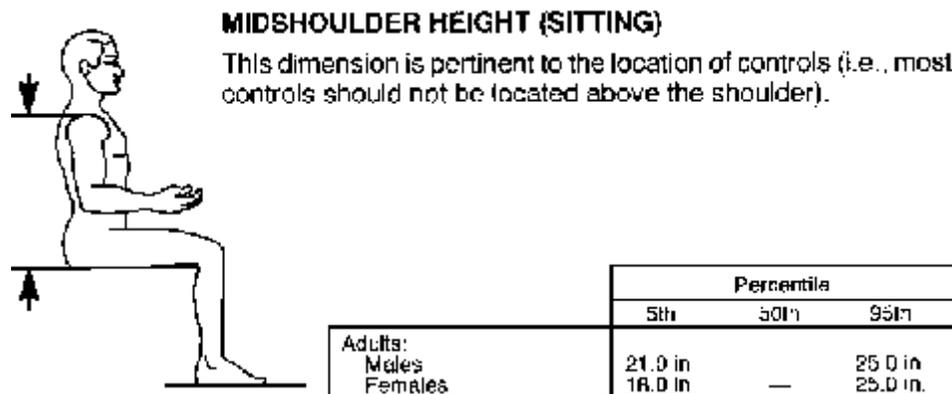
Figure 7-12. Sitting mid-shoulder height.

! **Buttock-to-knee length.** While buttock-to-popliteal length defines the limits of seat depth, this measure allows for accommodation of knee clearance at work stations (See Chapter 10 for specific design guidelines). (Figure 7-13)

BUTTOCK-TO-KNEE LENGTH

This dimension is pertinent to establishing under-console knee clearance for the seated operator. It should be used in conjunction with knee-height and thigh-clearance dimensions.

	Percentile		
	5th	50th	95th
Adults:			
Males	21.3 in.	23.3 in.	25.2 in.
Females	20.4 in.	22.4 in.	24.6 in.
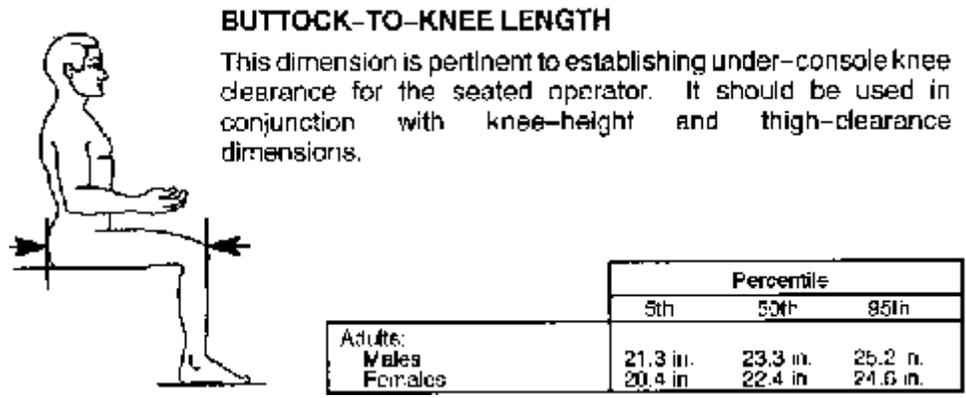
Figure 7-13. Buttock to knee length.

! **Popliteal height (sitting).** This is the height of the back of the knee above the floor. Seat height must be adjustable to allow for population variance in this dimension (See Chapter 10 for specific design guidelines). (Figure 7-14)

POPLITEAL HEIGHT (SITTING)

This dimension is pertinent to the establishment of appropriate seat heights, need for foot rests, and position of foot controls.

	Percentile		
	5th	50th	95th
Adults:			
Males	15.5 in.	17.3 in.	19.3 in.
Females	14.0 in.	15.7 in.	17.5 in.
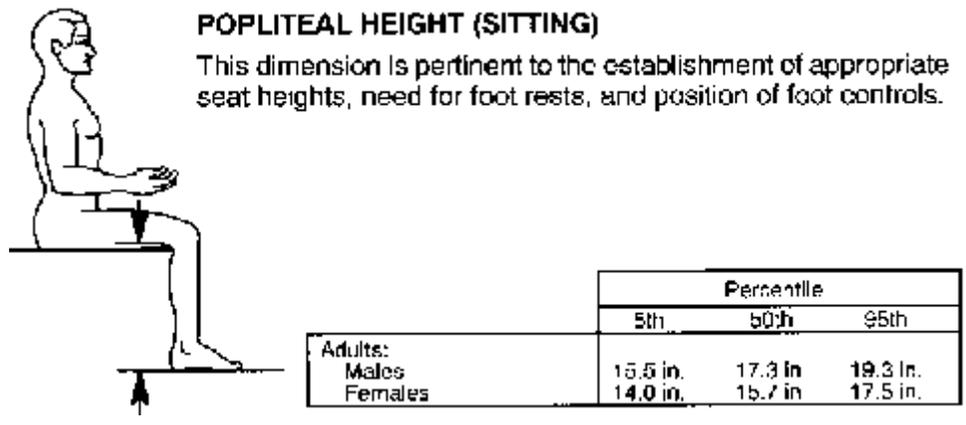
Figure 7-14. Sitting popliteal height.

! **Knee height (sitting).** Along with hip breadth and buttock-to-knee length, knee height allows specification of knee clearance (for clearance envelope in design of work stations, see Chapter 10). (Figure 7-15)
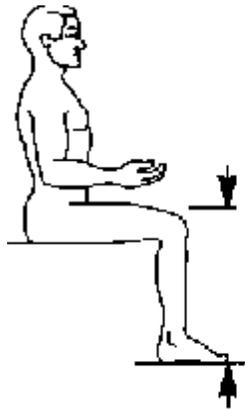
KNEE HEIGHT (SITTING)

This dimension is pertinent to the establishment of under-console knee clearance. It should be used in conjunction with buttock-to-knee length and thigh-clearance dimensions.

	Percentile		
	5th	50th	95th
Adults:			
Males	19.3 in.	21.4 in.	23.4 in.
Females	17.9 in.	19.6 in.	21.5 in.

Figure 7-15. Sitting knee height.

! **Elbow rest height.** This dimension is critical to specification of seating adjustment since work surface heights are generally fixed. (Figure 7-16)
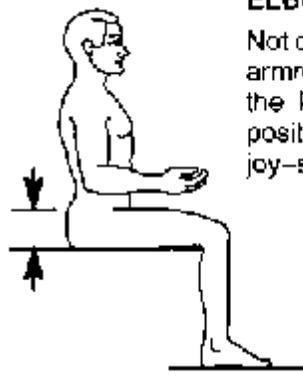
ELBOW REST HEIGHT

Not only is this dimension pertinent to the establishment of armrest heights, but it also provides a basis for establishing the level of a writing surface and/or the approximate position of the middle row of a keyboard, the location of a joy-stick handle or control wheel, etc.

	Percentile		
	5th	50th	95th
Adults			
Males	7.4 in.	9.5 in.	11.6 in.
Females	7.1 in.	9.2 in.	11.0 in.

Figure 7-16. Elbow rest height.

! **Shoulder breadth.** Side-by-side seating space and lateral clearance in passageways, that for some operational reason cannot be built to the more spacious and comfortable widths specified in Chapter 10, are derived from this measure. (Figure 7-17)

SHOULDER BREADTH

This dimension is pertinent to the establishment of lateral clearance between persons who may be required to sit side by side and to the establishment of the lateral clearance requirement for a worker who may have to squeeze into a tight space to work on an item of equipment.

	Percentile		
	5th	50th	95th
Adults:			
Males	16.4 in.	17.9 in.	19.6 in.
Females	14.4 in.	15.7 in.	17.6 in.

Figure 7-17. Shoulder breadth.

Anthropometry of persons in wheelchairs. Several TMC's have reported positive experience with operators who use wheelchairs. The TMC design should be planned from the outset to accommodate such workers. Consoles/desks should be designed to accommodate a standard wheelchair. Limitations in the reach envelopes of wheelchair-bound operators should also be taken into account in control placement. The following measures are provided to allow design consideration for handicapped employees as may be mandated under the Americans with Disabilities Act. (Figure 7-18)

FORWARD RESEACH LIMITS (ADULTS)
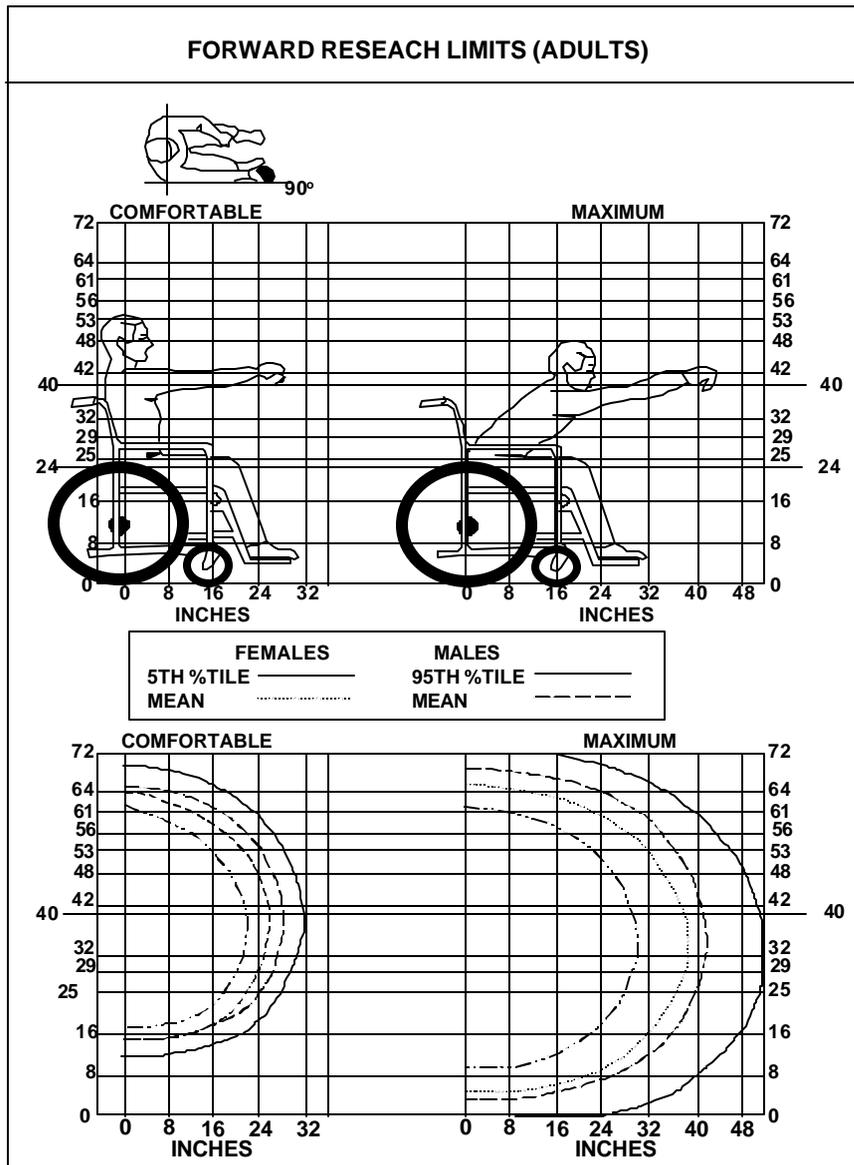
| TEST POPULATION FOR WHEELCHAIR REACH DATA									
MALE	**5TH %TILE**	**MEAN**	**95TH %TILE**	**SD**	**FEMALE**	**5TH %TILE**	**MEAN**	**95TH %TILE**	**SD**
FLOOR TO VERTEX	49.1	52.4	55.7	2.0	FLOOR TO VERTEX	46.9	50.4	53.8	2.1
FLOOR TO EYE	44.7	48.1	51.5	2.1	FLOOR TO EYE	42.7	46.4	50.1	2.2
FLOOR TO SHOULDER	38.4	40.8	43.2	1.5	FLOOR TO SHOULDER	35.4	39.3	42.2	1.8
FLOOR TO ELBOWS	24.9	27.3	29.7	1.5	FLOOR TO ELBOWS	23.2	26.7	30.2	2.1
FLOOR TO THIGH	23.3	25.4	27.5	1.3	FLOOR TO THIGH	22.8	24.7	26.6	1.2
SHOULDER WIDTH	14.3	16.8	19.3	1.5	SHOULDER WIDTH	13.5	15.1	16.7	1.0
HIP WIDTH	12.2	14.1	16.0	1.2	HIP WIDTH	12.6	14.3	16.6	1.8
TOE PROJECTION	3.7	5.1	6.5	0.9	TOE PROJECTION	2.6	4.1	5.6	0.9
LOWER LEG LENGTH	15.7	17.3	18.9	1.0	LOWER LEG LENGTH	14.4	16.2	18.0	1.1
AGE IN YEARS		34.7			AGE IN YEARS		32.1		

Figure 7-18. Forward reach limits of adults in wheelchairs.

The standard reach envelope. Particularly pertinent to TMC design is the *standard reach envelope*, a series of measures designed to allow good placement of controls and displays

relative to a seated operator. These measures will be of great importance in the design of TMC work stations.

Figures 7-19 and 7-20 show standard reach envelopes of seated and standing "average" operators. All frequently touched items (knobs, instruments, pushbuttons, keyboards, touchscreens, etc.) should be positioned within these reach envelopes.

7.3   Strength and Functional Anthropometry

This section provides a grounding in the biophysics of the application of force by the human body which, combined with data from the section on structural anthropometry, will help designers apply human measure in a dynamic setting. We have limited our discussions to those topics and measures that have relevance to a control room environment; but we include within that category the normal lifting, pulling, and other displacements common to any work place.

7.3.1   Strength and force limitations

Muscle force is composed of the following factors: [125]

> ❗ **Muscle tension.** Muscle tension decreases as the muscle shortens and as its rate of shortening increases; it is at its maximum when the length of the muscle is greatest.

> ❗ **Mechanical advantage.** Muscles can apply force best when links are properly positioned; this almost never occurs for any complex action, because most muscles are obliged to operate at some mechanical disadvantage. "Curling" a barbell (lifting the weight up with upper arms parallel to the trunk) is relatively advantageous. Lifting the same weight with the arms extended parallel to the floor is not advantageous.
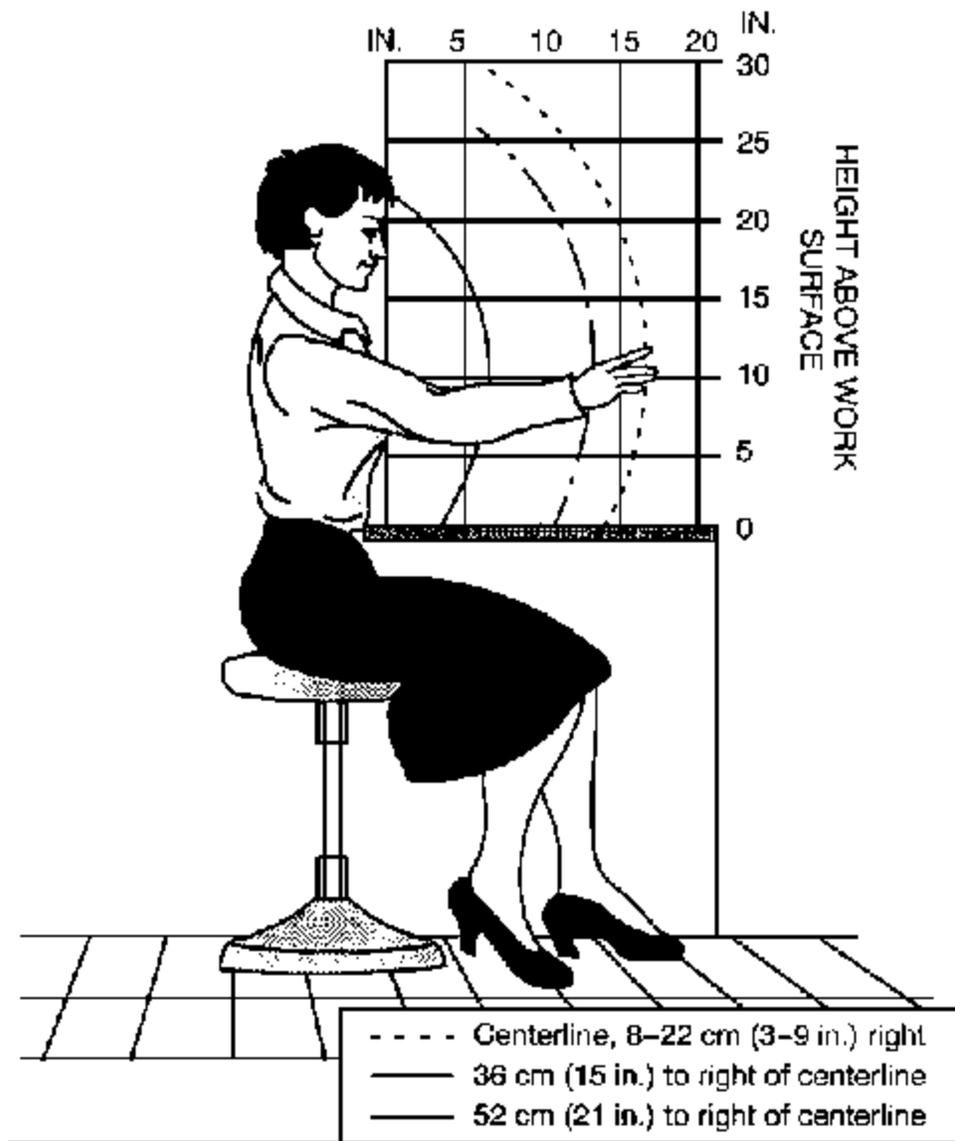
Figure 7-19. Reach envelope of average seated operator.

- **Age and gender.** Males and females have different mean strengths (adult females are approximately two-thirds as strong as adult males — though we should bear in mind that these are *mean* values, and variance is high, which means that some adult females will have more strength than some adult males). Both tend to build strength to a maximum between ages 30 and 40, with a decline to about 75 percent of maximum strength at age 65.

- **Body build.** In general, persons with larger and more muscular body builds have more strength. However, more slender persons may have more efficient oxygen consumption for a given task and may perform better at rapidly fatiguing tasks involving strenuous exercise.
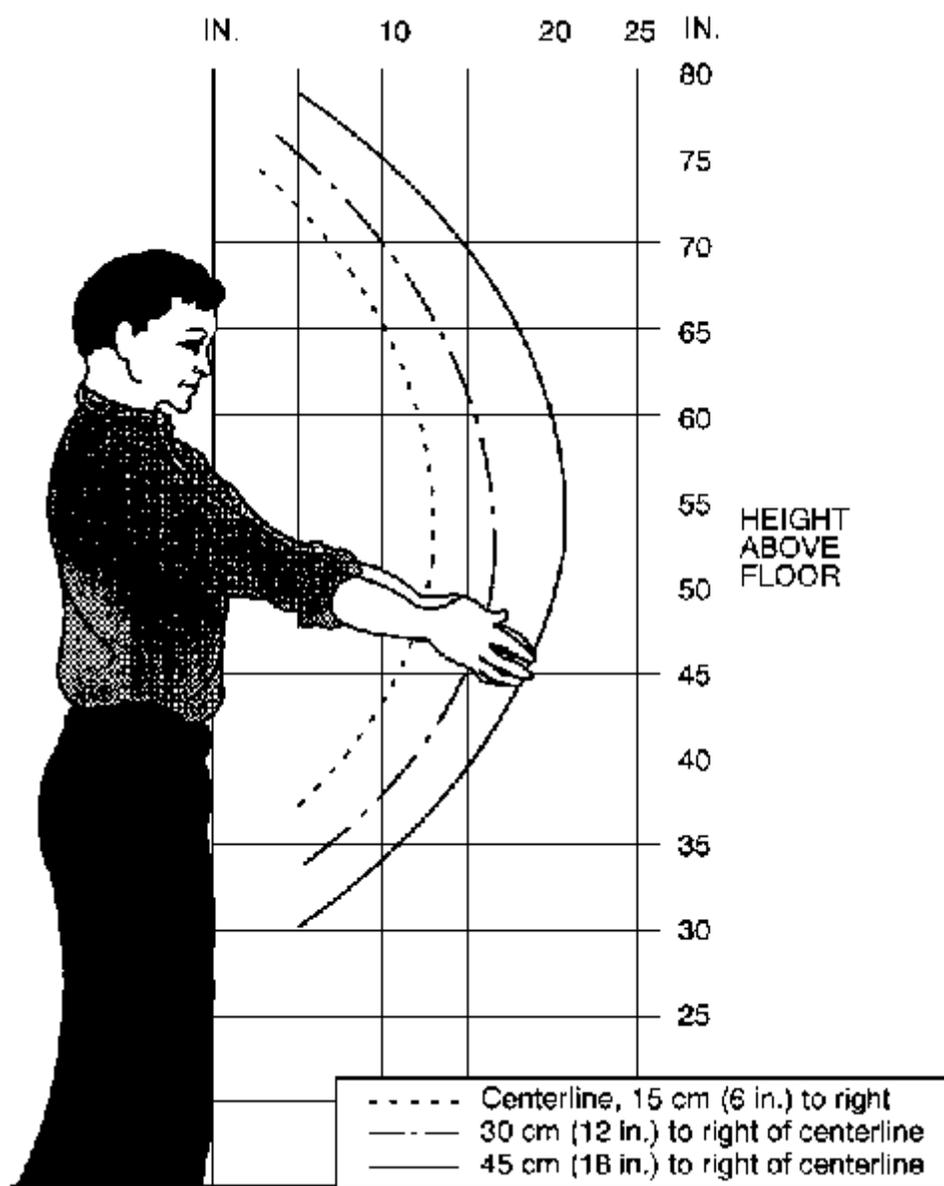
Figure 7-20. Reach envelope of average standing operator.

! **The thermal environment.** Heat may have a tendency to decrease strength (particularly in hot and humid conditions); however, general body mobility and finger dexterity are not significantly affected.

! **Emotional condition.** Strength may increase under conditions of fear or distress; however, skill and accuracy may be degraded. In emergency conditions, for example, an operator may tend to press the wrong control buttons or enter erroneous keyboard data.

! **Body position.** Humans will generally assume an advantageous posture for applying force (lifting, pushing, etc.) when they are unconstrained. A control room environment will not, however, be unconstrained. Operators may pass objects across obstructing work surfaces, pick up heavy objects while they are seated (which leads to frequent muscle strain), or perform other actions that may cause fatigue or strain.

! **Limb position.** Based on the principles of mechanical and vantage and the application of concentric and eccentric force, individuals will try to apply force in a mechanically advantageous way. This effort is hampered by poor design (e.g., crates and boxes without hand grips that must be carried in an awkward way, heavy equipment from a control rack that must be supported while being pulled out for maintenance).

7.3.2 Lifting

Most applications of significant strength in the TMC environment will involve lifting and carrying tasks. Important considerations include: [125]

! The location (accessibility) of the object to be lifted.

! The size and shape of the object.

! The height from and/or to which the object is to be lifted.

! The weight and weight distribution of the object.

! The relation between the object's center of gravity and grasp points.

! Whether the object is lifted by handles.

! Working-position characteristics (e.g., awkward or normal).

! Manipulatory accuracy requirements.

! Frequency and duration of lifting and carrying movements.

! Age, gender, fitness, and body dimensions of persons doing the lifting.

! Experience and training of persons doing the lifting.

Possibly the least efficient load in the modern information processing arsenal is the *boxed large computer monitor*. Components of information systems are packaged for ease of storage and shipment, not for ergonomic acceptability. Such containers are often oversized and without handy grasping points. The usual way of carrying such a load involves grasping the far edges, with the near side pressed against the abdomen. This method places undesirable strain *all at once* on the wrists, fingers, arms, shoulders and, especially, the back muscles, since the center of gravity is shifted well forward of the carrier's unburdened state.

Since the load is also both expensive and fragile, there is also a certain mental stress to be considered. No one, however burdened, wishes to be responsible for damaging an expensive electronic component; the average worker will suffer painful consequences rather than drop the thing or admit physical incapacity.

The packaging engineers have also made alternative strategies difficult. Most such delicate computer components are packed very tightly in form-fitting foam packing inserts. The worker who decides to open the crate and remove the monitor *before* carrying it to its destination often finds that the only way to accomplish this is to put the box on the floor, open the top, and pull the whole foam-packed weight up and out of the container. But many foam-pack liners are divided in such a way that the contents must be removed *as a unit*, foam and all (often a balancing act, since there is a tendency for the foam to detach itself from the monitor only after it is released from the restraints of the cardboard carton.) This task is made even more undesirable because the requirement to grasp the contents firmly assures that maximum strain will be placed on the back muscles.

7.3.3   Carrying

Maximum burdens for tasks that involve carrying objects are calculated not only for weight but also for configuration. The following guidelines cover most situations encountered in the TMC:

7/1 Carrying Packages with Handles   (Recommendation; 125)

When the package has smooth sides (e.g., a suitcase or similar package) and a top-mounted handle, it can be carried against the hip or leg without stress if weight does not exceed 20 kg (45 lb) for males and 18 kg (40 lb) for females.

7/2 Carrying Packages   (Recommendation; 125)

When package surfaces are not smooth (electronic equipment chassis, etc.) limit weight to about 16 kg (35 lb).

An equipment package weighing over 20 kg (45 lb) normally should be carried by two persons using dual handles. Two people should not be required to carry 45 kg (100 lb) more than a short distance.

7.3.4   Pushing and pulling

The act of pushing or pulling an object involves not only the object's weight but also inertia and friction. Table 7-1 shows allowable push and pull forces. [38, 125]

Table 7-1. Horizontal push and pull forces exertable intermittently or for short periods of time (male personnel).

HORIZONTAL FORCE*; AT LEAST	APPLIED WITH	CONDITION (μ: Coefficient of friction)
100N (22.5 lbf) push or pull	Both hands or one shoulder or the back	With low friction 0.2<μ<0.3
200N (45 lbf) push or pull	Both hands or one shoulder or the back	With medium friction μ~0.6
250N (56.2 lbf) push or pull	One hand	If braced against a vertical wall, 51 cm -152 cm (20 in - 60 in) from, and parallel to, the push panel
300N (67.4 lbf) push or pull	Both hands or one shoulder or the back	With high friction μ>0.9
500N (112.4 lbf) push or pull	Both hands or one shoulder or the back	If braced against a vertical wall, 51 cm -178 cm (20 in - 70 in) from, and parallel to, the push panel or if anchoring feet on a perfectly nonslip ground (like a footrest)
750N (168.6 lbf) push or pull	The back	If braced against a vertical wall, 58 cm -110 cm (23 in - 43 in) from, and parallel to, the push panel or if anchoring feet on a perfectly nonslip ground (like a footrest)

CHAPTER 8: DISPLAY DEVICES

CONTENTS

8.1   The Display of Information

The ITS-class advanced traffic management system allows the designer to specify a broad range of sensors and information sources, each of which can provide crucial dynamic information about roadway and resource status. A typical ATMS will collect and make available to operators highly detailed information about some or all of the following:

! Current traffic conditions.	! Current roadway conditions.
! Location of incidents.	! Type/severity of accidents.
! Emergency resources.	! Current/predicted weather.
! Current and future demands.	! Public confidence levels.
! Planned and unplanned events.	! Status of ATMS resources.

As the nerve center of the ATMS, the Traffic Management Center serves as the collection point for information. The TMC computers and operators must interpret this river of data to maintain awareness of traffic and roadway conditions. Then they must make appropriate decisions about how to use available resources to manage traffic, to provide advisory information to the public, to repair or work around malfunctioning components, and to support other agencies such as fire and police.

Without computer assistance, the volume of raw information would overwhelm TMC operators and hamper their performance. With well-designed data analysis software and user-computer interfaces, the operators can maintain a good mental picture of the roadway system.

Maximizing the usability of the information is a major concern of human factors engineers when designing the TMC. The design of information displays, their content and format is discussed in Chapters 11-13, which deal specifically with computer interface issues. In this chapter, we deal with more general display issues.

8.2   Visual displays

The bulk of numerical, spatial and system condition-related information is presented to operators using visual displays. Visual display systems in a modern control center encompass a range of technologies from simple signs to complex digital and screen displays. Care must be taken to select or design display types and formats to meet the requirements of the task. Selection of a visual display mode should be based on three fundamental criteria:

- **!**   The type of information to be displayed (map information, sensor status, VMS messages).

- **!**   The degree of operator interaction (advisory, integrated control, etc.).

- **!**   The workspace conditions (lighting, distances, etc.).

The discussions and guidelines that follow provide criteria for selecting and specifying the configuration of visual displays.

Specifying visual displays requires some understanding of the principles that underlie light and vision. A visual display must meet certain guidelines with respect to the *amount* of light, its *quality*, and the configuration.

This section deals exclusively with the characteristics of visual displays. A general treatment of light in the workspace is found in Chapter 9. Discussions of color and other human/computer interface issues are in Chapter 11.

8.2.1   Pictorial displays

Most TMC's employ large-scale maps, situation boards, and other information displays of significant size, designed to be viewed from a distance. Such designs should be guided by two fundamental considerations: (1) *what information does the user need, and* (2) *how should that information best be presented?* [101]

Big board displays are configured to provide an overview of the highway system map and

infrastructure that can be observed by most or all operators. These displays usually are one of three types:

- ! **Static wall maps.** Often displayed as "wallpaper" maps in the TMC, these are generally less useful than displays that show changes in traffic or system status. Within a fairly short time, most operators master the layout of the highway system under TMC management, and the static map quickly becomes more decorative than informative.

- ! **Dynamic wall maps.** These map displays show changing status information such as traffic volume or signal status by colored lights. These may not be cost effective in small TMC's; however, at larger and more complex facilities where coordination among operators is important, these maps are said to be useful for maintaining situational awareness.

A disadvantage of such displays is that, because of the complex electrical circuits, they are difficult and expensive to produce and maintain. Map changes typically involve cutting a hole in the map, patching it, and drawing in the revisions. These maps are often not updated with changes in the infrastructure. One innovative system in which the roadway map is computer-printed on a matrix of small plastic tiles provides a partial solution. Map changes require only that the outdated tile be popped out of the matrix and an updated tile popped into the empty spot to replace it. This approach is commonly used by the railroad industry in the United States.

- ! **Projection television screens.** These displays are increasing in popularity and have the advantage of being easier to change than fixed dynamic displays. Anything that can appear on a computer or closed-circuit television monitor can be displayed on a projection television monitor. However, limitations in resolution make finer details more difficult to discern. In addition, maintenance and electro-optical adjustment are frequently necessary. [75]

General guidelines. The following approaches are recommended for large-scale displays:

8/1	Amount of Detail	(Observation; 125)

Avoid excessive detail on the large map or status board.
Leave the detail to individual operator displays. Packing in detail usually requires reduction in size of individual characters and symbols, which may be hard to discriminate in a TMC control room environment. This is particularly true for video-projection displays, which at present have an inherently limited resolution.

This recommendation cannot be defined in terms of a single, precise, and prescriptive guideline. What constitutes too much detail will be a function of a number of variables such as range of distances from which data will be read, control room illumination, arrangement of information, and other factors. As a general rule, if there is doubt as to the need for detail on a map or big

board, put the detail on individual displays and reserve the large display for *integration* of status (e.g., keep information that pertains to the traffic flow as a whole on the central map, but place detail for a particular area on the operator's personal display).

8/2 Moving Objects (Principle; 125)

If moving objects are individually displayed on a map, keep the number at a minimum and display only those that move fairly slowly.
In cases where moving objects are displayed, there is information to be gained visually in two cases: if the number of targets is small, they may be tracked individually; when the number is large, only patterns of movement are readily discernible. Rapid movements, particularly numerous independent movements, are very difficult to track.

8/3 Neutral Background Color (Recommendation; 125)

If the display area must have a low ambient illumination in order for individual operator displays to be used effectively, use white or light-colored markings against a dark background for maps and status boards.
TMC's are generally kept at a relatively low level of illumination because of the video and CRT — and particularly video-projection — displays (See Chapter 10 for further discussion of illumination). A large highway map on a white or light-toned board will tend to distract the gaze of operators and may be hard to read when the operator has adapted to lowered light levels.

8/4 Background for Color-Coded Data (Recommendation;125)

If color-coded object information is to be used on the large map display, use a neutral color, such as dark gray, for the map background; this allows the color targets (e.g., map symbols) to have better contrast.
Color interactions in the eye often cause distortion. A bright or saturated background color is almost certain to conflict with a detail color. Flat black or a dark neutral gray are recommended. Care should be taken with projection displays because colors can often be customized with distracting results; in addition, the low luminance of such displays makes contrast critical (see Section 8.2.5).

8/5 Front Projector Position (Principle; 125)

When front projectors are used to project information on a large map

display, the projectors should be positioned so that they do not produce glare on operator workstation displays.

Such projectors are common in TMC's and other control rooms, and are generally effective. A possible mistake is to position the source of the projection before deciding where the operator stations and displays will be placed, resulting in the risk that the light source behind the operators will be reflected in the glass of the CRT screens. This could force the TMC manager to move the operator stations after installation or — more likely — turn off the projector. Video projectors, which convert video or computer display images to projected images, are not as likely to cause problems since they are generally mounted no more than three meters from the display screen, probably between the operators and the display. Rear-projected displays are an attractive alternative although they require substantially more space.

8/6	**Viewing Distance**	**(Principle; 125)**

Determine and provide the proper alphanumeric and/or symbol sizes on the large-screen displays in terms of the maximum viewing distances at which each set of characters and symbols must be read (see Section 8.2.2).

8/7	**Coding Rapidly Changing Data**	**(Observation)**

Use clear coding techniques to help operators easily discriminate between rapidly changing data versus slowly changing data.

Incident management information is typically refreshed at an interval of 5 to 10 minutes, while real-time status on system and traffic information through automated sources may be refreshed every two seconds. The coding system used to describe traffic or system status should draw the eye toward a new value or condition. The more critical the new information, the more eye-catching the code should be (e.g., a flashing light or, redundant coding such as flashing light and audible tone).

8/8	**Map Orientation**	**(Observation)**

Orient maps with north at the top.

There is a temptation to rotate maps of highway sections that run north to south in such a way as to make the best use of available wall space. This creates a confusing display, since most operators will tend to see the map as directionally skewed; this distortion will conflict with internal, map-oriented configurations.

Color coding. Color coding, particularly in combination with other techniques, can be helpful in providing the "big picture" for operators. In dynamic situation maps, color codes may be applied to critical sections of roadway in response to sensor input and other sources of information about traffic conditions. Local emergencies — accidents, blockages, malfunctioning signals, the start of a queue, etc. — may be indicated by visually attractive points (e.g., flashing lights). Such options are expensive and difficult to maintain for hard-wired dynamic displays, but are worth considering when the main display is projected from a computer-generated source.

8/9   Color Coding Practices   (Principle; 38)

Color codes should agree with commonly accepted practices. Typical guidelines are presented in MIL-STD-1472:

- ❗ **Flashing red   Emergency**
- ❗ **Red   Alert**
- ❗ **Yellow   Caution, recheck**
- ❗ **Green   Safe, go ahead**
- ❗ **White   Used when there is no right or wrong entry or condition**
- ❗ **Blue   Can be used to denote advisory, but preferential use should be avoided**

Arbitrary use of color can degrade visual processing and hence operator performance. Search time increases if other items differ only slightly in color (e.g., a yellow light among orange lights). Fewer errors will occur in counting tasks if items counted are the same color.

Closed-circuit TV displays. Some TMC's use an array of Closed Circuit Television (CCTV) monitors that display selected areas of highway which also have loop detectors. Loop detector occupancy data might suggest congestion at a particular location and display this on a dynamic big board. Operators could then inspect the appropriate CCTV view to verify the situation and obtain a better understanding of the state of traffic and any required response.

Experience at TMC's indicates, however, that operators tend to become overly dependent on CCTV displays, probably because of the natural presentation of information and the potential for detecting a traffic flow problem marginally earlier than would be likely with sensors alone. Over dependence on CCTV for incident and congestion detection can create a significantly higher workload than a well-designed graphics display that summarizes, for example, loop detector data. While no definitive guidelines are presently available, it would seem prudent to limit the number of monitors in use. [75]

A second problem with large CCTV wall displays arises when there are more cameras than monitors. Some TMC's use a salvo procedure in which groups of CCTV viewpoints occupy

the displays on a timed basis. A problem associated with this practice is the difficulty in recognizing at a glance the locations of the views currently being displayed. One aid to the operator is the use of location information superimposed on the video image (though contrast between such data display and the unpredictable background of the TV image should be considered (See Section 8.2.5 on contrast).

Finally, it is difficult — particularly with cameras remotely adjustable for pan and tilt — for the operator to tell at a glance which direction the camera is pointing. Time may be lost in critical situations as the operator attempts to orient the view and map it to the actual highway directions.

8/10 Camera Location **(Observation; 75)**

The name of the geographic location of the camera should be superimposed over the image on the monitor screen.
Or, for dedicated monitors, the name may be placed in a consistent location (e.g., above the screen).

WHICH CAMERA IS THAT?

A TMC control room frequently includes a bank of monitors displaying traffic conditions under observation by CCTV cameras. One such center had two large arrays of this type, but no monitors were labeled — typically, the operators had simply memorized the locations. In another center, the monitors had been labeled with 2 cm (0.75 in) marker tape. Because these characters were not visible from normal operating distances, they had been supplemented by a paper label taped on each monitor frame.

8/11 Camera Pointing Angle **(Observation; 75)**

The display at the operator's station should indicate the direction of view of each camera.
A rotating camera icon superimposed on the graphics display or a text display of the camera's compass pointing angle (i.e., N, NE, E, SE, S, SW, W, or NW) might be suitable.

8/12 Consistent Camera Location **(Observation)**

Consider using a consistent rule for camera location.
One TMC, for example, places all of its cameras on the south side of the

roadway.

8/13 Preset Pointing Angles   **(Observation)**

Specify control systems that have preset pointing angles.
Systems are available that can program the camera to turn to several selected positions. The operator can command, for example, "Central Street West" and the camera will realign itself to that angle from its previous viewing position. Such presets allow more efficient camera control. If they are used, though, the operator still needs the ability for fine control of the camera after it reaches its programmed position.

8/14 Multiple Camera Operators   **(Observation)**

Where cameras and monitors are controlled by more than one operator, develop procedures to give override authority to the operator whose task has the highest priority (e.g., an operator who has just received an incident alert in the given location).

8.2.2 Alphanumeric characters, words, and numbers

Much of the information on visual displays is composed of alphanumeric characters. Many of the display deficiencies in control centers are the result of poorly planned use of characters, in particular failure to provide for three essential dimensions: [101]

- ! **Visibility.** The quality of a character or symbol that makes it separately discriminable from its surroundings.

- ! **Legibility.** The attribute of an alphanumeric character that makes it possible for each symbol to be recognized.

- ! **Readability.** The quality that makes possible the recognition of the information content of material.

Character size. The determination of character size on pictorial displays is critical, and interacts with distance of observer from the display, character style, color and contrast.

To be legible, minimum character size should be 16 min of arc, and a maximum character size should be 24 min of arc.
The preferred size is 20 to 22 min. The maximum reflects the limits of the eye; the central area of vision imposed by the *fovea* of the eye is too small to read large text efficiently because too few letters can be recognized on one eye fixation.

Reducing this to more familiar terms: 22 min of visual arc is equivalent to a printed type face of 12 *points* in height (this handbook is printed in 12 point type), the designation generally used by printers and word processors, when viewed at normal reading distances. A point is approximately 0.35 mm (exactly 1/72 in). The point has no commonly used metric equivalent. A face of 10 to 12 points is preferred for readability at distances of 30 to 40 cm (12 to 16 in).

To compute a given character height use the following formula:

$$h = 2dTan\left(\frac{x}{2}\right)$$
Eq. 1

where h is the character height, d is viewing distance, and x is the desired angle subtended in radians. One radian equals 3437.747 arc minutes, or 57.296 arc degrees. Table 8-1 shows selected preferred character heights (21 arc min) for selected near viewing distances. Figure 8-1 shows recommended character heights (21 arc min) for viewing at long distances.

Table 8-1. Viewing distance, character size, and readability.

| Viewing Distance		Character Height	
mm	**in**	**mm**	**in**
400	15.6	2.4	0.10
500	19.5	3.1	0.12
600	23.4	3.7	0.14
700	27.3	4.3	0.17
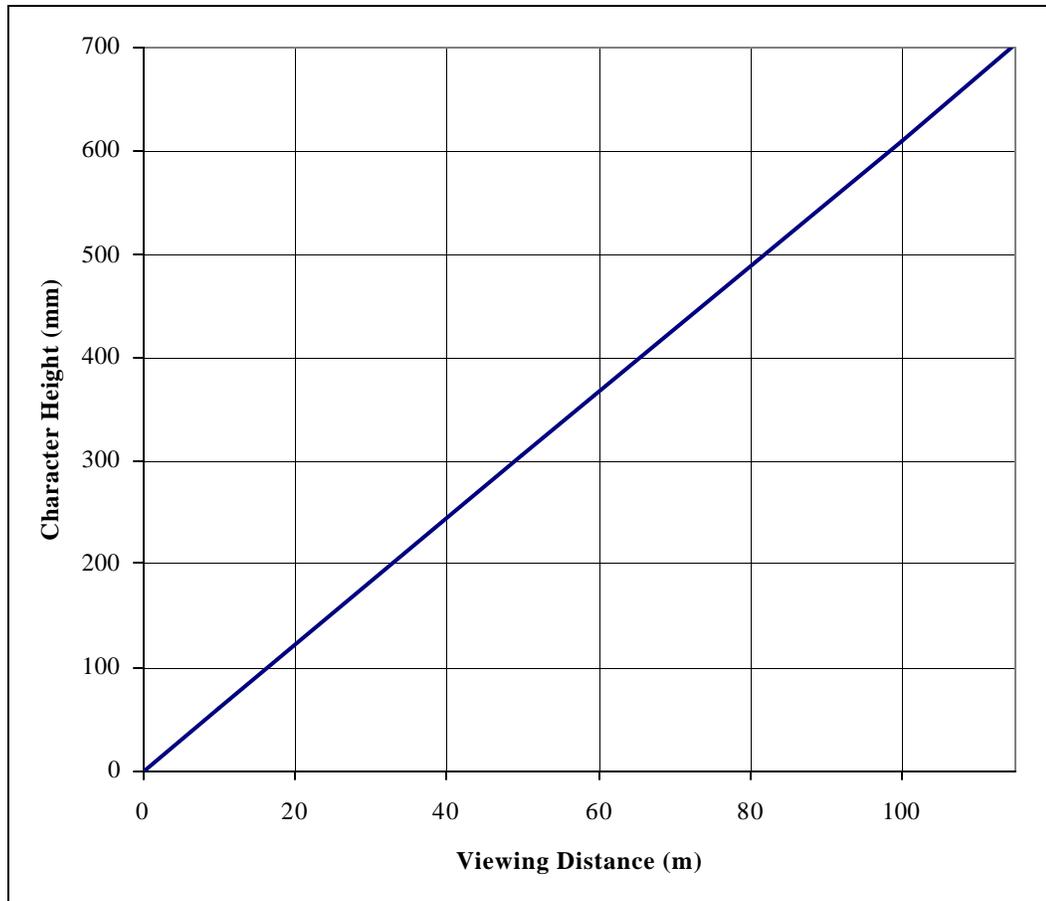
Figure 8-1. Recommended character height for longer viewing distances

Character style. The design style of alphanumeric characters also has an effect on legibility and readability. The wide range of typefaces now available at the touch of a keystroke has made this problem a critical one.

Figure 8-2 gives examples of the relationship between legibility/readability and such factors as stroke width, height to width ratio, and letter, word and line spacing. In many cases, these variables are driven by the defaults of a display. Newer computer systems, however, allow the operator to vary these factors, along with font and color arrangement.

ATMS

STROKE WIDTH
- UNIFORM
- A:B = 1:6 FOR DARK ON LIGHT
- A:B = 1:7 FOR LIGHT ON DARK

ATMS

HEIGHT TO WIDTH RATIO:
- A:B = 5.3 TO 3.2

ATMS

LETTER SPACING:
- A = B + B/2

ATMS DESIGN

WORD SPACING
- A = B x 3 + B/2

ATMS DESIGN

LINE SPACING (LEADING)
- A = B/3 (UPPER CASE)
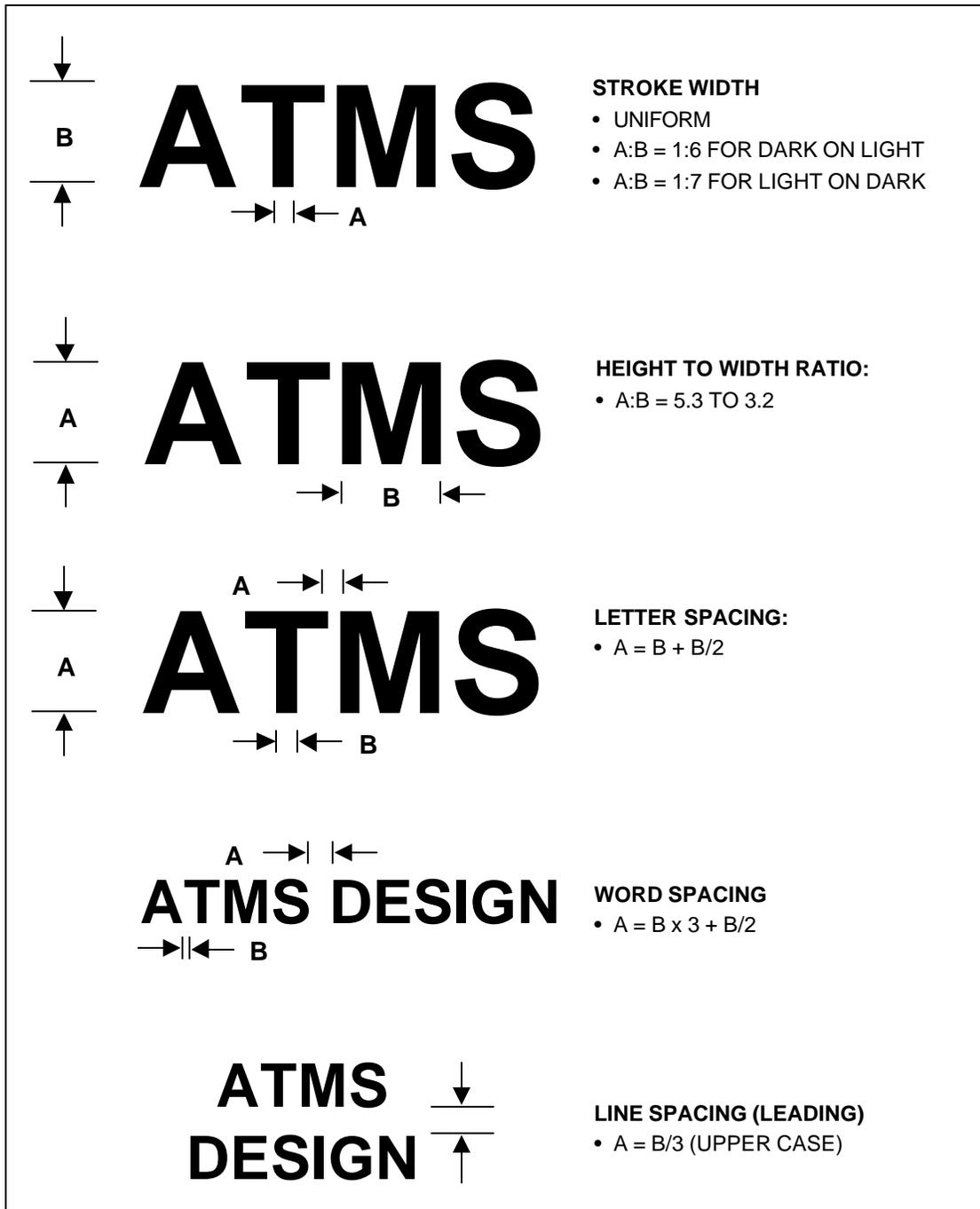
Figure 8-2. Recommended character and word dimensions.

In addition, large fixed displays (such as maps and the labels for monitors in an array) require design decisions with respect to character size and arrangement.

The shape of characters — font and other considerations — and their effect on legibility and readability have been studied extensively. The problems in this area of design have been increasing with the variety of font choices. Powerful graphic and word processing packages,

combined with laser printers, have provided the designer with a wide selection of confusing typefaces and the temptation to explore inconsistent applications.

Most printed text material uses a Roman-style serif face. This style is very legible and readable, and provides high discrimination between characters. In addition, its wide use has made us comfortable with the Roman "look." But this style is as "fancy" as good design permits. For signs and large displays, simple sans-serif fonts (such as Helvetica, Swiss, or Arial) are acceptable. Table 8-2 shows some undesirable styles.

8/16 Typeface Characteristics   (Principle; 125)

Avoid typefaces with these characteristics:

- ! **Letters with extended height-width ratios.**
- ! **Odd or stylized shapes, which are easily confused.**
- ! **Excessive stroke width or widely different stroke widths.**
- ! **Script faces.**
- ! **Excessive slope.**
- ! **Large serifs.**

Readability. Readability is improved by the following measures:

8/17 Text Reading Level   (Observation)

Design text to be easily read and understood by the least educated staff member.
Generally, for high school graduates, a sixth to eighth grade reading level is recommended. This is about the level of a general circulation newspaper. In general, a lower reading level is achieved by using shorter, more common words and shorter and less complex sentences. For reading during high workload and emergency situations, the lower the reading level, the better.

Table 8-2. Undesired type styles.

	Undesirable Type Styles	
a	ATMS	VERTICALLY EXTENDED CHARACTERISTICS
b	A TMS	ODD SHAPES, EASILY CONFUSED;EXCESSIVE STROKE WIDTHS
c	ATMS	SCRIPT, EXCESSIVE SLOPE, WIDELY DIFFERENT STROKE WIDTHS
d	ATMS	ILLEGIBLE SCRIPT
e	*ATMS*	ITALIC
f	ATMS	LARGE SERIFS
g	A T M S	STYLIZED KERNING
h	ATMS	LARGE SERIFS

8/18 Common Language   **(Principle; 125)**

Use common language terms on displays and user aids.
Jargon and acronyms are often hard to avoid, but the effort is usually well spent. For inexperienced staff members with limited detailed technical knowledge, jargon-filled messages may be meaningless or misleading.

8/19 Whole Words   **(Principle; 125)**

Use whole words rather than abbreviations.
Space is sometimes at a premium in displays, and there is a natural tendency to save it by using abbreviated forms. Consider the possible errors and confusion that could result if the abbreviation is not universally understood.

8/20 Instrument Labels	**(Principle; 125)**

To identify an instrument or graphical data presentation, use terms that indicate what the instrument *measures*.
For example, "Temperature: EC" rather than "Thermometer."

8/21 Homonyms	**(Principle; 125)**

Avoid words that have multiple meanings or might be interpreted as verbs or nouns in different contexts.
For example, "file" might refer to a record or to the action of filing information as a record. "Save" better conveys the intended meaning of the latter.

8/22 Letter Case	**(Principle; 125)**

Use capital letters for labels and short instructions. Where full sentences and punctuation are used, employ mixed upper and lower case.
Mixed upper and lower case is significantly easier to read when phrases are assembled in sentences and paragraphs.

8/23 Make Instructions Brief	**(Principle; 125)**

Make instructions as brief as possible while preserving clarity.
To improve readability, use short, common words and arrange them in simply constructed sentences averaging between 10 and 12 words in length.

8/24 Confusing Alphanumeric Symbols	**(Principle; 125)**

Avoid using alphanumeric symbols that can be misinterpreted.
For example, "I" and "1" can be an easily confused pair.

8/25 Character Orientation   (Principle; 125)

Characters should be oriented left-to-right, not around corners, on the side, or up and down.
For example, a display data field or window on a Video Display Unit might preserve active data space by labeling the window vertically down one side. It is more difficult, though, to read such labels, particularly if the letters are not rotated.

8/26 Manufacturers' Labels   (Principle; 125)

Manufacturer brand-name label should not overshadow the primary display labels.
Delete or cover manufacturers' brand names on visible parts of equipment to avoid visual clutter and distraction.

8/27 Consistent Label Positions   (Principle; 125)

Place identification labels for controls and displays in a consistent position (e.g., above the component).
This is particularly important on control consoles where controls and displays are densely arranged. Mistakes are extremely easy to make, for example, in an array of push buttons, a configuration common in older TMC's.

8/28 Adjacent Labels   (Principle; 125)

Allow sufficient space to avoid running adjacent labels together. This often occurs in older TMC's that use push button arrays.

8/29 Size or Color Code   **(Principle; 125)**

Use size coding and/or color coding to help the operator differentiate between levels of importance.
A malfunctioning signal controller may be more urgent than a malfunctioning loop detector and, if so, this difference should be indicated by a difference in color or size of the associated icon on the screen.

8/30 Resistance to Damage   **(Principle; 125)**

All labels should be as permanent as possible for resistance to damage and wear.
This is particularly important for labels that will be touched by operators' fingers on a regular basis, such as labeled buttons and entry keys. In particular, labels that have painted or dry-transfer characters are likely to wear excessively. If possible, labels should be engraved.

8.2.3 Segmented and matrix displays

Many instruments use segmented LED numeric displays, because of their simplicity, to indicate changing quantitative status. More complicated matrix displays are generally reserved for large alphanumeric displays that carry changing information (e.g., Variable Message Signs). Such digital displays have limitations imposed by their lack of visual continuity in individual letters.

Resolution, construction, selection. Matrix or segmented units are easily reconfigured and relatively inexpensive. Variable message signs, for example, almost invariably use matrix screens to display their information. The matrix provides adequate contrast and visibility for letters and numbers provided that matrix density is high enough (e.g., a 5×7 matrix may be difficult to read rapidly).

The matrix display is usually preferred if both letters and numbers are to be displayed, since the discrimination of letters relies heavily on curved components. Ten numeric characters can be differentiated adequately in a relatively low-resolution display (such as the segmented LCD displays on hand calculators). But displaying alphanumeric characters requires differentiation among at least 36 forms, beyond the range of simple segment configurations (which cannot, for example, distinguish between 5 and S, D and 0).

Higher resolution matrices are required if easy readability is critical (as in the highway variable message sign, because drivers should not be required to fixate on messages more than briefly).

8/31 Segmented Characters for Numbers   **(Principle; 125)**

Segmented characters are adequate when only numeric information is displayed.

8/32 Matrix Characters for Alphanumerics   (Principle; 125)

Matrix characters may be used for alphanumeric (words and numbers) displays. Higher-resolution matrices should be used for displays that require high readability.
Matrix or other digital displays have limited capacity to present the features that allow us to differentiate characters. Remember, for example, that VMS displays with small matrices tempt drivers to stare at a hard-to-read message instead of the road.

Standards for resolution. MIL-STD-1472D provides detailed guidance for determining minimum resolution for matrix displays. [38] The limits are summarized in Table 8-3.

Table 8-3. Standards for segmented and matrix displays. [38]

Segmented Displays		Dot Matrix Displays	
Character Type	Recommended Use	Character Type	Recommended Use
7 Segments	Numerical Information Only	5 x 7 Matrix	Minimally Acceptable
14 Segments	Preferred for General Applications	7 x 9 Matrix	Preferred
		8 x 11 Matrix	Minimum if symbols are Rotated
16 Segments	Preferred for General Applications	15 x 21 Matrix	Preferred if Symbols are Rotated

8.2.4   Visual alerting and warning displays

Coding of information for visual displays should support the operator's ability to differentiate between routine information and information that requires immediate attention.

Emphasize the following kinds of information with visual and/or auditory coding.
- ❗ **Critical information.** This must be considered with some care. Indication of a marginal or failed road sensor, for example, might not require immediate operator action; information relevant to an accident or highway safety condition usually will require immediate action. The coding system should differentiate between "action required at some point" and "take immediate action."
- ❗ **Unusual values.** Such output often indicates system malfunctions or other uncommon conditions.
- ❗ **Changed items.** Actions are most frequently required when a status *changes*, not when it is static. Special attention should always go to the design of change indicators, particularly if TMC experience shows such changes to be operationally significant. *Designers from outside the TMC environment cannot be expected to know these priorities.* Remember also that no two TMC's — or the traffic systems they manage — are alike. A display system that is perfectly satisfactory in Anaheim may not be the best for New York.
- ❗ **Items to be changed.** When dealing with a special situation, an operator may set some system specifications to special values or protocols (for example, defining a "greenway" for fast throughput of emergency vehicles or a temporary change of a VMS status); the operator may benefit from a reminder if there is a natural way of sensing that a change is needed.
- ❗ **High priority messages.** Information relating to accidents, traffic blockage, impending weather, the imminent raising of a drawbridge, police alerts and other messages must not be allowed to go into a queue with routine information. Many serious errors have historically occurred because urgent information was not highlighted.
- ❗ **Special areas of display.** The location of traffic congestion might, for example, be highlighted or color-coded or indicated with a blinking signal.
- ❗ **Errors in entry.** This is particularly important in computer interface, but may occur in more traditional controls and displays as well. If activation of a procedure requires depression of push buttons in a sequence, for example, there should be some ready indication if an improper sequence has been entered ("You have dialed the wrong number . . .").
- ❗ **Critical operator command entries.** If an operator command must be received by the system to cause a necessary event to occur (such as removing or changing a VMS message when it has become obsolete), the advisory signal should be readily discriminable from the background.
- ❗ **Targets.** [88] A target is a variable object of small size (e.g., an LED indicator) that must be visually discriminated from the background. A flashing LED on the big board that indicates possible congestion should, for example, be readily detectable against the other visual clutter.

The overriding consideration in visual alerting is that the display element should be significantly easier to detect than its background, [85] and should conform to commonly accepted practice. [4, 109, 113] This requirement is supported by the following guidelines:

8/34 Warning Light Visibility   **(Principle; 125)**

Warning or alert lights should be visible from the widest possible viewing angles.
Warning or alert lights should not be recessed in panels. A recessed light will be hard to see except from directly in front of the display.

8/35 Systematic Use of Color   **(Recommendation; 113)**

Use color systematically to highlight information and promote understanding. Arbitrary use of colors can degrade these effects. The modern computer system can produce far more colors than can be used with any reliable discrimination by the user, and it is too easy to "customize" a display into a confusing demonstration of computer capabilities instead of highlighting vital information. Use of color should always be to highlight information, not to create distracting decoration.

8/36 Blinking Lights Draw Attention   **(Recommendation; 38)**

Blinking or flashing lights can be used to draw attention to a warning. Use the following rules:

- ! **Use no more than two different blink rates; recommended: one at 3-5 Hz, one at less than 2 Hz.**
  Operators will not be able to differentiate readily between more than two flashing signals if the purpose is to attract attention.

- ! **Time ON should be greater than or equal to time OFF.**
  A 50 percent ON/50 percent OFF cycle is preferred.

- ! **Use blinking/flashing lights for alarms and for target detection in a high density display (such as malfunctioning signals on a wall map).** [18]
  In displays where information is displayed as dense arrays of points, a blinking light will be far more detectable than a different color, unless the color of the points is very uniform and contrasts with the target point.

- ! **Do not use blinking/flashing targets on long-persistence phosphor displays.** [18] A phosphor that is slow to fade will tend to add a ramp-down intensity function that defeats the purpose of the ON/OFF contrast.

8.2.5 Video displays

This section covers *physical* characteristics of video displays; human/ system integration questions that relate to the software interface are covered in Chapter 12.

Display screen visual characteristics. The term *video display* is used to describe the type of CRT used in desktop computers, work stations, and similar configurations. Most contemporary video displays are capable of color display and are of high resolution. The critical characteristics of the visible display itself are luminance and contrast.

Luminance is a measure of the amount of light emitted from a surface generally measured by a photometer. [106] The common term **brightness** is *not* quite equivalent to luminance. Brightness is the observer's *perception* of luminance.

Luminance is generally expressed in the metric term *candelas per square meter* (cd/m^2), and this measure will be used here in preference to the English equivalent *foot-Lambert* (fl). The unit cd/m^2 is formally defined as a luminous intensity from a point source of light equivalent to one candela reflected from a spherical surface with an area of one square meter. In practice, this parameter is simply expressed as a reading on a light meter or *photometer*.

8/37 Video Display Brightness   **(Recommendation, 4)**

A video display's brightest area should have a luminance of no less than 35 cd/m^2 (10 fL).
This should be *specified* before purchasing equipment.

Contrast ratio (C_R) is sometimes specified. It is the ratio of the higher luminance to the lower. As a consequence, it has no units of measure. Contrast ratio has been specified in a number of guidelines for Chapters 10 and 11.

8/38 Contrast Ratio   **(Recommendation)**

Contrast ratio between character and background on a video display should be no less than 3:1.

Color. The *color* of a stimulus consists of three dimensions:

!   *Hue* is the wavelength composition of a visual element within the visible spectrum. Different wavelengths correspond to different "colors." Hue is the characteristic we usually intend to communicate when we use the term "color" in a conversational sense.

In most color video displays, hue is produced by the summation of differing intensities of three primary colors (red/green/blue) at a given location.

! *Saturation* is the measure of *wavelength purity*. A saturated blue, for example, will appear intensely blue to the eye; as saturation decreases, the apparent color will begin to "gray out" until it reaches minimum saturation, at which point it will appear as a neutral gray.

! *Brightness* is the effective luminance of the visual element. The combination of hue and saturation is called *chromaticity*. (A helpful way to think of this is that chromaticity refers to the frequency or frequency spectrum of the light, while the brightness refers to the amplitude.)

Color offers a significant advantage over monochrome displays. Color can add clarity to location, association, grouping, coding, and image memory; it can highlight, segregate, imply physical characteristics, and aid learning. [113]

Research suggests that color may be used effectively for visual coding, particularly if the task involves searching for an item, grouping items, or tracking a moving object. Search time for a visual target increases if color differences are slight, or if the number of items similar in color to the target increases. Few errors occur in counting tasks if the items counted are the same color. [113]

Redundant coding (using color in addition to blinking, font, or other measures) can be more effective than a single code. Redundant coding also supports color-deficient operators, who, for example, may not distinguish between red and green, but will recognize other redundant codes. [38, 109, 110]

8/39 Color Discriminability   **(Principle; 4)**

When color is used for discriminability or to alert the operator, colors should differ significantly from each other.
All colors should differ from each other by at least 40 delta-E (CIELuv) distances (a reference to the 1976 CIE (*Commission Internationale de l'Eclairage*) color space). For design purposes it is probably sufficient to use colors that do not appear similar to a trained operator (avoid discriminating between similar colors such as red and orange, for example, or between blue and cyan). Where this appears to be a critical design issue, knowledgeable engineers with specialized measuring equipment should be consulted.

8/40 Number of Codes   **(Principle; 109)**

No more than six colors should be used to for coding on information displays.
Suggested are: white, red, green, yellow (amber), magenta (purple), cyan (aqua) on black, gray, blue, or brown background for shading. Use the smallest number of colors possible. This may become a difficult design issue for large situation displays in the TMC. If more than six colors must be used, expect performance declines on search, identification and coding tasks.

8/41 Size and Color Interaction   **(Recommendation; 67)**

Size of the symbol on the screen interacts with color identification. For small targets, use warm colors.
For symbols of less than 2 deg visual angle, "warm" colors (red, orange) are more readily detectable than "cool" colors (blue, purple).

8/42 Color Contrast for Readability   **(Recommendation)**

When color contrast is being used to enhance readability and absolute color identification is not required, text and background should differ significantly in brightness.
Avoid color combinations that provide poor contrast. The eye discriminates shape boundaries by brightness contrast, not color difference. Green letters on a red background of the same brightness, for example, will be almost unreadable. The good color combination if color must be used is yellow on blue (when saturated they have a strong luminance contrast).

8/43 Avoid Red/Blue Combinations   **(Recommendations; 4)**

Avoid using red and blue together on a dark background.
This combination may result in a visually disturbing effect called *chromostereopsis*, which causes the red and blue areas to appear at different depths (this is most evident when the colors are very bright against the dark background). It sometimes occurs with green and red as well. This effect could be distracting in a large projected display, creating an undesirable illusion of depth.

8/44 Blue on Dark Background   **(Principle; 4, 39, 109)**

Avoid using blue on a dark background for text or fine details.
There are three reasons: (a) blue phosphor has low luminance, (b) a blue image is likely to be focused in front of the retina because of the optical characteristics of the eye, and (c) the retina has comparatively few blue-sensitive receptors. One map display on a large screen and high-resolution CRT showed streets and street names in blue on a black background. The result was very difficult to read.

8/45 Color Code Important Dimensions   **(Observation)**

For monitoring or search tasks in which there are non-redundant coding of two or more dimensions, color code the most important dimension.
Where, for example, color is used to display one dimension (e.g., operational status) and shape is used to display another (e.g., sensor type) the color coding enhances discrimination of the color coded dimension but may interfere with the discrimination of shape.

8/46 Contrasting Brightness   **(Recommendation)**

Foreground and background colors should have different brightness if shape discrimination is important.
Icons or characters of blue or green on a red background will be very problematic if they are of similar luminance. The eye distinguishes shapes much more effectively by contours of differing brightness (contrast) than by differences of hue alone. TMC's frequently employ screen formats that can be "customized" for color in the foreground and background, between windows, etc. Poor color choices that lack brightness contrast may increase errors.

Glare Most video displays will produce glare if external light sources (windows, light fixtures, other displays) are located where they can reflect off of the screen. Glare can cause distraction

and eye strain for a variety of reasons, the most important being the masking of the actual video display image and that the reflected light is at a focal distance from the eye different from that of the screen. Glare can cause:

- **!** Distraction (the human eye tends to be attracted to bright sources).

- **!** Reduction of contrast between characters and background which affects readability.

- **!** Shifts in convergence because specular reflections are responded to as if they are the screen.

- **!** For bright reflections, accommodation shifts may hinder reading (The lens of the eye will shape itself to focus on the optically distant reflection, causing blurring of the desired image and eye strain).

- **!** Annoyance.

The types of glare that may be produced depend on the *type* of video display screen. A screen with a shiny or *specular* surface produces a mirror-like image. This style will produce no glare at all if there is no light source placed to reflect an image into the eye. If there is such a source, the glare will be distinct and distracting. A video display screen that uses a crazed or satiny outer surface (to reduce specular glare) will produce a *diffuse* veiling luminance that may wash out the contrast and sharpness of the image.

The most important measure for eliminating glare is to *design the work space to avoid extraneous light sources.* In general, lighting fixtures (luminaires) will be set well above the line of sight for operators of computers or work stations, but on occasion sources of reflection will creep in from subtle sources (desk lamps or exit signs, for example).

In general, glare problems are more common in TMC's that were established in environments designed originally for other purposes (office space, data processing centers, etc.). Windows are a common source of distraction in these facilities, but much of the trouble is actually incidental: desk lamps, exit signs, and cross-illuminating glare from adjacent units. Many such sources of glare can be solved by rearrangement of light sources.

Characteristics of the video display itself that may reduce glare include:

- **!** **Etching or frosting.** Many monitors are provided with this feature, which reduces specular reflections. However, it does not reduce *diffuse* reflection, and may cause some perceived blur and loss of contrast. [67, 101]

- **!** **Quarter-wave thin-film coatings.** These reduce both diffuse and specular reflections by as much as 90 percent; however, they are somewhat delicate, and show fingerprints and scratches. They do not reduce veiling reflections. [6, 67, 101]

! **Circular polarizers.** Act as neutral-density filters, but generally have highly reflective front surfaces, and thus are susceptible to specular reflection problems. [67, 101]

! **Neutral density filter.** This measure reduces the amount of light that passes through it without changing the color; since the brightness of the characters is reduced less than that of the reflection, the intended screen image stands out more clearly. However, the filter itself, unless treated, can be a source of specular reflection. [6, 67, 101]

! **Micro-mesh screens.** These resemble a black nylon stocking, and allow only light traveling perpendicular to the screen surface to pass through, eliminating most reflected room light. If the screen is not viewed head on, however, display brightness is reduced, making this alternative unsatisfactory for display that must be observed from off-axis locations. In addition, the mesh tends to collect dirt. [6,,67, 101]

! **Hoods.** This measure is generally used in industrial settings. The shadowing annoyance of hoods generally outweighs the possible benefits. [4, 67]

Research indicates that operators prefer treated screens (quarter-wave, mesh, etched) to untreated, but show no preference among treatment types. [98]

8/47 Video Display Glare Filters (Principle; 125)

The following should guide choice of optical filters:
! **If a filter is to be used, the neutral-density type is preferred because it minimizes distortion of color.**
! **If ambient lighting is low (dim-out conditions) and there is a reflection problem, use a circularized polarized filter.**

Above all, remove *sources* of glare in the arrangement of the work space. No filtering measure can match the effects of a good initial design that minimizes glare sources. This can be assessed most economically in the mockup stage, where light sources can be pinpointed and shifted in the design instead of physically reinstalled. Window blinds should be considered for outside windows. Operators should be encouraged to wear dark-colored clothing to reduce reflected light.

Display placement. Many problems can be avoided if the video display is properly positioned for the operator.

8/48 Video Display Viewing Distance (Principle; 38, 125)

Viewing distance for a 30 cm to 48 cm (12 to 19 in) video display should be 46 cm to 61 cm (18 to 24 in).

8/49 Large Screen Viewing Distance	(Recommendation; 38)

Large screen viewing distance should not be closer than one-half the width or height of screen (whichever is greater).

8/50 Video Display Viewing Angle	(Principle; 38,125)

Viewing angle should be within a 30 deg rectangle in the horizontal and vertical directions; that is, 15 deg left, right, above, or below line of sight. The best position is directly in front of the operator, with the display at eye level or slightly below. The operator's line of sight should be no more than 15 deg below horizontal.

Display control. Most displays have adjustment controls for position and for image quality (brightness, contrast, etc.). In general:

8/51 Video Display Control Location	(Principle; 125)

Adjustment controls should be located on the front of the video display. Avoid monitors that require the operator to reach around the structure to adjust brightness, contrast, and color; such adjustments should be made when the operator's head is in the normal work position.

8/52 Video Display Control Visibility	(Principle; 18)

All controls should be easily visible, available, and labeled.

8/53 Video Display Adjustability	

Video displays should be able to be adjusted for the comfort of the individual operator. The unit should tilt 15-20 deg backward and 10 deg forward.
This guideline presumes that the work surface and other variables (See Chapter on workspace) are configured correctly.

8.3   Auditory Displays

The term *display* commonly refers to visual presentation. However, much sensory information is transmitted using other modalities such as touch, taste and smell. The most common is sound. Auditory information may be in the form of voice communications, auditory alarms, auditory feedback to computer keyboard commands, and auditory status information. As a display modality, sound has unique advantages and unique limitations. For instance, an auditory display can often attract attention before a visual display. However, the location of an auditory display may be more difficult to identify.

8.3.1   Display types and selection criteria

Use the following selection guidelines for auditory displays:

For choosing medium of communication:

8/54 Public Address System Applications	(Recommendation; 125)

Use PA systems for nonspecific emergency announcements for all diversely located listeners. Do not use for routine messages intended for one individual if the announcement may interfere with localized communication.
The PA message should be audible in all TMC areas, including store rooms, kitchen, and rest rooms.

8/55 Intercom System Applications	(Recommendation; 125)

Use intercoms for small group-specific, two-way communication and/or for individual communication between people who are physically isolated from one another, where telephone dialing would create a considerable waste of time. Do not use where conversational privacy is necessary.

8/56 Telephone Applications	(Recommendation; 125)

Use telephones for situations requiring individual conversational privacy.

8/57 Two-Way Radio Applications	(Recommendations; 125)

Use radio for situations where long distances between conversants and/or when one or more of the conversants is moving from one location to another.

If more privacy is desired, cellular telephone should be considered.

For choosing type of communication interface:

8/58 Handset	**(Recommendation; 125)**

Use a telephone handset when at least one hand can always be free to hold the handset.

8/59 Headset	**(Recommendation; 125)**

Use a headset (earphone or earphones and microphone) when both hands are often occupied.

8/60 Wireless Microphone	**(Recommendation; 125)**

Use a wireless microphone when a fixed microphone, or hand-held microphone with cable, would restrict needed movement.

8.3.2   Signal selection

The TMC will generally use auditory signals (other than speech) for warnings. Such signals are extremely useful because they are from a different *modality*, and contrast with the flood of visual information the operator deals with in the course of a shift. Signals of this type might range from the beep commonly used to alert the operator to an incorrect keystroke to an alarm calling attention to a failing system. For selecting a *signal type*, the designer should consider the function of the display. Table 8-4 was taken from the current military standard, MIL-STD-1472D. [38]

Table 8-5 provides guidance for selection of specific tones.

8.3.3 Signal errors

8/61 False Alarms   **(Recommendation; 38)**

Minimize auditory false alarms.

The normal channel of information in the TMC is visual; an auditory warning (such as an advisory of subsystem failure) requires the operator to shift to an entirely different modality (looking to listening), and frequent false alarms will make the operator less likely to respond quickly.

8/62 Missed Auditory Signals   **(Recommendations; 38)**

Design auditory warnings to minimize missed signals.

This is the "miss" that is the complement to a false alarm. Both these failures contribute to a loss of operator faith in the reliability of the alarm.

Table 8-4. Signal selection.

Signal Type	Criteria For Use	Special Considerations
Continuous Tone	Use with tone will be equally loud in both ears, or for tracking tasks	Select a frequency outside ranges that make up background noise and other signals
Spoken Message	C Use when communication flexibility is necessary C Use when it is necessary to identify message source C Use when a stressful situation might cause a listener to forget a coded signal C Use when a coded signal cannot provide adequate directions C Use when ambient masking noises make simple tone signals hard to interpret C Use when complex tone signals have been exhausted	Use most concise possible message and minimize ambiguity
Intermittent Tone	C Single Impulse: Use for Start and Stop timing C Regular Pulse: Use for irregularly occurring signals (alarms)	Avoid a train of signals that may be confused with electrical systems noise
Warble and Undulating Tones	Use when masking noise characteristics are unknown or cover a broad frequency spectrum in a random pattern	Avoid a warble that mimics a beat frequency effect
Bell, Buzzer, Siren, Horn, Whistle	C Use bell for fire alarm C Use horn for emergency warning C Use buzzer for individual operator alert	Signal should be distinctive and readily discriminable from other sources Signals should be at least 10 dB above ambient noise Caution signals should be provided with reset and volume controls Concentrate signal energy between 250 and 2500 Hz, with signal readily identifiable below 2000 Hz

Table 8-5. Application of auditory signal types to different information functions.

Function	TYPE OF SIGNAL		
	TONES (Periodic)	COMPLEX SOUNDS (Non-Periodic)	SPEECH
Quantitative Indication	POOR Maximum of 5 to 6 tones absolutely recognizable.	POOR Interpolation between signals inaccurate.	GOOD Minimum time and error in obtaining exact value in terms compatible with response.
Qualitative Indication	POOR-TO-FAIR Difficult to judge approximate value and direction of deviation from null setting unless presented in close temporal sequence.	POOR Difficult to judge approximate deviation from desired value.	GOOD Information concerning displacement, direction, and rate presented in form compatible with required response
Status Indication	GOOD Start and stop timing. Continuous information where rate of change of input is low.	GOOD Especially suitable for irregularly occurring signals (e.g., Alarm Signals).	POOR Inefficient; more easily masked; problem of repeatability.
Tracking	FAIR Null position easily monitored; problem of signal-response compatibility.	POOR Required qualitative indications difficult to prove.	GOOD Meaning intrinsic in signal.
General	Good for automatic communication of limited information. Meaning must be learned. Easily generated.	Some sounds available with common meaning (e.g., Fire Bell). Easily generated.	Most effective for rapid (but not automatic) communication of complex, multi-dimensional information. Meaning intrinsic in signal and context when standardized. Minimum of new learning required.

8.3.4 Speech

Much of the information in a TMC must be transmitted by speech. Some will be direct and unaided, some via loudspeaker (though this should be rare speech), some through headsets and other hardware. In some cases, computer-generated speech may be used to alert the operator or to provide status information. Verbal messages carry potential for ambiguity and confusion,

and this problem is particularly acute for speech transmitted through electronic media. We suggest the following general guidelines:

8/63 Word Selection **(Recommendation; 125)**

In selecting words and phrases for use in recorded auditory warning signals, priority should be given to aptness, conciseness, and intelligibility. Messages should be tested for these factors before implementation.
One TMC conducts focus group tests of traffic messages to ensure that their content and meaning are clear before they are implemented.

HOW DISTRACTING IS DISTRACTING?

Auditory warnings can be — and should be — distracting enough to be noticeable. Sometimes this is amazingly difficult. One tragic example is of an airliner that crashed in the Everglades several years ago. The flight crew was so busy evaluating a landing gear warning light that it failed to realize the automatic pilot had shut down and the aircraft was losing altitude. The "black box" flight recording includes the clear sound of the ground proximity warning — a distracting hornlike sound — that might be expected to command immediate attention, but was ignored by the preoccupied crew.

A common fate of a distracting auditory warning is illustrated by the TMC crew that solve the problem of false alarms in the system simply by turning it off.

8/64 Speech Signal Characteristics **(Principle; 125)**

Speech signals should fall within the range of 200 to 6100 Hz; audio signal power to the listener's ear should be approximately 300 mW; signal-to-noise ratio should be at least 5:1.

8/65 Verbal Warning Content **(Principle; 125)**

A verbal warning display should consist of: (a) an initial alerting signal (nonspeech) to attract the listener's attention and to designate the general problem, and (b) a brief, standardized speech signal (message) that identifies the specific condition and suggests the appropriate action to follow.

8.3.5 Microphones and earphones

Headsets incorporating microphones and earphones are used routinely in TMC's for speech communication. Telephone style handsets are also used where hands-free operation is not a requirement. The following guidelines are commonly accepted for these speech communication items:

8/66 Earphone Frequency Requirements	(Principle; 38)

For all types, minimum acceptable frequency range is 250-4000 Hz; the system should respond optimally to 200-6100 Hz. Where several speech channels are to be monitored simultaneously, frequency range should be 100-4800 Hz.

8/67 Comfortable Handle	(Principle; 125)

The handset handle should be designed to fit comfortably in at least 90 percent of operators' hands.

8/68 Talk Switch	(Principle; 125)

When a talk switch is provided, it should be configured for easy use by either hand.

8/69 Telephone Cords	(Principle; 125)

Use coiled or retractable cords to minimize cord tangles.

8/70 Handset Weight	(Principle; 38, 125)

The total weight of a handset should not exceed 284 g to 312 g (10 to 11 oz).

8/71 Handset Stability   **(Recommendation; 125)**

Handset bases should be designed so that they are not easily displaced. Consider the use of rubber feet, suction cups, and/or other special holding devices to prevent unintentional sliding on the console surface.

8/72 Microphone Response   **(Principle; 125)**

Microphones should be designed to have smooth frequency response between 200 and 6100 Hz and a dynamic range great enough to admit a minimum of 50 dB variation in signal input. A close-talking microphone should not overload with signals as high as 130 dB.

8/73 Headsets   **(Principle; 125, 38)**

Headsets should be:

- ❗ **Completely adjustable for comfort.**

- ❗ **Lightweight, with minimum tension to hold the earphones snugly against the head.**

- ❗ **Constructed so that no metal components touch the head.**

- ❗ **Provided with a padded noise seal cushion large enough to cover the ear without pressing on it.**

8/74 In-Ear Headsets   **(Observation)**

If in-ear headsets are used, each operator should be supplied with a personal headset.

CHAPTER 9: CONTROLS AND INPUT DEVICES

CONTENTS

9.1   Controls and the Human/System Interface

Controls allow an operator to select, guide, or influence operations of the system. Whereas a wealth of literature is dedicated to the ergonomics of controls, only a small percentage deals with issues specific to control room environments. Consequently, the control and input device guidelines in this chapter address issues most relevant to the TMC.

Many of the concerns surrounding TMC controls arise from the designers' needs to develop usable computer interfaces. Standards for such interfaces

are a relatively recent addition to the design guidelines literature. As such, they may be subject to modification. In addition, requirements for TMC information systems change frequently. At this stage in their evolution, TMC information systems are undergoing a transition from traditional command-line interfaces that rely exclusively on keyboard control to menu and window environments for which mice and trackballs are typical control devices.

Such a major shift in interface design philosophy impacts TMC design. New control devices contribute to workstation clutter and create new requirements (for example, room for a mouse pad). Selection of appropriate control devices becomes more complex as such devices proliferate.

The initial guidelines in this chapter deal with input devices for computer systems (e.g., keyboards, mice, joysticks). The second half of the chapter is devoted to more conventional controls that might be found in the TMC (e.g., switches on a facsimile machine, pushbuttons on a communication panel.)

9.2   Guidelines for Information System Controls

Although TMC information systems are now in transition between command-based input (discussed at greater length in Chapter 11) and interface systems using a mouse or trackball, the keyboard will not disappear. All systems require a keyboard for alphanumeric input and will continue to do so until speech recognition systems and handwriting recognition software become reliable enough for application in high risk situations. Thus, in the TMC we must consider guidelines for both keyboards and novel and popular input devices.

9.2.1   Keyboard

While minor adjustments in function key and cursor key arrangement have occurred, a fairly standard alphanumeric keyboard design has emerged. An appropriate design can be achieved following some simple keyboard guidelines.

9/1 Keyboard Layout   **(Principle; 4)**

Keyboard layout should follow the QWERTY design standard.
This layout has become the generally accepted standard. It is familiar to most operators. While there are alternative keyboards available, the relearning time for a new layout generally serves to prohibit change.

9/2 Numeric Data Entry   **(Recommendation; 125)**

If a primary task requires input of numeric data, a numeric keypad should be present.
Most modern keyboards have one. The common arrangement is to the right of the QWERTY area and arranged in the adding machine pattern (rows, from the top, 789, 456, 123, 0), rather than the telephone style (123, 456, 789, 0).

9/3 Cursor Keys Layout   **(Recommendation; 4)**

Cursor keys should be arranged in a compass-type layout.
Arrangements where up and down arrow keys are aligned vertically and left and right arrow keys are aligned horizontally are easy to comprehend. The "cross" and "inverted-T" styles shown in Figure 9-1 are most common. The box arrangement is more difficult to become accustomed to. It is easy to miss-position fingers on the wrong row of keys.
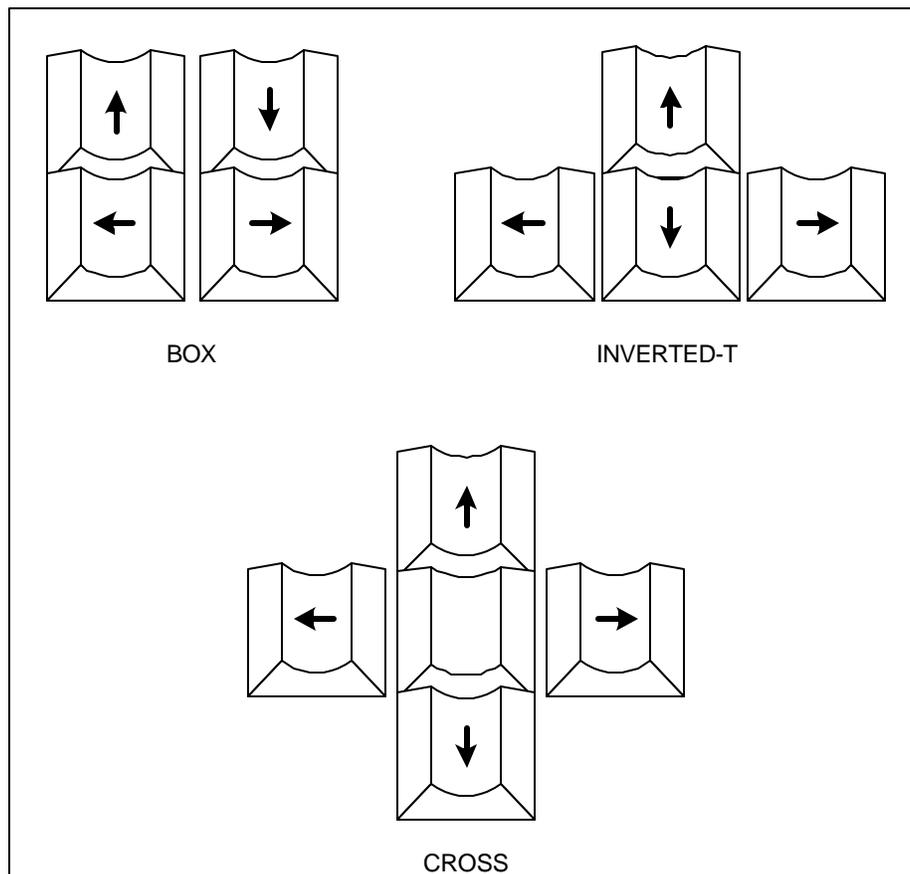
Figure 9-1. Cursor arrangements.

9/4 Keyboard Adjustment (Recommendation; 4)

Ensure that operators can easily reposition the keyboard on the work surface.
The keyboard should not be permanently mounted to a table top, counsel, or unmovable keyboard platform. Operators should be able to reposition the board to suit their individual work space layout requirements.

9/5 Keyboard Height (Principle; 4)

Keyboard height should be adjustable.
There is no set height, as this will vary with operator size and back angle. Height is measured for a given station as the perpendicular vertical distance from the horizontal support surface (table top) to the geometric center of the top key strike area in the home row [A-L] when the key is in the up (non-depressed) position. Note that the typical height of a writing desk top is too high for most keyboard users, and extensive use of a keyboard at that level can cause work-related health problems.

9/6 Keyboard Slope (Principle; 4)

Place the keyboard slope between 0 and 15 deg from horizontal.
Note that an increase in slope causes an increase in height. Whereas slope is often perceived to be a matter of personal taste, the reason for the slope recommendation is to prevent an unhealthy bending of the wrist that can increase pressure in the carpal tunnel of the wrist and contribute to carpal tunnel syndrome. For this reason, ANSI/HFS 100-1988 recommends a slope of 0 to15 deg. [4]

9/7 Keyboard Surface (Principle; 4)

The keyboard surface should have a spectral reflectance (gloss) less than or equal to 45 percent when measured by a 60-deg gloss instrument or equivalent device.
Keyboards — and, by extension, all computer equipment, should cause minimal glare.

9/8 Key Symbol Height and Luminance (Principle; 4)

Key symbols should be a minimum of 2.6 mm (0.1 in) in height and have a minimum luminance modulation of 0.5 (contrast ratio of 3:1). Key nomenclature may be darker or lighter than the background.
Most keyboards now in use exceed this standard. Many older keyboards still in use in legacy TMC systems have high-gloss key surfaces. These are easy to keep clean, but because of their smoothness and the concave top surface, they can present glare problems.

9/9 Stroke Surface Width (Principle; 4)

The minimum horizontal stroke surface width of a key should not be less than 12 mm (0.47 in).

9/10 Distance Between Keys (Principle; 38)

Center line distances between adjacent keys should be between 18 and 19 mm (0.71 and 0.75 in) horizontally and between 18 and 21 mm (0.71 and 0.82 in) vertically.

9/11 Vertical Key Displacement (Principle; 4)

Keys shall have a maximum vertical displacement between 1.5 mm and 6.0 mm (0.06 and 0.24 in).
The preferred displacement range is between 2.0 and 4.0 mm (0.08 and 0.16 in).

9/12 Key Resistance (Principle; 4)

Maximum force to depress keys shall be between 0.25 N (Newtons) and 1.5 N (0.06 - 0.34 poundforce (lbf)).
The preferred force is between 0.5 N and 0.6 N (0.11 and 0.14 lbf). One Newton (N) is approximately equal to 0.225 lbf.

9/13 Key Actuation Feedback   **(Recommendation; 85)**

Actuation of a key shall be accompanied by either tactile or auditory feedback or both.
Tactile feedback is preferred as it provides a manual sensation of the key "clicking into place" by a sudden reduction in key resistance as the keystroke is completed.

KEYBOARDS AND MECHANICAL FEEDBACK

Early portable computers saved space by using a pressure sensitive membrane keyboard, which essentially has no mechanical (tactile) feedback. Human operators *need* mechanical feedback to minimize keying errors. The membrane pads were a resounding failure from a human performance viewpoint. However, some membrane pads are used in industrial process control computers in factories where protection from contaminants is the highest priority.

9/14 Keyboard Stability   **(Recommendation; 4)**

Ensure that the keyboard is stable during normal keying operations.
The keyboard should not shake or slide while in use.

9.2.2 Mouse guidelines

The mouse, now a widespread input device, is part of an interface philosophy that is displacing the keyboard command-based interface. The mouse is designed to fit comfortably under the hand. A number of vendors offer ergonomic shapes for the left or right hand. The mechanical mouse transmits a relative cursor location to the screen. The cursor movement is activated by the movement of the roller, not by the mouse's position on the horizontal surface. An optical mouse with a digitizing tablet, by contrast, shows absolute cursor position corresponding to mouse position on an electronic grid in the tablet.

9/15 Mouse Orientation   **(Recommendation; 38)**

Design of the mouse and placement of the maneuvering surface shall allow the user to consistently orient the mouse to within +/- 174 mrad (10 deg) of the desired orientation without visual reference to the mouse.
This applies to all similar pointing devices (mouse, digitizer tablet, trackball, etc.).

Mouse dimensions should be generally as shown in Figure 9-2.
These recommendations were developed before the mouse came into such common use. Standards based on more extensive experience may be available. Because mice are inexpensive, consider allowing the operator to experiment with alternative designs.

1.0" TO 1.6"
(2.5 TO 4 cm)

2.8" TO 4.7"
(7 TO 12 cm)

1.6" TO 2.8"
(4 TO 7 cm)
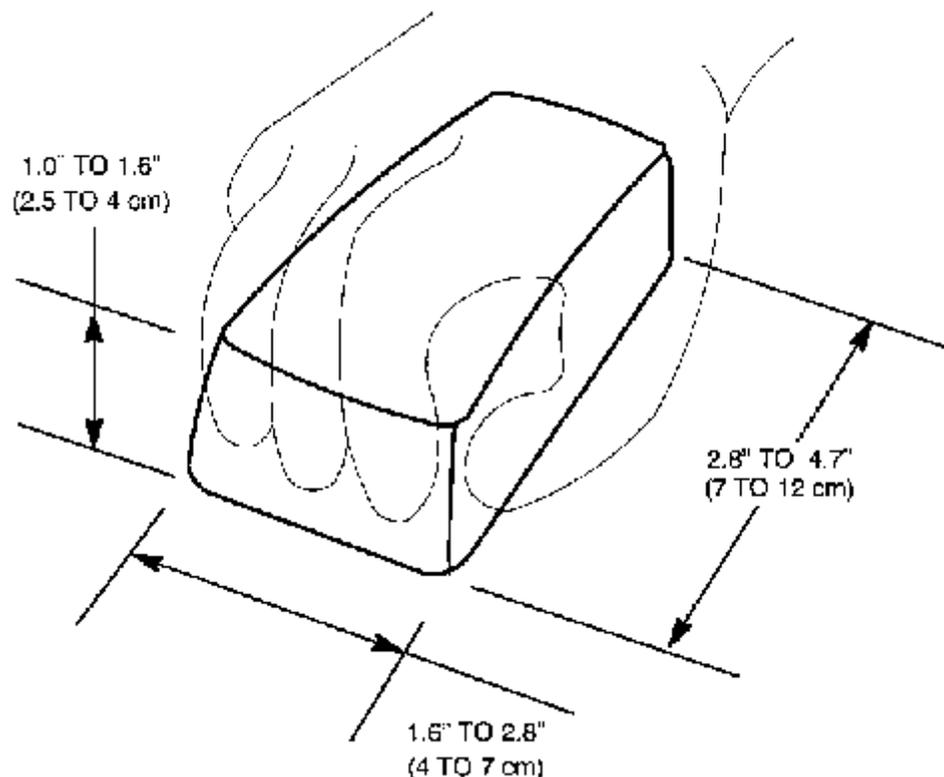
Figure 9-2. Recommended mouse dimensions.

Allow space for the mouse and mouse pad, if these will be used, in the dimensions of the work surface.
A mouse requires a space of 20 × 25 cm (8 × 10 in) for movement. Some operators also prefer space for the hand and wrist. Remember that left-handed users will want to place the mouse and pad on the left side of the keyboard.

9.2.3 Trackball

A trackball is generally used when there is insufficient space for a mouse. Since the trackball and housing are stationary, and all movement is contained within the ball housing, it can be packed into a snug space (some new versions are embedded in the keyboard or clip to the left or right edge).

Trackballs generally are used to provide zero-order (position) control under which a given rotation of the ball provides a proportional movement of the cursor. It may also be used under first-order (rate) control under which cursor movement is proportional to the rate of ball rotation. If so, the operator should also have the option of selecting zero-order control.

9/18 Trackball Rotation	(Recommendation; 38)

The trackball should rotate smoothly in any direction.

9/19 Cursor and Trackball Movement	(Recommendation; 110)

The trackball should be free of backlash or cross-coupling.
Backlash is a control system response in which the direction of movement is momentarily reversed when the movement of a control is stopped. In simple terms, the movement of the cursor shall match the movement of the ball without apparent mechanical slippage. Cross coupling occurs when X and Y movement are not independent. In the case of the trackball, this would cause erratic movement of the cursor in response to movement of the ball.

9/20 Trackball Cursor Positioning	(Recommendation; 38)

The trackball should meet the dual requirement of rapid, gross positioning and smooth, precise final positioning.
Both kinds of movement must be easy and intuitive. One approach is to use a trackball with approximately a first-degree control order in which the distance moved by the cursor is a function of the speed with which the controller is moved. Quick control movements produce rapid movement; slow control movements produce slow, precise repositioning.

9/21 Trackball Cursor Limits	**(Recommendation; 38)**

The trackball should not drive the cursor off the screen.

9/22 Trackball "Select" Mechanism	**(Recommendation; 38)**

The trackball should provide an intuitive "select" mechanism. Some trackballs have no buttons that can be used to select a menu response or capture a screen icon. If such "select" actions are part of the operators' tasks, the trackball system should include buttons or other trigger mechanisms.

9/23 Trackball Support	**(Recommendation; 38)**

The trackball workstation should support forearm and wrist.

Recommendations for trackball workstations are in Figure 9-3.

9.2.4 Light pen

A light pen is a stylus that emits light which can be detected on a video screen. Certain video screen/control card combinations will transmit this signal back to the computer. This makes the light pen an alternative pointing device for selecting items on the screen, drawing, or even writing free hand.

Light pens are satisfactory when only imprecise input functions are required, and are most frequently used when the principal task is primary data entry.

9/24 Light Pen Dimensions	**(Recommendation; 38)**

As shown in Figure 9-4, light pen length should be between 12.0 and 18.0 cm (4.7 and 7.1 in) and diameter should be between 0.8 and 2.0 cm (0.3 and 0.8 in).
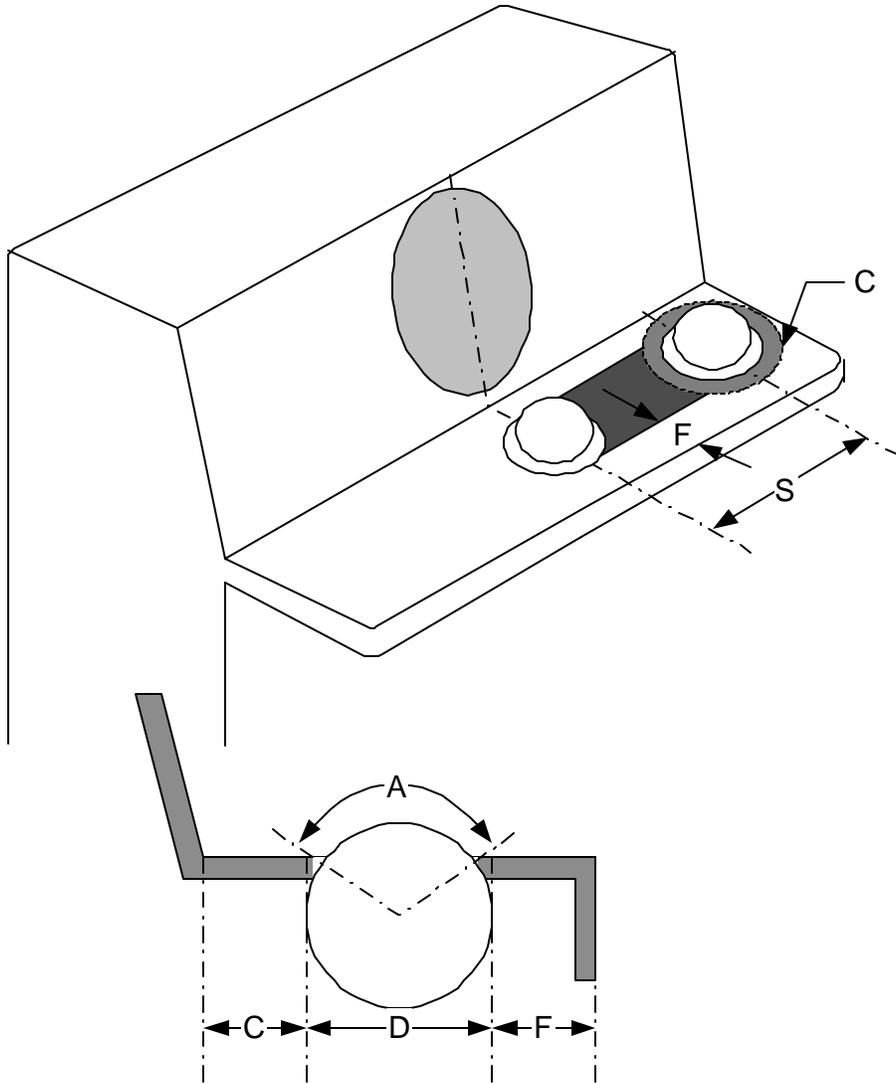
	Dimensions		Resistance		Clearance		
	D Diameter	A Surface Exposure	Precision Required	Vibration or Acceleratio n	S Display to trackball	C Around Ball	F Ball to shelf front
Minimum	50 mm (2 in)	1745 mrad (100 deg)	—	—	0	50 mm (2 in)	120 mm (4.68 in)
Maximum	150 mm (6 in)	2445 mrad (140 deg)	1.0N (0.23 lbf)	1.7 N (0.38 lbf)	320 mm (12.48 in)	—	250 mm (9.75 in)
Preferred	100 mm (4 in)	2095 mrad (120 deg)	0.3N (0.068 lbf)	—	—	—	—

Figure 9-3. Recommended trackball workstation dimensions.

9/25 Stylus Cursor **(Recommendation; 38)**

Movement of the stylus in any direction shall result in smooth
movement of the cursor.

11.9 cm to 18.0 cm
(4.7 in to 7.1 in)

0.76 cm to 2.0 cm
(0.3 in to 0.8 in)
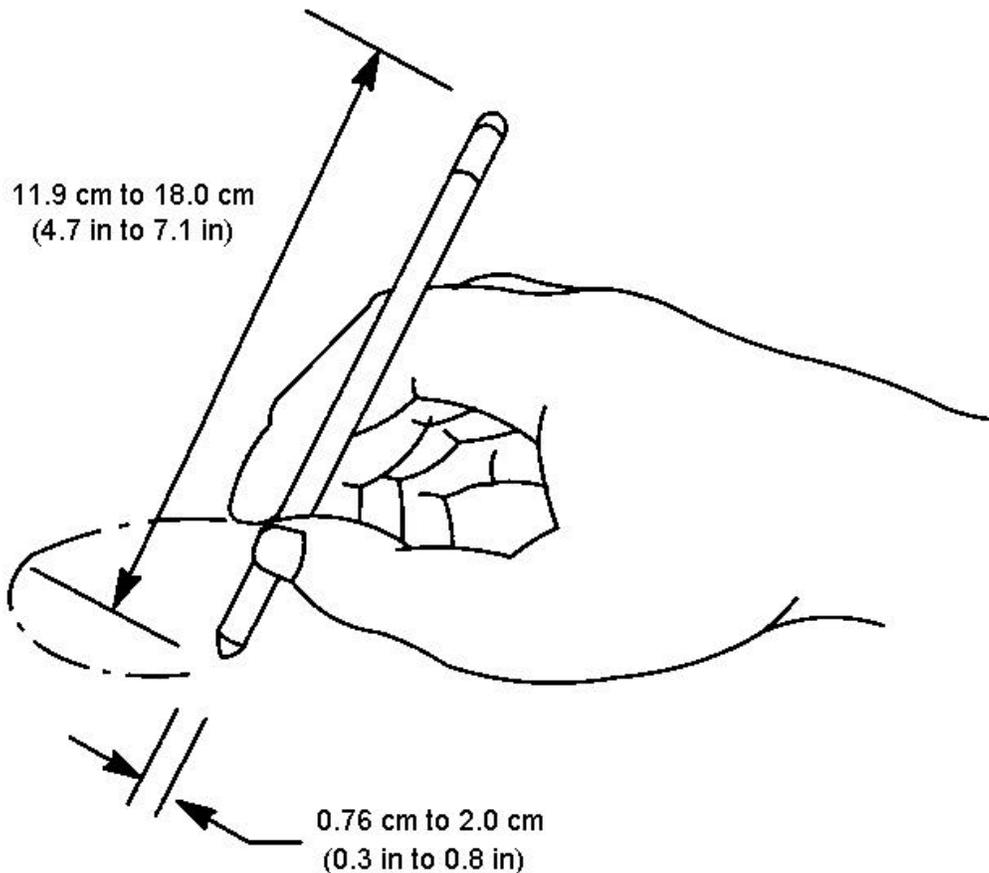
Figure 9-4. Recommended light pen dimensions.

9/26 Stylus Placement **(Recommendation; 38)**

With the discrete placement of the stylus at any point on the display,
the cursor should appear at that point.

9/27 Stylus Feedback **(Recommendation; 38)**

Provide onscreen feedback of cursor placement *and* a signal
indicating stylus actuation.

9/28 Refresh Rate	(Recommendation; 38)

The screen refresh rate shall be sufficiently high that the cursor appears to be continuously moving in conjunction with the stylus point.

9/29 Stylus Resting Location	(Recommendation; 38)

There should be a clip, preferably on the lower right side of the video display, to hold the stylus when not in use.

9.2.5 Joystick

A typical application of a joystick controller in the TMC is for aiming a remote CCTV camera. The joystick is a natural device for this task because its movement is intuitive, and displacement of the stick can be mapped directly to the resultant movement of the camera. In this application, the joystick should be located on the same housing as zoom and focusing controls, and clearly labeled.

9/30 Joystick Movement	(Recommendation; 38)

The joystick should be movable through an angle of less than or equal to 45 deg in any direction from vertical. (See Figure 9-5)
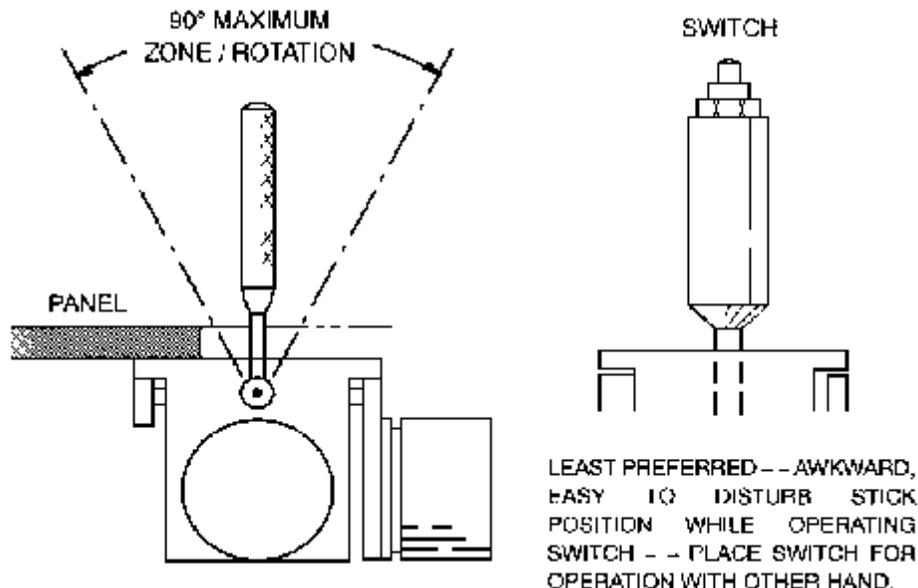
Figure 9-5. Joystick guidelines.

9/31 Joystick Cursor Movement	(Recommendation; 38)

There should be no noticeable backlash or cross-coupling.
Movement of the cursor shall match movement of the stick without apparent mechanical slippage or erratic movement of the cursor in response to stick movement.

9/32 Joystick Positioning	(Recommendations; 38)

Control ratios, friction, and inertia shall meet the dual requirements of rapid gross positioning and precise fine positioning.

9/33 Joystick Response Delay	(Recommendation; 38)

Delay between control movement and display response should be less than or equal to 0.1 sec.

9/34 Frequent Use of Joystick	(Recommendation; 38)

Forearm and wrist support should be provided if frequent use is required.

9/35 Joystick Stability	(Recommendation; 38)

Mount joystick to prevent slippage, movement, or base tilting.

9.2.6 Touch screen

Touch screens are useful for simple, intuitive inputs such as switching among menus or selecting icons. Their use is often strongly recommended on graphical or map displays. They are, however, not suitable for fine input because the touch-responsive areas must be large enough to accommodate the rather inaccurate placement of a fingertip. Other problems include glare, decreased screen brightness, and the difficulty in maintaining a clean screen surface due to oily fingerprints. Recommended design, spacing of actuation areas, and resistance are shown in Figure 9-6.
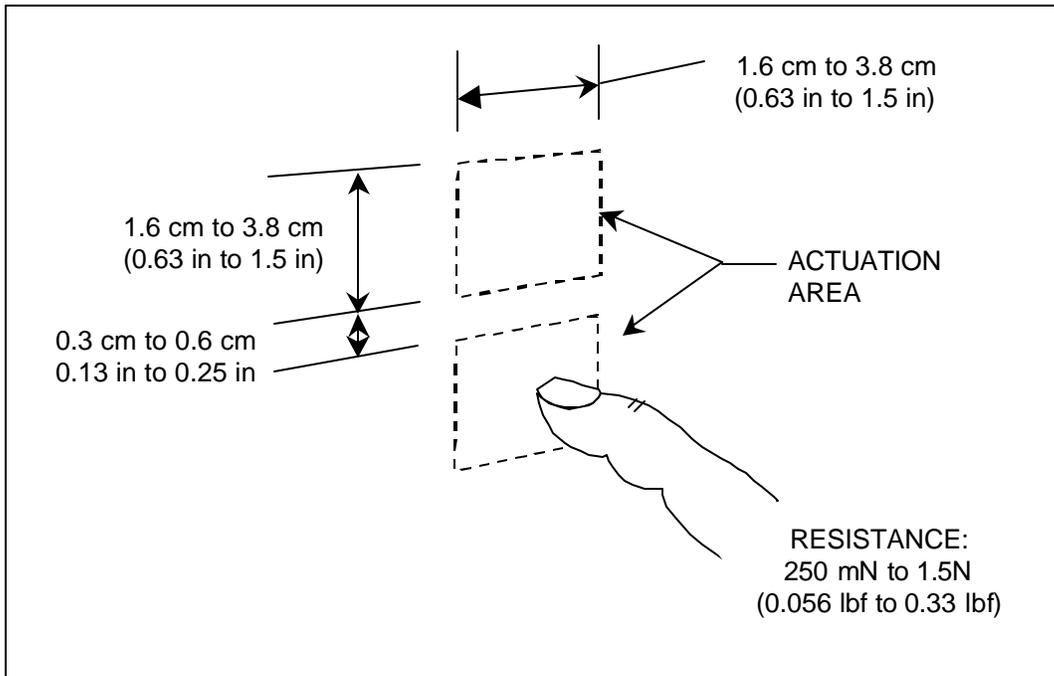
Figure 9-6. Recommended touchscreen control design.

9.3   Guidelines for Closed Circuit Camera Control

Closed circuit television (CCTV) cameras are a primary source of information for traffic monitoring and incident detection and verification in most modern TMC's. Typically, the operator has camera controls used for:

- ! Selecting a given camera image.
- ! Assigning that image to a given monitor.
- ! Panning the camera.
- ! Tilting the camera.
- ! Zooming the camera.
- ! Focusing the camera.

CCTV CONTROLS

One early-generation TMC employed a matrix of buttons for camera control. The rectangular plastic buttons were clearly labeled and backlighted. However, the arrangement of the buttons was not at all intuitive. The functions had simply been assigned in order, reading right to left, top to bottom, with no thought to making their placement appropriate to their functions. (At the very least, we should expect them to be arranged like keyboard cursor keys.) As is usually the case, operators conquered bad design by practice. But the poor arrangement of the keys made it necessary to keep glancing back at the control panel and away from the monitor, which slows the action considerably and causes frustration in finding an accurate point of aim.

Devices for controlling the cameras from the TMC include keyboards, button boxes, joysticks, mice, touchscreens, or trackballs. The design of the interface can have significant effects on the operator's workload and error rate. Guidelines based on the authors' experimental research are summarized below:

9/36 Touchscreen Selection	(Recommendation)

If a touchscreen is used to select traffic camera views from among icons for multiple cameras, ensure adequate icons size and icon separation.
Section 9.2.6 provides dimensions for icon separation and icon dimensions. In touchscreen research that populated maps with numerous camera icons, high error rates were reported. Errors included touches that selected the wrong cameras and touches that altogether missed camera icons.

9/37 Camera Selection Icons	(Recommendation)

A mouse interface is effective for traffic camera selection when cameras are represented by small icons, especially when the space between icons is small. Another alternative when icons are small or close together is to use a numeric keypad or keyboard to enter camera identifiers.
If a keypad is used, it should contain the 10 numerals, an "Enter" key, editing keys (e.g., Delete, Backspace), and any keys necessary to perform specialized functions associated with camera operation.

9/38 Keyboard-based Camera Selection	(Recommendation)

Keyboard-based camera selection should use logical and meaningful identifier strings for the cameras.
A meaningful identifier string might use road route number and milepost, for example. Avoid arbitrary identifier strings that are unrelated to camera location.

9/39 Keyboard and Mouse Camera Control   (Recommendation)

Keyboard and mouse interfaces are recommended for controlling remote cameras.
The mouse is the most effective device for selecting a camera from a map display, but not necessarily for controlling the camera itself. Keyboard interfaces allow operators to make the very precise control movements that are necessary to orient cameras. In experiments performed by the authors, the keyboard was found to be effective in both selecting and controlling cameras. Since keyboards are certain to be part of the TMC operators' workstation, their use for camera control would not require additional interface equipment or "boxes" on the console.

9/40 Rate of Panning   (Recommendation)

A nominal panning rate of approximately 12 deg per second for both azimuth and elevation allows the operator to accurately control the camera without taking undue time.

Unlike manually controlled cameras, preset cameras are designed to step automatically between a limited number of views. Typically, one control action (e.g., a single button press) quickly rotates the camera to the next programmed view. These preset locations may be individually programmed for each camera location due to differences in topography and road geometry.

9/41 Manual versus Preset Cameras   (Recommendation)

Cameras with preset views are more efficient to operate than manual cameras.
Manual cameras require much more manipulation than preset cameras. Continuous joystick manipulation or button presses are required to control the manual camera whereas a single joystick movement or button press will create the same response with a preset camera.

9/42 Primary Preset View   (Recommendation)

The preset camera should rotate through a full 360 deg. There should be a primary view for each direction of the roadway.
For example, for a camera along a north-south route, the primary view for the north direction should give the best possible view of both northbound (receding) and southbound (approaching) traffic.

9/43 Preset View Control   (Recommendation)

Controls for preset cameras should facilitate the quickest possible turn to the primary preset view of the other direction.
Much of the efficiency of the preset is the ability to rotate the camera more efficiently to a different view. A single control action should be available to turn the camera to parallel the roadway from any position.

9/44 Preset Angle Selection   (Recommendation)

Presets should be implemented to rotate the camera through a selected series of views that are likely to show incidents, and not as a linear sequence of views in which each control action turns the camera the same number of degrees.
Figure 9-7 shows one recommended preset arrangement including the camera response to various control movements.

9/45 Left vs. Right Preset Angles   (Observation)

Control over preset views should be implemented so that left and right control movements cause the CCTV view to shift to the next available preset view to the left or right respectively.

From View	Control Action			
	Left	Right	Up	Down
1	2	10	1	6
2	3	1	1	6
3	4	2	1	6
4	5	3	6	1
5	6	4	6	1
6	7	5	6	1
7	8	6	6	1
8	9	7	6	1
9	10	8	1	6
10	1	9	1	6
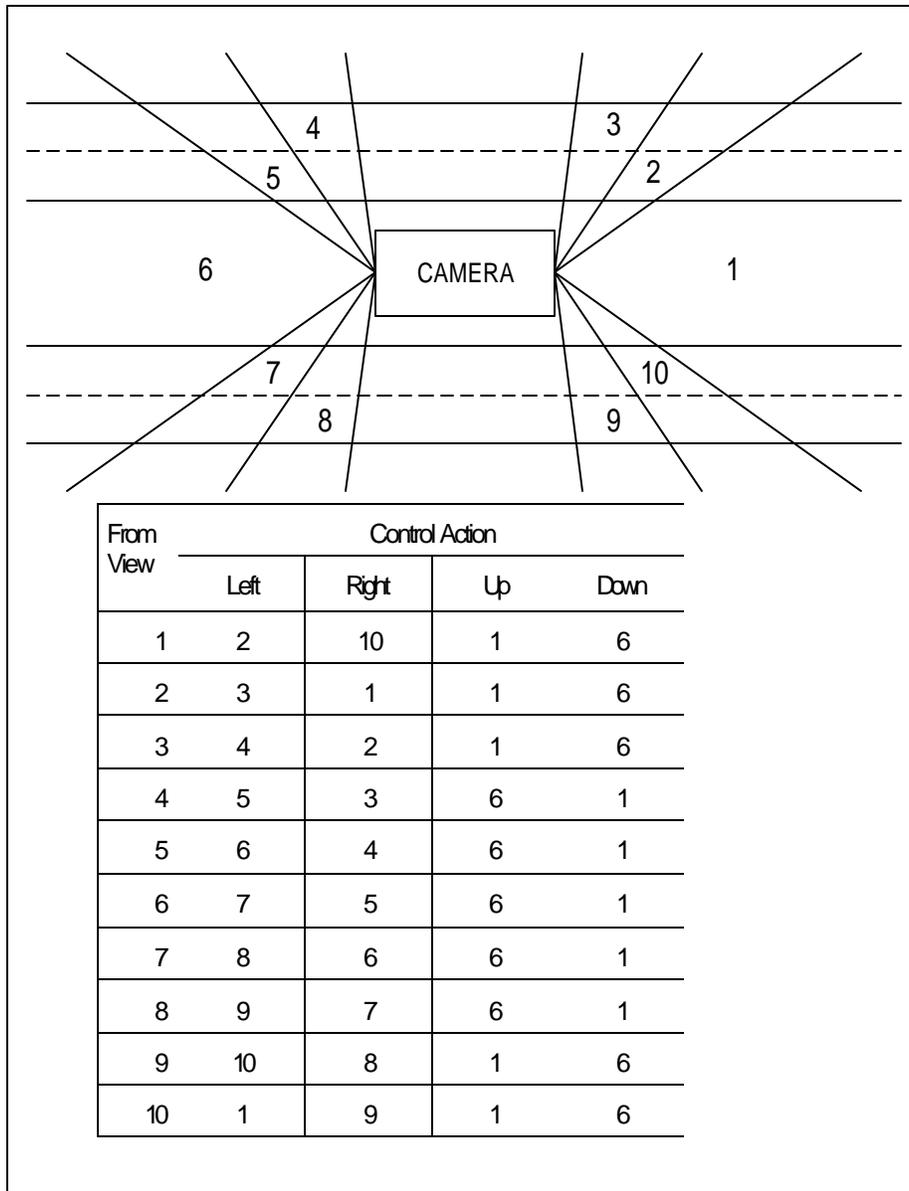
Figure 9-7. Possible preset camera views.

9/46 Preset and Manual Control   **(Recommendation)**

Camera control should combine both manual and preset control into a hybrid controller.
The disadvantage of preset cameras is that there may not be a preset view that gives a clear viewing angle toward an incident location. The primary advantage of manual control is that the camera can be precisely positioned to any location. The best interface is one that allows the operator to step between several presets, then switch to manual control for precise camera pointing.

Manual control of hybrid cameras should use a continuous controller.
There are at least two ways of implementing the manual control capability on a combined manual and preset camera for precise positioning. First, the camera may rotate slowly for as long as the controller is pressed. Alternatively, the camera may move a small amount (e.g., 0.1 deg) each time the controller is "pressed," usually requiring many control movements to move the camera to its desired position. Operators who use the latter option have expressed a strong preference for the former.

9.4 Guidelines for Variable Message Sign Control

Variable message signs (VMS) or changeable message signs (CMS) are a primary means of communication between the TMC and the driver. Under normal traffic conditions, the VMS sign is either blank or, in a few centers, it contains a generic message such as a safe driving admonition or the distance to the next exit. When drivers are to be warned of an emergency, advised to change routes, or guided to a particular location, an appropriate message is posted.

A VMS system is difficult to manage properly. One limitation of the sign is the small number of characters and words that can be displayed at one time because of space limitations and to the brief reading time (typically less than 8 seconds) available to the driver.

There are numerous alternative methods for the operator to select and post a message. In some centers the operator composes messages at the keyboard. In other centers, automated systems are used to help the operator select and post messages. From the perspectives of driver expectation and public confidence, it is important that the usage and wording of VMS systems are consistent within the TMC, and that messages are accurate and timely.

Develop and publish a manual of procedures defining when and how the VMS system should be used.
The procedures should define when the VMS should be used, appropriate messages to be posted, guidelines for message composition, and guidelines for altering and deleting messages. To ensure that recommended VMS messages are clearly understood, focus groups of local drivers have been used in some jurisdictions to test the clarity and understandability of various messages.

9/49 VMS Selection   **(Principle; 119)**

VMS should be used when there is a specific message that must be communicated to the driver.
A VMS should be used if: (1) drivers are expected to take a particular action, (2) the message is considered critical, (3) the message accuracy has been confirmed by a reliable source, (4) conditions can be monitored so that the sign can be updated as soon as events allow, and (5) the message does not tell drivers something that is already obvious.

9/50 Outdated Messages   **(Principle; 119)**

Messages that are no longer true or necessary should be updated or discontinued.
Messages should be updated if: (1) a change in driver behavior is no longer required, (2) the message accuracy is questionable, (3) the information on the sign is obvious, (4) too many drivers are ignoring the information, (5) the amount of delay changes significantly, or (6) the recommended alternate route changes.

In centers employing freeform (non-programmed) keyboard entry of VMS messages, a template of the VMS sign may be displayed on the computer monitor to assist the operator in formatting the message to fit appropriately on the sign. In some cases, the TMC may have a working scale model of the sign posted on a wall so that operators know exactly what the posted sign will look like. This interface should provide a capability to produce models of multiple- screen messages.

9/51 VMS Message Length   **(Principle; 119)**

The VMS message should not exceed two screens in length.
VMS messages may be presented on pairs of screens flashed on the sign in sequence. The length of the message should not exceed two screens; One screen in length is better due to the limited time available for the driver to read the message.

Many VMS systems provide the operator with a menu of "approved" phrases that may be combined to produce VMS messages. The operator selects the set of phrases that best present the appropriate message. More advanced and more highly automated systems use some type of rule-based expert system to prepare an appropriate response plan (messages for all related VMS signs) and either post the messages or present the messages to the operator for approval or modification. Discussions with operators of such systems found a broad range of personal

philosophies on when the operator should override the automation.

TWO DIFFERENT VMS PHILOSOPHIES

The authors interviewed two experienced operators at a highly automated freeway management center. During each interview, the operators were asked to show us how the response plan messages posted on overhead signs can be revised if the operator determines that they are incorrect. The first operator showed us how such modifications could easily be accomplished and stated that this was a very frequent task. Asked the same question, the second operator stated that it was not possible to modify the computer-generated response plan and that, even if it could be altered, this should never be done due to potential liability issues.

During experimentation, operators using automated support systems allowed the automation to post incorrect VMS messages on approximately 75 percent of incorrect messages (i.e., they detected 25 percent of the incorrect messages). This error rate was the same whether the message was automatically posted and then checked by the operator or the message was suggested and then approved by the operator. This was especially true during periods of high workload when operators tended to "shed" the VMS monitoring task to take care of tasks that required operator action.

9/52 Automated System   **(Recommendation)**

Design for imperfect operator supervision of automated support systems.
During periods of high workload, operators supervising automated VMS message posting systems tend to accept and approve recommended messages without carefully checking their accuracy. Automatically composed messages should contain only moderate warnings and recommended driver actions (e.g., a strong suggestion to divert to alternate routes should not be posted automatically unless an incident substantially reducing traffic flow has been detected and verified.)

In spite of this relatively high tolerance for operator error, experiments found that VMS systems using automated response plan message posting resulted in significantly faster VMS responses to incidents and significantly faster clearance of incident-related traffic congestion. For this reason, fully automated posting of VMS messages according to a predetermined response plan or response algorithm is recommended. The operators should, then, have a capability to modify incorrect messages.

9/53 VMS Automation   **(Recommendation)**

The design goal for a VMS management support system should be fully automated message posting with a capability for the operator to modify messages after they are posted.
From the perspective of operator performance, automated VMS posting provides the most rapid message posting with no significant increase in operator error rate.

9/54 VMS Inputs   **(Recommendation)**

Automated posting of VMS incident messages should be based on all available data, from both automated sensors and human sources.
Many automated VMS systems use traffic flow data to detect potential incidents and establish response plans for VMS posting. Higher reliability can be obtained if the automated support system uses operator verification data and any additions or modifications to traffic flow data entered by the operator.

Even with automated posting of VMS responses, the operators should maintain situation awareness of the status of VMS assets. VMS status displays must be designed to promote easy interpretation and strategic understanding of system status. This is especially true when multiple operators may be responsible for VMS operations. The following guidelines address this need.

9/55 Field Device Status   **(Recommendation)**

Provide the operators with a resource map that shows the location and status of all sensors, cameras, VMS´s and other TMC resources.
In addition to other data, it should indicate whether each VMS sign is currently in use. Before implementing a response plan for a specific incident, all related signs should be checked to ensure that they are not displaying an important earlier message for a different incident. This can be checked easily by indicating sign status on the TMC resource map.

9/56 Response Plan Display   **(Observation)**

Provide a display on the resource map that allows the operator to see the entire top-level response plan (the messages on all signs involved in an incident).

9/57 Incident and VMS Display	(Recommendation)

The operator's situation display should show where the incident is located in relation to the VMS signs to be used in the response plan.

9/58 Incident and Direction of Travel	(Observation)

On any status map of a divided highway, display unambiguously the direction of travel on which the incident is located.
Operators typically have difficulty identifying the direction of travel of an incident and remaining aware of this during periods of high workload. Showing this information on the situation display supports operator awareness.

9/59 VMS Status	(Recommendation)

Provide an easy way for the operator to modify or discontinue a VMS response plan or individual message that is no longer appropriate.
To maintain public trust in the VMS system, messages must be timely and accurate. To support this requirement, modification or discontinuation of a message must be easy for the operator, and thus reduce the possibility that this task will be "shed" during times of high workload. One approach would be a computer interface in which a mouse "click" on a VMS sign on the map display would bring up a screen menu. This menu would provide, at a minimum, alternatives to "MODIFY" or to "DELETE" the message on that sign.

9.5 Traditional Controls

In addition to unique information system controls (as discussed in the previous sections), designers may need to use more traditional controls, from knurled knobs to cranks and handles. The most common TMC controls will be those that change the status of a subsystem (ON/OFF controls or choices from a series of possible alternative states, such as telephone push buttons). The general guidelines for their use follow.

9.5.1 Push buttons

Push buttons are used to make discrete choices of status or to exercise control of movement or other continuous variables at a steady rate (as with cursor keys or push button control of CCTV cameras). Figures 9-8 and 9-9 illustrate guidelines for push button design.

9/60 Push Button Diameter	**(Principle; 38)**

The smallest push button diameter for bare-handed use should be no less than 0.64 cm (0.25 in).

9/61 Button Extension above Panel	**(Principle; 38)**

The button should extend far enough above its panel so that, when depressed, some of the button remains exposed above the panel.
This will ensure that the operator will be able to push the device far enough to make contact.

9/62 Push Button Design	**(Principle; 38)**

When button diameter is approximately 1.9 to 2.5 cm (0.74 to 1.0 in), it is helpful to add a concave top to the button so that finger centering is easier.

9/63 Location Aid	**(Principle; 38)**

If it is necessary to have an additional location aid (as in a button that is in a dark area, below a work surface, or some other location where visibility is limited), a tapered recessing bezel like that found on doorbells is helpful.

9/64 Emergency Button Size	**(Principle; 38)**

If a button is used for an emergency stop or for some other task that must be accomplished with a minimum of time and effort, the button should be larger than other surrounding buttons (See Figure 9-8).

9/65 Accidental Activation	**(Principle; 38)**

If it is critical to prevent accidental activation of a button, recess the button so that its surface is below the panel in which it is installed, with an opening at least 2.54 cm (1 in) in diameter, as shown in Figure

9-9.
Sides may be tapered to allow activation with less attention to accuracy.
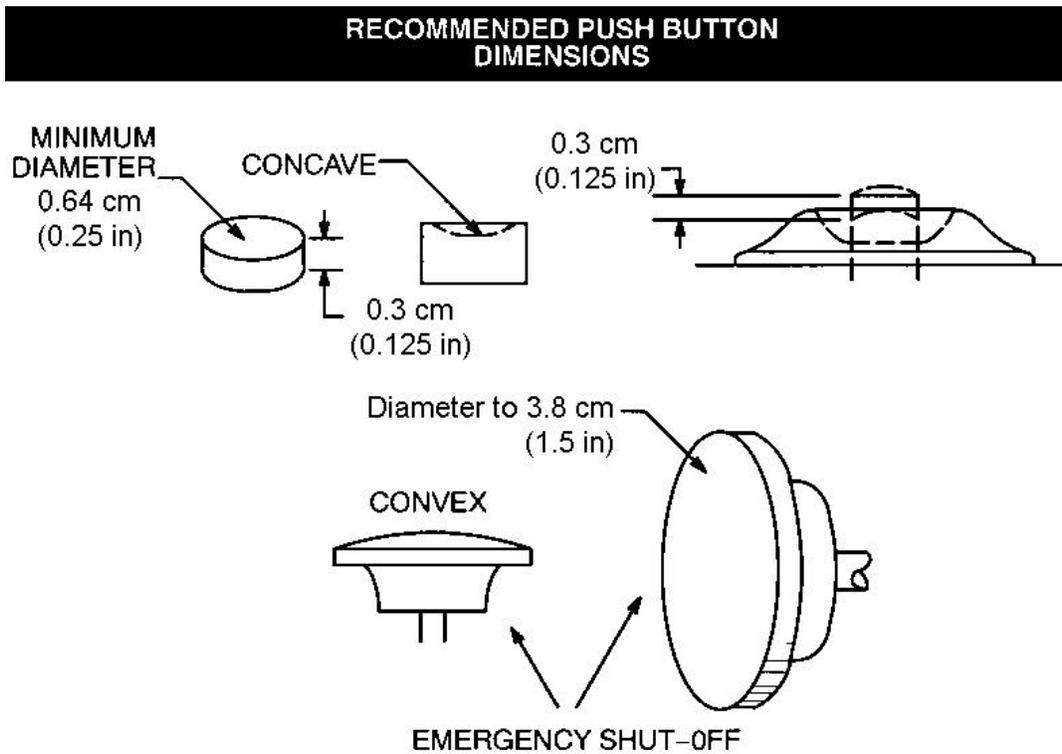
Figure 9-8. Recommended push button dimensions.
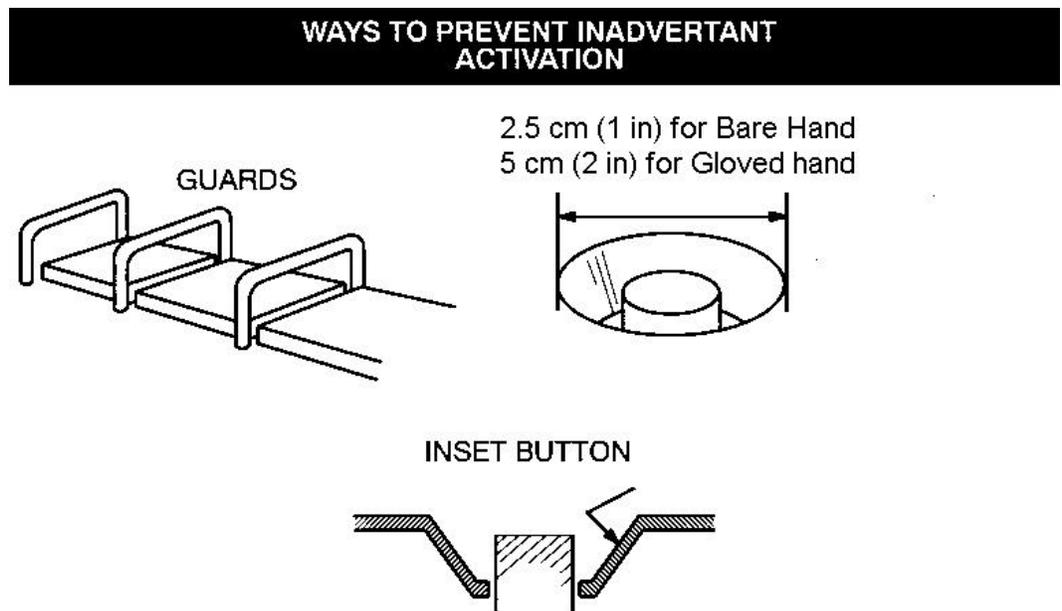
Figure 9-9. Designs that prevent inadvertent activation.

9/66 Button Separation   **(Principle; 38)**

Buttons should be separated as summarized in Figure 9-10 for most conditions that will be found in the TMC.

9/67 Push Buttons Cues   **(Principle; 38)**

Use button shape as a cue for functional significance, particularly when buttons are used in conjunction with advisory indicators.
As suggested by Figure 9-11, a round push button, for example, is not likely to be mistaken for a rectangular advisory indicator.

Arrangement	A	B	C	D	E	F
Vertical Plane (No Gloves) e.g., on wall:	1.9 cm (0.75 in)	1.6 cm (0.63 in)	0.48 cm (0.19 in)	0.64 cm (0.25 in)	5.72 cm (1.25 in)	1.9 cm (0.75 in)
Horizontal Plane (No Gloves) e.g., on desk:	2.54 cm (1.0 in)	2.22 cm (0.875 in)	1.11 cm (0.4375 in)	1.27 cm (0.50 in)	3.81 cm (1.50 in)	2.54 cm (1.0 in)
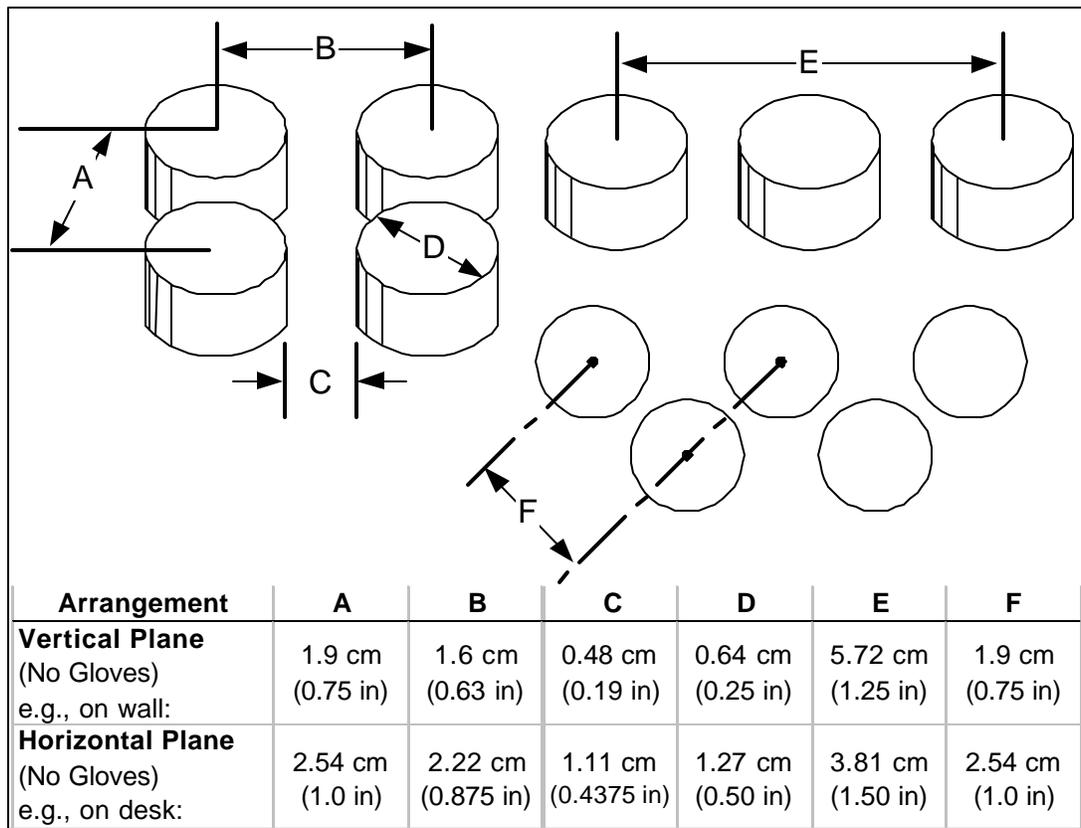
Figure 9-10. Minimum button separation.

9/68 Labeling Buttons   **(Principle; 38)**

Use backlighted rectangular buttons for controls that must be labeled.

9/69 Contrast Ratio of Labels   **(Principle; 38)**

Contrast ratio of label to background should meet the same standards as that for other labels (3:1 minimum).
(See discussion of contrast in Section 8.2.5.)

9/70 Push Button Activation   **(Principle; 38)**

Forces required to activate push buttons should be in accordance with Table 9-1.
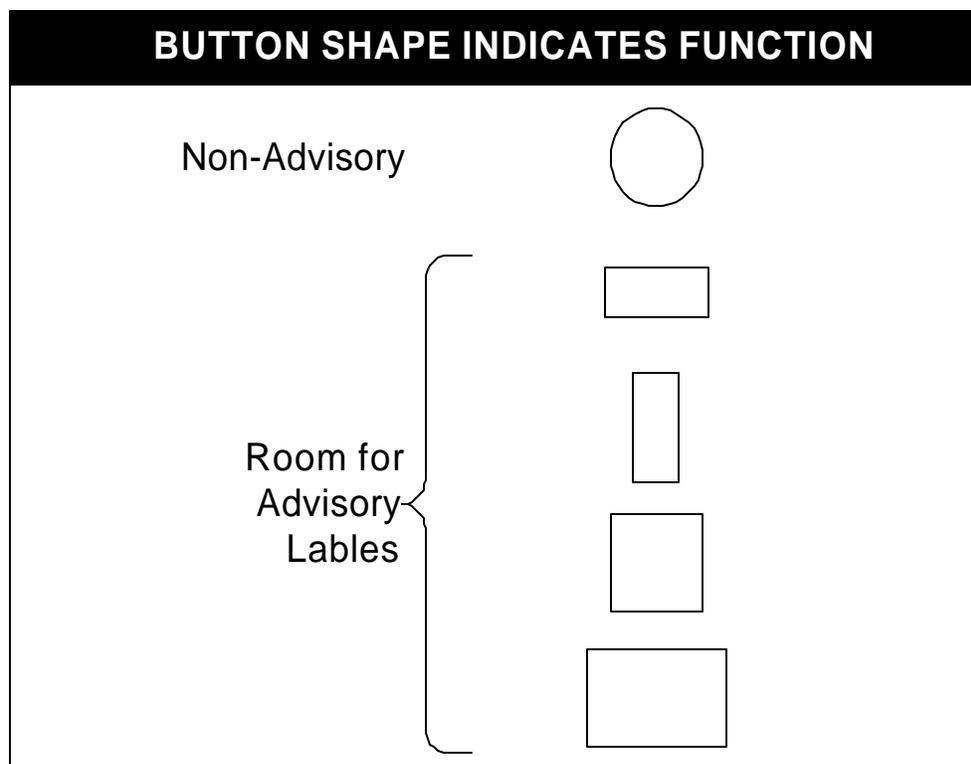
Figure 9-11. Relate button shape to function.

Table 9-1. Minimum and maximum pushbutton activation forces.

RECOMMENDED PUSH BUTTON FORCES (FROM MIL-STD-1472D)			
	RESISTANCE		
	SINGLE FINGER	MULTIPLE FINGERS	THUMB OR PALM
MINIMUM	2.8 N (0.63 lbf)	1.4 N (0.32 lbf)	2.8 N (0.63 lbf)
MAXIMUM	11 N (2.5 lbf)	5.6 N (1.26 lbf)	23 N (5.2 lbf)

9.5.2   Contact switches

The contact switch performs the same functions as a push button, but since it uses a pressure-sensitive substrate rather than a mechanical switch to sense activation, it provides no inherent feedback to the operator. Contact switches are most frequently used for noncritical functions. Contact switch panels require frequent cleaning. It is not visually obvious that the contact switch is a switch and not a display. Contact switches may be used with the following qualifications:

9/71 Switch Activation Feedback   **(Principle; 125)**

Provide clear visual or auditory feedback of switch activation.
A light behind or adjacent to the switch or a click or beep is adequate in most cases.

9/72 Switch Boundaries   **(Principle; 125)**

Provide clear graphic delineation of switch boundaries (Figure 9-12).

9/73 Recognition of Contact Switches   **(Principle; 125)**

Ensure that operators can easily distinguish contact switches from purely visual displays.
Contact switches, for example, should be of the same size, shape, and color of corresponding mechanical buttons.

9.5.3 Key pads

Key pads are most frequently used for quick input of number sequences, as with a telephone keypad. The suggested size and spacing of such arrays is shown in Figure 9-13.
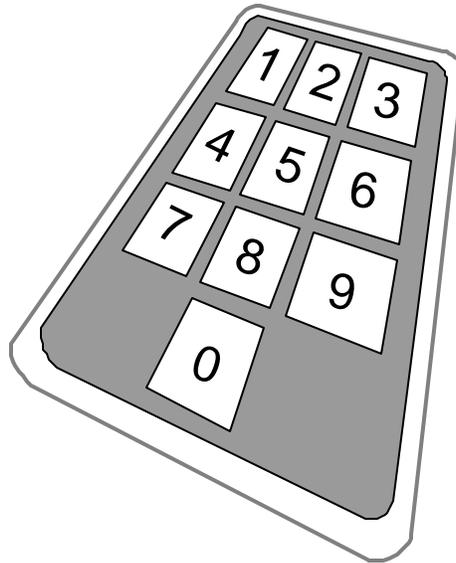
Figure 9-12. Contact switch.
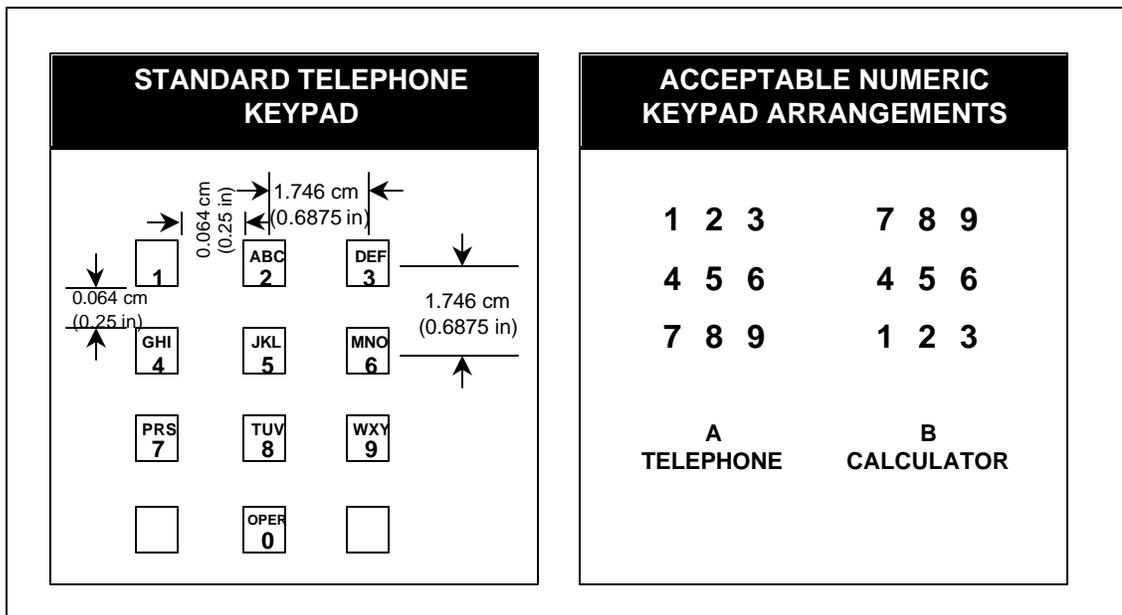
Figure 9-13. Recommended keypad size and spacing.

9.5.4 Rocker switches

Rocker switches can be used for up to three discrete positions (e.g., off, low, high). They have

an advantage of providing constant visual and tactile feedback on switch position. They perform the same function as toggle switches, but offer better possibilities for labeling and visual feedback; they are particularly preferred when the switches are arranged in a horizontal line. Guidelines for rocker switches are:

9/74 Switch Design   **(Principle; 125)**

As shown in Figure 9-14, switches should be designed so that the slope of the handle from the nominal plane is approximately 30 deg, **and the nominal plane of the switch should be at least 0.32 cm (0.125 in) above the plane of the panel on which the switch is mounted.**

9/75 Separation of Switch Centerlines   **(Principle; 125)**

As shown in Figure 9-14, switch centerlines should be separated by a distance of no less than 1.9 cm (0.75 in).

9/76 Switch Resistance   **(Principle; 125)**

Switch resistance should be between 2.2 N and 3.3 N (0.50 lbf and 0.74 lbf).

9/77 Rocker Switch Feedback   **(Principle; 125)**

Rocker switches should be designed to snap into place with an audible click.

9/78 Labeling and Coding of Rocker Switches   **(Principle; 125)**

Rocker switches may be labeled and color coded.
Labels and colors should be in accordance with guidelines in Chapter 8 with respect to choice of color and contrast/legibility.
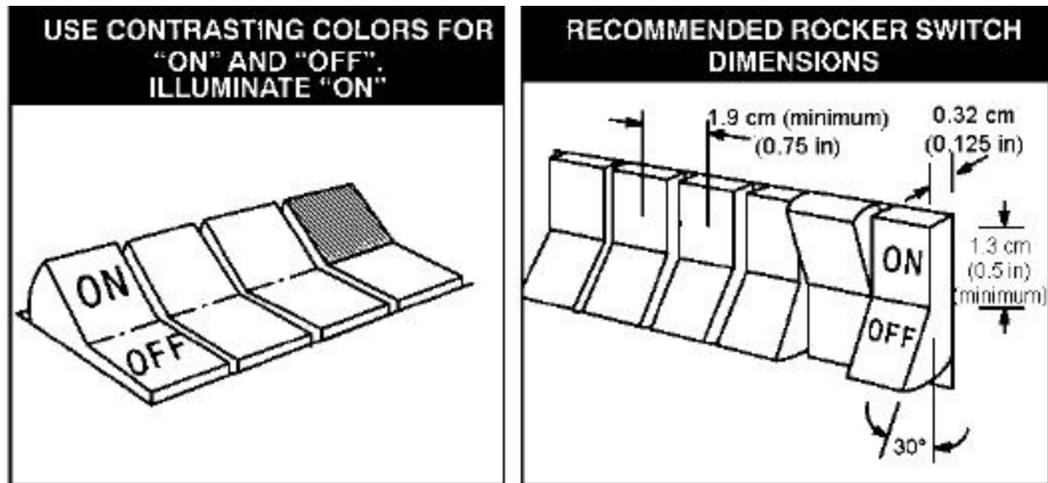
Figure 9-14. Rocker switch design and dimensions.

9.5.5   Other switches

Figure 9-15 shows a variety of alternatives to the common switches already discussed. They

are useful within the following guidelines:

9/79 Switch Resistance   **(Principle; 38)**

Finger-operated switches should have a maximum resistance of 8.3 N (1.87 lbf) or less.

9/80 Handle Length   **(Principle; 38)**

The minimum handle-length for resistances of 8.3 N (1.87 lbf) or less should be about 2.54 cm (1 in). Increase handle length for switches with greater resistance.

9/81 Slide Switch Resistance   **(Principle; 38)**

Slide switch resistance should not exceed 2.8 N (0.63 lbf).

RESISTANCE FOR FINGER OPERATED CONTROLS	
Lever Length (cm, in)	Maximum Resistance (Newtons, Poundforce)
Under 2.54 cm (1 in)	8.3 N (1.88 lbf)
3.81 cm (1.5 in)	13.4 N (3.0 lbf)

OTHER FINGER OPERATED CONTROL SHAPES
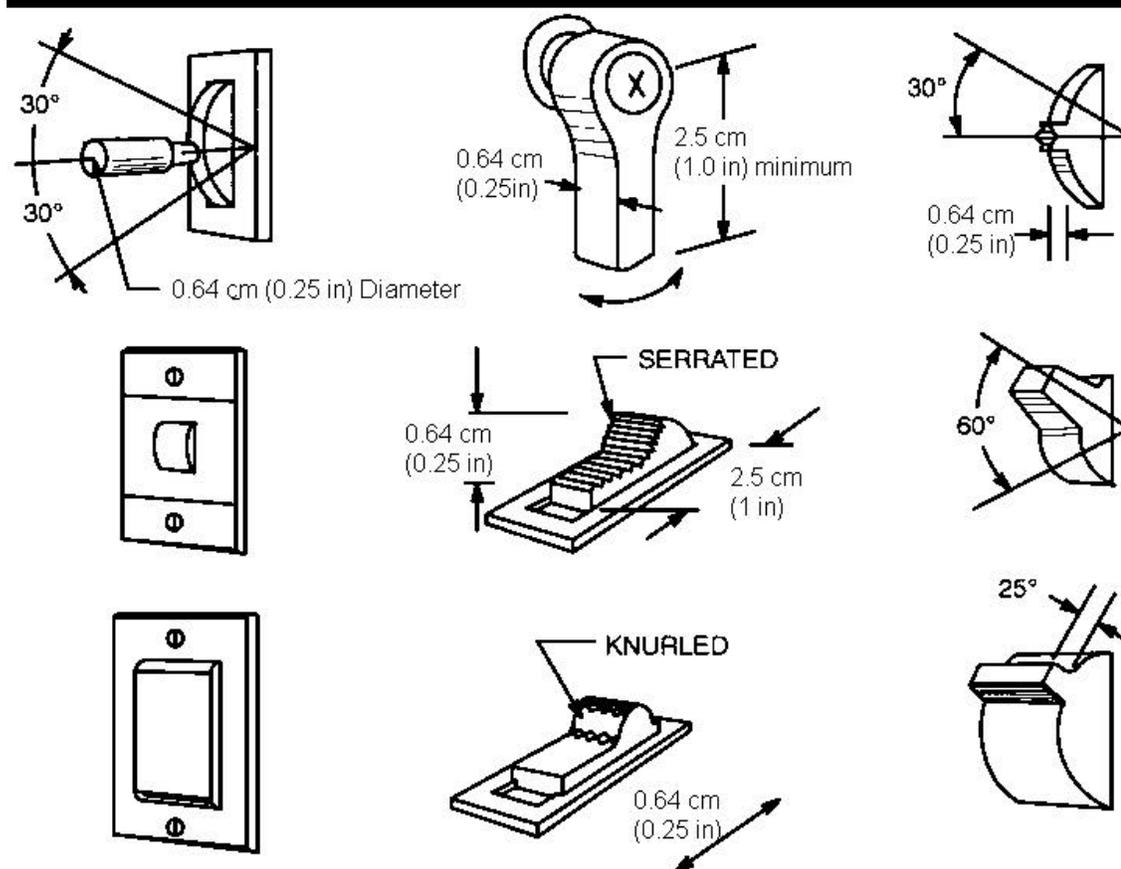
Figure 9-15. Other switches.

CHAPTER 10: THE WORK SPACE

CONTENTS

10.1 Ergonomics and the Work Environment

A traffic management center (TMC) operator must interact with a variety of subsystems in the physical environment. The design of work spaces for comfortable and efficient human use has received attention in recent years, but the attention has been somewhat superficial, often limited to the purchase of ergonomic work chairs, desks, hand tools, and other such accessories. This chapter will deal with the guidelines for making a TMC a comfortable and productive work environment.

The topics fall into three areas: the physical environment, architectural considerations, and furnishings. The division is arbitrary because, as we will see, the design components are interactive — choice of a luminaire will, for example, influence antiglare features, and heat-emitting properties of equipment will affect the overall heating, ventilation and air conditioning (HVAC) plan, to mention only two dependencies.

Many of these considerations can be best addressed by engaging an architect experienced in the design of facilities that house advanced control rooms. The architect can ensure that the facility conforms to standards of design including local building codes. This chapter is included to help the TMC design team understand some of the important design questions that the architect will raise for their consideration and evaluate the adequacy of the architect's solutions.

Because these factors will converge when the TMC begins operation, planning for the total system, including human engineering guidelines, *must* begin early in the design process — perhaps even before the architect is hired.

10.2 The Environment

The first consideration is the work environment: lighting, acoustics, and atmospherics. Most of these dimensions have very clear and strict standards.

10.2.1 Lighting

Traffic management centers in North America will, as a rule, employ artificial rather than natural light. The overall illumination of the center is a critical factor in design and practice. It should be specified early in the design process.

There are two types of artificial lighting:

> **!** **General illumination** is used for the center as a whole, and provides illumination for safe movement, observation, and maintenance.

> **!** **Supplementary illumination** is used for special tasks and areas in which general illumination is insufficient for reading and paperwork.

In the TMC, the question of interaction between general and supplementary illumination is critical. A control room is frequently provided with relatively dim general illumination because of the nature of the tasks and displays. 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, but individual operator tasks may require reading or detailed work for which dim general lighting is insufficient. For this reason, the lighting scheme and choice of luminaires must be viewed as an integrated whole, and not designed piecemeal.

The luminaire. Each light source that provides work area lighting, such as general illumination, spotlights, work station lamps is called a *luminaire.* The luninaire includes associated filters, reflectors, and housings as well as the light source. A work space is served by a complete and complementary set of subsystems. If this is forgotten, and lighting is not coordinated with other subsystems, the results may be unsatisfactory. Each new addition will upset the effects of others, causing a host of unforeseen problems. Unplanned supplementary illumination may, for example, create glare reflectance on a video display that cannot be moved or adjusted. The

selection and placement of luminaires should be planned ahead of time, and should mesh with the total TMC work area plan.

The most critical lighting challenge in the TMC will be the conflict between the need for dim general illumination and higher levels of local illumination. A nearly equal challenge is the need to plan illumination that will not cause distracting glare. *In general*, the overall illumination should be *indirect* and somewhat diffuse. Control room ceilings will usually be higher than standard office area ceilings, but lamp systems often prescribed for such situations may cause problems. Translucent globes, for example, may be useful for hotel lobbies. In the TMC, however, it would be very difficult to integrate them into the overall lighting system without causing distracting shadows and glare.

General illumination may be provided in several ways, depending on preference and the specific TMC configuration.

10/1 Overall Control Room Illumination   (Recommendation; 38)

Indirect lighting should be employed to provide overall illumination for the control room.
A variety of standard fixtures is available for indirect lighting. In selecting fixtures, designers must consider the nature of the walls and ceiling since the light must be reflected from these surfaces. Some TMC's have highly reflective ceilings. These provide efficient illuminance, but the specular patterns may be distracting. Ceilings of a light color are preferable to provide adequate diffuse illumination.

10/2 Supplementary Illumination   (Recommendation; 38)

Canister fixtures should be employed to provide supplementary illumination over work areas.
These are composed of light sources in recessed positions in the ceiling or console that can be pointed to specific areas. The likely areas are the operator console surfaces, which can be provided with sufficient light to allow close work while keeping intrusions into the greater control room area to a minimum.

10/3 Fixture Adjustability   (Recommendation; 38)

Adjustable fixtures should be used in work areas where more intense illumination is required.
For areas in which writing or reading of fine print is required, units with flexible mounts should be attached to the consoles and their direction should be adjustable to allow for different viewing heights and angles.

Illuminance levels. Illuminance level is measured by a small and relatively inexpensive instrument called a photometer. When illuminance (not luminance) is measured, the value will change as distance from the measuring point to the light source changes because light spreads as radiant energy.

The measure of light coming from the video display screen is expressed in terms of luminance in cd/m^2. To reach an acceptable ratio, it is sometimes necessary to adjust illuminance until the contrast ratio is satisfactory.

The problem of needing low illuminance for proper screen contrast and high illuminance for the associated paperwork does in fact cause conflicts in design philosophy, as well as some disagreement on optimum levels. The Illuminating Engineering Society (IES), for example, suggests 50 - 100 lux for general lighting where video displays are employed; this is too dim for many other tasks. This handbook recommends values considered to be the best compromise.

10/4 Video Display Illumination   (Principle; 38)

Where only video display units are employed, illumination should be 200-500 lux.
This is adequate background illumination for video display work and occasional reading of large or bold print, but is too dim for close work requiring reading of normal type and similar activities.

10/5 Paperwork and Video Display Work Illumination   (Principle; 38)

Where operators will have paperwork tasks along with video display work, illuminance should be 500-1500 lux.

For general office work, an illuminance of 540 to 755 lux is adequate. This level provides a good compromise between video display observation requirements and reading/writing requirements. Illuminance is measured at the writing surface. Designers should bear in mind that operators who are forced to shift continually between higher and lower illumination may suffer symptoms of eyestrain as the eye readjusts repeatedly to the changes.

Color. Illuminating lights in the work place are not generally thought of as having distinct color. In fact, the spectral composition of light is an important environmental factor. The composition of illuminating sources imparts a subtle cast to different surfaces in the work area.

Humans are accustomed to living in an environment of broad-spectrum white light provided by the sun. In the home incandescent bulbs are used, which have more energy in the red/yellow end of the spectrum, and produce an effect of warmth. In the office fluorescent light is used and produces a cool effect.

The color of illumination can cause unexpected shifts in the perception of objects as they move from one luminaire to another. In one case, a laboratory director ordered gray coveralls for the staff. The laboratory was illuminated almost entirely with fluorescent fixtures, and in the laboratory the coveralls appeared gray. However, when the staff went outside, they perceived the coveralls to be purple.

Manufacturers of dyes, paints, and other colored products generally test them against colorimetric standards. There are three common standard light sources used in these tests: *North Sky Daylight*, which is a close approximation of sunlight, *cool fluorescent*, and *incandescent.* The appearance of a surface varies with the quality of the incident light; before agreeing on a color scheme or purchasing equipment that will be visible in the TMC, give some thought to how it will look when installed and placed under a luminaire.

10/7 Luminaire and Room Color (Observation)

Specify the luminaire *before* choosing a color scheme.
Much control room furniture — including consoles, chairs, and upholstery —
is available in light blue or blue-gray color schemes. Colors will have a
different appearance to the eye depending on the nature of the light source,
so the source should be chosen with care. General lighting will probably be
cool fluorescent. Cool colors (e.g., blue, blue-gray, purple, blue-green, etc.)
will look cooler when illuminated by cool light sources.
Standards for this choice are somewhat subjective, but most references
agree that deluxe cool white fluorescent illumination provides the best overall
color rendering. [6] (See also guideline 10/13 on choice of colors.)

Reflectance and glare. There are two categories of reflectance: desirable reflectance (that is,
the amount of luminaire energy reflected off ceiling and walls to light the TMC) and undesirable
reflectance (glare from work surfaces and other sources).

10/8 Furniture and Machine Finish (Principle; 6, 67, 125)

**Furniture and machines should have a matte finish to keep
reflectance between 25 and 50 percent.**
Woodson, Tillman & Tillman (1992) recommend a reflectance of 30 to 40
percent. ANSI/HFS 100-1988 recommends 45 percent. *Percent reflectance*
refers to the proportion of light from the illuminating source that is reflected
from the surface in question rather than absorbed. A matte black surface will
absorb most incident light; a polished mirror will absorb almost none.
Because much of the furniture or other equipment will not be designed from
scratch, reflectance should be specified. Most manufacturers are aware of
reflectance recommendations, but occasionally designers opt for materials
that may eventually cause problems. Above all, avoid glossy surfaces.

10/9 Light Source Arrangement   **(Recommendation; 6)**

Sources of emitted or reflected light should be arranged so that they do not cause reflections on video displays.

- **!**   **Lights behind the observer will cause specular reflectance on screens.** Common examples include illuminated "exit" signs in the rear of the control room and light from windows.

- **!**   **Direct lights or bright indirect lights above can wash out characters and reduce contrast ratio.**

- **!**   **Light sources to the front of the operators can cause eye strain.** If the operator's eyes shift from bright lights to the display screen and back, the pupil will constantly readjust; this can result in eye strain and fatigue.

10/10 Ceiling Reflectance   **(Principle; 6, 67)**

Ceiling reflectance should be 80 to 90 percent.
A high ceiling reflectance is important to support diffuse indirect lighting.

10/11 Wall Reflectance   **(Principle; 125)**

Wall reflectance should be 50-85 percent in office areas but somewhat lower in the control room where video displays are in use.
In the TMC control room, wall reflectance is more problematic because of the various displays whose visibility should have prominence. Some TMC's use dark and even matte black walls.

10/12 Floor Reflectance   **(Principle; 6)**

Floor reflectance should be 15-35 percent.

Psychological effects of illumination and color. Little quantitative evidence exists on the psychological effects of this part of the environment. There are general rules of thumb that are worth attention during the design stage:

Optimize both the color temperature of the light and the general illumination level to obtain the appropriate level of perceived brightness.

Figure 10-1 shows the acceptable region (B) for color temperature. If color temperature is above the top line (A), surface colors are distorted and faded in appearance; if below the lower line (C), they appear cold and somewhat dim. This should be specified prior to choice of luminaires and colors.
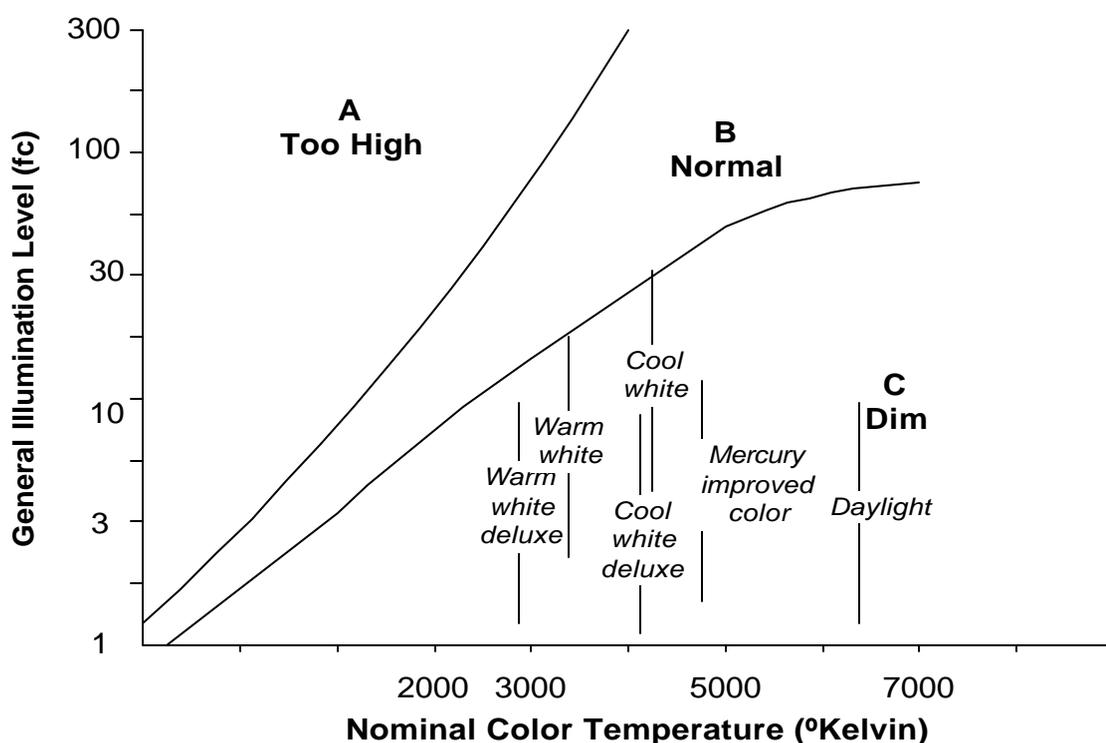
Figure 10-1. Nominal color temperature under different general illumination levels.

10.2.2 Acoustics

HVAC AND NOISE

Many TMC's have unexpectedly severe noise problems. While the ambient noise level from TMC operations is not generally high, computer fans and the HVAC infrastructure that keeps the room cool add a great deal of distraction. In some sites, fans, radio messages, and other sporadic noise cause communication problems, particularly during traffic peaks.

Most standards for acoustics are written to cover extreme cases — sound levels high enough to be hazardous. In the TMC, noise problems are most likely to result from distracting alarms or

radio and telephone communications by other operators. In some centers, significant noise levels are produced by data processing equipment.

Noise can affect worker comfort, job satisfaction, and performance. In general, the desirable condition is one in which speech interference is negligible. The objective is balance of sound sources so that local speech is unaffected, but levels are high enough to mask intrusive noise from adjacent spaces.

For most work places, the following rules on environmental noise apply:

10/14 Occasional Communication   **(Principle; 38)**

Areas requiring some telephone use or occasional direct talk at distances up to 1.5 m (5 ft) shall not exceed 75 dBA.
Note how this may affect workstation spacing where voice communications among operators is required.

10/15 Frequent Communication   **(Principle; 38)**

Areas requiring frequent telephone use or direct talk at distances up to 1.5 m (5 ft) shall not exceed 65 dBA.
This approximates the noisiest TMC.

10/16 Noise Sources Reduction   **(Observation)**

Identify possible noise sources during design. These include machines, telephones frequently in use, loudspeakers, and radios with speakers. Employ strategies for reducing noise levels including textured or sound-deadening wall and ceiling materials.

10/17 Noise Unrelated to Operator Activity   **(Observation)**

Locate noisy functions that are not tied to normal operator activity in a separate room or an area enclosed by acoustic partitions.

10/18 Headsets Use (Observation)

If noise sources cannot be isolated, use headsets for operators rather than loudspeakers.

10/19 Communication Area Noise (Principle; 38)

Areas requiring communication without difficulty should not exceed 45 dBA , (e.g., conference rooms, libraries, offices, and command and control centers.)
This approximates the desired standards for a functioning TMC.

10.2.3 The thermal environment

Operator comfort and performance are affected by temperature and air quality. For TMC design purposes, there are two areas of concern: general HVAC standards and the effects of local thermal conditions related to special equipment such as computers and video displays.

10/20 Personnel Enclosure Ventilation (Principle; 38)

Ventilation shall be assured by introducing fresh air into any personnel enclosure.
Ventilation requirements for large spaces such as the TMC are shown in Figure 10-2.
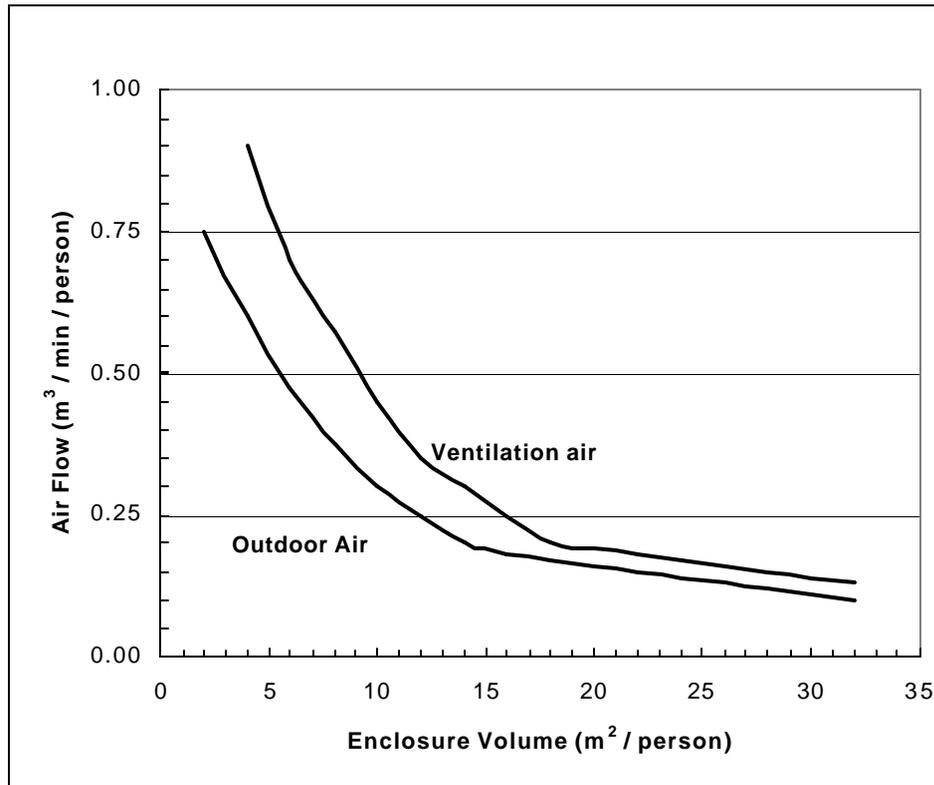
Figure 10-2. Minimum ventilation requirements.

10/21 Temperature in Personnel Area **(Principle; 38)**

Effective temperature should be maintained not less than 18° C (65° F), and not greater than 29.5° C (85° F).
These boundaries are rather liberal and temperatures near either extreme are likely to promote complaints. The temperature range for personnel in the TMC should be tailored to their preferences. A temperature of about 21.5° C (71° F) is usually acceptable. However, people vary greatly in their preferred temperature.

10/22 Relative Humidity in Personnel Area **(Principle; 38)**

Approximately 45 percent relative humidity should be provided at 21° C (70° F). The humidity should decrease with rising temperatures (at a rate of 2 percent relative humidity per degree F), but should remain above 15 percent to prevent irritation and drying of body tissues.

10/23 Temperature at Head and Floor Levels   **(Principle; 38)**

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

Equipment thermal standards. In addition to architectural specifications for the TMC that delimit the HVAC requirements, designers should keep in mind the effects of equipment used in the work area. Small computers, for example, can produce significant amounts of heat.

10/24 Forced-air Exhaust Units   **(Principle; 38)**

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

10/25 External Surface Temperatures   **(Principle; 38)**

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

10/26 Temperature Under Work Surfaces   **(Principle; 38)**

Heat build-up from equipment under the work surface (in the area of the operator's knees and legs) greater than 3° C (5.5° F) above ambient should be avoided.
Insulation or ventilation may be used to reduce the heat buildup.

10.3 Design of the Environment

The TMC is a work space like any other, with supporting spaces, fixtures, and special requirements. The rules that follow summarize the major concerns of the designer for safe, comfortable and efficient human use.

10.3.1 Entryways

Entry and exit considerations are central to architectural planning of space to be occupied by people. While common conventions for entryway design and placement exist, special

considerations for TMC's and other control rooms may require compromises.

Doorways. In specifying the doorways in the TMC, designers should take into consideration the following: [125]

- ! **Doorway clearance needs**. This applies not only to workers, but also to the equipment that must be moved in and out of the TMC for maintenance, installation, and other purposes.

- ! **Type of door**. This includes the material, door opening geometry, manipulating hardware, locking system, see-through requirements, door position retention, type of threshold, etc.

- ! **Automatic versus manual door articulation.**

- ! **Identification (e.g., signage, security).**

- ! **Sealing against drafts, extreme pressure differentials, water leakage, dirt, noise, and dust, etc.** The major considerations for the TMC are temperature control, noise, and contamination. In an environment that houses information systems, dust and other contaminants can be a long-term problem.

General guidelines for doorway design follow.

10/27 Door Styles   **(Principle; 125)**

Do not use revolving doors or all-glass frameless doors; these are apt to be misused and cause personal injury.

10/28 Door Weight   **(Principle; 125)**

Avoid the use of extremely large and/or heavy doors if they are to be manipulated by hand.

10/29 View Ports   **(Principle; 125)**

Provide view ports on free-swinging doors.
The view ports should be positioned to allow the shortest statured TMC staff member, less than 1.5 m (5 ft) in height, to see a person of similar height on the other side of the door.

10/30 Door Handle Style   **(Principle; 125)**

Avoid use of door handles that are hard to grasp or manipulate.
Use the preferred style shown in Figure 10-3.
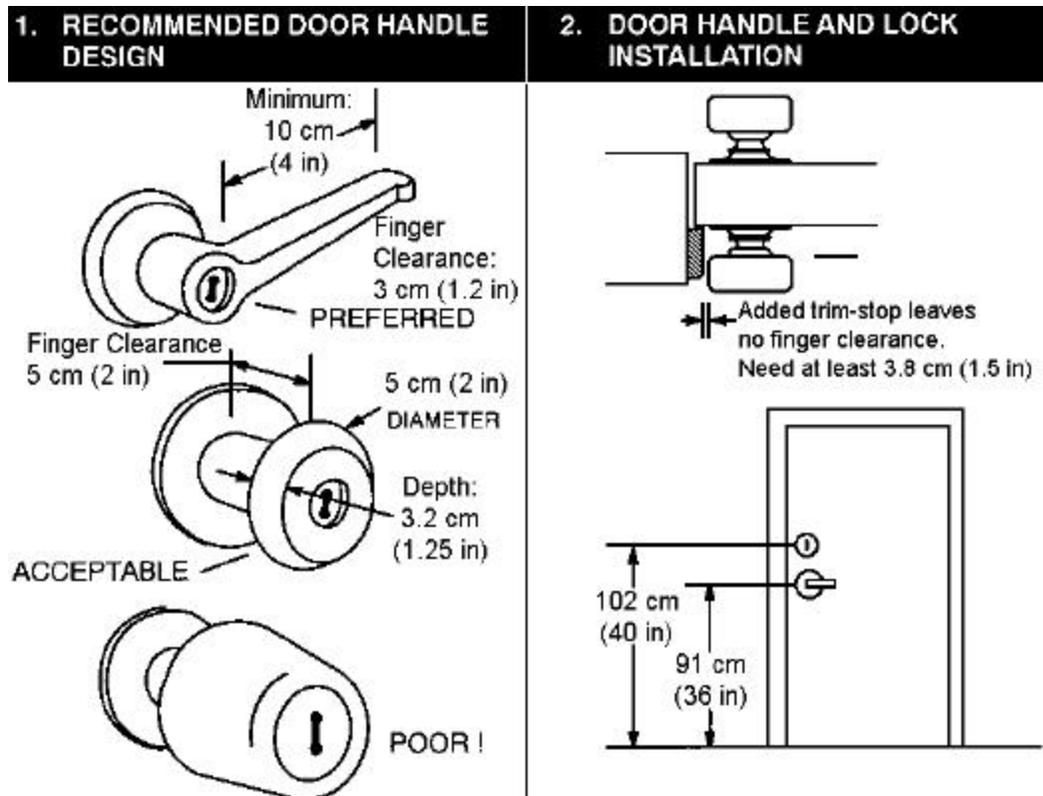
Figure 10-3. Door latching designs (after Woodson, Tillman & Tillman, 1992).

10/31 Placement of Door Handles   **(Principle; 125)**

Place door handles where they provide the best advantage for gripping and manipulating the door.

10/32 Door Handle Operation   **(Principle; 125)**

Door hardware should indicate to the user whether to push, pull, or turn a handle.
If the door is to be pushed, identify the side to push.

10/33 Location of Door Latches	(Principle; 125)

Select door latching or locking systems that are easy to operate and locate them where the operator will be able to visually guide the key.

10/34 Door Hardware	(Principle; 125)

Select door hardware that does not have sharp corners or edges that could cause injury.

10/35 Door Threshold	(Principle; 125)

Select and/or design floor thresholds that are relatively smooth so that pedestrians will not trip.

10/36 Door Height and Width	(Principle; 125)

In general, architectural doors should have a height of 203 cm (80 in) and a width of 91 cm (35 in).
The width is measured from the edge of the door frame opposite the hinge to the edge of the open door. The recommended width minimizes the need to dismount the doorway to move in furniture or other large objects. The minimum width is 76 cm (30 in). However, 91 cm (35 in) is required to allow standard wheelchair to pass.

10/37 Corner Doors	(Principle; 125)

Doors located in the corner of a room should open toward the corner.

As suggested by Figure 10-4, this facilitates exit from the room and reduces the chance that a person will collide with the door.

10/38 Door Opening at Hallway	(Principle; 125)

Doors should *not* open into hallways.
This eliminates the possibility that someone in the hallway might be struck by a door that is being opened from the other side.

10/39 Double Door Configurations	(Principle; 125)

Avoid double door configurations that have a narrow divider or post between them.
Experience has shown that people do not notice the divider and collide with it.

10.3.2 Walkways and hallways

Most TMC's are served by hallways and corridors. The human considerations include the following (see Figure 10-4):

10/40 Hallway Passage	(Principle; 125)

Interior hallways should allow people to pass without bumping into walls, other people, or equipment attached to walls (e.g., fire extinguishers). The minimum width is 1.4 m (54 in).

10/41 Door Placement	(Principle; 125)

Doors should be 1.5 m (5 ft) from hallway corners for safety (see Figure 10-4).

10/42 Floor Cove Designs	(Principle; 125)

Avoid floor cove (baseboard) designs that invite tripping.
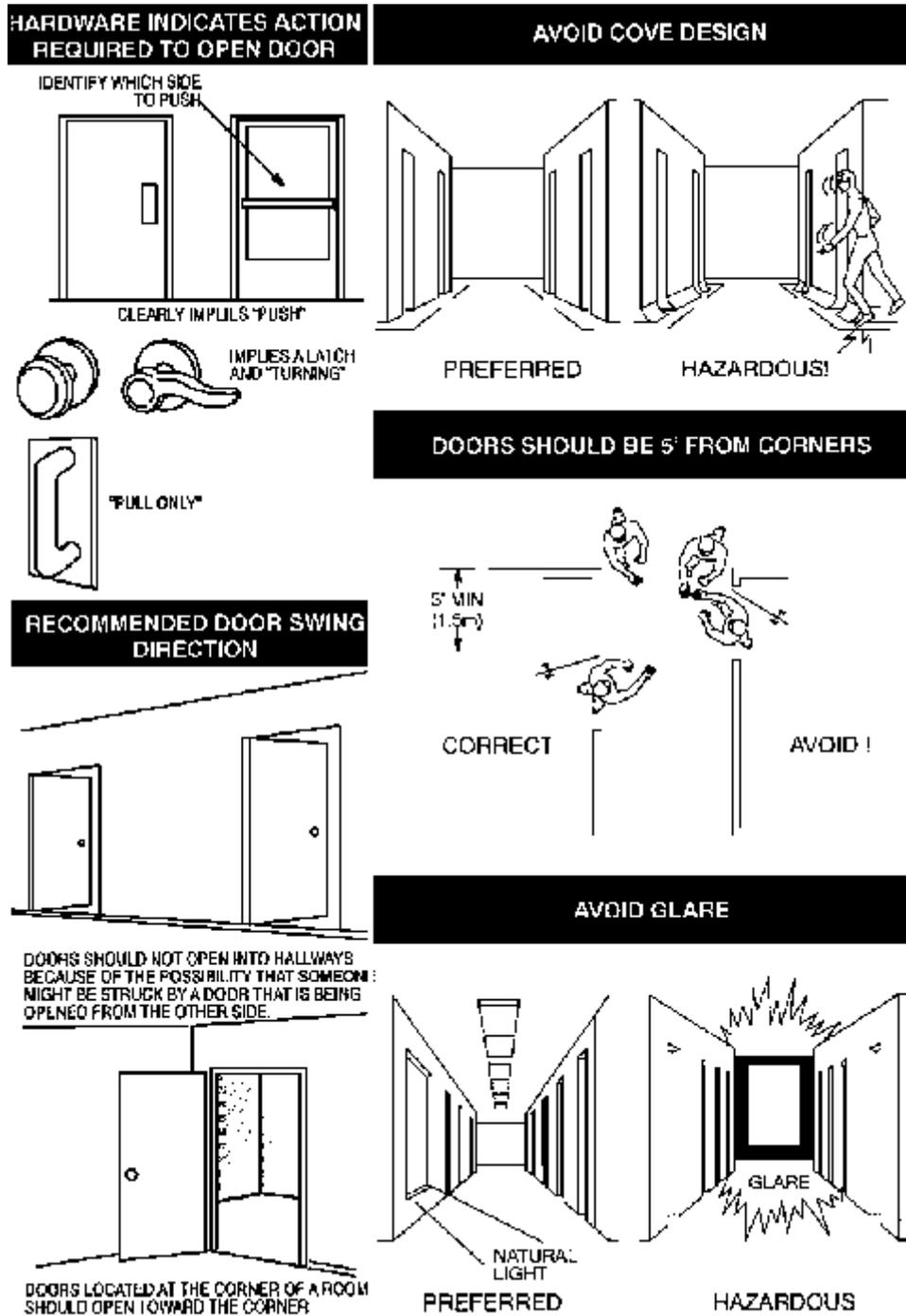
Figure 10-4. Door and hallway design guidelines.

10/43 Illumination of Hallway (Principle; 125)

Hallway light sources should provide an illuminance of no less than 108 lux (10 fc).

10/44 Natural Light in Hallways　　　　　　　　**(Principle; 125)**

Avoid natural light entering only at the ends of hallways.
A person facing a window at the end of a hallway may encounter glare from
daylight reflecting from hard surfaces.

10/45 Reflectance in Hallways　　　　　　　　**(Principle; 125)**

**Hallway walls, ceilings, and floors should be coated to meet
reflectance standards for office space — ceilings, 80-90 percent;
walls, 50-85 percent; floors 15-35 percent.**

10.3.3 Stairs and ramps

10/46 Ramp Accommodations　　　　　　　　**(Principle; 125)**

**The slope of ramps designed to accommodate handicapped users
should not exceed 5 percent.**

10/47 Handrails on Ramps　　　　　　　　**(Principle; 125)**

**Handrails should be installed on all ramps or platforms that are more
than 0.6 m (2 ft) above grade.**

10/48 Stair Design　　　　　　　　**(Principle; 125)**

**As suggested by Figure 10-5, design stairways without overhangs
that might catch toes.**
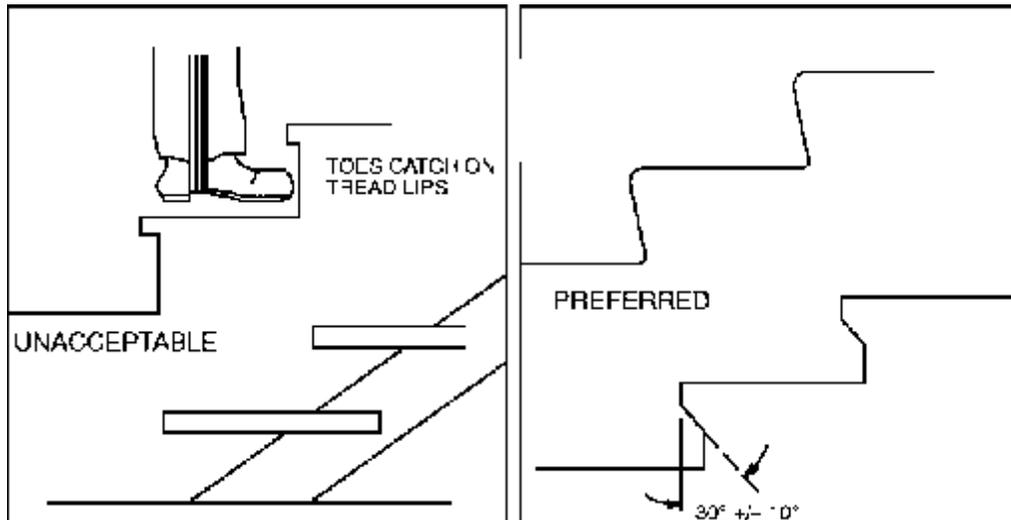
Figure 10-5. Stairway design to avoid tripping.

10/49 Large Object and Stairs (Principle; 125)

As suggested by Figure 10-6, design stairs to accommodate movement of large objects.
TMC's will be upgraded over time; equipment and furniture will need replacement. Plan for the task of replacing a TMC's large situation map or other large equipment elements.
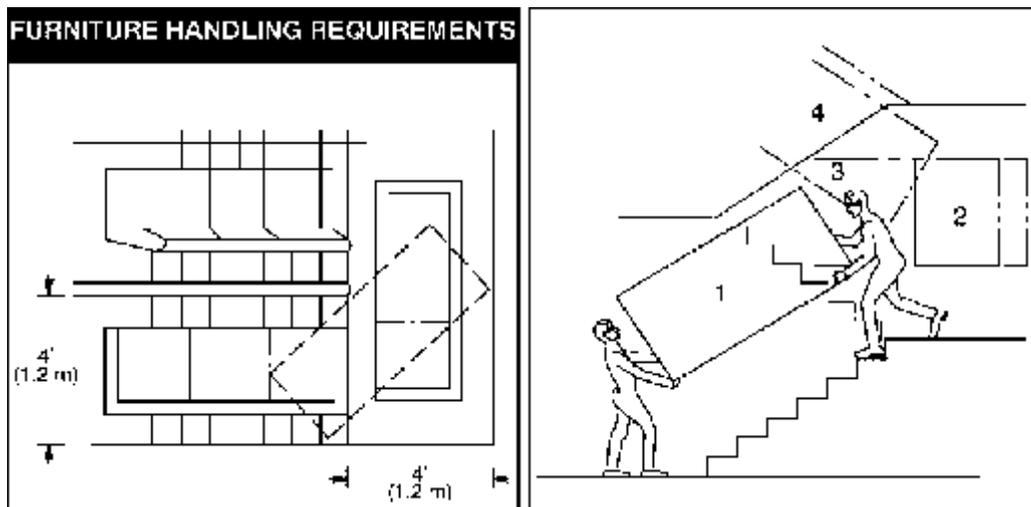
Figure 10-6. Stairway design for furniture handling.

10.4 Furnishings

TMC designers will rarely *design* the furniture for use in their facilities. The following guidelines are provided to aid in the selection and specification of furniture for the control room. The considerations are by no means cosmetic (though attractive furniture of good quality is desirable

as a hygiene factor in the work area). Productivity and health issues are paramount in these selections, and poor design may result in fatigue and physiological symptoms.

10.4.1 Chairs

The seating used by a TMC operator is an essential part of the human/machine system, not an afterthought. Productivity and health of workers who must operate in a work station environment for long periods are sensitive to comfort, circulation, posture, and spinal stress. A work station chair should provide postural support, adjustability, subjective comfort, and — particularly in the control room environment — mobility.

Chair design relies on a variety of production technologies, but it also requires knowledge of anthropometry. A chair used in work situations must be easily adjustable and adjustable enough to accommodate the practical range of body dimensions; this adds (unavoidably) to the complexity and expense of ergonomic seating. It is worth the price.

Figure 10-7 illustrates elements of ergonomic chair design. Seating should meet the following guidelines:

10/50 Adjustability of Chairs **(Principle; 38)**

Chairs should be adjustable to fit the 5th percentile female through 95th percentile male.

10/51 Seat Pan Height **(Principle; 38)**

Seat pan height should be adjustable within the range of 40.6 to 52.0 cm (16.0 to 20.5 in).
This range accommodates the 5th percentile female to 95th percentile male popliteal height. A foot support may be added to provide more comfort for operators with shorter popliteal heights.
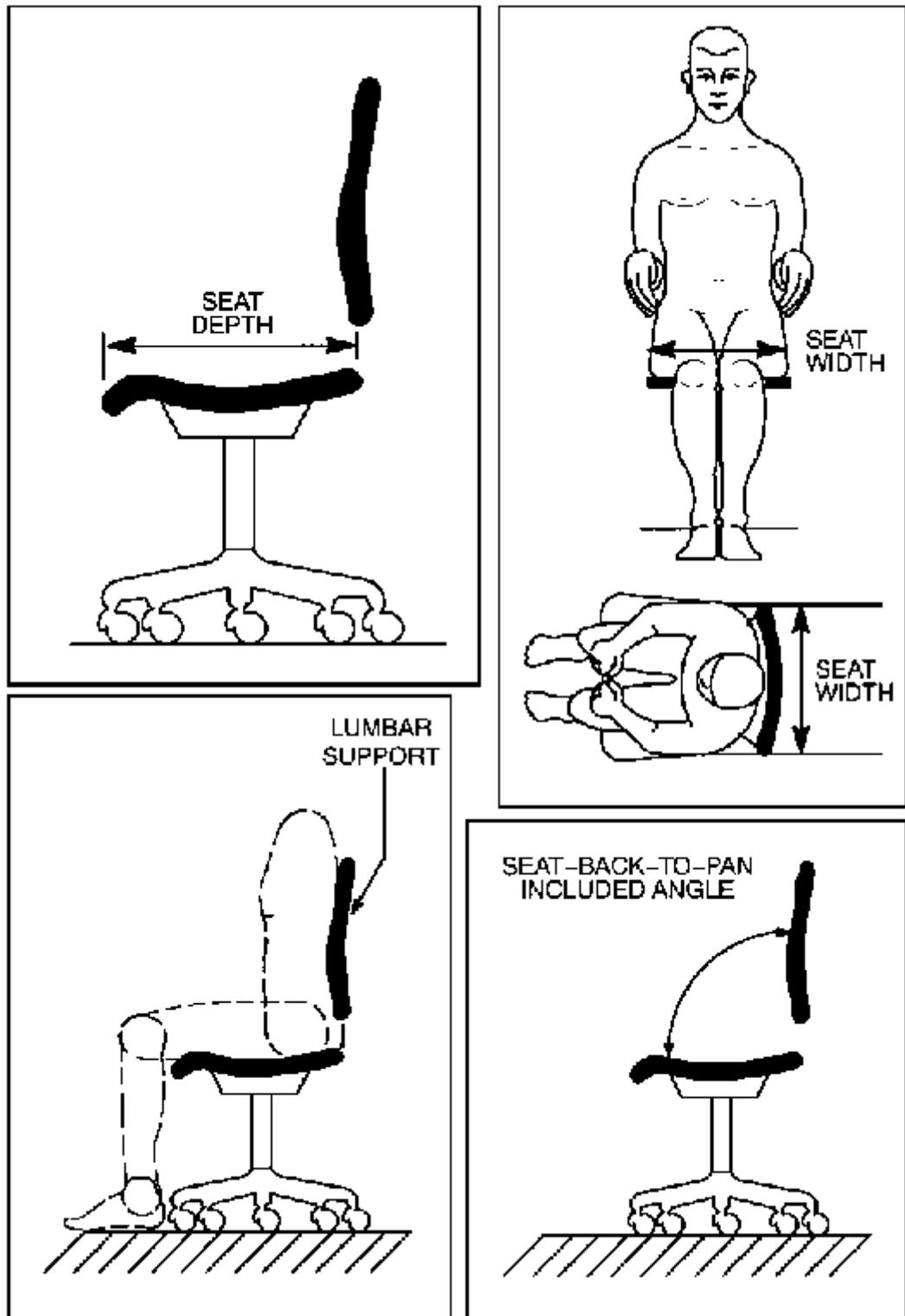
Figure 10-7. Elements of ergonomic chair design.

10/52 Seat Depth (Principle; 38)

Seat depth should allow contact of the lumbar region with the seat back without creating pressure between the front seat edge and the lower leg.
This requires a depth of 38 to 43 cm (15 to 17 in).

10/53 Front Edge of Seat (Principle; 125)

The front seat edge should be well rounded to minimize pressure on the bottom of the thighs to allow full blood flow.

10/54 Stability of Seating (Recommendation)

To promote stable seating, the chair should have five legs.

10/55 Chair Padding (Principle; 125)

Seat padding should compress 2.5 cm (1 in) or less under a seated person.

10/56 Weight Transfer (Principle; 67)

The seat should allow most of the weight to be transferred to the seat by the buttocks.

10/57 Seat Width (Principle; 38)

Seat width should be 45 cm (18.2 in) measured at the center directly over the support spindle to accommodate the general range of seated thigh width.

10/58 Seat Pan Angle (Principle; 38)

Seat pan angle should be between -10 and +10 degrees. Seat pan angle is the horizontal tilt of the seat forward and back.

10/59 Torso to Thigh Angle (Principle; 4, 6)

Angle between seat back and seat pan should permit the user to maintain a torso-to-thigh angle of at least 100 deg.

10/60 Lumbar Support (Principle; 38)

Angle the seat to provide support in the lumbar region.
This stipulation is used in place of backrest height.

10/61 Width of Seat Back (Principle; 38)

Provide a seat back width of 30.5 cm (12 in) in the lumbar region.
This width allows the worker to make shifts in working posture to relieve stress.

10/62 Caster Selection (Principle; 38)

Provide a caster selection which is appropriate to floor surface.
Most work stations will require mobility of the seated operator. Chair mobility is provided by casters. Even in the case of a relatively stationary task description, an operator will have to move the chair toward or away from the work surface. Different types of casters are available for hard and for carpeted floors, and should be specified when ordering.

10.4.2 Work surfaces

The complement to the seat in a work station is the work surface — the "mini-environment" in which the operator will execute most of the activities in the TMC. The work surface is home to information system elements such as the monitor, input devices such as mouse and keyboard, telephones, CCTV camera controls — as well as accessories such as a note pad or a coffee cup. As with seating, the work surface is a part of the system, and provides a mechanical infrastructure for the operator.

Critical problems with furniture, with its principal purpose being to support a work surface, include compatibility with seating, adequate space for all activities, durability, appearance (including surface glare), and ergonomic properties.

A serious problem encountered during on-site research was the tendency to store boxes, papers, and other baggage under the console work surfaces. This restricted clearance for operators' legs and feet; in many cases, they could not place their chairs and knees properly because of the obstructions, and were forced to lean over the edges of the work surface to reach keyboards or read displays. This posture can contribute to back pain and fatigue.

10/63 Work Surface Clearance Envelopes   (Principle; 38)

Enable work surfaces to accommodate the clearance envelope of the 5th percentile female to 95th percentile male.

The "clearance envelope" is a solid space below the undersurface of the work area that must accommodate the legs of the operator. The critical measures are thigh and knee height. Figure 10-8 and Table 10-1 show the dimensions of the clearance envelope for 5th percentile female and 95th percentile male.

10/64 Operator Clearance Envelopes   (Observation)

Ensure that operator clearance envelopes beneath the workstation or console are free from obstruction.

10/65 Storage Space   (Observation)

Plan adequate storage space.

This is a natural corollary to guideline 10/65.

10/66 Forearm Angle to Work Surface   (Principle; 4)

A work surface supporting keyboard and monitor should allow the operator to work with the forearm at a comfortable angle.

Figure 10-9 shows the method of calculation, which allows for the angle of the upper body (superior frontal plane). The forearm angle should be between 70+Y/2 degrees and 90+Y/2 degrees, where Y is the back angle from the vertical.

| Minimum Knee Space	5th Percentile Female		95th Percentile Male	
	cm	inches	cm	inches
Minimum Depth* –Depth at knee level* –Depth at toe level*	 31.0 47.5	 12.2 18.7	 38.0 59.0	 15.0 23.5
Minimum Width	50.8	20.0	50.8	20.0
Minimum Height** – Adjustable Surface – Nonadjustable Surface	 51.3 –	 20.2 –	 66.5 66.5	 26.2 26.2

* The minimum depth under the work surface from the user's side of the work surface
**From the floor to the bottom of a support surface

Figure 10-8. Knee clearance envelope for seated console.

10/67 Support Surface Height   **(Principle; 38)**

Provide a support surface height which permits the entire viewing area of the display to be located between 0 deg and 60 deg below the horizontal plane passing through the eyes.
This requirement is comfortably within the dimensions of most computer fixtures and monitors.
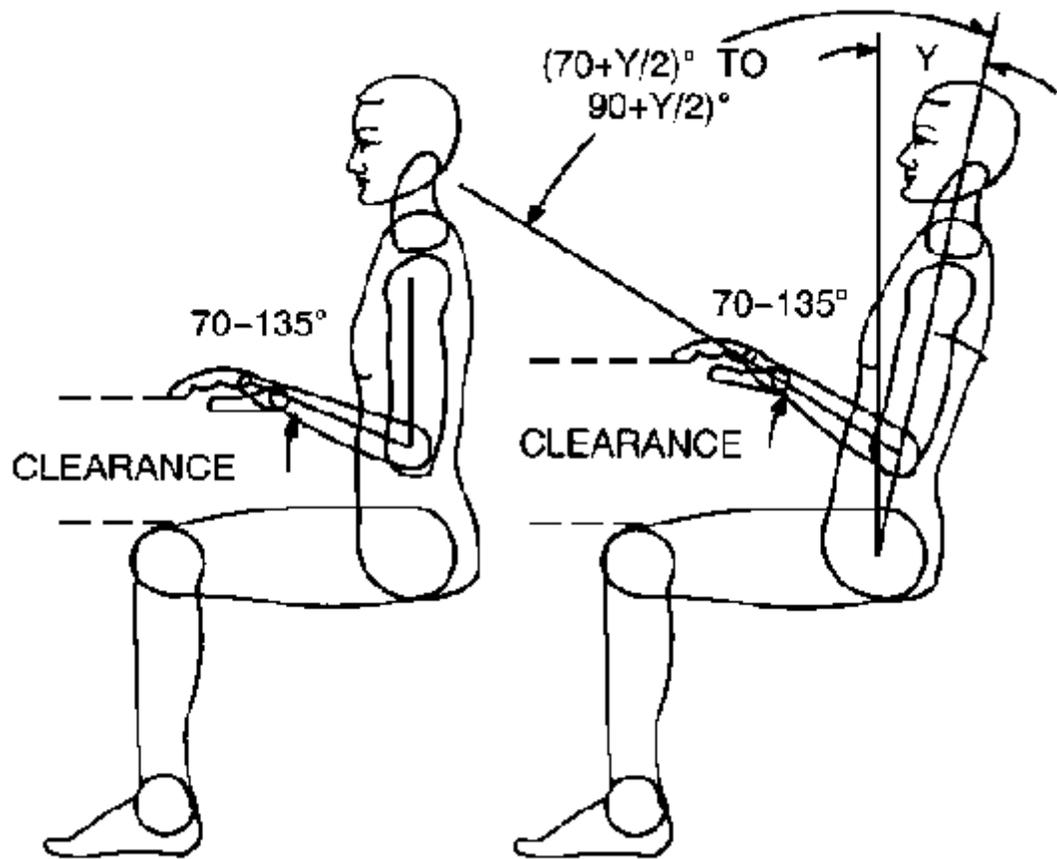
Figure 10-9. Measurement of recommended forearm angles.

10/68 Work Surface Height Adjustability   **(Principle; 38)**

For seated operators, provide an adjustable work surface (keyboard support) that ranges in height from 58.5 cm to 71.0 cm (23.0 to 28.0 in).
This range allows adjustment for 5th to 95th percentile operators.

10/69 Work Surface Edges   **(Principle; 38)**

Provide rounded edges for work surfaces that come in contact with arms, wrists, or hands to avoid repetitive stress; edges on which arms or wrists rest should preferably be padded.
A sharp edge will cause stress to the tendons of the wrist and possible work-related injury. For cases where the work surface is already in place, ergonomic keyboard pads are available commercially.

10.4.3 Control panels

A control room designed using the methods described in Chapter 2 (including link analysis and accessibility analysis) will require only a minimum of movement by operators. Most control panels in the TMC, therefore, will involve seated operator consoles. These generally involve a work surface and instrument console (as in Section 10.4.2). These will often be multi-operator stations located with a view of critical TMC displays such as situation maps and CCTV monitor banks. Design of the workstation/console often requires compromises and creativity, since the best arrangement of controls and displays may block line of sight.

10/70 Console Design Planning   **(Principle; 38)**

Planning for console design or selection should include the following factors:

- **!**   **Visibility over the top of the console**
- **!**   **Operator mobility (e.g., "sit-stand" requirements**)
- **!**   **Panel space**
- **!**   **Volume in the area below the writing surface**

10/71 Horizontal Layout of Controls and Displays   **(Principle; 6)**

Arrange controls and displays to allow horizontal scanning.
Eye and head motions in a horizontal direction are less tiring. Common controls and displays mounted in such panels will include video displays, keyboards, and other computer input devices, camera controls, telephone and intercom fixtures, and job aids. See Figure 10-10 for recommended console height measures.

10/72 Job Aids at Work Station   **(Observation)**

Allow space for job aids.
All work stations will eventually acquire essential job aids, such as procedural notes, critical instructions, telephone numbers, and reminders. These often take the form of "post-its" or taped pieces of paper. Some TMC's use small panels of white marker board to carry temporary notes and guidance. They may look messy, but they are often *essential* to effective operations. Accept their necessity and make them look neat and functional by adding them systematically to the display plan rather than taping them up as an afterthought. Standard procedure should be established for writing and posting such customized job aids.
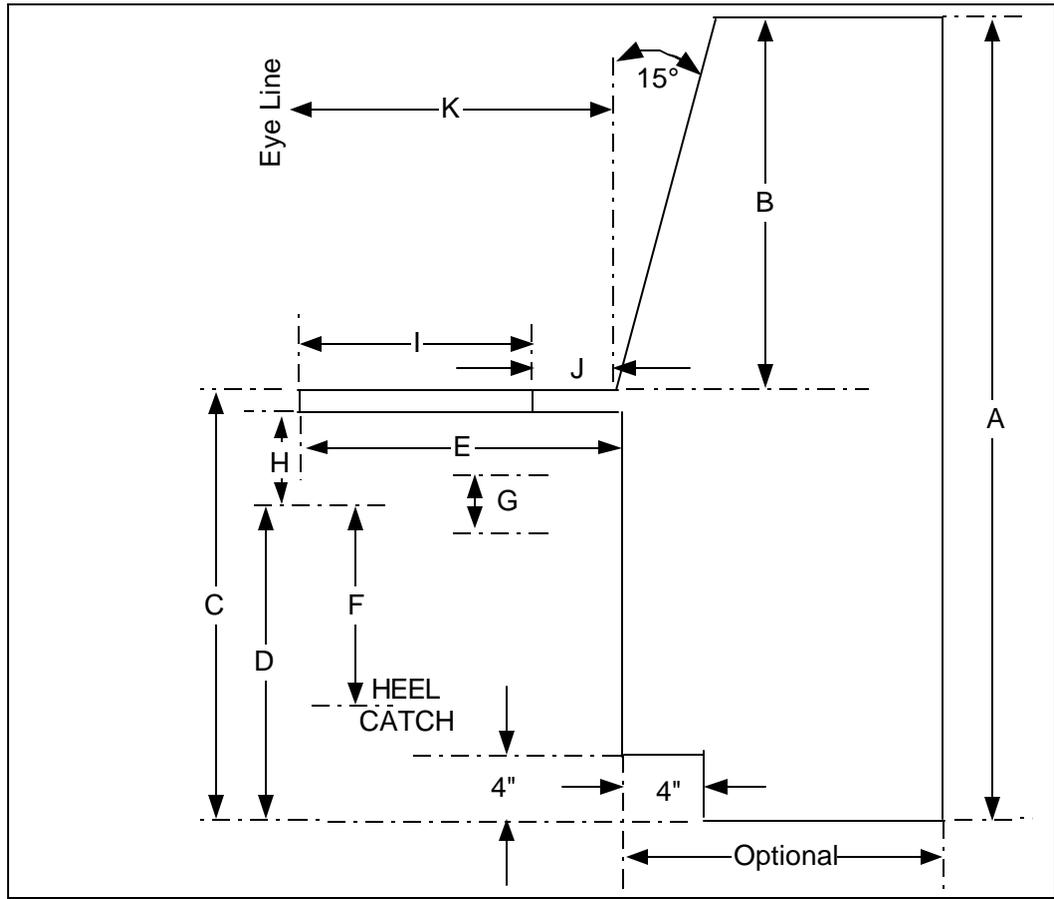
Figure 10-10. Recommended console dimensions (see Tables 10-1 and 10-2).

Table 10-1. Recommended console dimensions.

Key	Dimensions	Centi-meters	Inches
A	Maximum console height from standing surface (e.g., floor)	See Table 10-2	
B	Suggested vertical dimension of panel including sill	See Table 10-2	
C	Writing surface: shelf height from standing surface	See Table 10-2	
D	Seat height from stand surface at midpoint of G	See Table 10-2	
E*	Minimum knee clearance	46	18
F*	Foot support to sitting surface**	46	18
G*	Seat adjustability	15	6
H*	Minimum thigh clearance at midpoint of G	19	7.5
I	Writing surface depth including shelf	40	16
J	Minimum shelf depth	100	4
K	Eye line-to-console frong distance	40	16

* Not applicable to console types 4 and 5 listed in Table 10-3.
** Because this dimension must not be exceeded, a heel catch is required on chair if D exceeds 46 cm (18 in).

Table 10-2. Supplemental console dimensions recommendations.

Type of Console	Maximum Console Height from Standing Surface	Suggested Vertical Dimension of Panel (Includes Sills)	Writing Surface Shelf Height from Standing Surface	Seat Height from Standing Surface at Midpoint of G	Maximum Console Width (Not Shown)
	A	B	C	D	
Sit (w/vision over top)*	115 131.25 146.5	51.25 51.25 51.25	63.75 80 90	42.5 80 90	110 110 110
Sit (w/o vision over top)*	128.75 145 155	65 65 70	63.75 80 90	42.5 58.75 68.75	90 90 90
Sit stand (w/standing vision over top)	151.25	61.25	90	69	90
Stand (w/vision over top)	151.25	61.25	90	NA	110
Stand (w/o vision over top)	180	90	90	NA	90

*Three dimensions are provided to allow latitude in the height of the lower part of the console. Use values from a single row. Dimensions are in centimeters.

Incorporate anthropometric reach limit criteria in work space design. Refer to anthropometric standard reach envelopes discussed in Chapter 7. Since most units in the TMC are built for multiple operators, this analysis should take into account the *team operating procedures.* A mockup may be helpful.

Analyze placement of controls and displays. Chapter 2 discusses general tools for locating controls and displays (e.g., link analysis). There is, however, a more precisely objective method for critical components based on the *accessibility index* of a control. [8] The formula used for this approach is:

$$ I = r \& \mathbf{j}^s \left| \frac{\mathbf{j}^n f}{N} \right| \& S $$

(2)

where *r* is the Pearson product moment correlation coefficient of the operator/control distance and the ranked frequency of use of the control; f_i is the frequency of use rank of each control inside the standard reach envelope (see Chapter 7), and f_o is the frequency of use rank of each control outside the standard reach envelope; *n* is the number of controls inside, and *N* the number outside the envelope; and *S* is the number of operators used to collect the data.

Testing a proposed control layout in this way usually occurs during prototype or mockup, and should use a selection of operators that accurately represent the range of reach envelopes. Use of scenarios representing a range of TMC functions, combined with meticulous observation, will yield the frequency of use of different elements of the console (this information can also be derived from task analyses, though less reliably). If the work is performed carefully, the result will be an accessibility index with a range between -2.0 and +1.0. A low score suggests the need for redesign.

Designers should consider the room as a total system during planning. Visibility, accessibility, operator interactions, and other factors should be paramount, not simply meeting individual subsystem standards.

Several target sites suffered from an almost unavoidable expansion problem that resulted in what one analyst called "keyboard farms." As new systems and capabilities were added, individual operators were often confronted with three or four keyboards in a small area, with two or three pushed aside or stacked when not in use. (These sites also suffered the line of sight blockage due to the extra monitors.)

10/74 Workstation Space   (Observation)

Provide additional space at workspace to accommodate future components.

10/75 Multi-User Station Planning Process   (Recommendation; 125)

Multi-user stations should be planned systematically:

- **! Start with basic single-operator requirements.**
- **! Expand dimensions for additional operators.**
- **! Accommodate commonly used equipment.**

DESIGNING FOR A CLEAR VIEW

When planning the "see-over" height for TMC consoles, designers should not rely solely on published standards. For example, in several TMC's operators do not have a clear view *despite* the fact that their consoles are heights are within accepted dimensions. The problem is that general displays (big board and CCTV monitor banks) are rather large and, constrained by ceiling height, their bottoms are close to the floor. In these cases, operators adjust their chair seat heights to maximum, or stand, to view the bottom of the monitor banks or big board.

10/76 Use of Mockups   (Observation)

Use models or mockups in the planning phase.
Cardboard or Styrofoam models or mockups can help with the detection of layout and line-of-sight problems. Visibility problems can also be identified by using CAD systems with solid, 3-dimensional modeling and variable viewpoint capabilities (see Chapter 2).

10.5 Design for Individual Differences

Chapter 7 discusses the anthropometric guidelines for the design of control centers. In this section a few reminders are given for those who design the operator jobs as well as the work environment. Individuals differ on many physical and psychological dimensions. Some of these dimensions are valid personnel selection criteria; others are not. Since the enactment of the Americans with Disabilities Act, determining the physical and psychological selection criteria that can and cannot be applied legitimately is especially important.

Once legitimate selection criteria have been determined, designers should attempt to design jobs and environments that can accommodate (or easily be altered to accommodate) everyone who satisfies the criteria. Such design will benefit workers within the normal range of variation, as well as those with identified disabilities.

PLANNING FOR ALL OPERATORS

In a TMC, monitoring of TV screens and video displays is a common and critical task. Normal (or correctable to normal) vision is probably a legitimate selection criterion for operators. The communications tasks in a TMC may require normal hearing and speech abilities. However, there may be no defensible reason to limit a person with limited mobility from performing the operator job. The operator job should be designed to require minimum movement about the room. Workstation design should support task performance by an operator with less than normal mobility. In order to accommodate wheelchair-bound operators, one center in which staff members move between multiple levels for various functions now recommends that a single-level floorplan be used, or that ramps instead of stairs, be used.

10/77 Personnel Selection Criteria   **(Observation)**

Develop work-related personnel selection criteria that are based on documented task performance requirements.

10/78 Job Design for All Workers   **(Observation)**

Design the job and the work environment such that it fully accommodates the expected worker population.
This may include workers with sensory, motor and mobility challenges.

10/79 Adjustable Furniture (Observation)

Specify adjustable workstation furniture whenever practical to do so.
Additional furnishings, such as foot rests, may also be needed to make the workstation fit.

10/80 Design to Operator Limitations (Observation)

Design control/display layouts to support reaching, motion, stretching, bending, or lifting requirements for operators with limited capacity.

CHAPTER 11: THE USER-COMPUTER INTERFACE

CONTENTS

11.1 Designing the User-Computer Interface

The user-computer interface is a two-way communication link between human operators and the various devices and support systems that: (1) provide information to operators and carry out operators' instructions. The user-computer interface includes hardware devices for input and output (keyboard, mouse, display screens, printers, etc., discussed in Chapters 9 and 10), and the software for displaying information or taking the user's input. This chapter presents guidelines on the user-computer interface.

The system analysis approach to user-computer interface design is characterized by three basic principles: [61]

> ❗ **Early (and continuing) focus on users and tasks**. As is the case with other human factors issues, early design focus on the user requirements allows many interface problems to be detected or prevented before the complete package has been delivered.

> ❗ **Empirical evaluation**. Interfaces that have been thoroughly tested by representatives of the user population at various steps during the design process are more likely to prove satisfactory when the system is fielded.

> ❗ **Iterative design and revision.** Designs are rarely perfect the first time. User computer interface problems can be identified and corrected most effectively and in the most timely fashion by use of an iterative design/test/redesign/retest processes that use a careful prototyping process (see Chapter 2).

The early focus on users and tasks is intended to ensure that the interface and associated user aids, such as training materials, online help, tutorials, manuals and job aids, support the tasks that users need to accomplish. Empirical evaluation allows for direct comparisons among proposed interface designs in order to determine which prototypes yield the lowest error rates, fastest performance, and lowest cost. Decisions on design trade-offs are made in an informed manner before expensive programming efforts begin. *Potential users* are asked to educate the designer about their needs, help design an interface that meets those needs, respond to prototype simulations of the interface, and evaluate successive versions of the interface during

development.

11.1.1 Steps in the user-computer interface design process

An ideal design process as shown in Figure 11-1 incorporates each of the three main systems analysis principles into a phased implementation of the user-computer interface. In the first phase, *requirements analysis*, the system is operationally defined. User and task analyses are performed to determine *how users interact* with the functions and modes of operation of the interface. In the second phase, *empirical evaluation*, models of the interface are tested by potential users to ensure that the designers understand how the system should operate from the Users' point of view. Alternative designs are tested to arrive at a configuration that provides an acceptable level of operator performance. In the third phase, *test and implementation*, the full interface is evaluated by potential users and revised as necessary to ensure optimal performance and ease of use. Finally, the interface is integrated with the "operating" software required to run the computer.

11.1.2 Benefits of the systems analysis approach

The systems analysis approach is intended to avoid common, costly mistakes in user-computer interface design. Phase 1 is used to plan the interface and to develop functional requirements from a user- and task-oriented perspective. Phase 2 is used to test prototypes of screens, displays, and transactions. Iterative design is especially important in this phase, because changes made at this step (prior to extensive programming) can avoid costly changes once the interface has been developed. Phase 3 is used to develop the final version of the interface and to verify that it is programmed to meet all specifications. Phase 3 ends with implementation of a fully integrated system, that includes the user-computer interface and the operating software.

11.2 Consistency

Consistency of the user-computer interface is critical to efficient learning and use of the system. Consistency applies to many aspects of the interface, including screen layouts, colors, methods of interaction, navigation through the system, mapping of functions to Users' inputs, and definitions of data elements. The manner in which the system functions and appears to the user should be consistent with the rest of the system interfaces, procedures, and training.

PHASE 1: REQUIREMENTS ANALYSIS

Planning	→	User and Task Analysis	→	Functional specifications

Identify design
  constraints.
Define design activities.
Set schedules and
  milestones.
Identify resource
  requirements.

Analyze missions and
  functions.
Review comparable
  systems.
Define user roles and
  requirements.
Perform task analysis.

Identify design
  constraints.
Define design activities.
Set schedules and
  milestones.
Identify resource
  requirements.

PHASE 2: INTERFACE DESIGN AND DEVELOPMENT

Interface Concepts	→	Interface Design Studies	→	Interface Design Specifications

Develop screens and
  displays.
Specify interactions.
Define procedures for
  use.
Design decision aids.

Conduct simulations and
  rapid prototyping.
Define tradeoffs in
  interface design.

Specify design criteria
  for displays, dialogs,
  job aids, and user aids,
  etc.
Design users' manual

PHASE 3: TEST AND INTEGRATION

Design Verification	→	User Acceptance Testing	→	Design Integration	→	Interface Implementation

Verify displays,
  dialogs,
  transaction
  control,
  procedures, etc.

Individual and
  group tests with
  users.
Field tests.

Plan integration
  of interface with
  larger system.
Develop training
  plan.

Specify final
  procedures.
Develop training.
Finalize user
  documentation.
Final imple-
  mentation plan.

Figure 11-1. The ideal user-computer interface design process.

11.2.1 Benefits of consistency, negative effects of inconsistency

Consistent interfaces are both easier to learn and require less memory capacity on the part of the user. In a consistent interface, whatever the users learn in one part of the system (such as how to point to a particular item on a list) applies in all other parts of the system. In addition, users become more confident when using a consistent system.

Inconsistent interfaces cause users to make errors. For instance, when the meaning of a command differs depending on the context (e.g., *delete* can apply to anything from individual characters on screen to a file containing the user's most important data) the probability of errors increases. Errors can also occur when the procedure for implementing a command changes from one context to another (e.g., in an older generation TMC, checking the status of roadway loop detectors required the name of the roadway segment in one screen and the numeric identifier of the loop detector in another.)

11.2.2 Guidelines for consistent interface style

Figure 11-2 presents alternatives that define the "look and feel" of a user-computer interface. Decisions at the top level (those to be made first) determine the style of interaction: command-based, menu selection, and/or direct manipulation. Decisions about the second level of interaction determine how users will accomplish work with the interface. The decision regarding interaction style determines many of the options available under the second tier, and so selection of an appropriate interaction style is crucial to achieving a good match between task requirements and user performance.

Consistency in application of second-tier decisions (presentation issues regarding entry screens, windowing, highlighting, mapping, text, graphics, and tables) is critical for efficient operator performance. Inconsistency in these areas generates errors and frustration. [75] Each of the major headings presented in Figure 11-2 is discussed in detail in later sections of this chapter. Guidelines are presented in those sections.

11.2.3 Methods for evaluating consistency of user-computer interfaces

Evaluations of consistency should begin in Phase 2 and continue throughout the design and implementation phases. There are two methods frequently used for consistency evaluation:

- ❗ The questionnaire method.
- ❗ The "thinking aloud" method.

The questionnaire method. As the name implies, the questionnaire method involves a structured set of questions to be completed by users. [97, 121] The questionnaire is typically constructed to gather detailed assessments of consistency for many, but not all, aspects of the interface (from top-level considerations like method of interaction, down to specific workings of

commands and the wording of messages or the display of information). Users typically complete the questionnaire after having worked with the interface for a brief period of time. They are not, typically, asked to complete the questionnaire while interacting with the interface. The questionnaire can be delivered as a stand-alone survey instrument or may be completed as part of a structured interview between the system analyst and the user. Figure 11-3 provides a list of issues that a questionnaire should address.

TIER 1: INTERACTION STYLES

| Command-Based | Menu-Based | Direct Manipulation | Combined |

TIER 2: PRESENTATION

Entry Screens
- Navigation
- Active Field
- Cut / Past /Copy
- Verification Check
- Abbreviations
- Error Correction

Windowing
- Sizing
- Placement
- Active Window
- Customizing
- Switching

Highlighting
- Color
- Font
- Underlining
- Flashing
- Reverse Video
- Audible Signal

Mapping
- Orientation
- Scale
- Zoom in / out
- Location Selection
- Data Display Options

Text Styles
- Paragraph
- Bulleted Lists
- Verb Phrases
- Examples

Graphic Styles
- Bar / Line /Pie
- Collor Code
- Axes
- Labeling
- Raw Numbers
- Calculated Values
- Sizing
- Background

Tabular Styles
- Row / Column Headings
- Numeric Format
- Multiple Dimsions
- Raw Data
- Calcualted Values
- Sizing
- Background

Figure 11-2. Issues in determining the "look and feel" of a user-computer interface.

The advantages of the questionnaire method include a standardized and quantitative approach to user assessments (allowing designers to determine *how many* users are bothered by a given inconsistency) and some assurance that all users have at least *considered* the important parts of the interface during their evaluation. Disadvantages include the time it takes to complete an exhaustive survey and the method's reliance on Users' memory for inconsistency experienced during an earlier interaction with the system.

The "thinking aloud" method. In the thinking aloud method, the user is encouraged to verbalize while interacting with the interface. A systems analyst records the user's utterances

and asks for clarification as required. By listening to users attempt to work through real problems using the interface, system designers can find inconsistencies that require correction. [26, 61]

QUESTION	YES/NO	COMMENTS
INFORMATION ON CONTEXT FOR TRANSACTION CONTROL IS CONSISTENCY DISPLAYED.		
STANDARD ABBREVIATIONS AND ACRONYMS ARE EMPLOYED.		
CONSISTENT TERMINOLOGY IS USED FOR TRANSACTION CONTROL.		
THE USER IS PROMPTED FOR INPUT IN A CONSISTENT FASHION		
PROMPTS APPEAR IN EXPECTED, CONSISTENT LOCATIONS.		
ALARMS (WARNINGS AND ERROR MESSAGES) ARE DISTINCTIVE AND CONSISTENT .		
MENUS ALLOW ONLY ONE SELECTION AT A TIME.		
AVAILABLE, UNAVAILABLE, AND SELECTED MENU ITEMS ARE DISTINCTIVELY AND CONSISTENTLY HIGHLIGHTED.		
COMMANDS ARE ALL CONGRUENT WITH THE ACTION IMPLIED BY THE COMMAND NAME.		
EDITING OF ENTRIES IS SUPPORTED WITH CONSISTENT USE OF CURSOR CONTROL, INSERT, AND DELETE KEYS.		
COMMAND SYNTAX (THE ORDERING AND SPECIFICATION OF OPTIONS) IS CONSISTENT ACROSS ALL COMMANDS.		
THE MEANING OF COMMANDS AND COMMAND OPTIONS IS CONSISTENT ACROSS TRANSACTIONS.		
INFORMATION PROVIDED IN USER AIDS (JOB AIDS, MANUALS, AND ONLINE HELP) IS CONSISTENT BETWEEN THE DIFFERENT AIDS, AND MATCHES THE ACTUAL USAGE IN THE INTERFACE.		
THE MOST IMPORTANT, OR MOST FREQUENTLY USED COMMANDS ARE AT THE TOP OF MENUS OR GROUPS WITHIN MENUS		
PROGRAM FUNCTION (PF) KEYS HAVE CONSISTENT MEANINGS ACROSS OPERATIONAL MODES.		
HITTING ESC ALWAYS INTERRUPTS ONGOING PROCESSES AND DOES NOT RESULT IN LOSS OF WORK.		
HIGHLIGHTING IS APPLIED CONSISTENTLY THROUGH-OUT THE INTERFACE.		

Figure 11-3. User-computer interface consistency questionnaire.

Advantages of the thinking aloud method are that it targets the most noticeable problems and does not require additional time from the users involved in testing. Disadvantages are that the method does not yield quantitative results, is not standardized, and requires a substantial amount of analysts' time.

A combined approach. The two consistency evaluation methods work best when combined. The questionnaire method can apply to all users involved in testing the proposed interface. Their

answers can be assumed to apply to the most salient aspects of the interface. The thinking aloud method may yield data on aspects of the interface which had not been considered important or prone to problems prior to the test. For this reason, the thinking aloud method should be employed as an initial assessment with a small number of users. The utterances of these users can point to specific assessments that need to be added to the questionnaire. The questionnaire can then be given to all users as part of a more systematic evaluation of the interface.

11.2.4 Using inconsistency to "flag" important system events

Based on the principle that users become more aware of the interface when their expectations are violated, some system designers have taken advantage of this heightened awareness to alert users to important system events. [86, 99] Some system events are so detrimental to system functioning (such as inadvertent deletion of working files, shutting down the system, taking major components off-line, or issuing commands that change system status in inappropriate ways) that it is wise to require increased work on the part of the user to make them happen. The obvious solution, requesting verification of the input, is often not enough. Users become accustomed to automatically answering "yes" to such queries and will treat the response as an integral part of the original command (e.g., "delete" becomes "delete <pause> yes" in the user's mind). [86]

One way to use inconsistency to flag important events is to require an entirely different response method if the command is somehow "dangerous." For example, a system that allows the user to input two-letter abbreviations for most commands might require them to spell out the full name for "dangerous" commands like "delete' or "format." Input of an abbreviation will result in an error message and the inconsistency will act as an alerting mechanism. In a menu-based interface with mouse-selection of menu item, "dangerous" commands can be implemented such that the user must type in the name of the command rather than select it from a list. Some interfaces hide the dangerous commands under a heading like "advanced functions" (a menu or program area that the user must explicitly access in order to use any of the commands contained under that heading). The end result of any of these techniques is to alert users to an important event by raising their awareness of the interface through limited inconsistency. [17]

11.3 User Characteristics

Users of complex systems do not share the same knowledge of how the system operates, knowledge of the subject domain (in this case traffic engineering), or proficiency in operating the user-computer interface. The systems analysis approach recognizes the differences between Users' capabilities and attempts to meet the needs of various users either through user-centered aiding or by dynamically adapting to the demonstrated expertise of each individual. [44] In this section, differences among users are discussed and methods for identifying and meeting the varying needs of users are described.

11.3.1 Levels of expertise

Some users, by virtue of having had more practice or superior preparation, will outperform others. That is, they will make fewer errors, work more rapidly, and identify more effective solutions to problems than colleagues with less experience. Typically, researchers recognize three levels of user expertise: novice, intermediate, and expert. [99]

Differences between levels of expertise. There are substantial differences between the most and least able performers (system "experts" and "novices"). Experts are typically described as having complete knowledge of the system. They have organized the material into large, coherent blocks of information. Experts view the system as a set of highly interconnected procedures, concepts and principles. They solve problems using identifiable strategies and typically devote the initial period of problem solving to analysis. [20]

Novices, in contrast to experts, are typically described as having little or no knowledge of the system. They have not organized the material into any particular structure. Novices view the system as a set of isolated procedures, often not grasping the concepts and principles behind those procedures. Novices often solve problems using the same methods as experts, but take longer to arrive at the correct method and spend relatively less time analyzing the problem before attempting a solution. [20]

An "intermediate user" is typically defined as any user who is neither an expert nor a novice. It includes all users who know something, but not everything, about the system. "Intermediate" is such a large category that it is nearly meaningless for system designers. As a result, systems are typically designed either to meet the needs of novices (the lowest common denominator) or the needs of experts (typically the system's programmers or analysts). Little attention is given to designing a system that will support all levels of users throughout their "lifetime" on the system.

Interface design to meet the needs of multiple levels of expertise. A common finding in research on user-computer interfaces is that experts become extremely frustrated by interfaces designed to assist novices, and novices are often unable to work effectively on interfaces designed for use by experts. [17] A well designed user-computer interface will meet the needs of the entire user population. Task analyses and user analyses will help system designers determine how many levels of users exist and what task demands will be placed on users and on the system. These analyses are to be performed in Phase 1 of the systems analysis design process as was outlined in Figure 11-1.

Designing the interface to support users of varying expertise requires additional effort to ensure that adequate user aids are available and that the interface is neither too complex nor obscure for novices nor too elementary for experts.

User versus computer-initiated aiding. It is tempting, given the power of modern computers, to let the computer decide when and how much assistance to provide to any given user. At present, such computer-initiated dialogues have low user acceptance and there are no empirical studies demonstrating a superiority of computer- versus user-controlled aiding. [91, 105]

The major problems to overcome with computer-initiated dialogue include: [24]

! Users' frustrations and perceptions of losing control over the computer.

! Designers' inability to anticipate all possible contingencies.

! Task-dependency of Users' need for assistance and consequent problems of misdirected help provided by the computer.

The best solution is one that allows the user to select a level of interaction with the interface in a dynamic fashion. In essence, this approach allows users to control the amount of assistance they receive depending on their own perceived needs. When performing familiar tasks, users can act like experts and rapidly interact with the interface with no assistance. On less familiar tasks, the user may opt to access various built-in or hard-copy aids (such as job aids, manuals, error messages, on line help, tutorials, or decision support tools). Guidelines for the design of each of these aids are provided in Chapter 12.

It is important to recognize that aids designed to support one level of user are generally not acceptable for other levels of user. For this reason, it is necessary to carry out the systems analysis for all user aids. This requirement leads to trade-offs in the design of various user aids.

SELECTING APPROPRIATE LEVELS OF DETAIL: "DECLUTTERING"

There may be significant individual differences between operators in the amount of detail they want to see in their displays. Inexperienced operators, for example, may want to have street names displayed, while experienced operators may have many of them memorized. One form of dynamic screen redesign, a "declutter" capability, can help solve this problem. Using declutter, the operator can change the amount of detail on the screen by toggling the display through predefined levels of detail. [73]

11/1 Role of Job Aids   **(Observation)**

Job aids should provide, at a minimum, the instructions required to accomplish basic tasks using the interface (e.g., logging on, accessing help, displaying a map, etc.).
Job aids serve as procedural reminders for more experienced users but require special design efforts to meet the needs of novices.

11/2 Role of User manual   **(Observation)**

User manuals should be designed to provide exhaustive detail on use of all functions within the interface.
Most of this information is beyond the needs of novice users; however, the manual serves as an important tool for users to increase their level of expertise through self-study.

11/3 Role of Error Messages   **(Observation)**

Error messages should be written for the novice user and should provide useful pointers for recovering from the error.
"FATAL ERROR: E46" provides little useful information.

11/4 Role of On-line Help   **(Observation)**

Design on-line help in a "layered" fashion with the topmost layer providing assistance for novices to perform basic system functions and successively deeper layers providing greater detail in support of more complex use of the interface.

11/5 Role of Tutorials   **(Observation)**

Tutorials should be written to supply novices with practice performing meaningful tasks on the interface.

11/6 Role of Decision Support Tools   **(Observation)**

Decision support tools are intended for use by all levels of users and must, therefore, allow for optional levels of explanation and assistance depending on the user's current needs.

Methods for determining Users' understanding of the system. It is possible to empirically determine the users' levels of knowledge and expertise regarding any complex system, through a concept sorting task. The concept sorting task is capable of showing the differences between novice- and expert-level views of how the various parts of the system are related. In the concept sorting task, a set of cards is labeled with the names of major system functions and concepts. Potential users are asked to sort the cards into piles based on the relatedness of the

labels. Users are typically not constrained in the number of piles they can make or how many piles they place any given label.

The picture that emerges from concept sorting directly demonstrates the richly interconnected view of the system as an expert might see it and the more elemental view as a novice might see it. Designers can use such information to design the interface and the associated user aids to help novices see the system represented at a more expert level. In addition, designers can use the expert representation when designing user supports for more proficient users.

Ideally, the concept sorting task will be conducted with as many representatives from different user groups as possible. This opens the possibility of more accurate assessments of the groups as a whole rather than single individuals. Aggregating such data produces a picture of the interface as viewed by most members of any particular group and allows for comparisons between groups. Two statistical techniques, cluster analysis and path analysis, have proven useful in helping designers to aggregate data to discover the differences between experts' and novices' understanding of complex systems. [50]

11.3.2   User modeling: Users' intentions and goals

A user model is a set of beliefs that reflects the work users are attempting to perform, what they need to know about the system, and how users learn to operate a system. User modeling recognizes that people approach a complex system with specific purposes in mind. They have intentions and goals that may change as a function of time or task demands. [44]

The main purpose of user modeling is to ensure that the interface allows users to perform their intended work in an efficient manner. By knowing what users are hoping to accomplish when accessing any particular feature of the interface, designers can build that feature to assist rather than hinder users. For example, the most frequently accessed options can appear at the top of menu lists, frequently performed sequences of actions can be combined into one larger (macro) command, and text in the user manual and online help can be written to address specific issues related to accomplishing the user's goals.

11.3.3   Users' expectations and "crutches"

When systems are upgraded, the way tasks are performed may change. Users will have their own ideas of how the job should be done, and they will have "crutches" that they rely on to help them do the work. Crutches can be anything from a user-defined memory aid (e.g., a note posted on the workstation) to an integral part of the way the task is performed (e.g., use of pins on a map to log accident locations).

During Phase 1 of system design (see Figure 11-1), existing procedures should be examined to see how users are accomplishing tasks and to identify crutches or informal procedures they might be using. As part of the evaluation of alternative interface designs in Phase 2 of system design, designers should verify that leaving out a user crutch does not adversely affect

performance. Crutches that are necessary supports to performance should be programmed into the interface.

11.3.4 Users' conceptual models of the system

User modeling gives the designer a picture of what each type of user is likely to know in advance, what the users need to know, what they are trying to accomplish, and how they are likely to learn about the system. Users' conceptual models of the system are the set of facts and assumptions that individuals perceive about the operation and organization of the system.[86]

Users form incomplete models. Users typically learn enough about the interface to achieve proficiency, but usually do not go beyond that point to learn more sophisticated ways of doing the same tasks. This is best illustrated through examples from the familiar task of learning to use a word processor. [23] Users of word processing systems typically avoid using macros, mail merge, and mathematic functions even though these functions can save time and effort.

The issue is one of return for the time invested. If users *perceive* that it will take more time to learn the function than will be saved over repeated uses, they are unlikely to invest in that learning. As a consequence, Users' models of word processing systems are typically incomplete, and their use of the system is not as efficient as it might be.

Incomplete conceptual models influence performance. Users with incomplete models of the system fail to recognize shortcuts that could save time and reduce their workload. In addition, such users may fail to recognize their own inability to accomplish a desired goal with the interface. Unused, but useful, features of interfaces are found in every complex system. The consequences of underutilization are wasted resources for programming those features in the first place; longer than necessary times to task completion; failure to even attempt some tasks; and reductions in operator's ability to work on multiple tasks.

A TMC operator who does not know all the functions and options in the interface may take longer to perform tasks than one who knows the interface well. In the worst case, the less proficient operator may do an incomplete job or institute incorrect mitigation measures. In addition, operators with incomplete system models may be less able to cope with loss of system functions. If the familiar portion of the system fails, such operators may have difficulty finding any alternative ways of performing their assigned tasks.

How design can help users form more complete models. A system expert has complete (or nearly complete) knowledge of the system and its functions. Obviously, it is desirable to staff the center with personnel who are, or who rapidly are becoming, system experts. These are the individuals who will work rapidly, make few errors, and find creative solutions to problems.

Designers can help bring users to an expert level of knowledge through appropriate aids to performance. Some techniques include:

- **!** Training on concepts.[38]
- **!** Guiding exploration in tutorials.[15]
- **!** Blocking user errors during training.[28]
- **!** Providing high quality help screens.[20]
- **!** Providing expert-level advice in decision support systems.[25]

11.4 Task Models and Usability of the Interface

A task model is a description of the sequence of mental and physical operations that the user must perform in order to complete a task. It includes actions such as keystrokes, mouse movements, and other user inputs. It also includes mental events such as goal formation, planning, outcome evaluations, and decisions. Task models are used to help designers evaluate alternative methods of conducting user-computer dialogues prior to programming the interface. If the task models are accurate, they can reduce the number of design iterations, thus lowering the cost of the overall interface design.

Usability is *the number and complexity of the steps required to complete a procedure via the user-computer interface.* By knowing how many individual steps are involved and the approximate duration of each step, designers can predict how long it will take a user to complete any given task. Highly usable interfaces are those which require the fewest steps at the lowest level of complexity. By comparing different interface designs, it is possible to reduce the number of alternatives to only those that meet a minimum usability requirement (e.g., "it should take no longer than 15 seconds to compose and display a traffic alert").

11.4.1 An approach to task modeling

Many current approaches to operator task modeling start with the GOMS model. [25] GOMS stands for *Goals* (what the user is trying to do), *Operators* (the individual actions required to meet the goals), *Methods* (procedures made up of sequences of operators), and *Selection rules* (guidelines for choosing appropriate methods). Figure 11-4 shows outputs of a typical GOMS model.

The GOMS model has proven to be useful in evaluating interfaces in terms of the perceived difficulty of completing specific tasks. It provides designers with a list of tasks (equivalent to top-level goals such as "Alerting Motorists" or "Clearing an Accident") and with a detailed list of subgoals that an operator must form in order to accomplish a task. For each subgoal, the actions and procedures required to accomplish it are listed as well. Given this information, designers can identify procedures that are long, complicated, or place a large burden on the operator. By focusing design efforts on improving the usability on long or complicated procedures, it is assumed that a better interface will result. Priority should be given to those procedures that are performed most frequently and those that are the most difficult to use.

```
(A) TOP LEVEL OF MANUSCRIPT EDITING

        GOAL: EDIT – MANUSCRIPT

                GOAL: PERFORM – UNIT – TASKS
                (do until no more unit tasks)

                GOAL: ACQUIRE – UNIT – TASK

                GOAL: MOVE – TO – TASK – LOCATION
                        [USE POSITION CURSOR METHOD]

                GOAL: LOOKUP – TASK – FUNCTION

        GOAL: EXECUTIVE – UNIT – TASK
                SELECT: [INSERT– METHOD, DELETE – METHOD, COPY –
                        METHOD, MOVE – METHOD, TRANSPOSE –
                        METHOD]

(B) MANUSCRIPT FOR DELETING ANY TEXT STRING

        GOAL:   DELETE – TEXT

                GOAL: PRESS – DELETE – KEY

                GOAL: CHECK – DELETE – PROMPT

                GOAL: SELECT – RANGE
                        [USE – SELECT – RANGE – METHOD]

                GOAL: VERIFY – DELETE

                GOAL: PRESS – ACCEPT – KEY

                GOAL: FINISH – DELETE
```

Figure 11-4. Outputs of a typical GOMS model.

11.4.2 Cognitive complexity model; a quantitative approach

The GOMS model is not sufficient, however, as a tool for *quantitatively* evaluating the usability of a particular interface design or for comparisons between alternative interface designs. To reduce the number of design iterations, a model should be capable of predicting learning times and the time it will take the average user to complete any specified task. There are a number of variants of the GOMS model that are capable of producing quantitative predictions of this sort. One, the cognitive complexity model, has been shown to provide reasonably accurate predictions of the time required to learn an interface and perform tasks using it. [86, 89]

The cognitive complexity model can be described in two equations, one predicting learning times and the second predicting task execution times.

$$\text{Predicted Training Time} = t @ n + c$$

where *t* is the training time per production step, *n* is the number of steps, and *c* is the time to complete the parts of the task not involving the acquisition of new rules (e.g., the criterion run.)

$$\text{Execution time} = a @ NCYCLES + b @ WMIN + i$$

where *NCYCLES* is the number of cycles required to complete a task, *a* is the activation time per cycle, *WMIN* is the total number of add-goal and add-note actions, *b* is the time for an add action, and *i* is an integer presumed to be zero. The parameters *a, b,* and *i* are estimated using multiple regression techniques on experimental data.

The first equation predicts that learning times will be directly proportional to the number of new rules to be learned. Comparisons of ease of learning between interfaces are based on the differences between the number of new "if...then..." rules to learn in operating each interface to accomplish a specified task. The second equation predicts that task execution time is the total time required to activate all the "if...then..." rules required, plus the total time required to carry out the operations specified for each rule.

To generate predictions using the model, the parameters (t, c, a, b, and i) must be estimated based on data collected during user evaluations of interfaces. Linear regression is used to find best fitting parameter values.

11.4.3 Guidelines for using the cognitive complexity model

The cognitive complexity model and similar quantitative models are best used early in the design of an interface. They are intended to reduce the number of design iterations, and therefore the cost of programming and revising the interface. The main goal of using such a model is to make design revisions during the conceptualization and prototype phases, instead of later when substantial efforts have already been spent programming the interface. This requires designers to make a number of assumptions and test those assumptions using partial mock-ups of the interface (prototypes) during phases 1 and 2 of systems analysis (see Figure 11-1). Parameter estimates for the model may be based on timing of a few individuals. Apply the following guidelines to usability evaluations:

11/7 Comparison of Alternative Designs　　　　　　**(Observation)**

Use a usability model for comparisons between competing designs.
Most of the parameter values will be the same for all the interfaces under consideration. The shared values (such as the time needed to learn a new rule and the "cycle" time) cannot be the source of differences between interfaces since the same value appears in the model for all interfaces. These parameters can be estimated based on less rigorous data, sufficient to provide realistic predictions of Users' performance with each proposed interface. The number of rules (and number of new rules) required to complete any specified task will be a far more important determinant of the differences between interfaces.

11/8 When to Test Usability　　　　　　　　　　**(Observation)**

Evaluate usability as early as possible in the interface design process.
As the task analysis proceeds (in phase 1 of the design process), the system's designers will be able to identify tasks, the information required for task completion, and the steps an operator must perform to complete the task. At this point, users and designers can evaluate alternative proposed interfaces to see which require the fewest number of rules for the specified task, and which make the most frequent use of common rules (those that are learned once and applied in many tasks).

11/9 How to Test Usability　　　　　　　　　　　**(Observation)**

Combine modeling with rapid prototyping.
As prototypes are developed, parameter estimation can proceed based on data collected on user's interaction with each sample interface. These data can be used to build predictions of task completion times for new portions of the interface and to compare alternative versions of the interface prior to programming.

Perform separate evaluations of usability and user acceptance.
The interface design that yields the lowest time to task completion or time for initial learning is not always the one with the highest user acceptance. User acceptance depends on a number of factors in addition to ease of use and ease of learning. In order to maximize usability and user acceptance, both must be evaluated in a quantitative fashion. Revisions designed to improve one measure may have positive or negative effects on the other.

11.5 User Acceptance

User acceptance of an interface is as important as usability. User acceptance describes individual user's comfort and willingness to perform work using the interface. Users accept or reject interfaces for a variety of reasons, *including but not limited to those that determine the interface's usability.* This is best illustrated in online help systems.

An ideal online help facility gives brief advice that can be absorbed readily and applied directly to the immediate problem of the user. *Usability* of an online help facility is affected most by the brevity and clarity of the advice, as well as how rapidly the user can search for a specific topic. *User acceptance*, in contrast, is largely determined by the user's perception of the help text's relevance to the current problem. Achieving task-relevance is very difficult, even when the designers of an online help facility know a great deal about the tasks users are likely to perform on the interface. There are a great many help systems that are very usable (the user can navigate through the help files easily, and the text is brief and well written) but have low levels of user acceptance because the content of the help does not relate well to the user's goal.

11.5.1 The multidimensional nature of user acceptance

The dimensions along which Users' acceptance of an interface are measured include:

- Time required to learn enough for acceptable performance.
- Time required to complete routine tasks.
- Similarity to prior ways of completing the same tasks.
- Ease of performing procedures.
- Ease of recovery from errors.
- Memory, perceptual and activity level burdens placed on the user.
- Quality of interactions (tone, grade-level, efficiency).
- Intrusiveness of interactions (computer vs human control of dialogues).
- Support for pre-existing user crutches.

An effective way to ensure user acceptance is to involve users in the design and evaluation of

interfaces early enough in the process so that their input may be acted upon. User acceptance should be quantified and the results used during an analysis of design trade-offs.

11.5.2 The importance of user acceptance

User acceptance is crucial to overall system performance. In systems with low user acceptance, many of the problems associated with human-computer interaction become magnified. There is a tendency for users to stop exploring the interface once they have reached minimally acceptable proficiency (meaning they can complete the task within the required time). Raising user skill requirements is not nearly as effective a solution as building the interface to be acceptable from the start.

When systems lack user acceptance, users typically try to find a way around the system. In some environments, this means a return to the old manual ways of completing the tasks. In other environments, work-arounds develop that are not part of the approved standard operating procedure; often critical steps are skipped because users do not recognize their importance.

11.5.3 Methods for measuring user acceptance

User acceptance is typically measured through structured surveys or observations of users. Because user acceptance is composed of many different factors and users are typically asked to evaluate each portion of the interface on each acceptance factor, the surveys can become quite long. In addition, survey instruments are subject to the respondent's own interpretation of the questions. Elaboration is often not allowed or fails to communicate adequately the user's impressions. Observations of individual users can yield additional detail and allow for clarification. Observations are, however, more time consuming than completion of a survey instrument. By combining user acceptance testing with user testing (e.g., usability testing), some time can be saved. The following guidelines will assist in planning a realistic data collection effort for testing user acceptance of the new system.

11/11 When to Test User Acceptance Testing   (Observation)

Combine user acceptance tests with consistency and usability tests.
All of these data collection efforts presuppose the existence of prototype interfaces with which users will work.

11/12 Preliminary User Acceptance Tests	(Observation)

Observe a small number of users to obtain preliminary data.
The costly and intrusive observation method should be used sparingly.
Information gathered during observations will assist in developing focused
questions for a survey instrument that can be more broadly disseminated.

11/13 What to Test for User Acceptance	(Observation)

Survey users on all aspects of the interface.
Asking users whether or not any one particular feature is "acceptable" will
yield little useful information. Rather, users should be asked to report on
each of the factors listed in Section 11.5.1. Figure 11-5 provides sample
questions that apply.

11/14 How to Test User Acceptance	(Observation)

**Use the survey data to identify parts of the interface that need
improvement.**
At the completion of one round of data collection, system designers will have
information on perceived consistency of the interface, usability, and user
acceptance. This information can be used to identify the most problematic
parts of the interface. To prioritize these problem areas for revisions,
designers should also consider the results of the task analysis to determine
which of the problem areas are likely to be encountered most frequently.

Question	YES/NO	COMMENTS
Learning to operate the program was easy.		
It took a reasonable amount of time to complete most tasks.		
Procedures were simple and required a minimum number of steps.		
Errors were easy to recover from. The error messages gave useful information.		
The interface, menus and screens, were laid out in a logical fashion.		
The prompts and error messages were appropriate in tone (i.e. not degrading or condescending).		
Command names and options made sense.		
The computer did not take over the work or "get in the way."		
Pacing was comfortable, neither too fast nor too slow.		
Command names and what the commands did were easy to remember.		
There were few surprises. The computer worked as expected.		
Using the computer didn't require relearning how to do the job.		
Online help was informative.		
The user manual was informative		
It was easy to find the commands and information required to complete the task.		

Figure 11-5. A sample questionnaire for measuring user acceptance.

11.6 Managing Change

Once the interface is designed and implemented, it must be maintained. New functions may be added to the TMC that will need to be reflected in the interface. Problems may be discovered with existing functions that will necessitate program revisions. New and better ways to accomplish tasks will be suggested, some of which may require a change to the interface. Managing change is a common problem in large systems such as those required to operate a TMC. Program modules interact extensively so that changes to one section of software code can have unforeseen effects on other aspects of system performance. Changes are sometimes made without consulting or adequately informing users. Time and effort may be wasted as users attempt to adjust to revisions. Planning for the life cycle of the system can alleviate many of the potential problems associated with system revisions.

Ideally, revisions would be conducted using the same systems analysis approach recommended for the system design. This is rarely the case. As a consequence, systems that may start out as consistent, usable, and with high user acceptance can lose these qualities over time. Designers

and programmers involved in the revision process should adhere to the original standards document for the system, and they should, ideally, conduct user testing prior to release of revisions.

System maintenance is often overlooked during the design process. Lacking a predetermined maintenance plan (a process for evaluating modification proposals, a schedule for release of revised software, and a list of the tasks associated with release of a revision), many large systems lapse into a cycle of nearly continuous releases of software revisions. This gives the system maintenance staff a constant work flow, but forces users to absorb changes too frequently. Often, new changes are made before users have become familiar with the previous set of revisions. The following information illustrates some of the negative aspects of rapid change.

User errors increase. In rapidly changing systems, users have a difficult time staying current. This is especially true in work environments with high resource utilization rates. In such situations workers do not have time to learn about system changes either because they themselves are too busy or the system and terminals are in constant use so that there is no workstation time available for training.

A particular problem in rapidly changing systems is that infrequent users are incapable of performing their assigned tasks. This is because the system changes faster than they can learn.

Programming resources are wasted. In rapidly changing systems, it is not uncommon to see the same program module or section of code changed several times over the course of a year. Programmers involved in making each change must repeat the preliminary steps of familiarizing themselves with the section of code and how it interacts with other sections every time they begin a revision process. If, instead, changes are made less frequently and are bundled so that several changes are made in one section at the same time, some efficiency is gained.

Training becomes expensive. In changing systems, keeping users up-to-date is a constant challenge. There is a tendency to provide user updates in as inexpensive a fashion as possible (such as online bulletin board messages) and to generate these update messages as a last step in the revision process. Users do not absorb this material readily. [25] The alternative, providing tailored training for each change made to the system, is expensive and requires time for developing and delivering the training.

Users aids become obsolete. The requirement to update user aids is a frequently overlooked part of the software revision process. As a result, User manuals, online help, job aids, tutorials, and decision support systems become out-of-date and fall into disuse. Instead of helping users, these aids become a source of errors because the information they contain is no longer correct.

11/15 Software Revision   **(Observation)**

Once software is in the production cycle (e.g., in an opening TMC), changes should be infrequent.
Unless modifications are critical, do not begin a change cycle until a critical mass of desired modifications is reached. One-, two-, or three-year cycles are not reasonable. Plan to make accumulated modifications in a single design cycle, so that the same code does not need to be modified several items.

11/16 Software Revision and Software Support   **(Observation)**

Modify software support material to reflect software revisions.
On-line help, tutorials, and job aids should be included in the software modification schedule. The software support material should be released at the same time the modified software is put into production. Use the same guidelines for support material modifications that are recommended for initial support material design.

11/17 How to Revise the User Interface   **(Observation)**

Use the same procedures for designing and testing user interface revisions that are recommended for initial user interface design.
Failure to follow good user-centered design principles when making modifications to the interface may result in good designs going bad.

11.7 User Interface Guidelines

There are a number of published guides governing the design of user-computer interfaces. Such standards are typically detailed and are usually adopted by reference or used to explain optional implementations of features in the interface. The most frequently cited standards are:

Department of Defense. (1989). *MIL-HDBK-761A: Human Engineering Guidelines for Management Information Systems.* Washington, D.C.: DoD.

International Business Machines Corporation. (1989a). *Systems Application Architecture, Common User Access: Basic Interface Design Guide.* Cary, NC: IBM Corp.

International Business Machines Corporation. (1989b). *Systems Application*

Architecture, Common User Access: Advanced Interface Design Guide. Boca Raton, LA: IBM Corp.

Microsoft Press. (1995). Windows Interface Guidelines for Software Design. Redmond, WA: Microsoft Corp.

Smith, S.L., and Mosier, J.L. (1986). *Guidelines for Designing User Interface Software.* Bedford, MA: MITRE Corporation.

Other useful sources include:

Department of Defense (1992). *Defense Information Systems Agency; Center for Information Management. Human Computer Interface Style Guide (Version 1).* Washington, D.C.: DoD.

Powell, J. (1991). *Designing User Interfaces.* San Marcos, CA: Microtrend Books.

Schneiderman, B. (1987). *Designing the User Interface: Strategies for Effective Human-Computer Interaction.* Reading, MA: Addison-Wesley.

The decisions of which standard to adopt and which options to exercise within each standard are best made through discussions with users in the first phase of system design (see Figure 11-1). As noted in Section 11.2, adherence to an overall standard does not ensure consistency and usability. The design team should develop a style manual that will guide development of the interface, clearly specifying the interaction style (command-based, menu-based, direct manipulation, combination) and presentation issues (entry screens, windowing, highlighting, mapping, text styles, graphic styles, tabular styles) (See Figure 11-2). The standards listed above will provide examples of most of the options for presentation issues. The interface style manual should specify which options will be employed in the interface.

Many of the standards apply only to one type of interaction style. For example, guidelines for size and spacing of icons only apply to the direct manipulation interface. Location and access mechanisms for menu items apply only to menu-based interfaces.

11.7.1 Data entry screens

Data entry screens are used for tasks involving user input and can also be used to display some types of information. In the TMC environment, data entry screens are used for operator identification (logging on), selection of roadway segments for review, entering messages for motorist displays, and specifying values to use in an analysis.

Navigation

11/18 Screen Navigation Methods (Observation)

Support multiple methods of moving from field to field in the entry screen.
(For example, use TAB, ENTER and "arrow" keys, automatic movement when the current field is full, and mouse or other pointing device).

11/19 Backward Field Navigation (Observation)

Allow users to move back to previous fields and edit the previously entered information.

11/20 Movement Between Screens (Observation)

In multiple screen entry procedures, allow users to move between screens without losing information entered previously.
Allow use of the PAGE UP and PAGE DOWN keys, as well as other movement methods (e.g., END followed by ENTER keystrokes, using program function (PF) keys, a "go to" command followed by a page number, and pointer indication of a "next page" icon or menu item).

11/21 Page Numbers (Observation)

In multiple screen entry procedures, show the page number of the current screen.
Page numbers should be in the format "x of N" and should appear in the same location on each screen (e.g., in the upper right-hand corner).

11/22 Screen Titles (Observation)

Place a title at the top of the entry screen.
This is not critical for simple systems with few data entry screens. In a large TMC system, titles will help operators keep track of where they are in the interface.

11/23 Global Entry Cancellation (Observation)

Allow global cancellation of all entries on a screen.
Because global cancellation could result in unintentional deletion of useful
data, ensure that the user is aware of the risk. An inconsistent response can
be used to alert the user. For instance, in a menu dependent system, the
user could be required to *type* the cancellation command, or typing "yes" to
confirm.

Active data input field

11/24 Active Field Highlight	**(Observation)**

**Show users which field is active through use of highlighting (blinking
cursor, color change, shading, or other).**

11/25 Data Entry	**(Observation)**

Have users enter data directly into the active field.
Avoid a separate section of the screen for user inputs that are then
transferred to the active field.

11/26 Field Size	**(Observation)**

Make the field large enough for complete input of the required entry.
Unless the field is used for input of long text messages, always display the
complete information as entered. Avoid truncated fields that scroll right or left
to view the complete entry.

Cut/Paste/Copy

11/27 How to Populate Fields	**(Observation)**

**Automatically copy previously entered information into the active
screen.**
Avoid having the user re-enter information such as operator identifiers and
roadway names more than once.

11/28 Copying   (Observation)

Where applicable, allow users to copy information from one part of the screen to another.
In windowing environments, allow copying between windows.

11/29 "Undo" Capability   (Observation)

Allow the user to "undo" the most recent cut/paste/copy action. Note, if something is "cut" from one area and a "paste" is specified but then canceled, make sure the information is still retrievable. Alert the user when a failure to retrieve the information will cause it to be lost.

Verification checks

11/30 Data Type and Value Checks   (Observation)

Check the information entered in each field for mismatches against allowable data types and allowable values and provide an appropriate error message.
These checks should be immediate and should generate an error message prompting the user for correct information whenever a mismatch is discovered. This is especially crucial for operator identifications and roadway names. Do not wait until the user has completed the entire data entry screen to send an error message about invalid data in a field. Require the user to correct the information before proceeding.

11/31 Verification of Actions   (Observation)

Require the users to verify their intentions when the specified action will cause loss of data.
This is critical for global commands such as those used to cancel out of the data entry screen or delete all previously entered data.

11/32 Consistency and Validity Checks   (Observation)

When data accuracy is critical (e.g., when the data will become part of the "historical" record), insert checks for consistency and validity.
Prompt the user to confirm values that are outside of established norms by alerting the user to this fact and asking for verification.

Abbreviations

11/33 Data Entry Completion   (Observation)

For information that is contained in the system's database (such as a street name or the name of the operator), allow the user to enter the first letters/numbers of the identifier and have the software provide the matching choices.
If the input is not enough to specify a unique entity (e.g., the operator entered "Broad" and the locality has a Broad Street, Broadway, and Broad Industrial Park), the system should display all matching items and prompt the user to select one.

Error correction

11/34 Correction of Errors   (Observation)

Allow users to correct data entry errors.
It is important to allow users to correct entries appearing in previous fields and on previous entry screens. This requires support of special navigation functions to allow users to go back through fields on the current entry screen and back through previously entered screens. This can be accomplished by activating BACK TAB and PAGE UP keys, and/or supporting a pointing device such as a mouse or trackball.

11/35 Facilitation of Editing   (Observation)

Once the user has returned to a prior data entry field, editing should be facilitated through use of INSERT, DELETE, BACKSPACE and cursor control keys for navigation through text.

11.7.2 Windowing

Windowing allows access to more than one application (a program, file or graphic) at once. Typically, users require simultaneous access to compare or copy information, obtain multiple views of a situation, or get help on how to perform a specific task. In most windowing systems, a user only interacts with one application at a time. The corresponding window is said to be "active" while the other windows are referred to as "inactive" or "background" tasks. "Inactive" refers to the user's current interaction with the system — the user is interacting with one application and allowing the others to run without direct user input.

Figure 11-6 presents the features of a typical windowed application. These include:

- ! Title bar: lists the name of the application appearing in the window.
- ! Menu bar: displays the names (headers) of available pull-down menus.
- ! Hot buttons: display frequently used commands accessible through a single keystroke.
- ! Window frame: used to provide visual separation between adjacent windows and for expanding or contracting the active window.
- ! Window sizing buttons: used for expanding or contracting the window frame to preset sizes.
- ! Application area: space reserved for user input and information presentation.
- ! Scroll bars: used for user-controlled vertical and horizontal movement through the application area.
- ! Status bar: used for display of additional information such as cursor position, and application mode (e.g., select, edit, delete, etc).

Guidelines for design of windows and the options available for Users' interactions in a windowing environment are published by the developers of the software (e.g., Motif, Open-Look, Windows, and X-Windows). Most of these apply to direct manipulation, graphical user interface (GUI) designs. Some general guidelines may be found in the DISA/CIM *Human Computer Interface Style Guide*. [40]

11/36 Pointing Devices   **(Observation)**

Use a pointing device in windowing interfaces.
Most systems that support windowing use a pointing device (mouse, trackball, light pen, or touch screen). These devices are superior to keyboard entries for sizing, selecting, and positioning of windows.
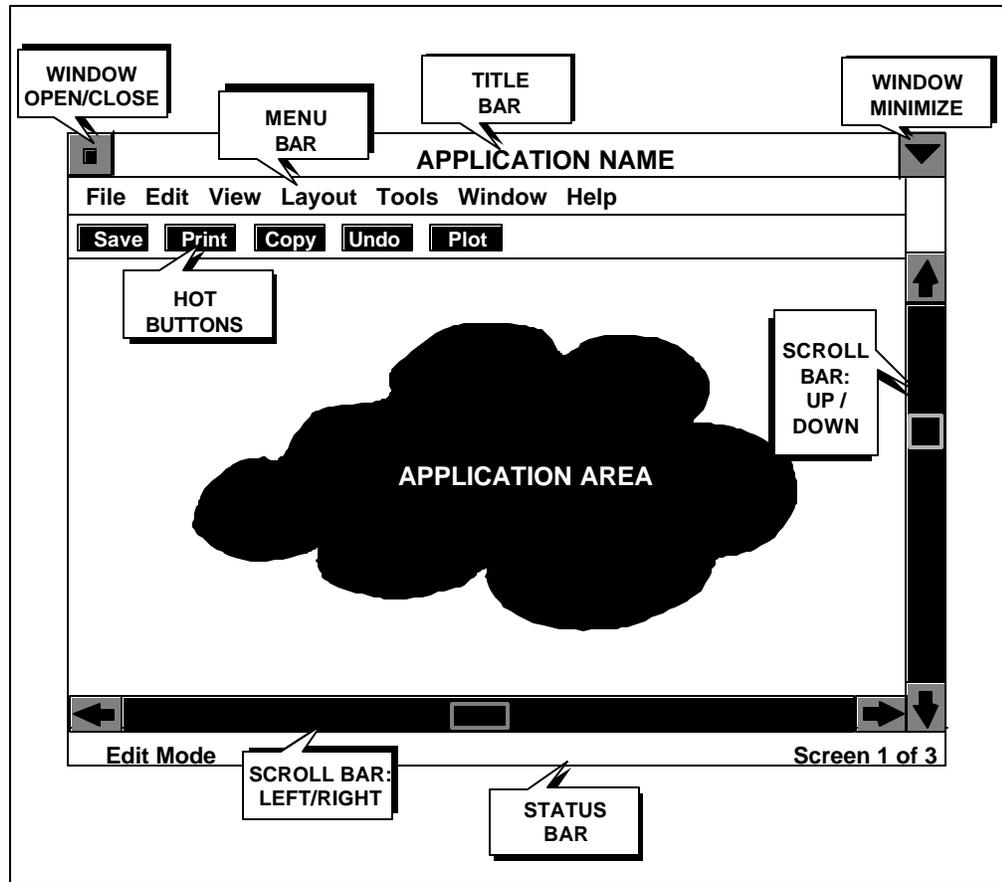
Figure 11-6. Typical windowed screen.

11/37 Window Size and Location **(Observation)**

Allow the user to resize and reposition the windows.
Save the user-determined window sizing and placement as the default for the next time the same application is accessed by the same user. Windowing can speed performance of tasks, however, the time saved may be taken up in sizing and positioning windows. However, saving window positions may be counterproductive if more than one user will inherit the saved settings.

With support for pointing devices, window sizing should be controlled through pointing at a corner or side of the window border followed by selecting and moving that corner or side. Positioning should be controlled through pointing at a title bar (a header placed at the top of the window) followed by selecting and moving the entire window to a new location. (These operations are typically called "point, click, and drag" movements.) Resizing and positioning through keyboard input is clumsy, but can be supported through menu selection or command inputs of new sizes and screen locations, if required.

Overlapping windows. Figure 11-7 shows a comparison of two presentation styles for multiple windows; tiled and overlapping. Users prefer tiled to overlapping windows, even when the tiled format slows down task performance. [60] Do not overlap windows such that *necessary* information from one application is covered when the user accesses another application. This is especially important for online help screens – users need to be able to read the online help and see how it applies to the problem they are attempting to solve. [31]

11/38 Warning and Error Message Windows   (Observation)

Windows presenting warning or error messages should appear in the center of the screen and overlap other windows.
Warning and error message windows *should* overlap and cover the windows for other applications. Figure 11-8 shows a tiled window presentation with an overlapping error message.

11/39 Window Size and Scrolling   (Recommendation; 16)

Avoid requiring users to scroll.
Scrolling takes time. Users prefer windows sized to present complete information. When this is impossible, left/right, up/down, and page up/page down scrolling should be available through scroll bars and cursor control keys.

11.7.3 Dialog and text quality

Despite major advances in GUI interfaces, text is still an important medium of information exchange between users and computers. As a result, the most critical factor determining usability and acceptance for most systems is the nature of the text-based interaction programmed into the user-computer interface. Users and the interface carry on a dialog as a necessary part of task completion. The user selects or enters commands, the computer responds with the requested action or a warning, error or help message.

The most effective dialogues are those in which the user's input is interpreted unambiguously by the interface and the desired result is obtained in as few steps as possible. Often, however, that the user's input is ambiguous and/or the computer's response is not fully comprehended by the user.

TILED WINDOWS

APPLICATION NAME

File Edit View Layout Tools Window Help

Save Print Copy Undo Plot

Edit Mode

APPLICATION NAME

File Edit View Layout Tools Window Help

Save Print Copy Undo Plot

Edit Mode

APPLICATION NAME

File Edit View Layout Tools Window Help

Save Print Copy Undo Plot

Edit Mode

APPLICATION NAME

File Edit View Layout Tools Window Help

Save Print Copy Undo Plot

Edit Mode

OVERLAPPING WINDOWS

APPLICATION NAME

File Edit View Layout Tools Window Help

Sav Print Cop Und Plot

Edit Mode

Figure 11-7. Tiled and overlapping windows.
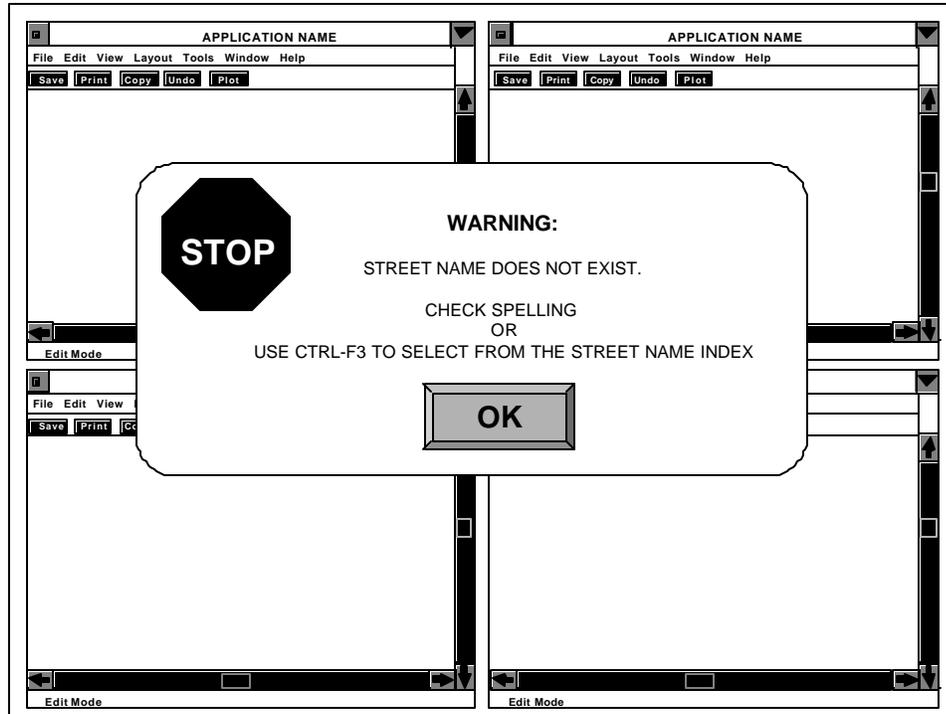
Figure 11-8. Warning message superimposed over windowed application.

At the most fundamental level, users interact with the system by selecting and/or typing words into the computer as commands that are intended to yield a desired result. Unfortunately, system designers sometimes select words that hold conflicting meanings in the system and in the experience of the user or are meaningless outside the realm of the user-computer interface. As a result, users are forced to learn that "kill" will remove a file from the disk, "mdir" will create a directory, "VVV" indicates that the computer is ready to accept input, and the like. Table 11-1 presents examples of the varying commands for removing a file from a directory in some familiar operating systems.

The system may present long strings of words to users in the form of error or help messages, and as support for decision making. If these messages are ambiguous, too long, hard to read, or perceived as impertinent, users will reject the assistance.

Improving the quality of the dialog between users and the computer is largely a matter of improving the text presented to users. The major issues regarding text presentation are:

- ! Precision and naturalness.
- ! Length.
- ! Organization.
- ! Readability.
- ! Tone.

Table 11-1. Alternative commands for deleting files.

ALTERNATIVE COMMANDS FOR GETTING RID OF FILES		
Operation System	Command	Root Word
UNIX	rm	ReMove
VMS, VME, OS/2, MS, PC	del	DELete
HARRIS	el	ELiminate
CP/M, VM/CMS	era	ERAse
OS/360	decatalog	DECATALOG
OS/400	dltf	DeLete File
After Gwei and Foxley (1987, 1990)		

Each of these issues is considered in the following guidelines:

Precision and naturalness of text

11/40 Command Name Selection   **(Recommendation; 51)**

Choose unambiguous, semantically correct names for commands.
If the user is typing in the command, allow but do not require abbreviations
(e.g. "mdir" and "make directory" should be allowable commands).

11/41 Command Language   **(Recommendation; 51)**

**Use natural English language phrases and support the use of
synonymous terminology.**
"ENTER" or "GO" are preferable alternatives to "F7QX359LM."

Length of text

11/42 Interaction Length	(Recommendation; 32)

Conduct interactions in as few words as possible.
Use concise commands, action words, and bulletized phrases rather than long sentences.

11/43 Decision Support Text Length	(Recommendation; 32)

Avoid long sentences and paragraphs in error, help, and decision support texts.

Organization of text

11/44 Lists	(Recommendation; 31)

Use bullets to present lists.

11/45 Highlighting of Key Information	(Recommendation; 32)

One way to highlight key information is to place it at the beginning of a message.

11/46 How to Organize Text	(Recommendation; 42)

Facilitate rapid scanning of long text items by use of highlighting and additional space around the most important information.

11/47 Presentation Order	(Recommendation; 31)

Present procedures with the steps listed in the correct sequence.

> **Use headings and subheadings to organize text into easily understood segments.**

11.8 Interaction Methods

The preceding guidelines pertain to all interfaces regardless of the method by which users and computers interact. The four main interaction styles are:

- **!** Command-based.
- **!** Menu-based.
- **!** Direct Manipulation (or graphical user interface – GUI).
- **!** Combinations.

11.8.1 Command-based interfaces

Figure 11-9 presents a sample dialog from a command-based interface. Typical command-based interfaces require users to enter keyboard instructions. Users usually rely on memory to recall the command name and the correct syntax. Advantages of such interfaces are low programming costs, low demand on computer resources, rapid response to user input, and Users' perception of having direct control over the computer. Disadvantages are that these interfaces place a heavy reliance on human memory, are difficult to learn, and promote learning about the computer rather than the task.

A WORST CASE SCENARIO

At two sites, signal control software presumed "all intersections" as a default value, with no "trap" to prevent unintentional lapse to the default (e.g., "Do you really want to set all signals to flash?"). A similar problem at another site suggested one extraordinarily troublesome scenario, one which is not an unlikely event, since entering <1> on this system will invoke an ordinary setup, and <11> will cause immediate system shutdown. Accidental double-keying is a common manual error. If an operator shut down the system by mistake, restoring the original signal condition could take several minutes. In addition, the system could be sabotaged with devastating effect by (1) deleting signal patterns, and (2) deleting backups. Correction would take days, during which all signals in the relevant area would flash red.

Common to these interface problems was one worrisome characteristic: In terms of number of keystrokes, *it was easier to make a mistake than to enter the correct commands.* In the example cited above, two errors are required in succession to bring the system to chaos (accepting a dangerous default then turning the system off). Both errors had already occurred in isolation; eventually they may occur in conjunction.

As computers have become more powerful, both in processing speed and memory capacity, command-based interfaces have become less popular, although many are still in use and will continue to be supported for the foreseeable future. In addition, command-based interactions still form a major part of interfaces that are generally considered to be menu-based or direct manipulation interfaces. Guidelines for the design of command-based interfaces fall into the following areas:

- **!**   Command naming conventions.
- **!**   Command syntax.
- **!**   Command sequencing.
- **!**   Reducing Users' cognitive load.

```
MAIN> MB

MESSAGE BOARD UTILITY PROGRAM
Enter desired message.

:Accident at Bradley Road (Exit 7)
:Expect 1 Hour Delay
:Detour: Exit 6 to Abrams Road West

MORE?> N

MESSAGE BOARD UTILITY PROGRAM
Enter variable message sign number(s):

4N95, 5N95, 6N95

YOU HAVE ENTERED THE MESSAGE
     "Accident at Bradley Road (Exit 7).
     Expect 1 Hour Delay.
     Detour: Exit 6 to Abrams Road West."
FOR DISPLAY ON VARIABLE SIGN NUMBERS:
     4N95
     5N95
     6N95
IS THIS CORRECT?> Y
```

Figure 11-9. Command-based dialog.

Command naming conventions. Relevant guidance is presented below and in Section 11.8.3.

11/49 Command Name Selection   **(Recommendation; 51)**

Choose relevant, meaningful names for commands.

Ideally, all command names should be tested with users to ensure that the majority readily understand what the command does and are not apt to confuse it with similar commands.

11/50 Common Names   **(Recommendation; 51)**

Select action verbs as command names.
For example, "save" is considered a better command name than "file" for specifying the action of retaining work for later use. One reason for this is that "file" is both a noun and a verb and users typically think of the noun first. "Save" is less ambiguous.

11/51 Definition Consistency   **(Recommendation; 51)**

Be consistent. Define each command to specify only one action and retain that command throughout the interface.

Command syntax. Some command-based interfaces require exact entry of the command (and associated options) including precise location of spaces and punctuation, and the use of upper or lower case letters. These requirements determine the command syntax. The following guidelines apply:

11/52 Command Syntax   **(Recommendation; 38)**

Be consistent with command syntax.
Users readily learn command syntax at a conceptual level and can use that understanding to reduce their error rates when using new commands. Important features of commands are the names of options and how they are specified, punctuation used for separating options from one another, and the specific ordering for options and other parts of the command (such as input and output file names or devices).

11/53 Option Names and Syntax　　　　　(Recommendation; 38)

Use unambiguous names for options.
Option names should follow the same guidelines as command names, with the exception that they are almost always single-letter abbreviations of the true name (e.g., "Y" for "YES"; "A" for "ABORT"). Option names should be semantically correct and not conflict with command names.

11/54 Selection of Default Options　　　　　(Observation)

Use those options that are most frequently used as defaults.
Default options are those that need not be specified when the command is entered.

Command sequencing. In a command-based interface, the user inputs a sequence of commands in a step-by-step fashion. Often, the sequencing of steps may not appear critical from the user's point of view but may be quite important for successful completion. The following guidelines apply:

11/55 Command Option Order　　　　　(Observation)

Use familiar sequences if available.
For tasks that are already performed prior to the design of the interface, maintain procedures in the current sequence.

11/56 Command Option Consistency　　　　　(Observation)

For steps that do not have a natural sequence, determine the best sequence through user testing and then use that sequence in all similar procedures.

Reducing the user's cognitive load. Command-based interfaces typically place more demands on the user than menu-based or direct manipulation interfaces. In particular, users of command-based interfaces are required to recall command names, options, syntax, and sequencing. In complex procedures involving several commands, the number of individual items to recall can exceed the user's capacity. These guidelines are aimed at reducing the load on users through training, online help, and user documentation.

11/57 What Commands Do   (Recommendation; 38)

Ensure that users understand the actions of each command.

Users who understand command functions through training and experience are better able to recognize errors than users who know only the names of commands and when to insert them into a procedure.

11/58 Action Flowchart   (Recommendation; 25)

Use graphical, flowchart-style presentations to explain the actions of each command.

Users more readily recognize command syntax errors when commands are explained in flowchart versus text-based fashion. In addition, flowchart presentations eliminate performance decrements typically seen for users attempting to learn complex commands (those with many options and/or requiring multiple file specifications).

11/59 Command Syntax for Online Help   (Observation)

Online help and other user aids should present the command syntax as the user should type it at the keyboard.

The header on the help screen or user aid should be the command itself, presented in the appropriate syntax for input by the user. Additional information should explain the use of the command and its options and provide the correct syntax for specifying options.

11/60 Online Help Examples   (Recommendation; 32)

Provide at least two examples for each command in online help; one showing the minimum input required (e.g. no options specified, all defaults accepted) and another showing the specification of several options.

The simpler example shows the user how to implement the command without having to know all of its various features. The more complex example shows the user a more sophisticated use of the command.

Figure 11-10 presents an acceptable help screen for a command in a hypothetical TMC. The first line of the help screen displays the minimum input required to display a message on a variable message sign. This line also defines the function of the command — what it actually

does. Note, in this hypothetical example, the command to display a message is part of a procedure requiring several commands of which the example shows only one.

A more complex example of the command's use is presented below the header. This example is shown in graphic form with each of the options labeled. The table below the complex example shows the defaults and allowable values for each of the command options.
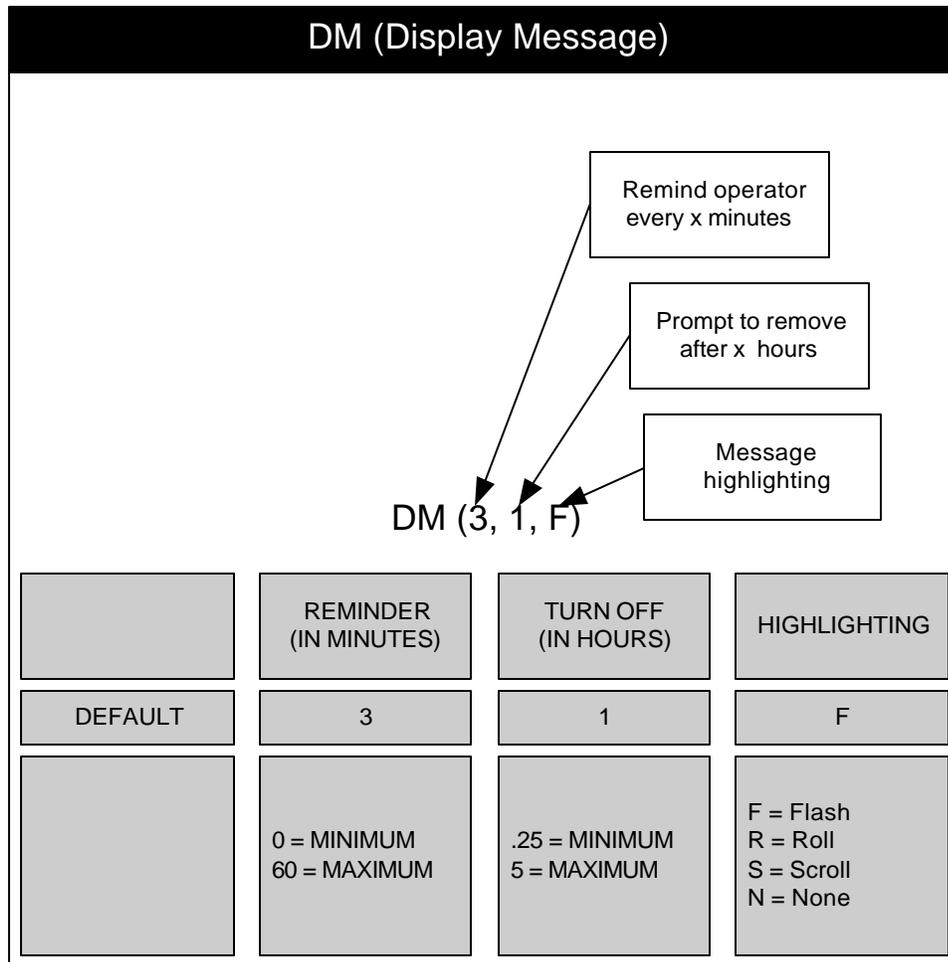
Figure 11-10. Help message for a command-based function.

Command-based interfaces can be cumbersome to use and difficult to learn. The name of the command for inserting a message on a variable message sign, for example, might be "DM;' an abbreviation of "Display Message." Many interface designs (including UNIX, MS-DOS, and IBM VM-CMS) make use of such abbreviations. The problem users face is that efficient operation of the interface requires that they remember large amounts of cryptic information.

11.8.2 Natural language interfaces

One solution has been to program the interface to accept commands written in standard English. Systems of this type are designed to translate a range of user inputs into the synonymous system-specific command. In the display message example, a user working on a natural language interface might be allowed to input any of the following commands and achieve the same result:

- **!** DM(3,1,F).
- **!** Display Message, 3 min reminder, 1 hr turn off, flashing.
- **!** Message Display, 3,1,F.
- **!** Show message flashing for 1 hr and remind me every 3 min.
- **!** Send message. Remind at 3 min intervals. Turn it off after 1 hr. Highlight by flashing.

To accomplish the necessary translation, the interface must be programmed to recognize key words and look up the synonymous command using a computerized version of a thesaurus. In addition, since users may input a variety of sentence types (from fragments to compound sentences), the program must be able to pick out the words specifying actions and options in order to translate them appropriately. Figure 11-11 presents an example of a simple system that provides a natural language interface for UNIX by allowing users to send their commands to an online thesaurus for translation. [55]

The main advantage of natural language interfaces is that they are easy to learn. If the user does not know the appropriate command, input of a synonym will *usually* achieve the desired result. Such interfaces can enable novices to perform effectively on their first exposure to the system.

There are disadvantages to natural language interfaces. The interface requires increased system resources (computer hardware and software) when compared to a standard command-based interface. Translating user inputs takes time and requires significant computer processing and storage resources. In addition, the advantages of allowing users to input commands in their own words may decrease over time. Experienced users tend to use the system's standard commands as these require fewer keystrokes than the English language forms. (This advantage may not hold true if commands are entered by voice rather than by keying.) When using keyboard-based entry systems, the benefits of natural language interfaces may be short-lived and restricted to novice users.

Guidelines for the design of natural language interfaces fall into the following areas:

- **!** User testing and acceptance requirements.
- **!** Dealing with ambiguous inputs.
- **!** Guiding users to system-specific command usage.

User testing and acceptance requirements. Because natural language interfaces are intended to make the system "transparent" to the user by accepting any equivalent input as correct, there are specific user testing requirements for the design of these systems.

```
+------------------------------------------------------------+
|         SAMPLE OF A NATURAL LANGUAGE DIALOG                 |
|            (based on Gwei & Foxley, 1989)                  |
+------------------------------------------------------------+

  (Computer prompts and responses are in normal font.
             User input is italicized)


MAIN> send message

       NOTE: To display a message on a variable message
          sign, you must first create the message using the
          Message Board (MB) utility.


MAIN> message board

MESSAGE BOARD UTILITY PROGRAM
Enter desired message.

:Accident at Bradley Road (Exit 7)
:Expect 1 Hour Delay
:Detour: Exit 6 to Abrams Road West

More? No

MESSAGE BOARD UTILITY PROGRAM
Enter variable message sign numbers(s):

Interstate 95, North. Exits 4 through 6

YOU HAVE ENTERED THE MESSAGE
       "Accident at Bradley Road (Exit 7).
           Expect 1 Hour Delay.
       Detour: Exit 6 to Abrams Road West."

FOR DISPLAY ON VARIABLE MESSAGE SIGN NUMBERS:
       4N95
       5N95
       6N95

IS THIS CORRECT?  Yes
Use display message (DM) command to implement

MAIN> send message
```

Figure 11-11. Natural language dialog to post variable message sign.

11/61 Acceptable Translation Performance	(Observation)

User's inputs must be translated within acceptable error rates.
There is no defined level of acceptable error so this guideline implies user acceptance testing specifically aimed at defining satisfactory performance for the translation functions. Ideally, the list of synonyms will be developed through user testing.

11/62 System Response Time Limits	(Observation)

Response times must be within acceptable limits.
Translation adds a step between user input and system action. This step will take some non-trivial amount of time to look up potential synonyms and to verify that the input is not ambiguous. System response is constrained, however, by the maximum delay that users are willing to accept. While user acceptance should be tested to define the acceptable limits, delays of more than a few seconds are unlikely to be tolerated.

Dealing with ambiguous inputs. In simpler, command-based interfaces, input that is not part of the interface command list will generate an error message. In natural language interfaces, there are potentially limitless numbers of acceptable inputs. Some of these inputs may remain meaningless to the system (i.e., they cannot be translated into a system command) while others may be ambiguous (i.e., they can be translated into more than one system command). In the first case, a standard error message (e.g., "Command or file name not recognized") will suffice. In the case of ambiguous user input, it is possible to provide assistance to the user by: [51]

! Requesting clarification of the last input.
! Listing the two or more system commands that appear to match the user's input.
! Perform, with positive verification by the user, the command that makes the most logical sense given the user's current task.

Guiding users to more efficient use of the system-specific commands. With a natural language interface, it is tempting to assume that users do not need training on the system's commands (i.e., the commands into which all other inputs are translated). Use of the system's commands is faster and requires fewer computer resources than use of synonymous commands. In addition, users should be able to converse with one another regarding system functions. This requires that they know a standard set of commands for operating the interface.

11/63 Natural Language Translation   **(Observation)**

Display the system command inferred from the user input.

This will display the correct command to the user for future reference. In addition, if the user intended a different command, showing the translation on-screen will serve as a verification step, giving the user an opportunity to revise the last input.

11/64 Natural Language Commands and User Aids   **(Observation)**

Use system command names in online help, job aids, tutorials, and manuals.

This will facilitate communication between users and help users become familiar with the correct command names.

11.8.3   Menu-based interfaces

Menu-based interfaces are designed to improve Users' performance by eliminating the need to recall command names from memory. Like command-based interfaces, menu systems accept only predefined command names as correct input. Unlike command-based interfaces, menu-based interfaces allow the user to select the correct command from a list (the menu) presented onscreen. Figure 11-12 presents a simple menu-based interface and introduces some of the terminology that will be used in this section.

Selection of menu items is typically via a pointing device, an ALT+key or Function key sequence, and/or cursor movement using the arrow keys. Menus are presented in one of three ways: onscreen at all times, pull-down from an onscreen list item, or pop-up from an onscreen item or "hot key" input (e.g., clicking the right-hand mouse button).

For commands that require further input, such as a file name or specification of options, supplemental menus and data entry fields are presented when the user selects the command. Guidelines for menu-based interfaces fall under five main areas:

- ❗   Composition and organization of lists.
- ❗   Presentation of menus.
- ❗   Presentation of menu items.
- ❗   Selection methods.
- ❗   User aids for navigating menus.

Composition and organization of lists. User-computer interfaces in the TMC environment make use of several hundred commands to control the various functions of the system. Organizing these commands into menus that users can select from effectively and efficiently

requires extensive user testing during the design stage. The following guidelines will provide good starting points for the initial design of menus which can then be revised as the result of user testing:
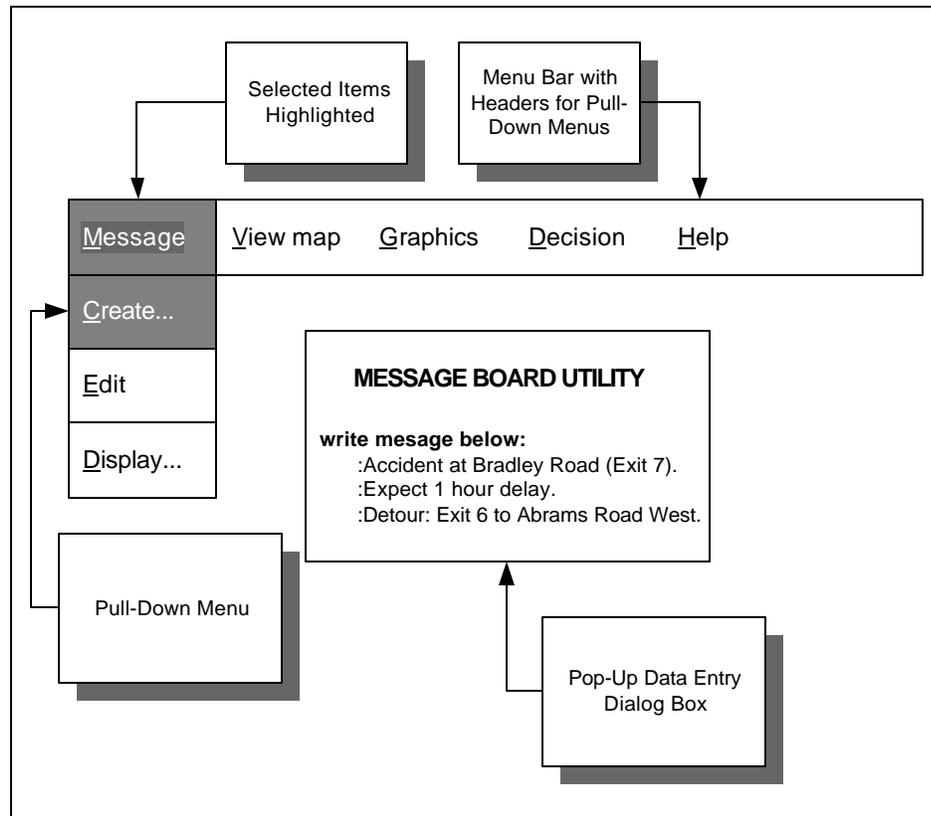
Figure 11-12. Menu-based entry screen.

11/65 Grouping of Related Commands   (Recommendation; 40)

Group logically related commands within menu lists.
Commands for cameras should be grouped together, commands for timing plans should be in another group, and so forth. Groups should be segregated by lines or white space.

11/66 Menu Item Order   (Recommendation; 40)

Present menu items in order of their frequency of use, importance, relationship to other list items, or sequence of use.
When the ordering cannot be determined by one of these criteria, alphabetical ordering should be used.

11/67 Menu Use in Different Contexts   (Recommendation; 40)

When the same menu is displayed in different contexts, the order of list items should remain consistent.
This is true even if the most efficient ordering of menu items is different for the different contexts.

Presentation of menus. There are three basic methods for presenting menus; onscreen constantly, pull-down, and pop-up. The three different methods are used for different purposes as described in the following guidelines:

11/68 Presentation of Frequent Actions   (Observation)

Use consistent presentation order for frequently used actions that apply in most contexts in the system.
Examples in the TMC environment might include the commands used to specify a roadway segment, view a map and view current data. Another type of constant presentation menu is used to display the headings of pull-down menus.

11/69 Pull-Down Menus   (Recommendation; 40)

Use pull-down menus to display a list of commands that are logically related to the header and branch from a menu item.
When the header is selected, the remainder of the menu should be immediately displayed below it. Headers are labels that describe the contents of the menu that will be displayed when that header is selected. For example, a header might be the word "Display," and the pull-down menu might contain commands for displaying a map, a graph, a table, or a video picture. Another header might be the word "Window" and its pull-down menu might contain commands not only for splitting the screen into multiple display areas, but also for sizing and arranging those screen areas.

11/70 Menu Appearance (Recommendation; 40)

Give menus a distinct appearance from other information on the display.
Various options include presenting the menu inside of a box, using larger highlighted fonts for menu items, and/or use a distinct color or reverse video for the menu to allow the operator to easily distinguish between menus and, for example, system status information.

11/71 Menu Extension (Recommendation; 40)

Menus should be confined to a single line (for horizontal menus) or column (for vertical menus).

Presentation of menu items. The ordering and spacing of items within a menu affects a user's efficiency in working with the interface. The following provide guidelines for the display of items within menus:

11/72 Headers for Pull-Down Menus (Observation)

Orient headers for pull-down menus horizontally across the screen. If the list is composed of headers for pull-down menus, put the menu at or near the top of the screen. Other menus that remain constantly on-screen can be oriented horizontally or vertically depending on user preference. Present horizontal menus in a single line across the screen.

11/73 Orientation of Menus (Observation)

All pull-down and pop-up menus should be oriented vertically in a single column.
Avoid lists that are so long as to require more than one column and/or columns that run the entire height of the page. At a minimum, leave sufficient room for sub-menus, thus giving access to the options for commands that are near the bottom of the menu list.

11/74 Separation of Groups of Items   (Recommendation; 40)

For lists longer than five to seven items, group items within the list and then separate these groups. Separation can be achieved with horizontal lines across the column or add additional white space (blank lines) between groups. Within each group, put the most frequently used commands first.

11/75 Display of Menu Items   (Recommendation; 40)

Display all menu items, even those that are currently inactive (i.e., those that are not available or applicable in the current context). Display inactive items in a deemphasized highlighting scheme such as unbolded text, italics, or in a light colored (e.g., light grey) font or surround.

Selection methods. Most menu-based systems allow for multiple selection methods. As users become more familiar with the interface, they will often use short-cuts where available, thereby increasing their efficiency. The following guidelines govern the methods used to select menu items:

11/76 Method for Menu Item Selection   (Recommendation; 40)

Use a pointing device (e.g., mouse, trackball, touch screen) as the main selection method.

11/77 Size of Pointing Area   (Recommendation; 40)

Design the pointing area surrounding each menu item to be sufficiently large. Small pointing areas lead to errors. This is especially critical for touch screen implementations since the pointing area has to accommodate the range of human finger diameters. Leave sufficient dead space between adjacent pointing areas to avoid selection errors.

11/78 Keyboard Menu Selection   **(Recommendation; 40)**

Allow menu selection via the keyboard cursor control keys as an alternative to pointing devices.

Typically arrow keys and TAB keys are used; other candidate keys include the Function, HOME, END, PAGE UP, and PAGE DOWN keys, depending upon the application.

11/79 Menu Selection Commands   **(Recommendation; 40)**

Allow users to implement commands without use of a pointing device or the cursor control keys.

Typically, this is accomplished by making each menu item accessible via an ALT+key sequence. For example, the command to save a file might be selected through the pointing device by selecting "File" to obtain a pull-down menu, then selecting "Save" from within that menu. The same action might be accomplished by keying ALT F followed by ALT S, where F stands for file and S stands for save. These ALT+key sequences function as a command-based interface for experienced users and provide short cuts as they typically take less time to perform than the typical selection using a pointing device.

11/80 Keyboard Command Indications   **(Recommendation; 40)**

When keyboard commands (such as the ALT+key sequences) are available as a means of menu selection, incorporate the correct key sequence into the menu item's label.

For example, if "File" can be accessed by keying ALT F, underline the letter F in "<u>F</u>ile" as shown. Use a single letter code that uniquely identifies each item in the menu. Avoid use of numeric coding as these labels are artificial and also constrain the system from later expansion. With an embedded letter code (using the first letter of each menu item where possible), menu items can change position on the list and new items can be added in their most logical location without changing pre-existing codes.

User aids for navigating menus. One of the drawbacks of menu-based interfaces is that users can quickly become lost in a complex structure. Even with well designed headers, it is not always possible for users to recall what items are in which pull-down menu. This is especially true for interfaces with several layers of menus. In addition, interfaces like those for the TMC often support multiple modes of operation (such as edit, preview, analyze, etc.) which cause some menu items to be activated and others to be inactivated. Users will benefit from cues that

remind them of the current operating mode and, thus, help them avoid looking for currently unavailable menu items.

11/81 Menu Hierarchy Map   **(Recommendation; 28)**

Produce a map of the menu structure showing which commands are in which menus.
The map functions as a job aid and should be provided to all users in paper form and posted in a visible location in the work area. Keep the map up to date.

11/82 Selected Menu Item Indication   **(Recommendation; 40)**

Highlight the selected menu item.
As users point to menu items, change the appearance of the currently selected item (e.g., change its color, size or brightness) so that users know where they are in the menu. Where necessary, provide a brief explanation of the currently selected item by presenting a definition at the bottom of the screen.

11/83 Menu Navigation   **(Recommendation; 40)**

Assign the function "back one menu level" to the ESC key.
By using the ESC key, a user should be able to back completely out of any portion of the menu system until arrival at the main application screen.

11.8.4 Direct manipulation interface/graphical user interface (GUI)

Most direct manipulation , or point and click, interface sare of the GUI variety so that the terms are used synonymously. Direct manipulation interfaces are almost always designed to operate in a windows environment. They are typically designed around a desktop metaphor, meaning that users are meant to view the interface as if it were their own desk consisting of a flat surface upon which files are arrayed. Software tools such as scissors, tape and notepads are present.

The main features of direct manipulation interfaces are the use of graphic on-screen icons that represent actions, programs and files available in the system. Figure 11-13 (next page) presents a sample of such an interface. They are called direct manipulation because there are no intermediaries (such as commands or menus) between the user and the work to be performed. The user works directly on the screen which displays information.
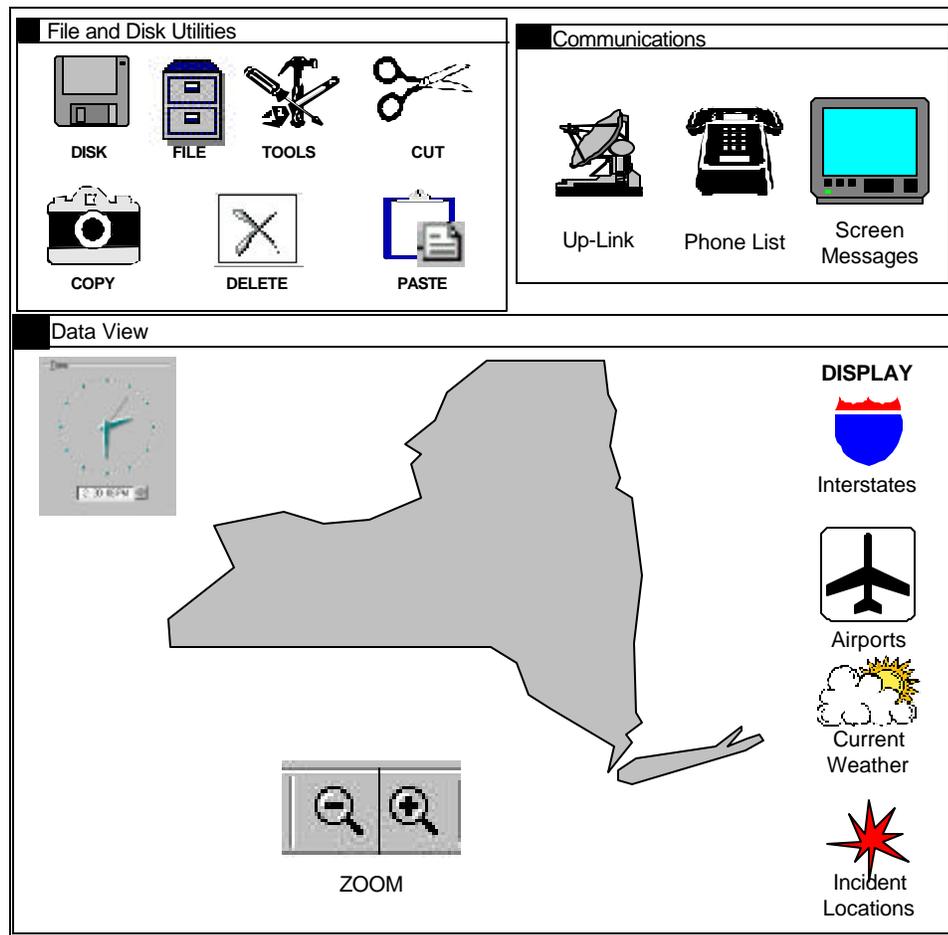
Figure 11-13. Sample direct manipulation interface.

The advantages of direct manipulation interfaces include their intuitiveness, simplicity and flexibility. Novice users find this type of interface easier to learn than an equivalent command-based or menu-based interface. The interfaces are adaptable to the needs of different users through customizing functions (placement and grouping of icons, sizing of windows, reduction of clutter, etc.) that each user can access to make the interface match their own preferences. In addition, direct manipulation interfaces allow system changes to be made transparent to the user. In command-based interfaces, when a command changes or the file reference changes, users must be made aware of the change in order to continue operating the interface effectively. In a direct manipulation interface, the changes are said to be transparent because the user need never learn the new command or file name – as long as the icon remains the same, users will still be able to perform the desired task.

Disadvantages include increased computer resource requirements (additional memory, faster processing units, more capable displays and graphics boards, etc.), slower performance for some tasks and consequently low acceptance among experienced users, and lack of standardization among users if they are allowed to customize their own interfaces.

Guidelines for direct manipulation interfaces incorporate those for windows presented in Section 11.8.2 along with some that are specific to the design and presentation of icons within the desktop metaphor. These guidelines fall under the following categories.

- ❗ Icon design and testing.
- ❗ Consistency and meaning in metaphor.
- ❗ User-specific customizing.
- ❗ Aids to navigation.

Icon design and testing. User testing is critical to the design of icons that are easily recognized and readily distinguishable by most users. Successful design will result in reduced training requirements.

11/84 Icon Testing	(Recommendation; 40)

Test icons among representative users.
The tests should consist of comparisons between alternative icon designs and the Users' perception of the match between icons and the associated actions, programs and files. User testing should also be used to ensure that the icons in the final set are easily discriminable.

11/85 Design of Icons	(Recommendation; 40)

Design icons to symbolize the actions, files, or programs that they represent.
Wherever possible use generally recognized objects as pictures of the represented item. This is simple and obvious for actions such as "cut" and "paste" where any of several satisfactory alternatives (e.g., scissors and glue) would be readily understood by users. Other items (e.g., predictive traffic model) may not have a good visual representation. User testing of alternative designs becomes critical in these cases. In many systems, using a word instead of the icon has proven to be the best alternative.

11/86 Color Use in Icon Design	(Recommendation; 40)

Use color in the design of icons. However, color should not be the only or the most salient difference between any pair of icons. Icons should be positive visual images (dark on a light background).

11/87 Icon Size	(Recommendation; 40)

The graphic portion of icons should measure *at least* 0.64 × 0.64 cm (0.25 in × 0.25 in).
This will reduce the time required to position the cursor and help to reduce selection errors.

11/88 Icon Size and Locations (Recommendation; 40)

Use consistent sizing, placement and groupings of icons.
Individual icons should, unless otherwise changed by the user, always appear in the same grouping and in the same location whenever the icon is displayed.

Consistency and meaning in metaphor. The most common direct manipulation interfaces were developed for the office environment and have been designed to make use of the familiarity of that environment among the user population. The desktop metaphor is readily understood by office workers for whom a file laying on a flat surface closely matches their normal way of working. Other metaphors are possible. The goal is to select a metaphor that feels natural to the user population and, at the same time, adds to its understanding of how the system operates. [7, 8] Whatever the selected metaphor, the following guidelines will help to ensure that it is applied consistently throughout the interface and results in efficient performance by the system's users.

11/89 Metaphor Selection (Recommendation; 22)

Choose only one metaphor and apply it throughout the entire interface.
Inconsistent application of a metaphor can confuse users and inhibit the formation of correct mental models of the system's functioning. [72]

11/90 Metaphor Meaningfulness (Recommendation; 17, 40)

Adopt a metaphor that is meaningful to the user population.
Ideally, the selected metaphor will be from the subject domain (e.g., traffic management), however the design trade-offs may be such that the most cost effective solution is the desktop metaphor. If so, make sure that this is a representation with which the intended users are comfortable and familiar.

User-specific customizing. One of the advantages of direct manipulation interfaces, adaptability to individual user's needs, is also a potential drawback. Problems can arise when a

user customizes the interface and then requires help from either a technical support person or another user. The differences between Users' screen setups can be large and may lead to confusion and inefficiency in cases when one user attempts to work with another's interface. The following guidelines are intended to constrain the types of customizing that individuals can perform, thus maintaining a minimum level of standardization between users.

11/91 Standardization of Icon Set   (Observation)

Adopt and maintain a standard set of icons.
Unlike most systems, in the TMC environment it will be necessary to block users from designing or assigning their own icons to actions, programs, and files. Lack of standardization will make it difficult for users to obtain assistance from anyone else in the TMC.

11/92 Configuration Files   (Observation)

Each user's setup configuration should be saved in a file, as should the default configuration.
At any workstation in the system, it should be possible to call up any of the saved configurations and reformat the screen accordingly. A user's own configuration should load automatically on any comparable workstation.

Aids to navigation. The icons in a direct manipulation interface are equivalent to the list items in a menu-based interface. Typically, icons are grouped within windows that can be considered the graphic equivalent of menu headers. In large systems, such as a TMC, it is impractical to show all the available windows and icons onscreen at the same time. For that reason, users are typically presented with one or more open windows, only one of which is active. Despite the abundance of onscreen cues, users must still rely on memory to know where to look for a specific icon. The following guidelines will help users navigate through the windowing system of a direct manipulation interface.

11/93 Default Presentation Style   (Recommendation; 40, 41)

Display all currently open windows onscreen as the default presentation.
Users may select a different screen appearance by expanding or decreasing the size of individual windows. The default presentation, however, should automatically size windows and/or overlap them in ways that show the title and menu bars (at a minimum) for all open windows.

11/94 Active Window Location　　　　　　**(Recommendation; 40, 41)**

Establish precedence so that the active window appears at the top (front) of the stack of windows in any overlapping window arrangement.

11/95 Appearance of Active Window　　　　**(Recommendation; 40, 41)**

Give the active window a distinct appearance from other open, but inactive, windows.
Typically the border and title bar of the active window are highlighted in a different color from the open inactive windows.

11/96 Closed Window Representation　　　　**(Recommendation; 40, 41)**

Present closed windows in a minimized representation.
Typically, minimized representations are a single icon that represents the entire window's contents. Selecting this icon opens the window and makes it the active window. Upon opening, it is restored to its previously defined position and size and is highlighted as active.

Many modern packages that use windows for navigation, warning, and other purposes make poor use of color. Some allow the user to choose borders, background and foreground colors from a wide palette of hues. These choices can have a bad effect on intelligibility, if users chose clashing, saturated combinations that advertise the capacity of the computer to generate color rather than the information that is displayed.

Contemporary applications tend to use color effectively. Color is useful in windowed displays because it reduces the prevalence of grid noise. Borders of quiet color can define windows without harsh, high-contrast lines and bars that detract from the readability of text. Tufte (1990) suggests that such fields be light in value (bright), and that selected windows be bordered in yellow (which is the only color available that can be both light in value and saturated; see Chapter 8 for definition of color attributes).

Another recent innovation in GUI interfaces, particularly of the windowed type, is the use of edge shading of active screen areas to reinforce the "button" metaphor. Such shaded (called "sculpted") areas create the illusion of a three-dimensional key or button, and, by extension, gives the operator the illusion of "pushing" the button with the cursor.

The three-dimensional effect is accomplished by placing a light edge on the upper and left edges of the rectangular area and a darker "shadow" on the right and bottom edges (reversing this pattern creates the effect of a recessed, rather than raised, button; for some reason, the visual system expects the light source to be in the upper left). It is also helpful to add a thin black border around the sculpted button, a trick that increases the effect of the light edges by a visual process called lateral inhibition, and adds the impression of a socket into which the "button" is fitted.

This may seem an extravagant way to use system memory, but it has the advantage of clearly identifying "active areas" that can be manipulated using the selector device.

11/97 Highlighting Within Active Window   (Recommendation; 40)

Within the active window, use highlighting to indicate the currently selected icon.
The selected icon is one which the user has pointed to, but not yet called into active status (e.g., the icon for a program has been selected but the program has not been launched or run). Indicate selection either by drawing a box around the currently selected icon or changing the background color of the icon and/or its label.

11/98 Presentation of Items On-screen   (Recommendation; 40)

When the user has exited a program or reduced the size of a window, all previously covered windows and icons should be presented on-screen without any change in their position or size.
All associated windows should close automatically when the main window is closed.

11/99 Locating Items in the Interface   (Recommendation; 40)

Give users a search function to provide a quick means of finding any item in the interface.
The typical way this is supported is through a combination of a file manager program and a browse function. Both of these allow users to search for items by name or file type. It would also be useful to allow users to enter commands directly in order to launch (run) programs, if they choose. In a direct manipulation interface, this equates to opening a dialog box and entering the command name.

11.8.5   Combination interfaces

There are almost no menu-based or direct manipulation interfaces that are purely of one type or the other. In addition, most interfaces include a command-based method of interaction. In a menu-based system, selection of menu items can become tedious, especially for repetitive uses of options that are two or more layers deep in the menu structure. Calling each successive menu takes time and displays more information than the user needs. Similar experiences are common with direct manipulation interfaces. Selection of an icon may be only the first step in a lengthy procedure which, if repeated often enough, becomes frustrating to users. In some cases users find it simpler and faster to enter a sequence of commands via the keyboard.

Presently, there is no clear body of research to supply guidelines for design of combination interfaces that will allow predetermination of when to support which method of interaction. Some preliminary guidelines can be stated in the following areas:

- Keyboard selection of menu-items and icons.
- Macro commands.
- User testing.

Keyboard selection of menu-items and icons. In menu-based and direct manipulation interfaces, users will often find it faster to select actions, files, or programs using the keyboard. This is especially true for items that are located deep in the menu structure or several windows deep in the windows structure. The following guidelines describe methods of keyboard input

that can be supported in menu-based and direct manipulation environments.

11/100 Command Support in Menu-Based Interfaces   (Observation)

In menu-based environments, support (ALT+key) sequence codes.
This is essentially a command-based interface embedded within the menu-based one. Experienced users will find it faster to access frequently used commands through the ALT+key sequences.

11/101 Icon Selection Support   (Observation)

In direct manipulation environments, support icon selection through use of a CTL+key, ALT+key, or Function key sequence.

11/102 Use of a Run Dialog   (Observation)

Allow users in either menu-based or direct manipulation interfaces to enter commands directly through a run dialog.
When users know the name of the command or program they wish to run, they should be allowed to avoid the menu structure and thus save the steps associated with displaying sequential menus or accessing any of the windows. Figure 11-14 shows the use of a Run Dialog box in menu-based and direct manipulation interfaces.

Macro commands. For frequently used procedures, users become frustrated by having to repeat the same steps each time. This is especially true when those steps involve accessing a series of menus or windows, followed by specification of options that had been set previously. The following guidelines describe the use of macro commands that automatically step through the procedure after only a single user input.
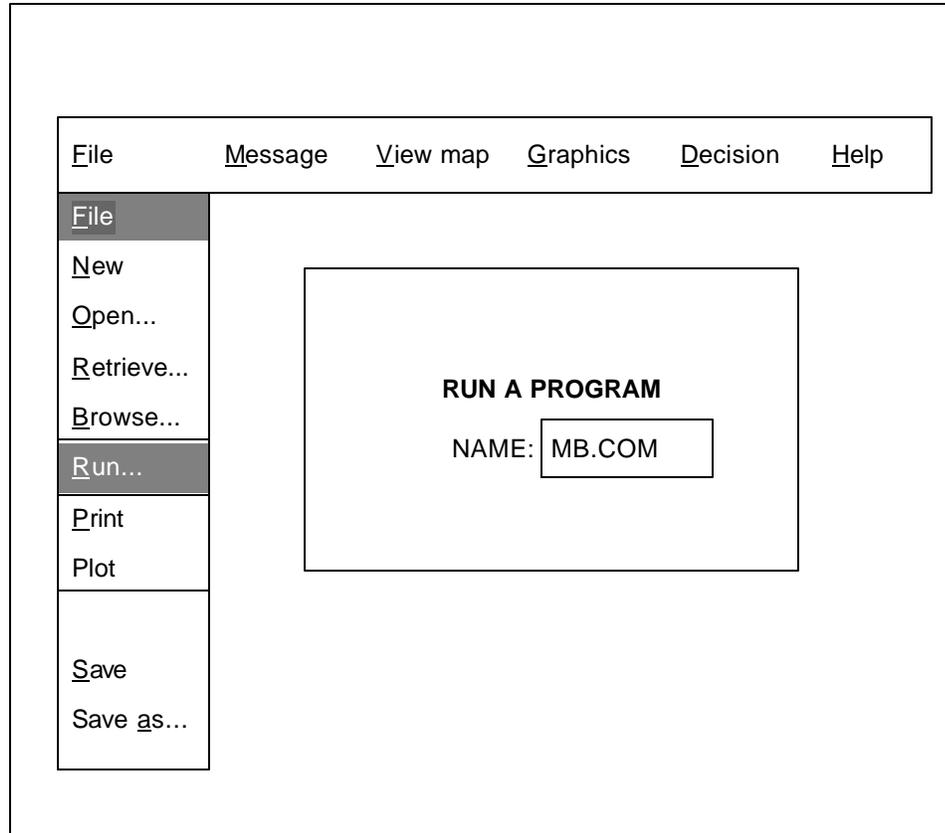
Figure 11-14. Use of a RUN dialog box in a combination interface.

11/103 Macro Commands   **(Observation)**

Build macro commands for the most frequently used items that are at least one layer deep in the menu or window structure to provide access to these functions at a single step.
In the TMC environment, the user and task analyses performed in phase 1 of interface design will help to determine which interface functions are most likely to be used. In addition to placing these functions in the most appropriate menu or window, consider presenting an on-screen "hot key" or "button" to allow implementation through a single selection. In menu-based interfaces, hot keys are constantly in an on-screen menu and can be accessed either through the pointing device, Function keys or an ALT+key sequence. In direct manipulation interfaces, buttons are on-screen labeled areas (typically highlighted to look like a pushbutton) that launch the associated command when selected.

11/104 Macro Commands for Procedures   (Observation)

In command-based interfaces, build macros that stand for procedures (sequences of commands).
This creates a new command that can be used to implement a procedure composed of several other commands. Macros in a command-based interface are implemented just like any other commands; the user enters the command name followed by any required and optional specifications.

User testing. In combination interfaces, it is possible to optimize the selection of interaction methods for the various functions, commands, files, and programs. This is accomplished through user testing on prototypes. The following guidelines apply:

11/105 Construction of Prototypes   (Observation)

Build and test prototypes of the interface that represent the range of interaction methods available.
Allow a sample of users to work with the prototypes in order to determine their preferences for interaction methods for major functions.

11.9 Matching Display Type to Information Requirements

The goal of user-computer interface design is to provide the human operator a tool that promotes rapid, accurate performance of tasks.

The form that information takes and the ways in which it is presented determines how useful it is to the operators. In many cases, information arrives as numeric data gathered through traffic monitoring. The best way to present this information depends on the operator's current task. For example, monitoring tasks may be facilitated by minimal information provided in an on-screen summary. Directing an incident response might require detailed information about vehicle movements on multiple routes.

To meet operators' information requirements at all times, designers need to understand the task-dependent uses for the information, the modes of presentation that most closely meet the needs, effective ways to highlight information, and how often to obtain and present updates. Guidelines for information presentation design fall into the following categories:

- Presentation modes and level of precision.
- Graphic data conventions.
- Tabular data conventions.
- Mapping conventions.

!   Information density.

11.9.1 Presentation modes and level of precision

Most of the data collected in the TMC will be quantitative, rather than qualitative, in nature. The power of numeric data are that they can be presented in a variety of formats and at various levels of precision. They can be plotted or placed in a table, combined with related data to form a composite measure, and aggregated over temporal and spatial intervals to give a more global picture and reduce the effects of random variation. Different tasks in the TMC will require different methods of data presentation. This section deals with the ways in which data can be presented onscreen and the strengths and weaknesses of each. Of particular importance is the relationship between presentation modes and the level of precision they support.

Guidelines on presentation modes fall into the following categories:

!   Task demands.
!   Operator familiarity.

Task demands. The match between presentation mode and task demands is an important factor in determining the timing and quality of operators' decision making. The following guidelines apply:

11/106 Use of Graphic Presentations   (Observation)

Graphs are the presentation mode of choice for showing trends (change over time), approximate values, and for comparisons between different sources of data (such as traffic volume at multiple road sensors or volume and speed for a single road segment). Graphic presentations come in several styles (bar, line, pie charts, and X-Y scatterplots). The major advantages of graphic presentations are rapid visual recognition of highlighted information, flexibility of highlighting, and efficient use of screen space.

11/107 Use of Qualitative Displays   (Observation)

Qualitative displays are effective for rapid determination of the relationship between current status and a threshold.
Qualitative displays come in many varieties, including text messages (e.g., "Status OK"), color codes (e.g., green = "normal traffic", yellow = "near capacity", red = "congested traffic"), and other visual highlighting (e.g., steady versus flashing lights). The advantages of qualitative displays are support for "at-a-glance" decision making, rapid information processing by operators, and focusing on the most critical information.

11/108 Use of Tabular Data Presentations   (Observation)

Use tabular data presentations when the task calls for precise numeric data.
Users find it easier to read a value from a table than to estimate from a graph. Tables have fewer style options than graphics, since they are typically arranged in a row and column format. It is possible, however, to highlight information effectively within this rectangular format.

Operator familiarity. Operator familiarity, in addition to task demands, plays a major role in determining the optimal data presentation to support decision making. Information should be displayed such that operators can readily understand it and make use of it. In part, the ability to understand the information is a function of user preferences. It is important that presentations are consistent and simple. The following guidelines apply to all presentation methods and will help to maximize Users' understanding of the information presented to them.

11/109 Information Presentation Labels   (Recommendation; 40)

Provide clear labels.
Graphs and tables should contain a title that clearly identifies the data presented by naming the source and whether the presentation is conditioned by time, location or other key variables. Names of variables should match those used in the graph axes, or rows and columns of the table. Figure 11-15 presents examples of a graph and a table with an appropriate title and labels for the axes and rows and columns.

Be consistent with indications of transformations to avoid operator misinterpretation or confusion.
This is especially important for indicating that the data shown are differences (e.g., "change", "percent change", "predicted versus actual", etc.) or ratios (e.g., "percent", "proportion", etc.).

Midtown Avenue Speed

Morning and Evening Rush Hour Speeds
(1995 - 1992)

Midtown Avenue Speed

Morning and Evening Rush
Hour Speed (m.p.h.)
1985-1992

	Year							
	1985	1986	1987	1988	1989	1990	1991	1992
Morning	18.0	19.0	20.0	22.0	24.0	26.0	27.0	27.5
Evening	14.0	13.0	13.5	15.0	15.5	14.0	14.5	15.0
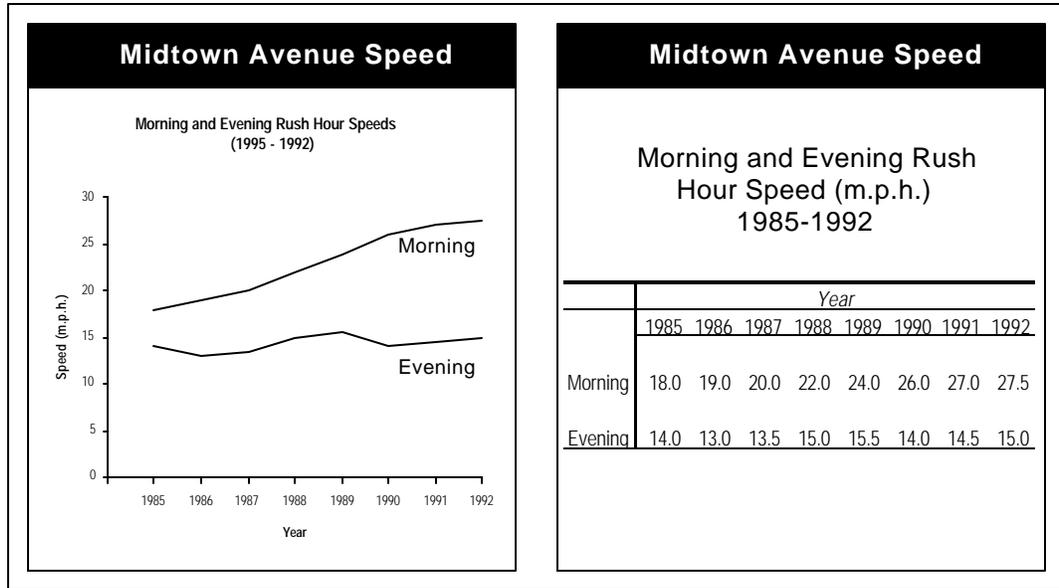
Figure 11-15. Sample data table and line graph.

11.9.2 Graphic data conventions

Graphic displays are best used for visualizing relationships among variables, providing approximate values, making comparisons between variables, and seeing trends across time or geographic areas. The main advantages of graphic displays are their ability to show complex relationships simply and the ease with which particular aspects of the data may be highlighted. Users are familiar with most simple graphic styles (line, bar, X-Y scatterplot, and pie charts) and can use them effectively. Graphics support rapid decision making, when the task does not require precise numeric estimation of data values.

This section presents basic guidelines for graphing data. These fall under the following areas:

- ! Graph styles.
- ! Axis orientation and style.
- ! Labels.

Graph styles. Graphs can be displayed in a number of styles. Most common are line, bar, and pie charts. Each of these, in turn, incorporates a number of stylistic options (highlighting,

perspective, shading, grids, etc.). The following guidelines apply:

11/111 Information Display Format   **(Recommendation; 121)**

Use the simplest possible format to display the required information.
Avoid complex formats presenting more than two dimensions. Also, avoid
embellishments such as pictures, shading, perspective, and decorative
items which do not add information.

11/112 Line Charts   **(Recommendation; 121)**

**Use line charts to display trends across time or distance, and for
comparisons between two or more trends.**

11/113 Chart Indications   **(Recommendation; 40, 41)**

**Use distinctive patterns and/or colors to distinguish between lines on
a multiple line chart and between sets of bars on a bar chart.**

11/114 Display of Projections   **(Recommendation; 40, 41)**

**Indicate the use of projections (interpolated and extrapolated data)
with a distinctive change in the line or bar.**
A change in color or change from a solid line to a dashed line can indicate
such a change.

11/115 Switching Between Charts   **(Recommendation; 40)**

Allow users to switch easily between line and bar charts.

11/116 Comparison Between Proportions **(Recommendation; 40)**

**Use bar charts and stacked bar charts to facilitate comparisons
between proportions.**

11/117 Stacked Area Charts Presentation   (Recommendation; 40)

In stacked area charts (surface charts or cumulative charts), plot the series with the least variation on the bottom and the one with the most variation on top.

Axis orientation, style, and labeling. Most charts will incorporate two axes, generally termed the x- and y-axes. The x axis runs horizontally, and the y axis runs vertically and the two meet at a right angle. Axis styles are more variable. The scale of either axis can run from -4 to +4. Typically, only a range from 0 to some positive value is shown, or a range from a negative to a positive value is shown. Axis labels can display numbers, dates, times, or merely names.

11/118 Assignment of Variables   (Recommendation; 40, 41)

Be consistent in the assignment of variables to the x or y axis.
In general, it is preferable to assign the measured or calculated variable (the dependent variable) to the y axis, and the conditioning variable (the independent variable) to the x-axis. Examples of y-axis variables include speed, volume, number of incidents, percent, and percent change. Examples of x-axis variables include time of day, day of week, time in 5 min increments, and location.

11/119 Origin Position in Graphed Data   (Recommendation; 40)

When graphed data represents only positive numbers, the graph should be displayed with the origin at the lower left.
When the data include both positive and negative values, the origin should be centered with respect to the axis' length. If both axes contain positive and negative values, the origin should be in the center of the graph.

11/120 Continuous Axes   (Recommendation; 40, 41)

Use continuous axes.
Avoid discontinuities in the range of values displayed on the axes wherever possible. If it is necessary to use a discontinuous axis, indicate that the range has been truncated by placing a clearly labeled gap in the axis line.

11/121 Comparisons Between Charts   (Recommendation; 40)

When comparisons are required between charts, present the same axes on both charts with the same range of axis values.

11/122 Use of Linear Axes	**(Recommendation; 40, 41)**

Use linear axes wherever possible.
Users find it difficult to comprehend nonlinear axes (e.g., logarithmic number scales). Extra time may be required to interpret information from charts with nonlinear axes.

11/123 Axis Range	**(Recommendation; 121)**

Tailor axis ranges to the user's need.
Too large a range on the y-axis will artificially suppress any visible differences between data points; too small a range will artificially exaggerate the differences. Unless there is a need to emphasize differences, the y-axis should begin at zero.

11/124 Axis Origin Value	**(Recommendation; 40, 41)**

Set the Y-Axis Origin to Zero
Users normally expect the origin to be a zero. If a deviation from this convention is necessary, emphasize the origin value.

Labels. Graph labels – title, axis names, axis and data point values, and legends – are critical to the Users' understanding of the information presented. Operators need to readily understand the scaling used on a particular axis, and recognize the labels and the names given to the axes.

11/125 Chart Title Location	**(Observation)**

Display the chart title at the top of the screen area in which the graph is presented.
Center the title with respect to the chart's width. Pick a title that meaningfully describes the data shown in the chart, naming first the dependent variable (y-axis) followed by the independent variable (x-axis), (e.g., "Northbound I-95, Traffic Volume by Time of Day")

11/126 Axis Label Location　　　　　　　**(Recommendation; 40)**

Label the y-axis label to the left of the y-axis, and x-axis label below the left axis.

11/127 Axis Label Orientation　　　　　　**(Recommendation; 40)**

Orient y-axis text horizontally.
Rotating the text creates more ink space for data, but makes reading the axis label more difficult.

11/128 Transformations　　　　　　　　　**(Recommendation; 40)**

Show the formula for y-axis variable transformations.
For instance, use "Vehicles/Hour/Lane" rather than "Traffic Flow." Or use "Flow (vehicles/hour/lane)."

11/129 Data Point Values　　　　　　　　**(Recommendation; 40)**

Allow users to select data point values in a selectable fashion.
Data value labels should appear near the associated data point or in a table, depending on the amount of clutter and the number of labels. User selection can be in the form of a global request (e.g., "label all data points") or on a point-by-point or line-by-line basis, depending on user preference and task demands.

11/130 Labels for Lines, and Bar Sets　　　**(Recommendation; 40)**

Label each curve or set of bars.
Place the label for curves and lines on or at the right end of the lines. If this is not possible, label curves and lines in a legend. Always list the lines or bars in the order in which they appear in the graph from top to bottom or left to right, respectively.

11/131 Legend Location   **(Observation)**

In charts requiring a legend, place the legend in a consistent location.
The legend should show both the line or bar format and the name of the corresponding data series. Usually legends are located at the right side of the graph.

11.9.3   Tabular data conventions

Tables are useful for presenting small amounts of alphanumeric data and for presenting numbers when precision is required. The main advantages of tabular displays are their simplicity and familiarity to most users, and the ease with which the precision of numbers can be increased or decreased without adding complexity to the presentation. Disadvantages are that tables do not show trends or exceptional values (outliers) very effectively. Guidelines for tabular presentations fall under the following main headings:

- ❗ Format.
- ❗ Highlighting.
- ❗ Labels.

Format. Virtually all tables are presented in a simple column and row format. Considerable variation is possible however, in both complexity and density of tabular data presentations. The following guidelines are chosen to provide users with rapid access to information with a minimum amount of search time:

11/132 Table Row and Column Organization   **(Observation)**

Organize table headings so that values increase left to right, and from top to bottom.
For instance, begin with January on the left and end with December on the right. Alemeda Drive near the top and Zuniga Place near the bottom.

11/133 Table Organization Consistency   **(Observation)**

Use the same organizational principles for row and column headings when generating new tables.
For instance, if Interstate exits are listed in milepost order in one table, they should be listed in that order on similar tables unless there is a compelling, task related, reason to use a different order.

11/134 Presentation of Complete Table   (Recommendation; 40)

Design the table such that the complete table is shown on-screen.
Tabular data should not extend beyond the screen space allocated.

11/135 Hierarchical Tables   (Observation)

Avoid displaying hierarchical tables (i.e., tables containing more than two dimensions).
Such tables are very difficult to understand and visualize.

11/136 Consistency in Spacing of Table   (Recommendation; 40)

Use consistent spacing throughout the table. Provide space between columns to avoid reading errors and to allow for adequate labels. In long tables, consider presenting the row variables in groups of three to five, skipping a row between groups.

11/137 Presentation of Numeric Data   (Recommendation; 40)

Present numeric data in a ready-to-use format.
Avoid requirements for the operator to compute values, perform interpolations or extrapolations, or mentally transform the data.

11/138 Justification of Numbers   (Recommendation; 40)

Columns of numeric information should be justified with respect to a fixed decimal point or right justified if there is no decimal point.
Present numbers within a column to the same level of precision (i.e., accurate to the same number of decimal places).

Highlighting.

11/139 Grouping of Data   **(Recommendation; 40)**

All necessary data to support a user's activity or sequence of activities should be grouped together.
The operator should not have to search through numerous screens for the information required to complete a routine task.

11/140 Data Grouped for Comparison   **(Recommendation; 40)**

Group data to clarify desired comparisons. If table entries need to be compared on a character by character basis, present them in adjacent rows of the same column.

11/141 Separation of Data Items   **(Recommendation; 121)**

Avoid internal grid lines.
Where possible, use row and column spacing to improve readability rather than separate data items with lines. Use internal grid lines only when the amount of data that must be presented requires dense spacing.

11/142 Presentation of Calculated Data   **(Recommendation; 40)**

If data values and calculations based on those values are presented in the same table (such as a series of numbers along with a total), present the calculated value in a distinctive fashion.
Use a darker font (bold), or a color change, to highlight the cell containing the calculated value. Make the corresponding row or column label distinctive as well.

Labels.

11/143 Identification of Variables   (Recommendation; 40)

The table's title should clearly identify the variables displayed.
It is important to name the measured variable which appears in the cells of
the table as it may not have a corresponding row or column label. For
example in a table presenting speed information for several locations
(column variable) in 1 hr increments (row variable), neither the column or row
label would identify that the data shown are speeds.

11/144 Row and Column Heading Labels   (Recommendation; 40)

Label each row and column with an appropriate heading.
Avoid abbreviation wherever possible.

11/145 Presentation of Labels   (Recommendation; 40)

Always display the row and column headings and the table's title.
If the table is so large as to require scrolling either horizontally or vertically,
ensure that the title, and the row and column labels corresponding to the
displayed region of the table remain onscreen.

11/146 Presentation of Measurement Units   (Recommendation; 40)

**Present the units of measure in the title, row or column labels, or in
each cell, as appropriate.**

11.9.4 Mapping conventions

Much of the information used in a TMC has geographical dimension (e.g., traffic conditions are
described at particular locations). Incorporating this information into an on-screen graphic map
is a powerful way to show current conditions, change from previous time periods, and
projections into the future.

Guidelines are presented under the following main headings:

- ! Map resolution, position, and orientation.
- ! Labels, features, and symbols.
- ! Location selection and data displays.
- ! Navigation, pan, and zoom.

Map resolution, position, and orientation. The following guidelines apply to map resolution, position, and orientation:

11/147 Level of Map Detail **(Recommendation; 40)**

The level of detail must match the task requirements.
All critical features should be legible and uncluttered. Allow the user to reduce clutter without eliminating important information by using a declutter function to hide less important information.

11/148 Orientation of Maps **(Recommendation; 40)**

Orient the map with North.
Allow the user to change the orientation only on their individual monitors. Place a compass rose indicator to point to North.

Labels, features and symbols. The following guidelines apply to the labeling of maps:

11/149 Map Label Positions **(Recommendation; 40)**

Position map labels consistently in relation to the labeled feature.

11/150 Symbol and Color Code Selection **(Recommendation; 40)**

Select a set of standard symbols and color codes.
Provide a legend on-screen and/or in a user aid (on-line help or a job aid).

11/151 Symbol Placement   **(Recommendation; 40)**

Do not allow symbols to overlap.
If overlap is unavoidable, allow the user to view masked symbols either by
calling them to the foreground or by turning off the concealing symbols.

Location selection and data displays. The following guidelines apply to selection of items on
a map:

11/152 Location Specification and Selection   **(Observation)**

**Use a pointing device as the main method for location specification
and selection from the map, e.g., selecting a specific camera or loop
detector.**

11/153 Display of Associated Data   **(Recommendation; 40)**

**Provide user-selectable display of data associated with specified
location.**
Ideally, such information would be made available through a pop-up menu or
display window. For example, when the operator selects a specific traffic
sensor a menu might appear listing the categories of data that are available
from that sensor.

Navigation, pan, and zoom. The following guidelines apply to the selection of areas of a map
and map detail:

11/154 Provision for Zoom Functions   **(Recommendation; 40)**

**Allow the user to zoom out and zoom in to obtain a larger area view
or more detail, respectively.**
Methods of zooming include drawing a box around the desired area followed
by expansion to fill the screen and selecting a zoom amount (expressed as a
percent magnification) from a menu of preset values.

11/155 Zoomed Map Display (Recommendation; 40)

When the entire map is not displayed (e.g., as the result of a zoom operation), display an inset image of the entire map highlighting the location of the currently displayed section.

11/156 Panning Within the Map Display (Recommendation; 40)

Allow the user to pan in any direction to view other sections of the map without changing the on-screen resolution.

11/157 Provision for Default Display Return (Recommendation; 40)

Provide a means (e.g., mouse click on a single button) for a quick return to the default display size and location.

SPECIAL PROBLEMS IN ZOOMING

In one TMC, multiple levels of zoom were defined for the geographic region in which the TMC was located. Several geographic sources were consulted and the data were merged, then a series of zooms and granularities was defined from the larger geographic region down to the intersection level (four levels of detail).

Operators with experience in using these zooms found that only two cases, a local regional zoom-in of several square blocks and the intersection zoom-in, were actually useful. Had this peculiarity been noted during prototyping, quite a lot of graphic code could have been eliminated. In addition, the distances between objects on the display were not strictly proportional to the true geographic distances. Interestingly, this did not prove to be a problem in practice; the general spatial relationships of critical locations appear to be more important than actual distances. (44)

11.9.5 Information density

With limited display space, designers often attempt to pack the screen full of information to cut down on the amount of screen switching that is needed. However, screens can become so loaded with information that operator performance suffers.

Guidelines for avoiding screen clutter are presented under the following main   headings:

- ❗ Screen packing density.
- ❗ "Chart junk."

Screen packing density. Screen density is defined as the amount of screen space used to display information, and is expressed as a percentage of overall screen area. In other words, screen density is inversely related to the amount of white space left on the screen. Operator performance with information displays varies as a function of screen density and the distribution of white space. The following guidelines are presented in reference to text displays. Similar but less specific guidelines have been published regarding graphic and tabular displays.

11/158 Amount of Text-based Material   (Recommendation; 51)

Text-based material should not fill more than 50 percent of the space available for character displays.
Densities below 25 percent are preferable. (Note that these are based on displays of alphanumeric characters. Optimal density for graphic displays may be much different).

11/159 Screen Display for Critical Tasks   (Recommendation; 51)

Critical tasks (those requiring high levels of accuracy and/or rapid processing by users) require lower screen densities than less critical tasks.

11/160 User Control of Screen Density   (Recommendation; 51)

Allow the user to control screen density.
In a window environment, give users control over window size and allow them to zoom in and zoom out to change the view of the information displayed within a window.

"Chart junk." One of the most effective ways to reduce screen density is to eliminate extraneous detail. Information density of a presentation is defined as the amount of "ink" devoted to present *data*, expressed as a percentage of the total "ink" used. "Ink," like white space, is a metaphor for the typical paper-based presentation of information. Unlike screen density, which is minimized in effective presentations, designers should strive to maximize information density. When information density is reduced, users are distracted from the data

because of the nondata information filling the display area. This noninformative filler is referred to as "chart junk" by Tufte (1983).

Figure 11-16 shows a typical example of a computer generated chart on the left. Included is an array of chart junk items placed in the figure, either because the graphics package does so automatically or simply to take advantage of the capabilities of the computer. The graph and the table in Figure 11-15 shows the same information with the extraneous detail removed. The improved clarity of this presentation can be expected to bring a corresponding improvement in operator speed and accuracy.

Examples of chart junk in common computer graphics might include false three-dimensional graphics (Figure 11-16), in which the added "ink" contributes additional information.
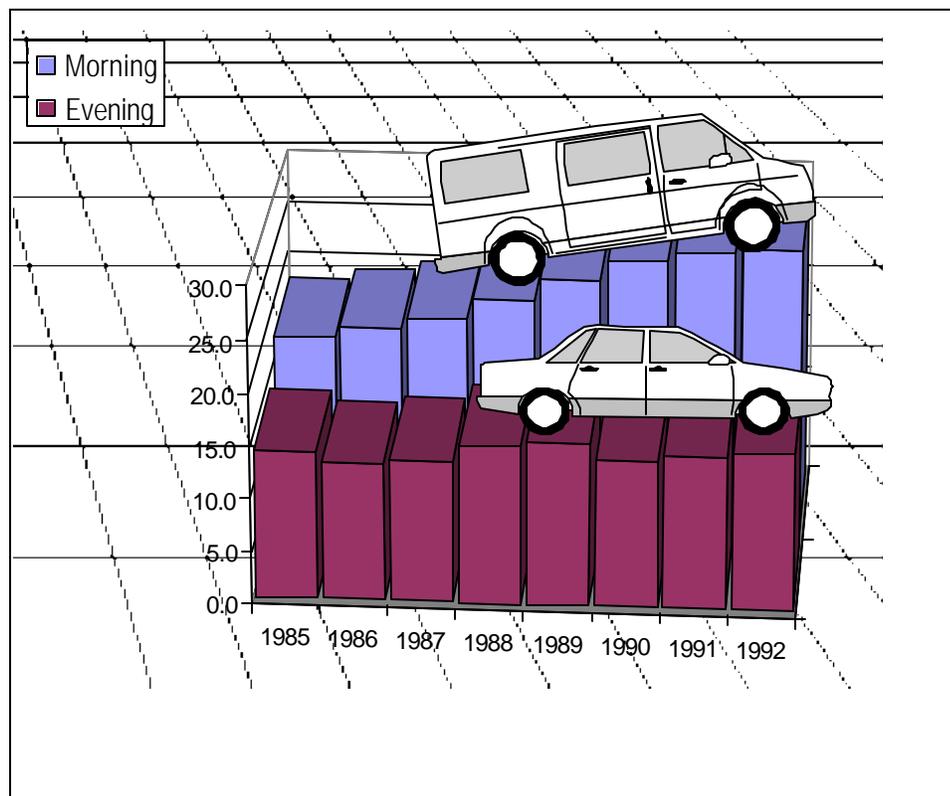
Figure 11-16. Computer-generated "chart junk" makes data hard to read.

The following guidelines are presented as aids to reducing the amount of chart junk in data presentations:

11/161 Provision of Essential Information   (Recommendation; 51)

Provide only the information that is essential to making a decision or to performing an action in accordance with task demands.
Dimensionless decoration, unnecessary border or grid patterning, annoying hatchures, and other computer chart junk add complexity and do not contribute information.

11/162 Information Density   (Recommendation; 112)

Maximize the information density of the display.
Use the active display area to present information, not lines, delimiters, boxes, arrows, or other non-data elements. Present non-data elements only to the extent that they are required by the user to interpret the data. Axes, labels, and legends, for example, are not data, but they support the user's ability to understand the data as presented.

11/163 "Chart Junk" Design   (Observation)

Where there is a desire to display "chart junk," design it to minimize interference with the operators' display interpretation.
In some TMC's, graphics of local tourist attractions are included in map displays for public relations purposes. Care should be taken that the size, color, and location of these graphics do not distract the operator. There should be consideration of a capability to toggle the chart junk "on" when the tour group arrives and "off" when they leave. Alternatively, these graphics might be included only on a seldom used map scale.

CHAPTER 12: USER AIDS

CONTENTS

12.1 Types of User Aids

Traffic management centers employ operators and other technical personnel with a wide range of skill and experience levels. Most personnel will interact with complex information systems. Performance will increase if operators are provided with user aids such as checklists and procedures manuals that help them manage these complex systems. Where well designed user aids have not been supplied or developed as part of TMC systems, employees have developed their own aids to fill the gap.

User aids come in a variety of on-line, hard-copy, and live presentation formats. Each format has a specific application. User aids are employed to support on-the-job training as well as operator performance. This chapter emphasizes the role that these tools play in the overall system. They are intended to assist operators working with the user-computer interface so that errors are reduced and user expertise is enhanced. This chapter provides guidelines for the design of the major kinds of user aids. The final section of this chapter deals with opportunities for integration among the various types of aids to save costs and to reduce the number of design iterations.

There are six types of user aids discussed in this chapter:

! Error messages.

- **!** Job aids.
- **!** User manuals.
- **!** On-line help.
- **!** Tutorials.
- **!** Design support tools.

In the sections that follow, definitions and guidelines are provided for each type of user aid. The first section discusses an incorrect assumption that is becoming more common with the advent of menu-based and direct manipulation interfaces; that no training or aiding is required if the interface is "intuitive" and "user-friendly."

12.1.1 The no-aiding fallacy

Menu-based and direct manipulation interfaces lift much of the cognitive load for remembering command names from the user. Memory of procedures is in the computer and not in the operator's head. [86] A common conception among designers of such systems is that this reduced memory requirement eliminates the need for training. Interface designs are described as "intuitive" and "user friendly," implying that novices can work effectively on first exposure to the system. However, it may never be possible to eliminate the need for training or to provide a range of user aids. The reasons for this are twofold: no user-centered design process is perfect, and even a perfect design process still results in an interface that places some cognitive burdens on the user.

In menu-based interfaces the user does not have to remember command names because they are presented in on-screen menus and dialog boxes. However, the user must still recall where to look for a specific command, and more importantly, what actions each command performs.

Direct manipulation interfaces may further reduce the memory burden on users by supplying the definition of some commands and actions on-screen along with the command name. This is done by exploiting an on-screen metaphor (such as the common desktop metaphor used in most graphical user interfaces) that helps users to recognize actions (e.g., opening, closing and deleting files) based on an icon that represents each action. Even in systems with robust metaphors and well designed icons, though, there are commands that cannot be easily represented in a graphic form.

Additionally, the actions implied by an on-screen icon may only *resemble* the actions actually taken when the command is implemented. Consider, for example, the different implications of an on-screen icon for deleting files. If the icon is a trash can, does that imply that its contents can be retrieved at some later time? If the icon is some other graphic representation (e.g., a shredder), does that imply that the deleted item is irretrievably gone? Clearly users need to know the difference between the implications of an icon and the actions that result from the associated commands.

12.1.2 Error messages

Error messages are feedback from the computer evoked by an incorrect or inappropriate input from the user and/or the result of unanticipated changes in system status. Most systems are designed to both detect and diagnose errors so that it is possible to generate messages that provide specific information about the cause of the error. The ability to generate these messages presupposes a sophisticated error handling routine as part of the computer software. Such routines are designed to assign probable causes to the system error codes. To do this, the software must keep track of input from the user and check for possible problems in command names, syntax, or application.

Users will most frequently make errors in the portion of the interface with which they need the most help. [24] Thus, the user's interaction with error messages may provide the opportunity for training. [91] Some designers overlook this possibility and present a diagnostic message without prescriptive advice. That is, the message says what is wrong but does not tell the user how to fix it.

Examples of typical, incomplete error messages include:

- ! "Bad Command or Filename."
- ! "System Error 24."
- ! "Not Ready Error From Device: LPT."
- ! "File Open Error."

None of these error messages explicitly tell the user how to fix the problem. In many cases, the message is ambiguous, giving neither advice nor any clear indication of what the true problem is. Guidelines for generating error messages that help users solve problems and become more proficient fall under two main categories:

- ! Content/style.
- ! Timing.

Content/style. In planning the content of error messages, use the following guidelines:

12/1 Error Message Content   **(Principle; 39, 40, 92)**

When feasible, error messages should identify the source of the problem and remedial steps that the user may take to recover from the error.

Preferred example: "That is not a valid VMS identifier; Check the identifier code number and reenter." A poor example might say "Error 673."

12/2 Error Recovery   **(Principle; 101)**

The steps for error recovery should be clearly identified and presented sequentially.
An UNDO command (which backs up processing to just before the error) will speed error recovery.

12/3 Command Corrections   **(Principle; 39)**

Error messages regarding syntax and options should present the correct syntax and available options.

12/4 Help Screen   **(Recommendation; 39, 91)**

Error messages regarding commands should contain information provided in the help screen for that command, or the user should be able to enter the help facility with a single keystroke and to call up help regarding the error message without having to navigate through the topic-selection features of the on-line help system. [39]

12/5 Concise Messages   **(Recommendation; 39)**

Error messages should be concise.
Error messages are presented while the user is attempting to perform some task. An ideal error message will help the user to return to the task quickly and directly.

12/6 Inappropriate Messages   **(Principle; 1, 39)**

Avoid patronizing or demeaning language.
Some authors write sarcastic error messages in an attempt at humor. Sarcastic or patronizing messages become an annoyance.

Timing. The following guidelines pertain to the timing of error messages:

12/7 Message Timing   **(Recommendation; 39)**

Error messages should follow immediately after the error.
It is preferable, for example, to catch entry errors separately for each field in a data entry screen rather than to wait until the user has finished making multiple entries. Users become extremely frustrated when they discover that they entered incorrect information throughout a form, or that they must reenter multiple fields because of a single error.

12/8 Cause of Error   **(Recommendation; 91)**

Error messages should identify the actual problem.
Often the error message reports what was going on when the error was detected, not what happened to cause the error. For example, in a signal timing data entry screen, a user might erroneously type in a cycle length of 12 sec instead of 120 sec and then proceed to fill in all the timings for various signal phases ultimately totaling 120 sec. On some systems, the error message comes late and points to the last number entered, not to the original typo several fields before. An ideal error checking routine might have questioned the 12 sec cycle length before proceeding. Alternatively, an error message at the end of the entry screen would point explicitly to the mismatch between the cycle length entered and the total of all the phases.

12.1.3 Job aids

Job aids are typically physical (as opposed to on-line) tools such as quick reference guides, overlays, flow charts, checklists, templates, and notes. They present some or all of the information needed to perform a task. [108] An example might be a checklist for dealing with an incident. The primary goal of job aid design is to reduce the need for learning, retention, and decision making on the part of the user. They are usually portable or posted on or near the workstation. They are typically designed to support task performance by experienced (intermediate and expert) users and must be augmented if they are intended for inexperienced (novice) users.

Guidelines for the design of effective job aids fall under the following topics:

- ! Content/style.
- ! Minimalist instruction.
- ! System maps.

! User design of job aids.

Content and style. As in any written material designed to inform, the style is essential to the message, and the emphasis in content must be planned carefully to support the intended goals.

12/9 Task Oriented Aids   **(Recommendation; 39)**

Job aids should be designed based on documented operator tasks.
They should be derived from an analysis of the procedures to be followed in performing a task. This will support accuracy and completeness. The focus should be on performance assistance ("how to do it") rather than skill or knowledge acquisition ("how it works").

12/10 Procedural Format   **(Recommendation; 104)**

Procedural information should be presented in a step-by-step fashion with task-relevant explanations and examples.
One approach to formatting a procedure is to divide the procedure page into two columns: the left column contains the sequential steps. The second column provides the supporting information (e.g., examples, background) which is paired with the steps. This approach separates the crucial information from the optional information.

12/11 Cross-reference Information   **(Recommendation; 90)**

Include cross-references to related information in other user aids (e.g., manuals, on-line help, and tutorials).

12/12 Information Coverage in Job Aids   **(Recommendation; 102)**

The job aids should concentrate on the tasks and information required for minimal proficiency.
Job aids need not cover all aspects of the user-computer interface.

12/13 Use of Graphics and Text in Job Aids　　　　　**(Observation)**

Use graphics and text to reduce the amount of time required to search for information contained in the job aid.
Graphics (e.g., flow charts or decision trees) are most efficient for displaying complex procedures (those with several choice points and options) and showing the relationships between commands in the user-computer interface. Text allows for elaboration which may be required for adequate understanding.

Minimalist instruction. Job aids should focus on what the user needs to know. Since use of a job aid is a detour from the path of getting the job done, words and ideas must be presented economically, with the objective of returning the user as quickly as possible from the aid to the job.

12/14 Minimal Instruction Set　　　　　**(Recommendation)**

Provide a standardized minimal instruction set to present basic procedures and commands that are necessary to use the interface.
The first card in the minimal instruction set should explain any start-up or log-on procedures requiring user input. The last card should explain the log-off and shut-down procedures requiring user input**.** The remainder of the minimal instruction cards should be task-oriented. The results of the task analysis performed during design of the user-computer interface should provide a list of the most important procedures to be performed by users. Cards should be prepared for each important procedure.

12/15 Portable Job Aids　　　　　**(Observation)**

Job aids should be easily portable to facilitate study away from the workstation.
Extra sets of job aids should be available for study. However, at least one set of job aids should remain at the work station at all times.

System maps. Many software interface systems are complex and hierarchical, with ideas and information nested in multiple levels. Operators cannot hold the complete organization in mind, and may need help understanding the logical relationships between levels and topics. This requires a system map that shows the menu nesting structure.

12/16 Menu System Map   **(Recommendation; 14)**

Provide users with a system map that shows the relationships between commands and procedures in the user-computer interface.
A hierarchical organization or flowchart format is preferable. This might consist of a graphical display showing the organization of menu hierarchies. If the scheme is complex, the design might include a simplified, high-level map and additional maps to show subelement details.

12/17 Two Menu Map Versions   **(Observation)**

Provide the system map in two versions — a large version posted in a location visible from the operator workstations and a small version included in the minimal instruction card set.

User design of job aids. As in other phases of system design, the user should be a part of the evolving processes.

12/18 User Design   **(Observation)**

Encourage users to propose and develop job aids.
A procedure should be developed under which such user-developed aids can be approved for posting on the console or other appropriate location.

12/19 Job Aid Validation   **(Observation)**

Review and validate user-designed job aids to verify that important procedures are not erroneously described.

12.1.4 User manuals

User manuals are designed to serve as a complete reference for operation of the user-computer interface. The manual should contain detailed descriptions of commands, procedures and concepts as they apply to the interface. The user manual is intended as an aid to task performance, not as a support tool for system developers. For example, it is not source code documentation. User manuals can be in hard-copy or on-line formats. On-line manuals have

lower costs over the life cycle of the system; hard-copy manuals, on the other hand, meet with greater user acceptance and support off-line study by operators. Guidelines for producing effective User manuals fall under the following main headings:

- ! Content/style.
- ! Meeting multiple goals.
- ! Organization and navigation.

Content and style. As in other job aids, the user manual should reflect the user's needs. To assure that the manual is designed for the user, consider the following guidelines:

12/20 Layering in User Manual   **(Observation)**

Entries in a manual should be written in a layered fashion.
Simple, "how to do it" information, with examples, should be presented first. Then, more complex uses and detailed explanations of how the procedure or command works and why one would use it should follow the simple information. Finally, information on relationships to other commands and procedures should be highlighted at the end of sections.

12/21 Reading Level   **(Principle; 20, 65, 101)**

Entries in a manual should be written to match the reading level of the intended audience.
For TMC operators with a high school education, sixth to eighth grade reading level should be appropriate. This can be measured by one of several available scales.

12/22 Positive Instructions   **(Recommendation; 101)**

Instructions should be written in a positive style.
Use positive statements (e.g., "Do the following . . .") unless negative forms *add to understanding.* "Operators should log out before shutting off power" is a weak usage if such an action will cause system problems; in this case "DO NOT SHUT OFF POWER UNLESS YOU HAVE LOGGED OUT" makes up in emphasis what it lacks in positive construction, since the key point is what the operator should *not* do.

12/23 Authors of User manual   (Recommendation; 20, 76)

Technical writers, not system designers, should be given primary responsibility for writing the User manual.
Experienced technical writers are often better able to prepare effective documentation *because* they are unfamiliar with the system and hence think more like the user. Systems analysts and designers should assist the writing and editing process by supplying details about system operations. The writer and the technical expert should complement each other in the preparation of user manuals. [102]

12/24 Examples for Procedures and Examples   (Observation)

Include realistic examples of procedures and commands.
Multiple examples at varying levels of complexity are helpful for commands and procedures with many options or decision points. One common mistake in user documentation is the use of overly generic examples that make the user look elsewhere for a concrete example of how a command should look.

12/25 Graphic Presentations   (Recommendation; 102)

Use graphic presentation of steps in a procedure and command syntax to help users quickly grasp the information presented.
A simple process flow chart can be helpful.

12/26 Evaluation of User manual   (Recommendation; 101)

Test the content and presentation format of the User manual for completeness, accuracy, and relevance.
Methods for iterative user acceptance testing are found at Section 2.2 and include methods such as interviews, focus groups, and performance tests.

Meeting multiple goals. User manuals serve several purposes in complex systems. They are complete reference manuals for operation of the system. They support effective task performance. Finally, they support learning. The following guidelines describe a method for satisfying each of these goals in a single manual:

12/27 User manual Content   **(Observation)**

**The user manual should contain a description of every procedure
and/or command incorporated into the user-computer interface.**
Incomplete user manuals frustrate users and lead to low user acceptance.

12/28 Multiple User Levels   **(Recommendation; 102)**

**Design the manual to support all levels of user (novice, intermediate,
and advanced) through appropriate content and organization.**
The layered presentation style discussed in a different guideline is designed
to satisfy the requirements of users at various levels of proficiency.

Organization and navigation. The User manual should be designed so that a user can locate discussions of a topic without prior knowledge of the manual's organization. A common user complaint is that answers to common problems cannot be readily located by referring to the Table of Contents or Index. To improve usability, consider the following guidelines:

12/29 Manual Organization   **(Recommendation; 76)**

The overall organization of the User manual should be task-oriented.
Procedures and commands should be grouped into sections based on their
relationship to tasks identified in the task analysis. A common problem is
that a manual is written to reflect the way the application was designed, not
the way it will be *used*. When writing a manual, organize it to answer the
probable questions of the user.

12/30 Headings, Contents and Index   **(Recommendation; 102)**

Provide clear chapter headings, a table of contents, and an index. The
index should be alphabetically ordered.

12/31 On-line Search Strategies   (Observation)

Design on-line User manuals to take advantage of nonsequential search strategies via hypertext links and keyword searches.
An "on-line user manual" is a computer application that allows the user to search through a hierarchy of displays, including on-screen text and graphics. "Hypertext" and aids of similar nature allow the user to designate a key word in the on-screen display and move instantly to a definition or discussion of that concept. Hypertext links and keyword searches should be designed from a task-oriented perspective and should be verified as useful and complete through user testing.

12/32 Diagrammatic Index   (Recommendation; 102)

Use a system map, a flow chart or tree diagram showing the relatedness of procedures and commands within the interface, as a diagrammatic index to the manual.
Manual designers can place a copy of the system map in the manual as a search tool. Use of edge tabs, page cuts, color coding, or other highlighting methods will help users to identify major sections based on the system map. We recommend that the manual contain no more than seven major sections highlighted with edge tabs. More than seven tabs may result in overlapping labels and/or sections that contain only a few pages.

12.1.5 On-line help

On-line help is a form of user documentation intended for access during performance of a task. The purpose of on-line help is to provide readily usable information about how to do something with the user-computer interface. It is important for designers to realize that on-line help is essentially a database program. As with any database, the information contained within its structure can be made easy or difficult to obtain depending on how the program is written and what types of searches are supported. The goals of on-line help are to present information that is brief, easily understood and relevant to the user's current task. Guidelines for accomplishing these goals fall under the following main categories:

- ! Content/style.
- ! Access.
- ! Navigation.

Content and style. The following guidelines pertain to on-line help provisions:

12/33 On-line Help Strategy   **(Recommendation; 65)**

On-line help should emphasize the actions "how to do it."
Describe all of the physical behaviors necessary to complete a task. On-line help should use the same terminology as the interface. Information that is not directly related to accomplishing a goal through the use of the procedure or command should appear when requested. [39]

12/34 On-line Help Organization   **(Recommendation; 29)**

If the program is complex, on-line help should be presented in a layered fashion, with the top layer providing the minimum information required for implementation of the command, procedure or concept.
Lower layers should present information on the topic's relationship to other procedures and commands, examples of how the procedure or command works, and detailed definitions of what actions are performed when it is implemented. [65, 105]

12/35 Amount of Text and Graphics   **(Recommendation; 105)**

Text should be minimized and use of graphics maximized to improve user's comprehension and reduce the time required to obtain required information.
Opportunities for graphic representation include labeled displays of command options, sequence flow diagrams of procedures, and an on-line version of the system map that shows where to find a given command within the menu structure.

12/36 On-line Help Modifications   **(Recommendation; 51)**

Improve the content of on-line help through an iterative process that reflects user evaluations.
Improvement criteria should include brevity, consistency, accuracy, completeness, and relevance.

Access. In most cases, access to help is initiated by the user, rather than computer controlled (one exception is the link between error messages and on-line help — see Section 12.4). The following are guidelines for implementing help access:

12/37 Access Consistency   **(Recommendation; 21)**

Use consistent access methods throughout all portions of the interface.

12/38 Help Meaning   **(Observation)**

In command-based systems, the word "help" should be a system-reserved command name which calls up on-line help. Typing "help" followed by a topic (procedure, command or concept name) should result in presentation of the screen for that specific topic without having to navigate through the main help screen.

12/39 Help Activation   **(Recommendation; 39)**

Maintain a means for activating help on-screen at all times.
In menu-based interfaces, a menu header labeled "Help" is typically presented as the first or last item in the continuously presented menu bar. In direct manipulation interfaces, "Help" typically appears as the last item on the active window's menu bar or is represented with an on-screen icon that can be selected at any time. In addition, allow users to access help through the program function keys. For keyboard access, a *de facto* standard has developed which assigns F1 as a "hot button" to call up the main help screen. [40] The highest numbered F key (F10 or F12 on most keyboards) is also used in some systems, especially when that F key lines up well with the menu bar item labeled "Help" (i.e., the menu bar item and the highest numbered F key are at the right hand side of the screen and keyboard, respectively).

12/40 Help Error Message   **(Recommendation; 91)**

Present relevant help with any error message.
Context-sensitive help should be available to provide detailed information about recovery from an error without requiring the user to navigate within on-line help function. That is, upon receipt of an error message, the user should be able to access help on that error with a single keystroke or menu/icon selection. [39]

Navigation. *Navigation* refers to the user's ability to find topics within on-line help. Navigating through help systems can be accomplished in several ways. Providing different ways supports different user requirements. The following guidelines apply to selection and implementation of appropriate methods for finding topics within on-line help:

12/41 Topic Selections   **(Recommendation; 20)**

Provide several means for locating topics within on-line help.
The methods include: Alphabetic indexing, keyword searches, references and/or hypertext links to related topics, and direct input of the command, procedure, or concept name.

12/42 Alphabetic Indexing   **(Recommendation; 10)**

Use alphabetic indexing of all topics contained within on-line help.
It is important that this list be complete and incorporate synonyms that users are likely to substitute for the system-specific names. User testing and task analyses are essential to developing a complete list of topics. Incomplete lists lead to frustration and user rejection of the help facility.

12/43 Database Searches   **(Recommendation; 10)**

Use databases to search for specified words or phrases within the help file.
Any topic with a matching keyword is added to the search results and is then available for selection and display. Designing effective search functions requires extensive user testing because users may input words that do not match those used by the designer. Keyword searches should respond to the synonyms that are likely to be used.

12/44 Keyword Searches	(Recommendation; 112)

Keyword searches should present the results of null searches (when no matches are found) and, where possible, offer the user some assistance in identifying appropriate search terms.
When possible, refer the user to an appropriate section of the User manual.

12/45 Return to Previous Screens	(Recommendation; 40)

When the user is performing keyword searches or navigating via hypertext links, provide a means for returning to previous help screens.
It is easy for users to become lost in a complex help file. Allow the user to back out of a given search path by returning to the previous screen and by returning to the help index or keyword search facility. It should always be possible to leave on-line help with a single keystroke or menu selection. In addition, users should be able to return to the main help screen with a single keystroke.

12.1.6 Tutorials

Tutorials are aids designed specifically to train users. The domain to which tutorials can apply is typically much larger than that for on-line help, User manuals, or job aids. The main purpose of tutorials is to ensure a minimum acceptable level of performance by all users. In addition, tutorials can introduce users to new program feature changes, improve Users' expertise beyond the minimum acceptable level, and act as a refresher for skill maintenance training.

There are two basic types of tutorials – paper-based and on line. The selection of paper-based versus on-line tutorials can be made as a result of a cost effectiveness analysis that takes into account the life-cycle costs of the training aid.

Most tutorials are used once by a user. Costs of tutorials are best compared against the cost of delivering the equivalent training via other single-use methods such as classroom instruction. Guidelines regarding tutorials fall under the following headings:

- ! Tailoring information to meet user requirements.
- ! Training effectiveness.
- ! Sophistication of presentation.

Tailoring information to meet user requirements. Because tutorials are typically used once by a user, it is desirable to only present information that is immediately used. Additional information represents a waste of time. For this reason, most tutorials are written to meet the needs of system novices who are the mostly likely to have easily identified information needs. Designing tutorials to meet the needs of other users requires detailed analyses of those users' information requirements. The following guidelines apply:

12/46 Skills and Knowledge Requirements (Principle; 45)

Perform requirements and task analyses to determine the skills and knowledge required to accomplish the tasks that novice operators should be able to perform.
Design tutorials for use by novice operators on each of these tasks. These basic tutorials should be designed to yield acceptable performance after a single use. See Chapter 3 and Sections 2.2.4 and 11.1 for task analysis procedures and guidelines.

12/47 Advanced Tutorials (Recommendation; 97)

Design advanced tutorials to meet specific needs, reduce error rates, increase operator proficiency, and/or encourage use of more sophisticated features of the interface.

12/48 Off-line Study (Observation)

Generate the tutorials in a form that allows off-line study when possible.
Allow the operators to take paper-based or personal computer-based materials home for self-study.

12/49 Tutorial Use at Work (Observation)

Encourage use of tutorials by allowing operators to study them during slow periods at work or by building training time into the weekly work schedule.

Training effectiveness. Tutorials are a form of training that can lead to high performance

levels at relatively low cost. Unfortunately, many tutorials are ineffective due to poor lesson pacing, inferior content, and/or inadequate feedback. The result is wasted operator time and lower than expected operator proficiency.

12/50 Tutorial Feedback (Observation)

Design tutorials to provide specific, diagnostic feedback for user entries.

"Diagnostic" feedback informs the user whether the input was correct or incorrect, and, if it was incorrect, why it was so and what the correct input was. Feedback can be based on expert knowledge of the underlying causes of user errors.

12/51 Tutorial Pace (Observation)

Allow the user to control the pace of the tutorial.

This is accomplished by requiring user input before proceeding to the next part of the lesson. This may be as simple as requiring the user to press the ENTER key to continue. However, it is better to require the user to enter a meaningful response as part of the lesson.

12/52 Tutorial Length (Observation)

Keep the overall length of any single lesson (a tutorial on any one topic) less than 15 min.

Shorter lessons are preferred by users and make it more likely that an experienced user will use a tutorial as a refresher.

12/53 Realistic Practice (Recommendation; 25)

All tutorials should provide practice on realistic tasks.

Even for basic lessons (e.g., how to log on, how to navigate through help, how to move the cursor), it is better for users to learn in the context of real-world tasks than in isolated practice that only demonstrates the mechanics of operating the interface. For example, show the user how to move the cursor in the context of entering a street name rather than in an abstract lesson.

12/54 Multiple Tasks	(Recommendation; 102)

Provide ample opportunities for practice by having multiple tasks available.
Allow users to jump ahead if they feel comfortable with their new skill. Allow them to practice more if they are uncomfortable after performing the prescribed lesson.

12/55 User Tests	(Recommendation; 102)

For crucial skills (i.e., those defining minimally acceptable proficiency) test users during and after the tutorial.
Performance feedback during the tutorial should diagnose errors and guide the user to correct responses. After the tutorial, test users on their newly acquired skill and knowledge. Give users feedback on their overall performance (e.g., they met or did not meet the performance criterion) and on individual test items or topics. Allow the user to return to practice mode on any item in the test by re-entering the tutorial at the point(s) where that item is presented.

Sophistication of presentation. Tutorials vary from simple statements of a correct procedure (analogous to a job aid) to complicated interactive computer programs that alter the lesson based on the user's input. Some tutorials operate in multiple modes so that they can either instruct ("show me how") or perform ("do it for me"). As with other decisions regarding tutorial design, the choice of a level of sophistication should be based on careful analysis of user requirements and a comparison of the costs and benefits of the various delivery strategies.

12.1.7 Decision support tools

Decision support tools are designed to improve the quality (speed and accuracy) of operators' decisions. To improve decision quality, it is first necessary to understand the decision process. It is convenient to think of decision making as a four-stage process:

- **!** Stage 1: *Identify* the problem.
- **!** Stage 2: *Describe* the problem.
- **!** Stage 3: *Select* and *perform* an analysis.
- **!** Stage 4: *Choose* a solution.

The first stage involves *diagnosis*. The problem is recognized, narrowed down and focused into a set of critical issues. In the second stage, the decision-maker *translates* the problem's critical

issues into terms that can be analyzed. The third stage involves selection and performance of appropriate *analyses*. In the fourth stage, the decision-maker arrives at a *decision* based on the results of analyses conducted in stage 3.

There are relatively few aids for identifying and diagnosing problems (stage 1). Warning lights and buzzers may serve an alerting function, but the operator must still decide that a problem exists and then work to identify the source of the trouble. An example in the TMC environment is the use of a flashing red indicator to alert the operator to slow moving traffic over a detector. The operator must determine if the traffic is really moving as slowly as indicated or if the detector may be failing. If the traffic is slow, the operator then attempts to determine whether the slow down represents recurring congestion or an incident.

Describing the problem (stage 2) involves translation into terms with which the decision support tool can work. Again, there are few aids to assist users at this stage. In the TMC environment, data displays are often linked to a particular device in the field (such as a detector or controller) so that the operator can describe the problem numerically. Other data sources may be available for comparison (such as the historical averages for the affected location or listings of events that are currently in progress and their predicted effects on traffic). Operators must decide which data are relevant to include in an analysis that will ultimately lead to a course of action. Advanced decision support systems assist users in describing problems through the use of fuzzy logic. Fuzzy logic is a way of including qualitative descriptions (e.g., traffic is "heavy") or uncertain events (e.g., there is a 30 percent chance of rain) into an analysis. This allows operators to use all the relevant data, even if it cannot be precisely quantified.

Most decision support tools support the mechanical aspects of performing analyses (stage 3). In the TMC environment, a tool that performs analyses could be as simple as a spreadsheet program that calculates predictions based on values input by the user. For example, the operator might wish to know the effect on highway traffic of lengthening the red phase on ramp meters by 5, 10, or 15 sec. A spreadsheet program could use standard approximations to build three predictions showing highway traffic following each of the optional changes.

Some decision support tools go further by suggesting alternative analyses to the user. In the ramp metering example, a more advanced program might suggest analyses that point to other courses of action besides a change in ramp metering (such as using HAR and CMS messages to divert some of the traffic off the highway) or in combination with the strategy suggested by the user. The most advanced analytic tools can provide dynamic predictions of what will occur over time after an action is chosen. Such predictive systems are often called "look ahead" models as they show the most probable unfolding of events based on the operator's proposed decision.

Some of the most sophisticated decision support tools furnish recommendations to assist users in choosing a decision (stage 4). It may seem obvious that the user is going to select the "best" of the options currently available. The problem with this assumption is that the user may not be

considering all factors when making a decision. The remedy for a current traffic problem may cause other problems that an operator does not anticipate. In the previous example, highway traffic flow may be best helped by a long red phase on the ramps. This action may have an unwanted effect on surface street traffic as the ramps back up. A decision support tool can be programmed to meet multiple goals (e.g., optimize highway traffic with minimal impact on surface streets).

Guidelines for implementing decision support tools fall under the following main headings:

- **!** Task dependent selection of presentation styles.
- **!** Choosing among various aiding options.

Task dependent selection of presentation styles. Decision support tools rely heavily on presentation of quantitative information. Guidelines for effective decision support include the following:

12/56 Graphs vs. Tables   **(Recommendation; 5, 11)**

Use graphs for displaying trends and comparisons; tables are better than graphs when precise numbers are more important than trends.

12/57 Actual vs. Projected Data   **(Observation)**

Provide a clear distinction between actual and projected data.
For example, a display of traffic flow data from a predictive traffic model should be shown in different formats (e.g., dotted vs. solid lines) or colors than actual sensor data. If color coding is used, ensure that it does not lead to confusion with other color codes.

Choosing among various aiding options. Categories of user aids include simple lists and reminders, basic on-line help, and more sophisticated approaches such as hypertext structure and expert systems. The designers' choice of an approach has a significant effect on both cost and system performance.

12.2 Integrating User Aids

The guidelines in Section 12.1 present each type of user aid in isolation. This is useful for determining when to apply a given aid, but does not exclude the use of more than one type. It

should be recognized that the best aiding solution may be a mix of strategies to meet the needs of various users. [102]

Each aid should be the product of a user-centered systems analytic approach to design. The costs of generating user aids can be minimized by integrating the various aids, thus reducing the number of items to design and the number of iterations required to produce separate aids. This section presents guidelines for integrating user aids.

12/58 User Documentation Needs   **(Recommendation; 10)**

User documentation should derive from the user requirements and task analyses performed during system design.
Like other aspects of system design, documentation should be task-driven. The documentation should meet the needs of the user, *not that of the designer.*

12/59 User Aids Overlap   **(Recommendation; 39)**

Error messages, on-line help, User manuals and job aids should overlap extensively.
In particular, error messages should contain (or be immediately linked to) the on-line help about the procedures or commands. Job aids for the most important commands and procedures repeat the step-by-step information on usage as contained in on-line help. All of this information should be contained within the User manual. In effect, all user aids, no matter what the medium, should follow the same logic and be mutually supportive. The user may be confused, for example, by a brief on-line help message and seek more depth in the user manual. If the expanded user manual uses a different logic or approach, the user will have to start over in his or her attempt to understand the process.

When opportunities for shared information among various user aids arise, use the same presentation format across all aids.
For example, every entry in the User manual could replicate, then expand upon, the on-line help presentation for the same topic. Likewise, any job aid on a topic could show a portion of the help screen. Users should not have to adjust to varying formats, especially when the information presented is essentially the same. [10]

CHAPTER 13: PRESENTING DATA

CONTENTS

13.1 TMC Operators Rely Upon Data

TMC operators make decisions by using data from a variety of sources. This information can
come from detectors, cameras, on site personnel, citizens, spotter vehicles, aircraft, or
predictive software models. Information must be *accurate*, *relevant*, and *timely*. From the
system designer's point of view, data must be *reliable* and *valid*. In addition, data should be
diagnostic, such that they help the operator to correctly interpret events. This chapter begins
with a discussion of data reliability and validity. It also describes how designers can assure data
diagnosticity (i.e., the degree to which data facilitate decision making). It contains discussions

of the various data sources commonly found in TMC operations and those envisioned in ATMS TMC's of the future. The remainder of the chapter presents the concept of *data fusion*: the aggregation of information over time or geographic location. Through the appropriate fusion of data, TMC operators are more likely to obtain a stable, reliable representation of existing traffic conditions.

13.2 Data Definitions and Construct Validity

This section addresses three issues:

- **!** The importance of accurate data definitions.
- **!** Construct validity.
- **!** Changes in data definitions.

13.2.1 Accurate data definitions are important

Inadequate data definitions have contributed to major industrial accidents. Consider, for example, the Three Mile Island incident, where a "shut off" indicator only revealed that *the switch had been thrown*, not that the *valve was shut*. TMC's could have a problem with multiple definitions of traffic-system performance indicators. For instance, the indicator of "speed" has several definitions and different contexts.

Engineering Terms	Layman's Terms	Sources of Speed Estimates
time mean speed	spot speed	**A** or **B**
space mean speed	average speed	**A** or **C**

A calculated speed (from a model)
B detector–based speed
C probe vehicle–based speed

Data labels must be accurate. *Assign data item names such that they are sufficiently specific and inclusive.* For example, in a TMC that uses more than one type of speed data, each presentation of speed information should clearly identify the corresponding type. Labels should go beyond simple differentiation (such as "speed A" or "speed B"). Rather, they should be descriptive (such as "spot speed obtained from a detector").

Operational definitions suggest how data are collected and processed. Descriptive labels (e.g., "spot speeds") may be insufficient to ensure that operators recognize the limitations and derivations of the data presented to them. Consequently, users may need an operational definition. Operational definitions provide detailed information on how data were collected and processed prior to their final presentation to the user. [77] An operational definition of "detector–based speed" might include the following information:

- **!** Detector type (e.g., inductive loop, radar, digital video).
- **!** Data collection method (e.g., distance between detectors divided by time between crossings, estimation from sequential axle crossings of one detector).
- **!** Data handling technique (e.g., running average, simple average, snap–shot, average at several locations, rejection of extreme values).
- **!** Constraints (e.g., center lane only, passenger vehicles only).

Operational definitions ensure that operators are provided sufficient information to make well-informed decisions. Without the operational definition of speed, operators may incorrectly presume that the data available to them are applicable to their current problem — or, they may just as incorrectly assume that the data cannot be used. Some forms of detector data are preferable to others. Exact counts are better than estimates, and receiving data from all lanes is better than receiving data from a single lane. The "best" presentation may depend on the operator's current task.

13.2.2 Construct validity must be established

Operators' perceptions of the usefulness of data are subjective assessments of the *validity* of the operational definition and the *reliability* of the measurements source itself. *Does the information tell me what I want to know? Can I trust the information?* Validity is used here in the statistical sense of construct validity — an assessment of whether or not the data actually measure the parameter of interest. [77] For example, speed measurements can be obtained in a number of ways: double loop detectors, radar, laser, eyeball estimates, and stopwatch and checkpoints. Some approaches provide more accurate measurements than others. Also, some approaches measure space mean speed, which provides accurate estimates of travel time, while others provide only spot speeds, which provide much-less-reliable estimates of travel time. Those that involve the direct measurement of speed obviously provide greater accuracy than eyeball estimates.

13.2.3 Changes in data definitions may occur

Data definitions can change for several reasons: system upgrades (e.g., the installation of a new type of detector or the implementation of a new traffic model), system or component failures, and changes in data presentation. When system upgrades occur, two training tasks must occur. First, valid measures of traffic conditions must be maintained. Second, operators must be alerted through training or information display to any changes in operational definitions. For example, as additional detectors are added to a roadway network, the detail with which volume, occupancy, and speed data are recorded per lane mile is increased. Estimates of speed at a specific location, for example, may be based on data from the nearest detector installation. With denser detector coverage, chances are better that the data being displayed provide a more accurate representation of traffic conditions at that location than was previously the case.

In some TMC's, overall system performance can be maintained even as individual components

fail. One means of accounting for data lost is to use estimation techniques based on data available from the nearest set of detectors. When such a contingency strategy is implemented, users must be alerted.

Finally, data definitions may change with or without an explicit request from the user. For example, a decision support tool might support several methods of presenting traffic flow data (e.g., averaged over time, averaged with respect to locations, running averages). The appropriate method for displaying data may depend on the operator's required task. In one case, the operator may be seeking to mitigate traffic problems at a specific location as quickly as possible (e.g., an incident near a sports arena just before the game is over). In another case, the operator may want to optimize flow over a large section of roadway that includes both surface streets and freeways. The method of data presentation might need to be different in each case. Operators must recognize how these data presentation methods should be applied (if at all) in solving current traffic problems.

13.3 Variability and Repeat Reliability

Meeting the validity criteria outlined in Section 13.2 does not ensure that data are useful in reaching decisions. When data are viewed as being highly variable, operators may distrust them. Whereas distrust might result from many causes, two possible sources that TMC's can control are discussed here: (1) variability in data, and variability of the operator (repeat reliability). [77]

13.3.1 Variability implies deviation from an average

The numbers from any given data source will fall within a range of values that center on an average. Statistical measures of variability attempt to quantify the "average" amount of deviation or difference from the central value. Mathematical formulae for the statistical concepts of *variance* and *standard deviation* are expressions of this "average size of the difference" concept. [59]

For the purposes of TMC operations, it is important that an operator have a sense of the expected range of values from a given data source. As experience with the system grows, operators learn to expect data within a certain range to indicate "normal" traffic conditions. Values outside of that range will indicate "special" conditions (perhaps an incident or a system component failure). If, for example, traffic volumes drop below 35 vehicles per minute at a given time of day (as reported by a detector), operators may suspect that an incident upstream of the detector's location has occurred, or that the detector has failed. Two aspects of the data allow operators to arrive at such conclusions: sufficient baseline data and recognition of extreme values.

Sufficient baseline data allow operators to recognize deviations from the "norm." In order to recognize an unusual pattern in the data being presented, operators must have a good idea of what is typical. There are no standard rules for specifying how much experience is

enough for an operator to sense normal data patterns for a given location, time, or system. The less variable the data are, however, the faster this intuition will build and the more confident users will become in making judgments.

Recognizing outliers helps in identifying problems. Before operators can decide how to manage a traffic problem, they must first realize that a problem exists. In most TMC's, recognizing a problem equates to recognizing that field data extend beyond some "typical" range. Decision support systems may flag data that are outside this range (where the typical range will most likely be defined by historical data) and perhaps recommend a course of action. However, the operator must still recognize that the data are atypical. Relying on previous experience will assist in determining if the incoming data are outside the expected range, whether or not they indicate a traffic problem and, if so, how to resolve it.

Operators maintain a concept of "normal." Humans are habitual pattern recognizers. The stronger a pattern is, the more obvious deviations from that pattern are. Consider the following two "data streams" as examples of strong and weak patterns:

1 2 3 4 5 6 8 7 9 10

2 4 1 5 7 6 3 9 8 10

In the first data stream, the *8* and *7* seem to be misplaced in a sequence of increasing numbers. In the second data stream, one senses that data values are increasing, but violations of strictly increasing order are common and therefore, less noticeable. From a statistical point of view, these two data streams have exactly the same mean and variance (variability).

The difference between these two patterns is considerable. An operator receiving data values one at a time would be much more likely to respond when presented with the misplaced *8* in the first sequence than at any point in the second sequence when misplaced data values appear. [51]

The fact that operators perceive and react to changes in data that are not meaningful at a statistical level is important for designers. From a statistical point of view, this phenomenon might be called *operator bias*. From a traffic management point of view, such biases may be desirable — making the operator an important part of fine tuning traffic management strategies.

One result of such operator behavior is that locations with a history of stable data patterns and little variability can be expected to draw attention more quickly when abnormal data patterns arrive than are locations with less stable patterns and greater variability. Such a response may or may not be desirable from a traffic management perspective because the same resources applied to the more variable location may yield a greater improvement in overall system performance. If operator biases must be overcome, decision support tools, training, and standard operating procedures are most effective in modifying behavior.

13.3.2 Variability affects operators' perceptions of data usefulness

Increased data variability may cause operators to ignore the data altogether. In the absence of an obvious pattern in the data, operators may not recognize changes unless they are very large or very small. Some detectors may provide data so variable that the only decision operators are willing to make is that the detector is (or is not) functioning. Short of this extreme case, locations with highly variable data are likely to receive slow responses to traffic flow changes because operators will review a relatively large amount of data before deciding that a problem exists.

Operators are likely to overlook trends in highly variable data. In the two data streams presented in Section 13.3.1, the trend of increasing data values is far easier to identify in the first stream than it is in the second because the first stream has a more recognizable pattern than does the second. Suppose the two sequences of numbers in Table 13-1 reflect values of some traffic flow parameter at 14 different locations during morning and evening rush hours.

Table 13-1. Traffic flow parameter values as a function of location.

Location:	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Parameter Value:														
Morning Rush Hour	02	04	06	08	10	12	14	16	18	20	22	24	26	28
Evening Rush Hour	01	05	04	10	07	15	13	17	18	20	20	26	27	27

Figure 13-1 plots each sequence of values as a function of location. The left plot of Figure 13-1 shows morning rush hour data as a function of location, and the right plot shows evening rush hour data as a function of location. The second data sequence is more variable than the first. Note that the trends indicated by the two scatter plots reveal almost identical slopes, suggesting that both sequences describe an increasing pattern. However, given both sequences of data as text-based streams, operators will be less likely to identify the trend that exists in the second sequence. It appears less reliable due to its many reversals and plateaus. Figure 13-1 suggests that the variability of the second sequence is really not so large, and reveals the strongly increasing trend.

Methods for handling data variability are available. Among these methods are *data fusion* (averaging values over time and/or distance), *data transformations* (logarithmic transformations or *z*–score transformations), [11] and *decision support techniques* (assigning cut points to ranges of data and alerting the operator to any shifts between ranges). [54] Figure 13-2 replots the data in Figure 13-1 after averaging across adjacent data points. As may be seen in Figure 13-2, averaging adjacent data points completely eliminated the differences between the two data sequences.
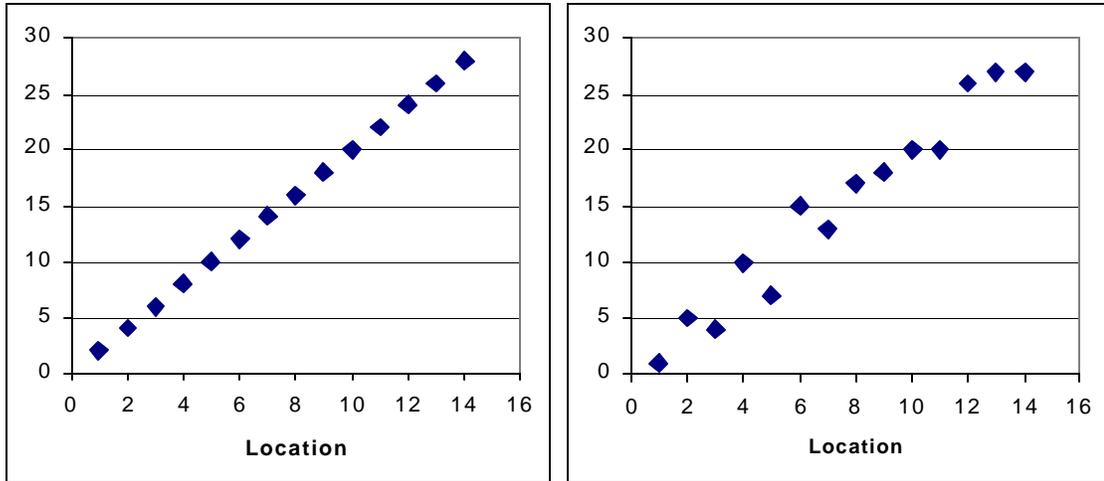
Figure 13-1. Scatterplots of traffic flow data.
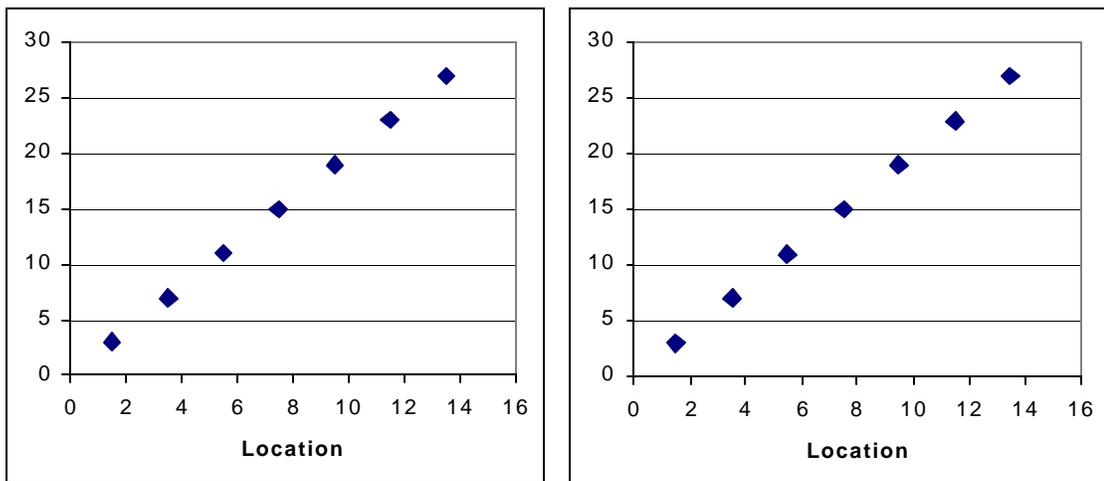
Figure 13-2. Scatterplots using averaged data.

13.3.3 Repeat reliability is an indicator of operator consistency

Operators represent a source of variability. This type of operator variability, referred to as *repeat reliability*, indicates how consistently any single operator uses data. The TMC is a system, and system outputs depend on data received and the operators' responses to those data. If operators are inconsistent in handling incoming data, the system will be inconsistent. Operator variability cannot be totally eliminated, but it can be controlled by design techniques to improve operator reliability. These design techniques include (1) standardizing procedures and training, (2) running periodic checks against standardized scenarios, and (3) increasing/maintaining operator proficiency through sufficient exposure to system operation.

13.4 Inter–Operator Agreement is Important

Agreement among operators is critical to the consistency of TMC operations. Without agreement in standard operating procedures (i.e., what to do in response to different traffic scenarios), the driving public may perceive TMC actions to be haphazard. Consider the task of programming variable message signs. If operators must program variable message signs without guidelines for designing messages, the messages displayed to motorists may be inconsistent.

Inter–operator reliability indicates agreement and consistent actions among operators. Because individuals differ in experience, competence, and knowledge, perfect agreement between operators is difficult to achieve. Additionally, no two traffic situations are ever exactly alike. In order to guide operator behavior once a decision has been reached, most TMC managers have established standard operating procedures. For instance, instructing an operator on the circumstances under which a changeable message sign should be used (and when it should not be used) is difficult. (Such knowledge is typically the result of experience.) On the other hand, providing guidelines that specify (1) how to word the message, (2) what information to include, (3) the order in which information should be presented, and (4) where to display the message is easier.

Several methods are available for ensuring that inter–operator reliability is as high as possible. Even for those aspects of the decision process that may be best left to the operators, training and discussion will improve consistency and agreement. A set of standard scenarios is helpful for training new operators to develop expert behavior. Also helpful are regular discussions, where operators are free to discuss actions and alternatives with their peers and supervisors. If the clear, stated goal of these meetings is to improve consistency and to learn from others, operators will have a non-threatening forum in which they can learn.

13.5 Various Data Sources Provide Information to the TMC

Various data sources provide information to the TMC. The data from these sources differ in their reliability, validity, and hence, their usefulness to operators. The differences relate not only to the variability of incoming data, but also to the manner in which data are handled prior to their presentation to the operator. In this section, the limitations of various data sources are discussed, and guidelines for handling data associated with each source are offered.

13.5.1 Roadway sensors

Roadway sensors include both temporary and permanent devices that detect vehicles, temperature, precipitation, or other roadway or environmental conditions. Detector data are used to make an inference regarding some quality of the system that cannot be measured directly (e.g., traffic flow or pavement slickness). Sensor data can be extremely variable (as is the case with second–by–second vehicle counts) and require careful interpretation. Also, a detector only reports data that represent the point along a roadway where it is located. It does not measure traffic characteristics between detector locations. Accuracy is directly related to the number and placement of detectors on a roadway network.

Loop detectors. Loop detectors are designed to count vehicles crossing the pavement in which they are installed. Each count is "time stamped" so that it can be used in deriving an average frequency over a period of time. With two detectors in series, the system can also detect vehicle speeds. Speed calculations are based on the difference in arrival times at each detector. With proper placement, increasing the density of detectors per mile will increase the probability of locating a detector near an incident site. Detectors are sometimes spaced close together in areas where a quick incident response is crucial and farther apart in areas where response time is less critical. Detector data are usually monitored by automated algorithms that compare current data with previous trends. However, these algorithms are not fool proof. When a faulty detector "fools" a monitoring algorithm, the operator is often the last line of detection.

13/1 Detector Status Feedback   (Observation)

Provide a method for operators to declare whether detectors are operational, suspect, or not functioning so that this information can reach maintenance crews.

Road surface condition detectors. A variety of sensors capable of detecting potential hazards due to weather have been developed. They indicate road surface conditions based on temperature, precipitation, and the effects of temperature and precipitation on traction at a specific location (e.g., a bridge that may freeze before the adjacent roadway).

When alerting motorists to hazards caused by weather conditions, TMC credibility is on the line. Deciding when to alert motorists must be based on a balance of safety concerns and the motorists' perception that the TMC is a reliable warning source. In the long term, too many false alarms from the TMC (i.e., warning drivers when no actual hazard exists) may cause drivers to disregard warnings provided when the hazards are real.

13.5.2 Automated Incident Detection Systems

Many TMC's have automated incident detection and locating systems (IDLS). These systems perform statistical analyses on traffic flow data (typically, traffic speed, volume, and density or detector occupancy). IDLS computer algorithms search for abrupt changes in traffic flow characteristics at a given station, or patterns of flow discontinuity between stations. When the data cross a predefined threshold, the operator is alerted to a possible incident.

Obviously, these systems are not perfect. Minor incidents (e.g., stalls) are often missed because they don't create enough congestion to trigger an alarm. Sometimes an incident may be falsely reported because the traffic flow happens to mimic patterns found near an incident. One way of increasing IDLS accuracy is to increase the length of the time that traffic is measured before reporting an incident. However, increasing the amount of data used to make the decision

increases the length of time before the operator is alerted and can respond to the incident. Therefore, it is more common to use multiple data sources and multiple decision thresholds to trigger an incident alarm.

13/2 Incident Detection Location System (IDLS)   (Recommendation)

Provide automated incident detection support systems to improve operators' performance of incident detection tasks.
Results of ATMS experiments contrasting manual incident detection (NO IDLS) and automated incident detection (IDLS) conditions provide evidence that operators can enhance their incident detection performance when given access to an automated incident detection system.

13/3 IDLS and Incident Location   (Recommendation)

Incident detection support systems should automate the specification of incident location information.
Empirical results indicated that incident location information was specified more accurately under the IDLS condition than under the NO IDLS condition. One common operator mistake was to report the incident on the wrong side of a divided highway.

13/4 Secondary Incident Detection Mechanism   (Recommendation)

A color-coded map (where color coding provides traffic flow information), in combination with remote video cameras, can assist operators in detecting incidents.
In general, comments concerning the usefulness of the color-coded map were favorable. By and large, our pilot data suggested that subjects found the color-coded map to be a useful incident detection tool as colors turned to red representing poor traffic flow. Then CCTV cameras were used to verify a suspected incident. The major performance enhancements are reflected in improved location accuracy and in lower detection time.

Given supplemental incident detection tools (e.g., remote video cameras, color-coded traffic flow information), operators can compensate for deficiencies in hit rate and detection latency that may be inherent to an automated incident detection support system. Merely providing a system that automates the incident detection task does not guarantee that an operator will interact with it as a means of obtaining incident detection assistance. Experimental results suggest that operators, when given supplemental incident detection tools, can compensate for deficiencies – such as long detection latency and low hit rate – built into an automated incident detection system.

The incident detection algorithm can be adjusted to (1) minimize false alarms by accepting poor detection rate and detection latency performance, (2) maximize detection (hit) rate by accepting poor false alarm performance, or (3) shorten detection latency by accepting poor false alarm performance. It is not possible to simultaneously optimize performance in all three performance dimensions.

13/5 Hit Rate and Detection Latency   (Recommendation)

An automated incident detection support system should be designed such that it operates at the highest hit rate and shortest detection latency that are practical to achieve.
Operators are willing to accept a higher number of false alarms if they are able to quickly identify and dispose of them.

13/6 False Alarms   (Recommendation)

The operator should have an easy means of rejecting any report recognized as being a false alarm.

Designing a support system with the highest hit rate and shortest, most practical detection latency will result in a relatively high false alarm rate. One key to effective performance was to make it easy to reject false alarm reports supplied by the IDLS. This feature should be facilitated through design of the user interface. One approach is to implement a set of four buttons (*Report*, *Put in Background Log*, *Mark as Duplicate*, *Reject*) that allow operators to manage IDLS reports. Upon verifying a false alarm, the operator clicks the *Reject* button, and the report is immediately disposed.

13/7 Incident Verification   (Recommendation)

When presented an incident report, the operator should be provided with a means for readily verifying the incident.

Note that current data are more recent and potentially more relevant than the accumulated data that triggered the report. However, the operator's primary task is to ascertain whether an incident truly exists. A camera view of the possible incident site, perhaps automatically selected by the IDLS, is an effective approach. With one control input (for executing a "select camera" command), the operator can display the view associated with that incident.

13/8 Task Interruption   (Recommendation)

New incident reports should not interrupt an operator working to complete a previous report.

Higher-priority tasks, such as completing an incident report, should not be interrupted by a new report from the support system. The operator should be allowed to manage one report at a time – and either dispose of it or delay its handling (e.g., selection of the *Put in Background Log* button) – before considering a new report.

Short detection latencies can minimize incident detection and verification time.
Shorter detection latencies designed into automated incident detection systems will reduce the time operators need to file incident reports (where the filing of an incident report involves receiving timely notification of a potential incident, verifying that an incident has occurred, and ensuring that incident location information has been recorded). This will ultimately speed the process of dispatching incident management field assets and emergency vehicles to the site, and minimize the incident duration.

13.5.3 Video images

We often assume that video–based information is the best indicator of traffic flow. After all, the operator can simply observe what is happening. However, standard video is not easily quantifiable. Individuals are less accurate and reliable when their judgments are based on video images than when their judgments are based on a numerical assessment of the same situation. Digital video data collection represents an attempt to obtain accurate quantitative traffic data from real–time video images. It, too, has limitations that must be addressed.

Direct observation provides data. Closed circuit television (CCTV) has become a major source of information for verifying incidents and judging traffic flow characteristics. Qualitatively assessing of traffic flow parameters from real–time video displays is a threat to repeat reliability among operators. Real–time video data provide "fuzzy" descriptors (e.g., "fast" or "slow"), rather than an accurate measurement of a traffic flow parameter. Operator knowledge of the roadway is an important filter for judgments. Landmarks in the video image can become of critical importance.

One difficulty in the use of CCTV is that much information is lost when viewed at night or in extreme fog or smoke. Technologies developed for the military might be adopted to improve these images. Infra-red and light-enhancing cameras are available but are expensive. An alternative technology that presents images based on integrating several seconds of exposure is an inexpensive alternative. Though rapidly moving objects appear as a blur, still objects, such as stalled vehicles, can be seen clearly.

Label video images with an adequate amount of location information.
In TMC's where more than one operator can control a camera, operators may have trouble orienting themselves after someone else has redirected the camera. In order to use video information effectively, operators should be able to orient themselves rapidly and with a high degree of certainty. A problem with many video displays is that they provide no indication of the direction in which the camera is currently facing.

Even in static display arrangements, with a one–to–one mapping of cameras to displays, task performance will be faster and more accurate if screens are labeled with location *names*, rather than numbers. Labels should include references to cardinal direction, route name and location (e.g., Eastbound I-68 at Genessee Ave.)

Video image processing is used as an alternative to in–road detectors. Image processing of digital video can provide count, classification, speed, headway, and occupancy data from a single source. The technology relies on the optical recognition of vehicle configurations (length, width, trailer connections, etc.) from above. Reliability is limited by (1) the ability of the vehicle recognition software to accurately sort vehicles into classes and (2) the contrast between the background and the vehicles in the scene being recorded.

Spotter (probe) vehicles provide data. Spotter vehicles can provide data to the TMC through automated instrumentation or through radio communication between the driver and the TMC operator. By traversing the roadway network, the spotter vehicle (and driver) provide a first-hand experience of traffic patterns. Operators must understand the "spot" nature of spotter vehicle data. These data correspond to the spotter vehicle's current location (at the current time) and may become out-dated soon after the vehicle leaves the location.

13.5.4 Voice communications

TMC's will have extensive communication links to field personnel and to the driving public. Information obtained from these sources is as reliable as the individuals providing it. Much of this type of information will be qualitative in nature. TMC staff must be trained to properly handle communication with the public.

Citizen call-ins. With the increased availability of cellular phone hot lines, roadside call boxes, and citizen's band radio, the nearly immediate notification of incidents and traffic problems is possible. Information received from citizen call-ins, however, is likely to be less reliable than communications from trained professionals (e.g., uniformed personnel or TMC field personnel). The following guidelines may improve reliability:

13/13 Roadway Locator Signs (Observation)

Provide an adequate density of locator signs (e.g., mile markers).
Such infrastructure is critical to making it easy for citizens to accurately identify locations when calling. Many agencies now post mile markers every one-tenth of a mile. Exit numbers and cross street or bridge names should also be posted.

13/14 Citizen Call-in Handling (Observation)

Designate a special group of personnel to be responsible for answering citizen calls.
If there is a large volume of cellular phone calls, the TMC might need to dedicate personnel to answering the citizens calls on a full-time basis, screening the information, and passing it to appropriate operators.

13/15 Operator Interactions with Public (Observation)

Provide training to all personnel who deal with the public.
Such training will inform personnel how to present a professional, customer–oriented attitude. In order to extract accurate information from a motorist, operators must convey an appropriate attitude and be able to direct the conversation such that it generates useful information.

13/16 Citizen Call-in Encouragement (Observation)

Encourage citizen call–ins through media campaigns and by posting a hotline number at strategic locations.
Strategic locations include state boundaries, highways departing airports and freeway segments approaching congested areas or high-accident locations.

Traffic reporters and uniformed personnel. Many TMC's have developed relationships with local traffic reporting organizations (e.g., radio and television news programs). One obvious advantage of such relationships is the TMC's ability to disseminate traffic alerts through the media. Many news organizations have aerial data collection capabilities that can significantly enhance the TMC's ability to monitor traffic conditions. Uniformed personnel (e.g., fire, police, ambulance) can serve a similar role by notifying the TMC of incidents or traffic problems. Although some TMC's are co-located with emergency response dispatchers, most are not afforded such close contact. In addition, the needs of the TMC for logging incidents and coordinating incident responses are often different than those of emergency dispatchers.

The ability to obtain usable information from traffic reporters and uniformed personnel depends on cooperation and knowledge. The goal should be to ensure that the information supplied by these sources is trustworthy – so that the TMC can respond to it without conducting a site verification. The following recommendations will ensure that information provided by traffic reporters and uniformed personnel will adequately support TMC operations:

13/17 Pertinent Traffic Information   (Observation)

Train traffic reporters and uniformed personnel to gather pertinent traffic information and report it such that it meets TMC needs. Such information will likely identify incident location and severity, as well as the incident's effect on traffic flow. Ideally, location identifiers can be standardized through automated means, such as GPS. Accident severity and traffic consequences are more difficult to assess, even by experienced personnel.

13/18 Special Event Planning   (Observation)

When planning for major events or a traffic–related emergency response, train field personnel to help monitor and consistently report traffic conditions to the TMC. Field personnel should not have to develop operating procedures and communication protocols at the time an emergency occurs.

13.5.5 Real–time traffic models

Computer-based traffic models may be introduced to the TMC to estimate traffic behavior, provide data on expected traffic problems and predict the results of strategies used to mitigate such problems. Models require fine tuning (to ensure accuracy) and operator experience (to reduce the likelihood of misinterpreting information). Models differ according to the types of traffic parameter estimates they offer, and each model has strengths and weaknesses that must be considered.

System performance. System performance estimates are useful for planning special events and in developing emergency response plans. A model can estimate volume and speed throughout the roadway network.

13/19 Strategic Planning and "What if" Analyses   (Observation)

Conduct "what if" analyses to help develop contingency plans for a variety of incident scenarios involving critical roadway segments.
Such analyses of alternative scenarios allow planners to test predictions.

13/20 Extreme and Routine Situations   (Observation)

When conducting strategic planning exercises, run models such that they consider a minimum of three scenarios--two extreme scenarios and a routine scenario.
The routine scenario will be based on average values extracted from a historical database. These values will lead to predictions that reflect the most typical outcomes. Traffic data can demonstrate wide variation. Consequently, running a model under two extreme conditions (i.e., conditions for which minimum data values apply and conditions for which maximum values apply) is prudent. This analysis strategy will assist in the forming of contingency plans and will enhance model credibility. The specification of *routine*, *minimum*, and *maximum* values is subject to consideration by TMC operators and managers. Suggested minimum and maximum values are the 5th and 95th percentiles, respectively.

13/21 Model Assumptions   (Observation)

Familiarize operators with model assumptions and with the manner in which plans are generated.
Model results are based on assumptions, instructions, and algorithms that are specific to the model. Within some traffic scenarios, these assumptions, instructions, and algorithms may have no meaning. Viewing model results for such scenarios, while having no knowledge of the conditions under which the model is valid, can cause operators to misinterpret the results.

Comparisons with historical and theoretical performance. A real–time traffic model can be used to validate its own accuracy. Ultimately this type of validation exercise, will help in calibrating the model over time.

13/22 Model Prediction	**(Observation)**

Validate the accuracy of model predictions.
In this manner, operators will become familiar with a model's capabilities and have a means of forming accurate impressions on the usefulness of the model's predictions.

13/23 Post-hoc Analyses	**(Observation)**

Run post–hoc analyses to compare actual results with predicted results.
Such analyses assist in assigning appropriate parameter weights, where these weights will be applied to model parameters in future predictions. In this manner the model will be calibrated. A post–hoc analysis enables operators to compare actual results (measured at the time of a given traffic event) with predicted results (provided by the model).

Look-ahead models. Faster-than-real–time traffic models, when fielded, will allow operators to test various mitigation measures prior to implementing them. [46] The model can be instructed to provide near-term predictions (e.g., 10 minutes after mitigation).

13/24 Look-ahead Model	**(Observation)**

Provide effective discrimination between results from look-ahead models and current traffic status.
Look–ahead models are intended for real–time use at operator workstations. In order to ensure that operators do not confuse predictions with current traffic data, model results must be presented in a distinctive manner.

13/25 Look-Ahead Model Interval "Look-Ahead" Time	**(Observation)**

Allow operators to vary the length of a model's "look–ahead" time. In practical terms, as the length of a look–ahead time increases, prediction accuracy decreases. Random variation, plus any other incidents that occur between the current time and the look–ahead time, will cause the model's accuracy to degrade. Such degradation will tend to undermine operators' confidence in an otherwise useful tool.

13.5.6 System self–tests

A number of advanced TMC's have established self-diagnostic capabilities, as well as procedures for resolving hardware and software problems. While operators will be responsible for relatively few diagnostic and maintenance activities, sustaining operators' awareness of current system status is important (e.g., identifying components that have failed). Operators must also understand the implications that may occur as a result of component failures (e.g., degraded system performance).

Detector and controller status data must be provided. Indicators that reveal the current status of input and output devices are common within TMC's. Unfortunately, unless a device fails completely, its respective status indicator is difficult to interpret. For example, a "stuck-on" loop detector may provide inaccurate volume and occupancy information. Data arriving from an intermittently-operating detector may in fact resemble data that indicates a traffic problem. The following guidelines will help to reduce such uncertainties, as well as the time operators spend verifying detector and controller status:

13/26 Detector Failure   **(Observation)**

Provide positive indicators of detector failure.
In identifying a detector failure, operators should not be required to view a "stream of zeros." Improved communications protocols and data handling procedures will allow the system to distinguish a malfunctioning detector from a traffic stoppage. These improvements will also allow the system to recognize intermittent problems and thus inform operators of the potential for erroneous data.

13/27 Detector and Controller Failure   **(Observation)**

Provide only significant information on detector and controller failures.
Many systems' failure logs report relatively insignificant communications failures. For example, some systems poll devices once per second. If a communications link failed during a single polling attempt, a failure record is generated and displayed – even though the link may be reestablished in the next second and continues to operate properly. Only those failures that significantly impact system performance should be displayed. Otherwise, failure data logs will be dominated by temporary problems capable of resolving themselves, and could hide serious problems for which action is required.

Computer status information must be provided. The automated systems of advanced TMC's are highly sophisticated combinations of computer hardware and software. Such systems, capable of running self-diagnostic tests (and then isolating and compensating for failed

components), rarely experience complete failure. Rather, continued performance in less than fully-operational modes will be more common. Operators must understand system capabilities and recognize how the system's status influences their decision-making activities.

13/28 Critical System Status	(Observation)

Provide meaningful status indicators for all critical system hardware and software components.
Task analysis results can identify components requiring status indicators. This set of components can be derived from operational sequence diagrams (OSD's) generated during early system and task analysis.

13/29 Response Strategy for System Failure	(Observation)

Assemble an operators' forum to discuss system failure modes and response strategies.
This discussion might result in an on-line help facility, user manuals, or perhaps a tutorial. It will serve as a reference for operators, assisting them in the selection of appropriate responses to various system failures.

13/30 Degraded System Effects	(Observation)

Identify any data that are affected by degraded system status.
Operators may be alerted to such data through effective on-screen messages. Operators should be aware of any special data handling approaches (e.g., estimation techniques used to accommodate for any gaps in the data). In addition they should adjust their actions accordingly. (See the discussions concerning warning indicator displays in Sections 8.2.5 (visual) and 8.3.2 (auditory), as well as the discussion below.)

Warning indicators. Most warning indicators are visual or auditory alarms. They are automatically triggered when a measured system parameter exceeds (or in some cases fails to exceed) a threshold. Consider a traffic volume indicator that alerts operators to conditions of low traffic volume. When the computer determines that traffic volume is less than the threshold, say 10 vehicles per minute, a red light flashes and a buzzer sounds. In many TMC's, thresholds for warning indicators are too sensitive. Consequently, warning indicators become sources of distracting background noise, and they provide no meaningful indication of system status. Physical characteristics of warning signals are discussed in detail in Chapter 8. The following guidelines are intended to assist designers in developing meaningful, effective warning signals:

13/31 Warning Signals	(Observation)

Provide warning signals to operators for critical traffic conditions and system failures.
Consider, for example, the "annoyance factor" associated with a warning buzzer that alerts operators to failed detectors. These devices are prone to frequent failure. Consequently, for a system with enough detectors, such an alarm would be activated constantly.

13/32 Warning Ambiguity	(Observation)

Use multiple criteria to trigger warnings to reduce warning ambiguity.
Data may not uniquely define traffic or system conditions. Recall from an earlier example that an unusually high occupancy data may indicate an accident or congested traffic, but it may also indicate a detector failure. An approach for removing ambiguities is to define a *set* of conditions (rather than a *single* condition) that, if satisfied, would trigger a warning.

13/33 Disabling of Alarms	(Observation)

Allow operators to turn off alarms only under controlled conditions.
An alarm that is of sufficient importance to be presented, should be disabled only upon the completion of an explicit operator action to reject it as a false alarm or to place the record into a background file for later handling.

Consider innovative display techniques. New graphical computer displays allow designers to discard older display techniques that included mechanical gauges and even alphanumeric data screens. Designers might also consider using multiple presentation modes (e.g., visual and auditory). Such an approach will increase the operator's likelihood of noticing the warning signal and reacting quickly.

Consider tasks requiring TMC operators to monitor system status. For such tasks, displays must often be configured such that the status of many different parameters can be judged at a glance. Columns of numbers are difficult to interpret, particularly when the operator has additional task demands--which is typically the case.

Our research has shown that an integrated traffic flow display providing bar-graph displays of traffic speed and density at a series of locations can be used effectively by operators in diagnosing traffic flow anomalies. The data might be presented for all traffic lanes at a given roadway location or for a single lane in several consecutive locations.

Another alternative display technique, one that has been used successfully in control room environments, is the *axial chart*. This type of display exploits the visual system's high sensitivity

to regularity of form. The axial chart is represented by a polygon (pentagon, octagon) which is symmetrical around at least one axis. The polygon connects a set of axes which all originate at the center of the polygon. Each axis represents the status of one input channel. Input channels might, for example, include signal levels from sensors, or perhaps functioning levels (on/off) of signal lights. If all input levels are "nominal", the bounding figure is a regular polygon approximating a circle. The advantage to this configuration is that the smallest deviation from a nominal value will be reflected as an asymmetry in the polygon. Visual distortions of this sort are very easy for the eye and brain to detect. The axial plot uses only one dimension (length) to represent input levels, and confusion resulting from the incorporation of additional dimensions (e.g., color) is eliminated.

System logs provide data. System logs record changes in system status and actions taken by operators to mitigate traffic problems. (e.g., component failures, a system's return to "on-line" status). In multiple-operator TMC's (where the work day is divided into multiple shifts), a central source of system status information, as well as a log of operator responses to traffic events, must be provided. System logs can be maintained electronically or in hardcopy form. Standard procedures, readily understood by all operators, must be followed whenever critical information is recorded.

13.6 Data Fusion Reduces Data Variability

Data fusion is the act of combining data across time, locations, or sources. In many cases, data fusion results from counting the number of events that occur within a given time interval and expressing the total number of events per unit time, or averaging the data from two adjacent detectors. Data fusion reduces data variability, and through a reduction in data variability, operators are provided a more stable description of traffic conditions. However, data fusion rules must be developed carefully to ensure that the reduction in variability does not mask detection of critical traffic events.

13.6.1 Temporal data fusion

Temporal data fusion refers to the combining of data over time. A number of temporal data fusion techniques are available. Table 13-2 describes how four of the most common temporal data fusion techniques (total, average, moving average, weighted average) are performed. Two important reasons for applying temporal data fusion techniques are:

- **!** To reduce the amount of data being assessed during decision-making activities.
- **!** To reduce data variability.

Consider, for example, an operator who is monitoring raw data from an inductive loop detector placed at a location x. The operator must decide whether traffic volume at location x has increased significantly. If the raw data were displayed as a constant stream of *ones* and *zeros*, detecting a trend of increased volume would be extremely difficult. Consequently, data of this

form might be presented only on diagnostic displays that allow operators to determine if reliable data are actually arriving.

Consider a simple *total* (obtained over some meaningful time interval). An operator might compare a number of different totals, each obtained during a different interval. In this manner, the operator might detect trend information (e.g., a trend of increasing (or decreasing) traffic volume). In many scenarios, simple totals are insufficient in helping operators reach appropriate decisions. In addition, totals are only meaningful for frequency data. An alternative might be to *average* across several intervals. In this manner, data that are relative to a standard time–based reference can be reported. Averaging can stabilize data (i.e., reduce variability). The period of time in which data are averaged must be chosen carefully so that the average reduces short-term variability (noise) while retaining sensitivity to long-term variability, which could indicate and incident.

Table 13-2. Temporal data fusion techniques.

Technique	Definition
Total	Data received during a discrete interval of time are summed. Note that this technique is only meaningful when applied on frequency data. *Examples*: total number of vehicles (during a 3-minute interval); total number of pedestrian crossings (during an hour interval)
Average	Data are received during n discrete time intervals, and the data within each interval are aggregated. (The manner in which each interval's data are aggregated is dependent upon the type of data being collected. Frequency data might be summed, while speed data would be averaged.) The n aggregates are averaged, and this average value is reported. *Examples*: average number of vehicles (detected during three-minute intervals); average number of pedestrian crossings (detected during hour-long intervals)
Moving Average	Data are received during n discrete time intervals, and the data within each interval are aggregated. The n aggregates are averaged. When data for the time interval $n+1$ arrive, they are aggregated, and the data aggregate for the oldest time interval is discarded. A new average (using the data aggregate from interval $n+1$) is computed. *Examples*: average number of vehicles (detected during the most recent minute-long intervals); average number of pedestrian crossings (detected during the most recent 3-hour intervals)
Weighted Average	Data are received during n discrete time intervals, and the data within each interval are aggregated. Each aggregate is multiplied by a "weighting factor," and the n "weighted" aggregates are summed. *Examples*: average number of vehicles (detected during one-minute intervals – where the most recent data aggregates are weighed more heavily than the oldest)

Moving averages and weighted averages also reduce variability. Moving averages consider only the most recent data received by the TMC. Weighted averages allow data from different time intervals to be "prioritized." For example, the most recent data might be weighed more heavily than the oldest data. In this manner any changes in the current traffic pattern will show their effects more quickly.

13/34 Data Fusion Technique Awareness	(Observation)

Inform the operator of the data fusion technique being applied.

13/35 Data Fusion Technique Consistency	(Observation)

For data that operators must compare (e.g., across different locations, across different days, or across different times), apply a consistent data fusion technique and time interval.

13.6.2 Geographic data fusion

Traffic networks provide data that arrive from geographically distinct locations. Detectors, for example, are not typically spaced at standard intervals along roadways. Instead, they are placed to take advantage of nearby sources of power and communications capabilities. Important intersections and ramps are more likely to be monitored and controlled than those considered less critical to traffic flow.

Geographic (or spatial) data fusion refers to combining data from distinct locations in a given roadway network. Two geographic data fusion techniques are averaging and weighted averaging. Geographic data fusion allows TMC operators to learn of traffic conditions in the vicinity of (1) a given location or (2) between several locations. Suppose an operator must obtain traffic flow information at a location that is not monitored by a detector but is equidistant from two detectors. Under these conditions, geographic data fusion is an important tool for providing required data. *Totals* may be used to indicate the volume of vehicles entering or leaving a region during a given time interval. Averages may be used to estimate critical indicators (e.g., average occupancy of an outbound bridge, average volume of inbound tunnel lanes). Weighted averages may be useful when estimating traffic conditions at a location near two or more detectors, where the subject location is closer to some detectors than others.

13/36 Non-Standard Averaging Techniques	(Observation)

Use weighted averages and other non–standard averaging techniques (e.g., geometric averages) with caution.
Such numbers may be difficult to understand, and operators may use them without fully understanding how they are computed.

Identify the set of detectors that are supplying the traffic data.
The most straightforward approach is to highlight this region on a map. If map displays are unavailable, clearly label the data and describe the region from which they are being collected.

GLOSSARY OF TERMS

The terms below have been selected because they are likely to be unfamiliar to designers who do not possess a human factors background. The parenthetical number following each item refers to the chapter(s) in which the term is found; terms in boldface are defined elsewhere in the glossary. Definitions taken directly from sources (e.g., Stramler, 1993) are indicated.

accommodation (8) The process by which the optical structures of the eye adjust to allow focus of images from varying distances. Accommodation results from varying tension of the *ciliary muscles* that surround the lens of the eye, effectively changing the focal length of the lens and causing the image to resolve at the retina.

action verb (11) A word that identifies an activity. In the design of a computer interface, for example, the command "file" may mean an action or a thing; if the intent is to store a file in memory, the action verb "save" is superior because it specifically identifies an activity.

ambient sound level (10) The sound level associated with an environment. In a TMC, the ambient sound level is the background **noise** associated with the work area.

ambient illumination (10) The level of light associated with an environment, usually a work place. Ambient light can influence **visibility** of light sources, such as **video display units**, signs, warning lights, and CCTV display monitors.

anthropometry (7) The systematic study of the physical dimensions and proportions of the human body. (*adj*. **anthropometric**)

attention (5) The general, allocation of sensory-perceptual functions, possibly involving motor functions as well, to a subset of possible inputs. (Stramler, 1993)

attention, divided (5) The form of **attention** required when an operator must perform two or more concurrent **tasks**.

attention, focused (5) See **attention, selective**.

attention, selective (5) The ability to continuously or willfully focus on a restricted set of desired inputs, to the exclusion of the remaining concurrently impinging sets. (Stramler, 1993)

backlash (9) A response of a **control** system in which the system response being controlled is briefly reversed after completion of the movement of a control. A joystick, for example, might be affected by backlash if the cursor it drives moves slightly in reverse after the control is released.

beta test (11) A final phase of pre-release testing of software. Beta-testing generally occurs immediately before release to the market, and generally represents a form of the software very close to the final product.

brightness (8) The psychological counterpart of **luminance**; brightness is the subjective judgment by an observer of the relative amount of light reflected from or emitted by a surface. **Luminance** (*q.v.*) is the corresponding objective **photometric** term.

caffeine (5) A chemical constituent of some food products that causes elevated neural functioning that may affect behavior.

candelas per square meter (8) A **SI** measure of **luminance** (abbreviated **cd/m^2**, and sometimes called a *nit*). The equivalent older unit **foot-Lambert** (fL) is also used, but with decreasing frequency.

canister fixture (10) A **luminaire** configuration in which a light source is mounted in a recessed, usually cylindrical, fixture.

chromaticity (8) the color of a light source defined in terms of its dominant wavelength and wavelength purity (**hue** and **saturation**), excluding its **brightness**.

CIE (8) *Commission Internationale de l'Eclairage*; source for world standards of **color** specification. Coordinates on the CIE 1933 (*x, y*) or 1976 (*u', v'*) color space are frequently used to specify color.

circadian rhythm (5) A biological rhythm with a period of about 24 hours.

circular polarizer (8) A type of filter used to reduce **glare** from a **VDU** display by filtering reflected light in certain orientations.

clearance envelope (10) Physical space, based on **anthropometric** data, required to accommodate a human in a particular work location; e.g., leg and knee space clearance envelope for work stations.

cognitive (*adj.*) (5) Involving the higher mental activities or intellectual functions. (*n.* **cognition**)

color (8) An attribute of a visual perception derived from stimulation of retinal cone cells by light energy from the electromagnetic spectrum of the wavelengths associated with "visible light." As a defined attribute, light consists of three specifying elements: **hue**, or dominant wavelength (loosely equivalent to the common term "color"); **value**, or **brightness**; and **saturation**, or wavelength purity. For purposes of human factors engineering, color is often described using the **CIE** color system.

color temperature (8) The temperature (in Kelvin) of a radiating blackbody having the same

chromaticity or spectral distribution as a given color light source. (Stramler, 1993) Color temperatures are specified for representative wavelengths in each of the **CIE** standard illuminants. Many environmental and display specifications require precise illuminant sources, including specification of color temperature.

command-based interface (11) A human-computer interface system based upon line entry of specific commands by the operator for execution by the computer.

cone vision (8) Central vision in the human retina, characterized by a high density of cone-type receptor cells that provide sensitivity to **color**. Cone vision is effective in daylight (photopic) conditions, ineffective when light levels are low (scotopic).

consistency (11) Attribute of performance or action that repeatedly falls within certain specified limits. (After Stramler, 1993)

construct (2) A postulated attribute assumed to be reflected in observable behaviors or events. (Stramler, 1993) If improvement in operator performance in a TMC follows implementation of a new incentive system, we might presume that motivation accounts for the change; motivation is a construct, a word "invented" to account for the change.

construct validity (2) The extent of the relationship between what a test measures and how test scores are reflected in behavior and performance. (Stramler, 1993) See also **validity, internal**.

contrast (8) The relative difference in luminance between the brightest and darkest areas of a visual display or scene. Contrast is calculated by

$$C = (L_{MAX} - L_{MIN})/L_{MIN}$$

contrast ratio (8) The ratio between the luminance of the brightest and darkest areas of a visual display or scene. Contrast ratio is calculated by:
$$c = L_{MAX}/L_{MIN}.$$

control (9) A device that allows an operator to direct the action of a machine or system.

convergence (8) The inward rotation of the eyes to focus on an object close to the viewer.

correct rejection (4) One of four possible outcomes of a signal detection task — stating that no **signal** is present when in fact there is no signal present.

coupling (3) In **function allocation**, the combination of human and computer actions.

criterion validity (2) See **validity, criterion**.

cross-coupling (9) A situation in which an event occurring in one aspect affects or causes an event to occur in another aspect. (Stramler, 1993) For example, movement of a **mouse**-type input device in a vertical direction causes changes in the signal associated with lateral motion.

dark adaptation (8) The period required by the eye to adjust to a change from bright (photopic) to dim (scotopic) **illumination**. Adaptation will generally require 20-30 minutes.

decision support tool (11, 12) Any aid used to assist an operator in making a decision.

decision criterion (4) The conditions under which a certain decision is assured (**Signal Detection Theory**); specifically, the level of signal energy necessary to prompt a sensory decision from an observer with a given probability.

decision aid (11) See **decision support tool**.

default (11) A value, condition, or state which is automatically selected by a computer or other system unless overridden by an operator or program. (Stramler, 1993)

dependent variable (1) In experimental procedure, a variable whose value is determined by one or more **independent variables**. The dependent variable is the value measured in an experiment to ascertain whether manipulation of the independent variable causes a systematic, causal change.

detection (8) [1]The response of an observer to the recognized presence of an object, event, or condition; [2]the process by which the presence of an object, event, or condition is recognized.

dialog (11) The content of a structured sequence of steps in an interaction between a user and a computer. (Stramler, 1993)

diffuse reflection (8) Reflection of an incident energy flux in many directions from a surface. White typing paper is relatively diffuse in its reflectance properties; a mirror is non-diffuse (**specular**).

direct-manipulation interface (11) A user-computer interface in which the entity being worked is continuously displayed, the communication involves button clicks and movements instead of text-like commands, and changes are quickly represented and reversible. (Stramler, 1993) A **graphical user interface** (GUI) manipulated by mouse is an example of direct manipulation.

display (8) [1](*v*)The presentation of information — data and/or graphics — in a manner designed to be perceived through human senses (e.g., VDU, earphones, mapboard). [2](*n*) A device that presents information.

divided attention (5) That form of attention in which an individual must perform two or more separate **tasks** concurrently, all of which require **attention**. (Stramler, 1993)

Dvorak keyboard (9) A keyboard with key placement AOEUIDHTNS on the "home" row, alternative to the standard and familiar **QWERTY** keyboard.

empirical data (2) Information obtained by objective measure or observation; rigorously collected, not result of opinion or subjective bias.

ergonomics (10) The study of humans at work; roughly equivalent to **human factors engineering**. This term is the preferred usage in Great Britain.

error (4) An inappropriate response by a person or a system.

error of commission (4) An **error** resulting from an system taking an action when no action is required.

error of execution (4) An error in which the operator begins an action sequence with the correct actions in mind, but fails to implement one or more actions properly.

error of intention (4) An error in which the operator applies the wrong action, thinking that the action was correct.

error of omission (4) An error resulting from a system's failure to take action when action is required. (See also "lapse.")

error probability (4) The mathematical likelihood that an **error** will occur. The error probabilities associated with Type I and Type II errors are a and ß, respectively.

etching (frosting) (8) In visual displays, a **glare**-reducing treatment that causes reflections to be diffuse. Most desktop computer VDU's have etched glass outer surfaces that prevent sharp background reflections from causing visual strain.

expectancy theory (5) Theory that seeks to explain a decrement in **vigilance** performance when an observer has been *trained* in an environment with a high number of targets, then must perform in a "real world" situation with far fewer targets. The difference between *expectations* and reality contributes to a vigilance decrement.

expert system (11) A **job aid** for decision-making, generally computer-based and using artificial intelligence technology.

external validity (2) See **validity, external**.

false alarm (type I error) (4) In **Signal Detection Theory**, an **error** in concluding that a **signal** is present when there is no signal. The probability associated with a **false alarm** is a.

fatigue (4) A state or human activity associated with low energy, motivation, and productivity, generally caused by physical or mental exertion.

feedback (9) The return of meaningful **information** within a closed-loop system so that system performance can be appropriately modified. (Stramler, 1993) A **joystick** used to control cursor position, for example, provides mechanical feedback through the user's fingers; the cursor position provides visual feedback.

fine positioning (9) The precise positioning of a pointer, cursor, or other movable target. **Gross positioning** requires rapid general placement. **Pointing** devices such as a **mouse** and **trackball** must meet standards for both gross and fine positioning. To meet both requirements, the device (e.g., a mouse) must be able to move smoothly and rapidly over long distances while being adjustable with high resolution in a small target area.

Fitts list (2) Common list of criteria for allocating functions to human or machine (after Paul Fitts, who developed the technique).

flow chart (2) A design tool composed of standard symbols and annotations used to describe a process in a given operation by breaking it down into its component steps. (also flowchart, flow process chart; see also **operational sequence diagram**)

fluorescent illumination (8) A category of light source in which **illumination** is produced by passing an electrical current through a tube containing mercury vapor and lined with fluorescing substances. Fluorescent illumination differs from sunlight and other light sources in its spectral composition.

font (8) A family of **typefaces** that shares similar features of style and is designed for esthetic compatibility. This term is frequently misused, most often confused with *typeface*. A font (e.g., Times Roman) will include faces in italic, boldface, and other styles in a variety of sizes. The font was a typesetter's wooden cabinet that contained lead type of a given class (font) in all sizes and styles (hence a *typeface* defined as "12-point italic from the Times Roman font"). The term is used in computer displays in a more general sense of the style of alphanumeric characters displayed.

foot-Lambert (8) An old unit of luminous intensity; the **luminance** of a perfectly reflecting surface receiving 1.0 lumen/ft^2. Largely replaced by **SI** unit **candelas per square meter** (**cd/m^2**).

fovea (8) The portion of the retina of the eye (*area centralis*) characterized by a dense array of receptors and a high population of cone-type receptors which yield visual images of high resolution and color differentiation, but which have relatively low sensitivity to light.

frosting (etching) (8) See **etching**.

function allocation (2) The step in design of human/machine systems in which system operations are assigned to the operator, to automated processes, or to a combination of human and machine

processes.

general illumination (10) The approximately uniform background **illumination** within a specific area or volume. (Stramler, 1993) In a TMC control room, this is the overall illumination level, independent of specific supplemental light sources for individual work stations or other areas.

glare (8) Excessive, unwanted illumination in an operator's field of view that distracts or strains visual performance. Common undesirable effects of glare include poor adaptation (sunlight from a window causing the operator's pupil to contract, making discrimination of VDU images difficult), distraction (phototropic response, in which the operator's gaze is attracted or disrupted from the intended area by bright illumination), and reflected glare that resolves at a distracting focal distance (as when the reflection of an exit sign on a VDU screen resolves at twenty feet, while the focal distance from operator's eye to display focal plane is 18 inches).

graphical user interface (GUI) (11) A **direct manipulation interface** that employs **icon** symbols, **windows**, and other graphical metaphors. Generally referred to by the acronym, pronounced "gooey."

gross positioning (9) The general positioning of a pointer, cursor, or other movable target.

Fine positioning requires precise placement. Manipulation devices such as the **mouse** and **joystick** must meet standards for both gross and fine positioning. To meet both requirements, the device must be able to move smoothly and rapidly over long distances while being adjustable with high resolution in a small target area.

highlighting (11) In visual displays, the use of a feature that contrasts with the general background to make some point or element of information more noticeable.

hit (4) In **Signal Detection Theory**, a correct response in which an observer states that a   **signal** is present when the signal is in fact present.

hot key (11) A key on a computer keyboard that causes an action to occur by a single key press. Keys on the function row of a PC keyboard are usually "hot."

hue (8) A dimension of color defined by dominant wavelength (other dimensions are **brightness** (luminance level) and **saturation** (wavelength purity). Hue is approximately equivalent to (and sometimes confused with) the common definition of **color**. The terms red or green refer to the attribute hue.

human error (4) Any **error** in a system attributable to a human action or lack of action.

human/system interface (1) The point of interaction between the human and non-human parts of a system.

icon (11) A graphical representation of an action or object; most frequently applied to **graphical user interfaces** (GUI's). An icon showing a file folder, for example, may be used to represent the action of saving a file.

identification (4) The action of recognizing/categorizing information in a display. **Detection** is limited to sensory response (something is there); identification, which follows detection, involves categorization (what is it?).

illuminance (8) The luminous flux density incident per unit area on a surface. (Stramler, 1993) Luminous flux is the light energy projected by a source; illuminance is the amount of light that reaches a given place (e.g., the upper work surface of a work station).

incandescent illumination (10) Illumination produced by light from an **incandescent source** (i.e., an incandescent lamp, usually an electrical filament in a sealed bulb). Incandescent sources have spectral characteristics that make them ''warmer'' than other sources (e.g., **fluorescent illumination**).

independent variable (2) In experimental procedure, a variable manipulated by the experi-menter with the expectation that changes in one or more **dependent variables** will result.

indirect lighting (10) Illumination so designed that most of the luminous flux is directed toward a surface other than the task surface. An indirect fixture, for example, may illuminate a ceiling and provide indirect illumination on desks or other work areas. Indirect lighting is less likely to produce certain kinds of **glare**.

individual differences (6) Known or estimated distributed variations in human size, strength, or other physical or mental performance variables that must be accounted for in job and task description and design and in the design of the workspace.

information (4) [1]The meaningful collection of facts, figures, and/or data; [2]in information theory, that which reduces uncertainty (typical unit is the *bit*). (after Stramler, 1993)

intensity (8) A measurement of energy per unit time per unit area. Luminance flux is an example of a measure of light intensity.

interface (11) A common boundary or point of connection between two parts of a system or between systems. A **human/system interface** is an interface between a human and a non-human part of a system.

internal validity (2) See **validity, internal**.

irradiation(8) An optical effect caused when bright, boldly designed images are presented against a dark background. Bold white letters against a black field, for example, will appear to have fuzzy or

indistinct, glaring, outlines due to irradiation.

isometric action (7) A muscular dynamic in which muscle tension increases without concomitant changes in muscle length; pushing the hands together without movement after contact is an isometric action.

isotonic action (7) A dynamic muscle action in which the muscle length of one or more muscles shortens and movement of one or more body links occurs, with constant muscle tension throughout the movement.

job (3, 6) The sum of all the tasks and duties assigned to and carried out by one or more workers toward the completion of some goal.

job aid (5, 11, 12) Any measure that enhances work performance. Also **user aid** (generally applied to information systems), **work aid**.

joystick (9) A stick or lever control device used for hand or finger generated system input having at least two degrees of freedom. A joystick may control some electro mechanical input (e.g., an aircraft pilot's control) or a **cursor** or some other element of a computer system. Also *joy stick*.

kerning (8) An attribute of typography that addresses variable spacing of letter elements for a more pleasing visual arrangement. Kerning is available in some advanced word processor and desktop publishing programs.

keyboard (9) A computer input device similar to a typewriter mechanism.

knowledge, skills, abilities (**KSA's**) (2) A commonly used descriptor of human attributes needed to accomplish some task. KSA's are frequently cited in descriptions of job qualifications.

lapse (4) A memory (storage) failure, in which an operator forgets the appropriate sequence of actions.

leading (8) In typography, the space between lines of type. Small leading will produce dense, less legible, text. Pronounced "ledding" (from lead strips used by old hot-lead typographers.)

legibility (8) Attribute of displayed alphanumeric elements; ability of an observer to discriminate individual letters or numbers. Note that **readability** is the degree to which meaning can be extracted from the text, and is not the same as legibility. Text rendered in all uppercase may be just as legible as the same text in mixed upper and lower case, but less readable.

link analysis (2, 10) An analytical design tool that measures the interactions among individuals and nonhuman system elements, usually by noting the frequency of interaction.

load stress (3) Stress caused by sensory overload such as a requirement to monitor too many

channels of information.

lumbar support (10) Ergonomic support for the lumbar region of the spine; an attribute of seating systems.

luminaire (10) A complete lighting fixture including the lamp, housing reflector, guard, etc. A complete lighting system is usually composed of several luminaries.

luminance (8) The measure of luminous flux per solid angle reflected from or emitted by a surface. The "**brightness**" control of a VDU actually adjusts the luminance.

lux (8) The **SI** unit for measure of **illuminance**, generally replacing foot-candle (fc).

macro (11) A set of commands or keystrokes that may be executed by a single command.

matrix character (8) A character displayed by use of a usually rectangular matrix of on/off elements (e.g., the characters on a VMS display).

matte (8) Having diffuse reflective characteristics or a dull or non-glossy surface (e.g., unglazed porcelain).

menu-based interface (11) A computer interface so designed that instructions from the user to the system are chosen from a displayed list of options rather than input by the user as a series of memorized commands (see **command-based interface**).

micro-mesh screen (8) An anti-**glare** screening device for video display units consisting of a fine mesh that limits the path of light to and from the screen surface.

miss (type II error) (4) An error in which the observer fails to detect a signal that is present; the probability associated with a type II error is **ß**. (See **false alarm, type I error**, a)

mockup (1) A full-scale model of a work station or item of equipment used as a design tool.

modality (11) Any sense, such as vision or hearing. (Stramler, 1993) A warning indicator that combines a flashing light and a beeping tone is *multimodal*. Also *sensory modality*.

modulation contrast (8) A measure of visual **contrast** computed by:

$$C = (L_{MAX} - L_{MIN})/(L_{MAX} + L_{MIN})$$

monitor (8) (*n*) A video display unit. Because of confusion with the verb, this term is not frequently used.

monitoring (3) (*v*. **monitor**) The act of observing a situation or event (e.g., an operator monitoring input of traffic sensors on a display) over an extended period of time.

mouse (9) A computer input device consisting of a hand-held structure with one or more buttons, used to move a **cursor** and to select an object or choice; generally used with a **graphical user interface**.

natural language interface (11) A computer interface style in which the vocabulary or syntax of entries and commands approximate normal language.

navigation (11) In human-computer interfaces, the action of moving from one interface mode or location to another (e.g., within menu hierarchies).

neutral density filter (8) A filtering device that reduces intensity uniformly across the spectrum, hence without distorting color attributes; used as a glare-reduction device for video display units.

noise (8) Components of a measured energy that may interfere with a signal, particularly that which reduces **signal** clarity. **Note**: "noise" in this sense is not necessarily sound, but may affect any sensory **modality**.

operational sequence diagram (2, 3) A tool for **task analysis** that uses a systematic flow description of actions, inputs, decisions, etc. to allow precise and objective understanding of an element of work, particularly activities involving human and machine elements. The OSD is similar to a **flow process chart**, but more detailed.

peak load (11) The maximum rate or capacity which a system or component either is designed for or is able to perform or support.

perceptual load (11) The quantity of information that an operator is expected to perceive and act on during a task within a given time period.

persistence (of phosphor) (8) The attribute of a phosphor screen that describes the time required to go from an excited state to a null state. A television screen uses a low-persistence phosphor, since movement of images with high persistence phosphor would tend to leave "trails" of slowly dimming bright areas. An oscilloscope, which traces lines that must be visualized after movement, uses high persistence phosphor.

photometer (8) A light meter. Photometers measure levels of luminance or illuminance to some required degree of accuracy. A *spectrophotometer* measures not only light intensity, but spectral components as well.

phototropism (8) The unlearned response of an organism to the presence and direction of a light source.

point (8) Standard measure of type size; 1 point = 1/72 inch.

pointing device (8) A device used to highlight or indicate a selected portion of a display.

popliteal (7) [pop·li·te·al] Describing the crease of the leg joint immediately behind the flexed knee (*popliteum*). The distance from buttocks and floor to the popliteal crease is an essential factor in the design of chairs.

population (2) All possible members of a group having a distinct set of characteristics. (Stramler, 1993) In designing components of a TMC, the characteristics of the target population (education, physical size, etc.) should be considered. For test and evaluation, any **sample** of test **Subjects** should be representative of the intended population.

processing time (5) The time required or allowed to complete a process.

prototype (2) A model or preliminary version of a product which is produced prior to fabrication of the production item and is representative of the final system for testing and evaluation (Stramler, 1993).

psychometrics (2) The use of psychological tests and measures and statistical techniques in the study and analysis of human behavior.

quarter-wave coating (8) An optical coating process used to reduce some aspects of glare in video display units.

QUERTY keyboard (9) The standard **keyboard** arrangement, in which the sequence of letters in the row above the home row is QWERTYUIOP. See also **Dvorak keyboard**.

rapid prototyping (1) A computer-assisted method for rapid development of interfaces, displays, and controls, using a graphical representation of the final product that can be manipulated and easily modified as part of the design process.

readability (8) The attribute of text in a display that addresses the ability of an observer to read, or acquire the meaning of, words and phrases. Readability is related to visibility (can the display text be seen?) and legibility (can *each* letter or number be identified?).

redundant coding (8) Information coding that includes more than one way of recognizing and processing a message (e.g., a warning device that includes a blinking light and an audible beeping tone).

reflectance (8) The ratio of energy reflected from a surface to the energy incident on that surface (Stramler, 1993). A mirror has high reflectance; a surface of matte black has low reflectance. Reflectance may be **specular** (unidirectional, as in a polished surface) or **diffuse** (multidirectional: for example, rough, unglazed porcelain).

reliability (1) [1]The probability that a system will perform its functions under specified conditions; [2]the likelihood that repeated tests of the same phenomenon will yield the same results.

rod vision (8) Vision associated with the periphery of the retina (populated by *rod cell* photoreceptors), hence peripheral vision. Rod cells are very sensitive to quantities of light and to movement, relatively insensitive to color and not acute in form perception. **Cone vision**, or **central vision**, is associated with the **fovea** or area centralis of the retina, populated by *cone cell* photoreceptors, which are not as sensitive to small quantities of light, but are sensitive to details of form and **color**. Rod vision is critical under low levels of light.

sample (2) A group selected from a total **population** for study.

sans serif (8) A **typeface** designed without serifs; that is, without the ornamental flourishes like Roman-style type. (This is a sans-serif face.)

saturation (8) The attribute of **color** that describes wavelength purity. A saturated color will appear intense and pure to the observer; an unsaturated color will appear "grayed."

scan (3) To **search** a selected area for a specified detail (e.g., scan a display of a street plan for indications of faulty sensors).

scrolling (11) Advancing through a **display** line by line under operator control.

search (3) A basic element of a task in which an operator locates a target among other stimuli.

seat angle (7, 10) The angle of the **seat pan** plane above a horizontal reference with the origin at the seat reference point. (Stramler, 1993)

seat height (7, 10) Vertical dimension of a seat from floor to top of **seat pan**; hence, in a properly designed chair, the distance from floor to the **popliteal crease**.

seat pan (7) The portion of a seat on which the thighs and buttocks rest. (Also seatpan)

see-over (10) The design attribute of a component that assures that an operator's view of critical displays will not be blocked.

segmented character (8) A text character in changeable displays constructed from a limited number of segments, or fundamental elements. LED displays are generally segmented.

selective attention (4) The ability to consciously or willfully focus on a restricted set of desired inputs, to the exclusion of the remaining concurrently impinging sets. (Stramler, 1993)

Sensory Decision Theory (4) See **Signal Detection Theory**.

serif (8) The ornamental flourishes that decorate Roman-style and certain other typefaces. (See **sans serif**.)

short-term memory (5) See **working memory**.

SI *Système International d'Unites*. Internationally accepted units of scientific measure, commonly known as the "metric system."

signal (4) **Information** transmitted by some means: visual, auditory, tactile, electromagnetic, etc. See **noise**.

Signal Detection Theory (5) A psychophysical method used to describe an observer's decision as to whether a **signal** is present against a background of **noise**. The theory includes the ratio of signal to noise, operator biases, and risks associated with decisions.

slip (3) An execution failure in which an action sequence continues to the wrong conclusion.

specularity (8) The attribute of a surface that determines the degree to which incident light is reflected directly or in a multidirectional, diffuse manner. From L. *speculum*: mirror.

speed stress (4) A condition of overload caused when the rate of **information** exceeds the ability of an operator to process it.

stress (4) The collective mental and physical conditions resulting when an individual experiences one or more biomechanical, physiological, or psychological stressors above comfortable levels. (Stramler, 1993)

stroke width (8) The width of a displayed line.

structural (static) anthropometry (7) The measure of the human body at rest.

stylus (9) An input device, generally pen- or pencil- shaped, used for computer input.

Subject (1) A member of a **population** under study selected for inclusion in an experiment or evaluation. When used in this sense, the word is generally capitalized; in scientific writings, often abbreviated *S* (plural *Ss*).

supplementary illumination (10) Lighting installed or supplied in addition to the general lighting (e.g., a desk lamp).

sustained performance (5) Measure of quality of **task** execution over a specified time period; in particular, the effects of boredom, **stress**, and **fatigue** on performance.

syntax (11) In computer commands, the meaning or significance associated with the order of words or commands (e.g., <command><parameter><argument>).

task (2, 3, 6) A logical, describable group of related activities (subtasks) that comprise a discrete component of a job and which are performed within a job classification. (After Stramler, 1993)

task allocation (6) The division of **tasks** across a team. This differs from **function allocation** in that the latter divides tasks between humans and automated components.

task analysis (2, 3) A systematic breakdown of a **task** into its elements, specifically including a detailed task description of both manual and mental activities, task and element durations, **task frequency**, **task allocation**, **task complexity**, environmental conditions, necessary clothing and equipment, and any other unique factors involved in or required for one of more humans to perform a given task. (Stramler, 1993)

task complexity (2, 3, 11) Measure of the nature of a **task**, accounting for the number of subtasks and their individual and aggregate difficulty.

task difficulty (2, 3, 11) Measure of the nature of a **task**, based on the likelihood of an **error** occurring in its commission.

trackball (9) Input device for human/computer interface consisting of a free-turning sphere in a restraining framework, upward-facing and capable of finger manipulation to adjust a **pointing device**. Also track ball.

type II error (miss) (4) See **miss**.

type I error (false alarm) (4) See **false alarm**.

typeface (8) See **font**.

undo (11) A command or menu selection that reverses the execution of the immediate prior command.

usability (11) The measure of the ease with which one may use a product or learn how to use a new product. (Stramler, 1993)

user-centered design (11) A system design process that focuses on or specifically accommodates the capabilities and limitations of the human(s) in the system.

validity, construct (2) See **construct validity**.

validity, criterion (2) The degree to which a test accurately predicts job performance. (See also **validity, external**.)

validity, external (2) In experimental usage, the degree to which the results of a test can be applied to the "real world."

validity, internal (2) In experimental usage, the adequacy of experimental design; the degree to which a test measures the variable under study. (See also **construct validity**.)

variance (2) A deviation from a standard or otherwise normal or specified value. (Stramler, 1993) In statistics the variance generally refers to the dispersion of measured values around a mean; the second moment of a statistical distribution.

video display unit (VDU) (8) A visual display, widely used in human/computer interface designs, in which information in the form of text and/or graphics is displayed on a cathode ray tube.

viewing angle (10) The angle within which an observer can view a control or display.

viewing distance (8) The line-of-sight distance between the observer and the display being observed.

vigilance (3, 5) A state in which an individual sustains a high level of **attention** in an attempt to detect a signal, a change in **signal**, or a particular activity. (Stramler, 1993)

visibility (8) The degree to which an object can be perceived by an observer; obstacles to visibility might include low **contrast**, low **brightness**, interposition of other objects or surfaces, and distance. See also **legibility** and **readability**.

visual angle (8) The angular size of an object being observed, relative to the observer; calculated by distance from eye to target and height/width of the target.

work modules (2, 3) Aggregations of discrete **tasks** that are temporally related or combine to achieve a coherent objective; a tool of **task analysis** that allows many separate tasks to be clustered in a meaningful way.

work pacing (6) The rate at which a **task** or activity is done, whether externally- or self-paced.

work station (10) The physical configuration of an individual work unit, usually including work surface or console, controls, displays, supplemental lighting, and other furniture.

work surface (10) The surface, usually a horizontal or near-horizontal plane, on which an operator performs tasks. In a TMC **work station**, the work surface might support a **keyboard, pointing device**, and space for notes and **job aids**.

working memory (5) A form of memory of limited capacity and duration generally used for a requirement at hand; after a short period, working memory is either encoded into long term memory or decays beyond accessibility. Also **short term memory**.

workload, mental (5) An indicator of the level of total mental effort required to carry out one or more **tasks** at a specific performance level.

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GUIDELINE INDEX
(Terms are followed by numerical identifiers of related guidelines)