NASA TM-84942

NASA-TM-84942 19830011206

A Reproduced Copy

OF

NASA TM-84942

Reproduced for NASA

by the

NASA Scientific and Technical Information Facility

LANGLEY RESEARCH CENTER
LIBRARY, NASA
HAMPTON, VIRGINIA

FFNo 672 Aug 65

(NASA-TM-84942) HUMAN FACTORS ASPECTS OF CONTROL ROOM DESIGN: GUIDELINES AND ANNOTATED BIBLIOGRAPHY (NASA) 357 p
HC A16/MF A01 CSCL 05H

N83-19477

Unclas
G3/54 08796

NASA

Technical Memorandum 84942

HUMAN FACTORS ASPECTS OF CONTROL ROOM DESIGN: GUIDELINES AND ANNOTATED BIBLIOGRAPHY

Christine M. Mitchell, Lisa J. Stewart, Alexander K. Bocast and Elizabeth D. Murphy

DECEMBER 1982

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

LIBRARY COPY

JUN 28 1983

LANGLEY RESEARCH CENTER
LIBRARY, NASA
HAMPTON, VIRGINIA

N83-19477#

TM 84942

HUMAN FACTORS ASPECTS OF CONTROL ROOM DESIGN: GUIDELINES AND ANNOTATED BIBLIOGRAPHY

Christine M. Mitchell
Lisa J. Stewart
Alexander K. Bocast
Elizabeth D. Murphy

Decision Sciences Faculty
George Mason University
Fairfax, Virginia

December 1982

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

CONTENTS

		Page
I.	Introduction	1
II.	Anthropometry	7
	A. Definition	7
	B. Scope	7
	C. Applications	8
	D. Relevance of Anthropometry to GSFC	11
	1. Control room design	11
	2. Control room operations	11
	3. Communications	11
	4. Capabilities and limitations	11
	5. Tradeoffs	12
	E. Anthropometric Data	13
	F. Design Rules	15
	1. The "Average Man" Fallacy	15
	2. The Fifth and Ninety-Fifth Percentile Specifications	15
	G. Anthropometry: Special Topic—Standardization Versus Efficiency	17
	H. References	20
III.	Environmental Issues	21
	A. Goals of Environmental Design	21
	1. Performance support	21
	2. Organizational support	21
	3. Normal environment	22
	4. Assisting learning	22
	B. Physical Environment	22
	1. Temperature	22
	a. heat and performance	22
	b. cold and performance	23
	c. recommended temperature levels	23

PRECEDING PAGE BLANK NOT FILMED

Page

2. Air quality 23

a. humidity levels 23
b. ventilation 24

3. Illumination 24

a. recommended levels 24
b. glare 26

4. Noise 26

a. effects on communication 26
b. effects on safety 26
c. recommended levels 26

5. Maneuvering space 28

6. Vibration 28

7. Ambience 28

C. Social Psychological Environment 30

1. Shiftwork 30

a. physical effects 31
b. effects on performance 31
c. effects on health 31
d. psycho-social effects 31
e. design of shiftwork 32

2. Presence of others 32

3. Personal space and privacy 33

4. Role definition 33

D. Further Research 33

E. References 34

IV. Workstation Design 37

A. Pre-Design Considerations 37

1. Review documentation 37
2. Hardware 37
3. User population 38

Page

B. Physical Layout 38

1. Accessibility 39
2. Coverage 39
3. Furniture and equipment 39

a. visual access 39
b. communication access 40
c. circulation 40
d. maneuvering space 40

4. Peripheral concerns 40

a. documents 40
b. supervisor access and communications 41
c. other personnel access 41

C. Equipment Design 41

1. Console dimensions 41

a. standing operations 41
b. seated operations 42
c. sit-stand operations 43

2. Seating dimensions 43

D. Communication Systems 44

1. General requirements 44
2. Telephone systems 45
3. Radio systems 45
4. Announcing systems 45
5. Auditory warning systems 46

E. Command Panel Displays 46

1. Selection and choice 46

2. Coding 48

a. color 49
b. other coding techniques 49

Page

F. Command Panel Controls 51

1. Selection and choice 51
2. Compatability 51
3. Coding techniques 54

a. color 54
b. size 54
c. shape 55
d. location 55
e. labeling 55

G. Command Panel Layout 56

1. Sequential arrangment 56
2. Frequency arrangement 56
3. Functional arrangement 56
4. Importance arrangement 58
5. Graphic or pictoral arrangment 58

H. Further Research 58

I. References 58

V. Human Factors of Computer Systems: The Hardware 61

A. Introduction 61

B. Ergonomics of Video Display Terminals (VDTS) 62

1. Health and safety hazards and complaints 62
2. Environmental and workstation design 67

a. general considerations for workstation design 68

1) working level 70
2) desk height 70
3) chair, seating height, and back support 70
4) foot rests 70
5) document holders 70
6) arm reach and working level 71
7) display height 71
8) viewing distance 71

b. environmental design considerations for computer workstations

1) illumination or ambient light level 71
2) luminance ratios 71
3) glare and reflection 71

Page

4) temperature 72
5) noise 72

3. Visual properties and ergonomic aspects of video display terminal hardware 72

a. image and screen attributes 73

1) flicker 73
2) luminance 73
3) symbol contrast 73
4) image polarity 74
5) phosphor 74
6) color 74
7) adjustability of the screen 74

b. character formation and display legibility attributes 74

1) resolution 75
2) symbol dimension 75
3) character font 75
4) cursor 75
5) backspace capability 75
6) cursor control 76
7) screen memory and scrolling 76
8) display enhancement features 76

c. keyboard attributes 76

1) general criteria 76
2) key characteristics 77
3) keyboard layout 77

d. miscellaneous considerations 77

C. The Ergonomics of Color Attributes 78

1. Technical definition 79
2. Color perception 85
3. Information contents 87
4. Guidelines in the use of color 88

D. Interaction Techniques and Tasks 92

1. Touch panel 96
2. Light pen 98
3. Tablet and stylus 99
4. Mouse 99
5. Joystick 99

Page

6. Trackball 99
7. Cursor control keys 100
8. Power region control keys 101
9. Alphanumeric keyboard 101
10. Function keyboard 105
11. Soft keys 105
12. Chord 105
13. Voice 106
14. Sensors 106
15. Guidelines 107

E. Issues For Further Research 109

F. References 110

VI. Human Factors of Computer Systems: The Software 113

A. Introduction 113

B. Design Issues for Computer-Based Information Displays 114

C. General Principles for Effective Designs 116

D. The Design of Interactive Dialogues 118

1. Basic properties of interactive dialogues 118
2. Types of interactive dialogues 122

a. form-filling 122
b. question-and-answer 123
c. menu selection 123
d. command languages 124
e. query languages 125
f. natural language dialogue 125

E. Coding Techniques 126

1. Alphanumeric coding 127
2. Shape coding 127
3. Color coding 127
4. Highlighting 129
5. Blink coding 130
6. Miscellaneous codes 130

F. Computer-Generated Messages 131

G. Informational Properties of VDTs 132

1. Display density 133

Page

2. Formatting computer-based displays 134
3. Graphical vs. nongraphical displays 135
4. Formatting tabular data 135
5. Formatting graphical data 136
6. Formatting alphanumeric data 136
7. Labelling 136
8. Further research 137

H. System Response Time 137

I. References 139

VII. Conceptual Issues in Human-Engineered Systems 141

A. Introduction 141

B. Conceptual Models of Information Processing 142

1. Definitions 142
2. Human vs. computer information processing 143
3. Short term memory/long term memory model 145
4. Semantic/episodic long term memory model 148
5. Design implications of the STM/LTM model 149
6. Strategies for information processing model 150
7. Levels of processing model 153
8. Serial vs. parallel processing 154
9. Design guidelines 154
10. Summary 157
11. References 160

C. The Human as System Supervisor 163

1. Allocation of responsibilities 163
2. Interface for the human-computer dialogue 172
3. Summary and conclusions 177
4. References 178

D. Issues in Multiperson Control Teams and Multiperson Supervisory Teams

1. Communications between system and team 188

a. displays 188
b. control instruments 188

2. Communications between and among team members 190

3. Communications for teams separated spatially and temporally . . 194

Page

4. Summary 194

5. References 194

E. Management Philosophy 195

1. Case study 198
2. References 201

VIII. Tools For Human Factors Design and Evaluation 203

A. Introduction 203

B. Task Analysis 203

C. Link Analysis 206

D. Onsite Observation 210

E. Mockups 211

1. Introduction 211

2. Mockup test facility 211

3. Mockup techniques 214

a. paper mockup 215
b. soft 3-dimensional mockup 215
c. hard mockups 216
d. other mockups 217

4. Determining type and level of mockup 217

a. miniature-scale mockups and models 218
b. use of drawings and paste-ups 218
c. erector set mockups 218

5. Experimenting with alternative panel layouts 219

6. Human-machine system and environment 219

7. Choosing subjects for mockup evaluations 220

8. Determining the number of evaluators 220

9. Establishing the basis for test subject selection 220

10. Evaluation design 221

Page

11. Conclusion 221

F. Mathematical Modelling Techniques Used in Human Factors Analysis 222

1. Information processing models 223

2. Manual control models 224

3. Models of decision making 224

4. Newer modelling approaches 226

a. queueing theory 226
b. fuzzy set theory 227
c. production systems, Markov chains, and pattern recognition 227

5. Summary 228

G. Human Factors Engineering Methodologies 228

1. Introduction 228
2. Department of Defense 231
3. Nuclear Regulatory Commission 238
4. National Aeronautics and Space Administration 242
5. George Washington University 243
6. Summary 248

H. References 249

IX. The Cutting Edge: Directions for Future Research 253

Appendices 257

A. Annotated Bibliography 259

B. Vitae of Research Personnel 319

Index 333

LIST OF FIGURES

Figure		Page
3-1	Recommended exposure time to heat as a function of activity and temperature	25
3-2	Comfort zone as a function of relative humidity vs. temperature	25
3-3	Recommended illumination levels in footcandles	27
3-4	Voice level as a function of distance between speaker and listener and ambient noise level	27
3-5	Vibration exposure criteria for longitudinal (upper curve) and transverse (lower curve) directions with respect to body axis	29
4-1	Relative evaluations of basic symbolic indicator types	47
4-2	Recommended colors for alarm and status words	50
4-3	Twenty-two colors of maximum contrasts	50
4-4	Common types of controls and their preferred functions	52
4-5	U.S. population stereotypes of control actions and corresponding functions	53
4-6	Advantages and disadvantages of various types of coding	57
5-1	The most important aspects in the design of VDT workspaces	69
5-2	Response characteristics of the eye	82
5-3	Luminosity response of the eye	82
5-4	RGB color cube	84
5-5	RGB color cube viewed along principal diagonal	84
5-6	Single hexcone HSV color model	86
5-7	Double hexcone HLS color model	86
5-8	Preferred configuration of cursor control keys	102
5-9	Power region interaction technique control key set	103

PRECEDING PAGE BLANK NOT FILMED

Figure		Page
5-10	Power region resolution	104
6-1	Properties of human-computer dialogues	120-121
6-2	System response time as a function of user activity	138
7-1	Bits of information per item	144
7-2	Flow diagram of human/computer information processing system	144
7-3	Flow diagram of human processing/computer processing loop	146
7-4	Short term store/long term store model	146
7-5	Range of absolute discriminations	151
7-6	Short term memory span per item	151
7-7	Flow chart of information processing within a system	156
7-8	The channel capacity of senses for different unidimensional stimuli	158
7-9	The channel capacity of senses for multidimensional stimuli	159
7-10a	Advanced control system	164
7-10b	Automated control system with a human supervisor	165
7-11	Human-computer dialogue fragment from the proposed automated MSOCC-1	170
7-12	MSOCC display for SAGE	175
7-13	Team organizations	184
7-14	Standard geometry for single person workstation	191
7-15	Wrap-around geometry of multiperson team workstation	192
8-1	Guideline for selecting appropriate methods and formats for analyzing various types of tasks and activities	205
8-2	Non-directional link diagram	209
8-3	Simple directional link diagram	209
8-4	Top down design methodology outline	248

LIST OF TABLES

Tables		Page
5-1	Colors associated with wavelength spectrum	80
5-2	Interaction techniques	94
5-3	Interaction tasks	95

LIST OF APPENDICES

Appendix		Page
A	Annotated Bibliography	259
B	Vitae of Research Personnel	319

PRECEDING PAGE BLANK NOT FILMED

ACKNOWLEDGEMENTS

We would like to express our appreciation to several people whose time, expertise, assistance and encouragement was invaluable in publishing this document: Paula Van Balen; Teresa Duron; Sarah Seeberg; and especially Sandy Slater and Donna Anderson of George Mason University's Word Processing Center.

Christine M. Mitchell
Lisa J. Stewart
Alexander K. Bocast
Elizabeth D. Murphy

PRECEDING PAGE BLANK NOT FILMED

CHAPTER ONE

INTRODUCTION

Advances in technology have provided more efficient, comfortable, and safer places in which to work as well as faster, more energy efficient products, equipment, and tools. However, despite these advances, many facilities, products, devices, and workstations are frustrating because of their complexities, inconveniences, and stress-producing demands which detract from the intended advantages.

Many of these problems occur because designers have neglected or paid insufficient attention to the interface issues between the product and the user, especially issues concerning human capabilities and limitations. Poor interface is particularly worrisome in real time situations. Nowhere are problems in the human-machine interface more apparent or their impacts more critical than in real time command and control environments. The time critical nature of real time command and control tasks exacerbates the effects of poor design which can result in operator inefficiency, increased mental workload, or, in the worst case, operator error. Many operators, not unreasonably, have argued that so-called human errors caused by poor design are not really human errors at all, but rather designer errors; their point is that if a tool or machine has not been designed for use by humans, the blame should be placed at the door of the system designer and not attributed to the human operator.

Over the past several decades, a good deal of knowledge has been accumulated about product, equipment, and workplace design. Numerous documents provide detailed guidelines for various human factors aspects in the design of the human-machine interface. However, some dimensions of the interface have, as yet, received little attention and, as a result, are poorly understood. The research effort documented in this report undertook the task of surveying the literature in an attempt to define and

summarize what is known and to explore those areas which are important but, as yet, poorly defined.

The filter and organizing framework used in this literature review was the human factors aspects and issues most relevant to NASA-Goddard's control rooms. Any time a human interacts with a machine or tool or, indeed, any artifact created by another person, human factors issues arise. This research attempted to limit the domain to those issues which were particularly relevant to multiperson, real time, automated and semiautomated control environments as typified by Goddard's Multisatellite Operations Control Center (MSOCC).

This report contains an annotated bibliography which catalogues all the literature acquired and reviewed for this endeavor as well as a short description of each entry (Appendix A). The body of the report presents guidelines and user considerations for various human factors aspects of control room design. The organization parallels the state of current knowledge for these areas. The first topics are those which have the most known about them. They are well-defined, well-researched, and have clear-cut design guidelines. Subsequent chapters move into areas where the design principles become more speculative. Principally because of the recency of the issues (e.g., human factors aspects of computers in control rooms), there are many more questions than answers in some of these areas. The material presented in this report summarizes what is known and identifies human factors issues where existing knowledge needs to be augmented by additional research.

In chapter two, the areas of anthropometry and anthropometric design are defined and described. Anthropometry is the study of the human body in its structure and mechanical function. Anthropometric data provides design guidance for population norms; they describe such things as reaches for workspace layout, dimensions for working

positions, and range of movements of body members. Although such considerations may seem trivial or obvious, they are often overlooked with not insignificant consequences. The design of a system, workplace, or tool with less than acceptable dimensions may jeopardize performance, operator safety, and system reliability. Anthropometry is an area which has been thoroughly explored by system designers in both military and government agencies as well as the private sector. There is a comprehensive data base for the various anthropometric aspects of equipment and system design. The guidelines in this document provide a road map to anthropometric considerations of system design and suggest sources of design data.

Human factors aspects of the workplace environment and workstation design are well-defined and have received almost as much research attention as anthropometry. The design of workplace environments includes consideration of such issues as air, temperature, humidity, noise levels, and shift work. Workstation design addresses issues which include the specifications of controls and displays, panel design and layout, and visual and reach distances. As with anthropometric data, industries involved in process control, aerospace flight deck design, military weapons design and, more recently, nuclear power plant control rooms have all contributed to both the extensive body of knowledge and the related guidelines for these areas. The material in this report highlights the major issues and guidelines, providing an overview for system designers.

The next two chapters directly address human factors issues which have arisen as a consequence of the introduction of computers and associated technology into the workplace. Although the distinction between hardware and software is not always clear-cut, examination of the literature, design guidelines, and current research suggests that this may be a useful conceptualization. The hardware issues, which include the traditional ergonomic concerns as well as the use of color, and interaction techniques,

are generally a bit better defined and understood than the software or informational issues concerning what to put on the screen (e.g., types of dialogue, properties of dialogues, coding techniques, iconic displays, and displays with cognitive fidelity). These two chapters summarize the current body of knowledge for these areas and suggest areas which need further research.

Chapter seven is a potpourri of topics which are so speculative that design principles or guidelines have yet to be formulated. However, these topics are important enough to warrant careful consideration in system design. The first topic, theories of the human as an information processor, outlines the prevailing psychological underpinnings for a significant portion of the design principles which currently exist. Although most designers are not trained psychologists, it is important that they have some sensitivity to the models and theories which attempt to describe and characterize the human component of the system. Many designers, particularly those with an engineering education, are thoroughly grounded in the mechanics, strengths and weaknesses of the hardware components of the system and totally ignorant of the human component. A human factors approach to system design requires a thorough understanding of human capabilities and limitations.

Discussion of the next topic in chapter seven explores some of the problems and design considerations which result when automation is introduced into the control room. The most significant change in the human's role is a promotion from a position of a manual controller to that of a system supervisor overseeing banks of computers which typically take over the manual control functions which formerly occupied the majority of the operator's time. This change in role warrants an examination of the type of information the human requires, types of interfaces he/she needs with the system, and several other design issues. At this time, these issues are merely questions; there has been little research as yet to provide answers.

Historically, research into the human factors of control rooms has been supported by aerospace and military system industries. As a result, such research has focused on one, and occassionaly two-person control environments. NASA-Goddard's control rooms as well as process control and nuclear power control rooms are rarely single person environments; much more typically, they are multiperson, multistation control rooms wherein teamwork and coordination are serious human factors issues. The final section in chapter seven reviews a number of philosophies of management and examines some of the implications of management style on project productivity and employee morale.

Chapter eight describes a variety of tools which can be used for human factors design and evaluation. They include some fairly straightforward strategies for analyzing systems from a human factors perspective as well as more sophisticated mathematical modelling techniques. The chapter concludes with a review of more speculative engineering methodologies.

The final chapter contains a review of topics and issues which require further research. In essence, this chapter lays out the broad outlines of a research agenda of topics and user considerations which are important human factors aspects of Goddard's systems, but, at this point, do not have any clear-cut guidelines.

CHAPTER TWO

ANTHROPOMETRY

DEFINITION

Anthropometry is the quantitative study of human beings within a given population. It is an essentially empirical study of the measurable characteristics of individuals. A body of statistical data, descriptive in nature, is collected by the anthropometrist from a sample drawn from a specific population. Some populations for which anthropometric data have been collected include: astronauts, Korean foot soldiers, Air Force pilots, wheelchair-bound handicapped, and English stewardesses. The concentration of anthropometry upon specific populations puts this discipline into the category of applied sciences. The statistical distributions derived from anthropometric measurement are used in the design of products and systems to ensure that these products and systems are safe, usable, and effective when used by a specific category of people, such as aircraft pilots. European anthropometry places somewhat more emphasis on the safety and comfort of workplace products and environments, while American anthropometry tends to concentrate on fitting humans to technical systems.

SCOPE

Classic descriptive anthropometry focuses on the physical characteristics of a population. These measureable features include bodily dimensions, ratios of one body part to another, weight, volume, strength, and ranges of movement. Since World War II, especially in relation to the highly technical weapons systems, airborne systems, and the manned space programs, anthropometry has expanded to include the measurement of sensory capabilities, mental and psychological variables such as those involved in

PRECEDING PAGE BLANK NOT FILMED

PAGE 6 INTENTIONALLY BLANK

information processing, and physiological limitations. Physiological anthrometry concerns itself with acceptable environmental ranges and tolerances. Environmental contaminants, illumination, sound, temperature, and humidity are evaluated for their effects on human performance.

Anthropometry also provides dynamic as well as static measurements (functional as well as structural). Static or structural measurement is concerned with the body at rest, as it might be in standing or sitting. These measurements provide useful guidelines for the proportions and arrangements of products and their components. Dynamic or functional measurement is concerned with the body at work, as it might be in running or driving. These measurements provide useful guidelines for the procedures governing the conduct of work. For example, on an assembly line, static anthropometric measurements might guide the designer in the placement of controls, while dynamic anthropometric measurements might guide the designer in the timing and duration of rest breaks to ensure the best productivity from the line.

APPLICATIONS

Anthropometry guides us in the design of products intended to be used by people. Products designed to the capabilities and within the limitations of human beings are safer to use, more comfortable and less fatiguing, less prone to inadvertent human error and misuse, and more conducive to productivity and to successful completion of tasks. While some anthropometric considerations may be obvious—we seldom build doors that are only four feet high—others require the application of more specific knowledge. The record is filled with tragic examples of the failure to apply anthropometric guidelines, ranging from the strangulation of babies in cribs, whose bars were far enough apart to allow the infant's head to slip through but not enough so that the head could slip back, to the death

of aircrews who could not fit through the escape hatch with their parachutes on. Less dramatic perhaps is the question of illumination. We all know that a workplace must be lighted. However, few of us know intuitively the correct intensity and wavelength of illumination for specific tasks.

The application of anthrometric knowledge aids the process of human-centered design. The most widely used anthropometric data are those of physical and physiological anthropometry. These guide the designer in the development of apparel and personal items, tools and equipment, habitats and work spaces, and healthful and benign environmental conditions.

While clearly the most advantageous time for the application of anthropometry is during design and development stages, anthropometric data can also be quite useful during evaluations such as acceptance testing. Anthropometric knowledge of the user population can guide the design of such tests. Rather than a general criterion like "must be easy to open," the acceptance test can specify the fifth-percentile strength of the studied user population, i.e. that 95 percent of the population have the strength to perform the "opening" task.

Clearly, the productivity of a tool user is closely related to the efficiency of the tool, to the speed and accuracy with which work can be performed using the tool. Not only is this true from a strictly quantitative analysis, it is also true from studies of the interactions between people, their tools, and their tasks.

This part is well illustrated by a study examining the role of the tool as an intervening variable between pay and motivation, based upon Locke (1968). Two groups of students were hired to fell trees. One group was given axes whose blades had been sharpened and honed. The other group was given axes whose blades had been deliberately dulled. They were asked to cut down trees for a certain number of hours at a particular

hourly wage rate. It was observed that the group with sharp axes completed the task. On the other hand, the group with dull axes suffered rapid attrition as people quit in disgust, in spite of raises in the stipulated hourly wage.

It is a pleasure to use products which are well designed and properly engineered for human use, with their characteristics such as weight, size, and proportion matched both to the task and the user. In contrast, poorly designed products, which ignore anthropometric data, are difficult and unpleasant to use. Not only will these tools not perform efficiently, people will tend to avoid using them. Rather than submit to using a poorly designed tool, people will, if at all possible, contrive some alternative way to accomplish a given task. Rarely will the efficiency of the ad hoc approach match even that of the poorly designed tool. In the light of human behavior, products which ignore anthropometric guidance are a bad investment twice over. They are inferior in terms of technical performance; and, if they are not used, they are a dead-loss investment, creating further inefficiencies in the process of their circumvention.

This report provides guidelines for the design and operation of control rooms, specifically in the context of Goddard's mission of real time support for satellites. The products and systems supported by Goddard are reasonably complex and relatively expensive. The costs of mission failure are high. A high level of productivity must be maintained, and error must also be stringently minimized. The tools in use must be efficient products, coupling speed with accuracy in the hands of human controllers. To achieve these goals, the tools, products, and environment in which the tools and products are used must be matched to the capabilities and limitations of their users. This matching process necessitates the application of anthropometric knowledge to the design and operations of Goddard control rooms. Much of the guidance and many of the guidelines contained in this report are founded upon anthropometric data.

ORIGINAL PAGE IS
OF POOR QUALITY

RELEVANCE OF ANTHROPOMETRY TO GSFC

Control Room Design

Anthropometric data will underlie the physical geometry of the control room, the sizing and relative placement of equipment, the type and colors of displays, and the shape and functioning of tools used within the control room. Largely, it is static anthropometric data which will be used as the basis for the detailed design decisions involved in creating the physical control room package.

Control Room Operations

Anthropometric data will underlie the environmental conditions to be maintained in the control room. In addition, they will be used to design procedures, such as the timing and sequencing of activities within the control room. Largely, it is dynamic anthropometric data which will be used as the basis for the detailed design decisions in creating the environmental and operational control room package.

Communications

Anthropometric data will underlie the design of communications to be used for both internal and external information flows among human staffers.

Capabilities and Limitations

Goddard control rooms will need to be designed to take advantage of human capabilities and to compensate for or avoid human limitations. While there is little anthropometric data available for the Goddard population specifically, there is little reason to expect that Goddard populations would deviate from standard American anthropometric profiles. However, there is reason to expect, given the current use of interlocking functional teams by Goddard, that there may be significant differences among anthropometric profiles across control room teams operating in different

functional areas. Payload Operations Control Center (POCC) personnel are different from Data Operations Control (DOC) personnel. Our knowledge of these differences at this point is merely anecdotal; we do not know if there are significant statistical differences among different user populations at Goddard.

Tradeoffs

Anthropometric data can be used in evaluating the costs between the system and the human user. The provision of an interface which appears transparent to the user is usually a complex technical effort. The adequacy of personnel training is closely related to the tasks at the interface of the system to its operators or supervisors. Simplicity of the interface from the perspective of the user reduces the training requirements while increasing technical requirements laid on the system itself.

A clear example may be seen in the development of language translators and operating systems for computational machines. In the beginning, only low level machine languages were available for the programming of computers. Operating systems which automated the tasks of physically controlling the computer were not yet conceived. Consequently, the programming of a computer required highly skilled and very technically oriented personnel, typically, graduate level scientists, engineers, and mathematicians. These people were then (as now) expensive and the completion of a programming task that we now would perceive as trivial required considerable time.

Over the years, more and more complex interfaces have evolved, ranging from high level languages such as Pascal to multiple user operating systems with virtual memories. The evolution of complex technical interfaces between the user and the underlying mechanisms of the computer has brought about a marked decrease in the skill and training levels required to program and operate computational systems. Not only can high school students now perform the same tasks that formerly required scientists, but

ORIGINAL PAGE IS
OF POOR QUALITY

these tasks can be performed in a much shorter time and with greater reliability.

To the extent that anthropometric data have less influence on the design of products, the more circumscribed will be the pool of personnel who can be trained to use those products and the more involved their training must be. Conversely, the greater the influence of anthropometric data on design, the larger the pool of personnel who can be trained and the less involved the required training. (Parenthetically, these relationships illustrate how good design can serve social agendas within the larger society, such as equal opportunity employment and affirmative action.)

ANTHROPOMETRIC DATA

A large bank of anthropometric data has been compiled by NASA in support of the manned space program. The three-volume set, Anthropometric Source Book, prepared for NASA by Webb Associates (1978), is divided into Anthropometry for Designers, A Handbook Of Anthropometric Data, and an Annotated Bibliography of Anthropometry. This set is probably the most comprehensive source of anthropometric data available at this time.

This three volume publication brings together a large mass of anthropometric data which define the physical size, mass distribution properties, and dynamic capabilities of United States and selected foreign adult populations. While it is aimed specifically to meet the needs of design engineers engaged in the design and manufacture of clothing, equipment, and workspaces for the NASA Space Shuttle Program, the series is designed to be of use to human engineers in a wide variety of fields. It is not only a comprehensive source of specific anthropometric data, but also a guide to the effective application of such data. Subjects covered under Anthropometry for Designers include physical changes in the zero environment, variability in body size, mass distribution

properties of the human body, arm and leg reach, joint motion, strength, sizing and design of clothing and workspaces, and statistical guidelines. The first volume includes 1985 body size projections and manikin cutouts. Volume II, A Handbook of Anthropometric Data, contains data from surveys of military and civilian populations of both sexes from the United States, Europe, and Asia. Some 295 measured anthropometric variables are defined and illustrated. The last volume, the Annotated Bibliography of Anthropom..., covers a broad spectrum of topics relevant to applied physical anthropology with emphasis on anthropometry and its applications in sizing and design.

Another extremely useful anthropometric data source and tool is the Humanscale series developed by Diffrient, Tilley and Bardagjy (1981). Humanscale is a set of heavy plastic cards containing data dials and accompanying explanatory brochures. Each Humanscale card is concerned with a different facet of human factors data, including basic anthropometric d... These include body measurements, link measurements, seating guides, seat-to-...ble guides, geometries of wheelchair users, special data on the elderly and the handicapped, safety assurance, human strength, hand and foot controls, displays, workspaces, body access, and light and color. Humanscale is a marvelous and compact reference.

These data, of course, are not specific to user populations to be found at Goddard or to Goddard's specific tasks. While there is little reason to suspect that Goddard personnel will differ greatly from more general populations in the United States, this absence of statistically significant difference remains to be verified or confirmed. Additionally, since anthropometric data are gathered with reference to some task environment, within which the data will be applied, the comparability of tasks at Goddard will also need to be confirmed in relation to general anthropometric findings.

Later in this report, under Mockups, general recommendations are presented to conduct such anthropometric studies at NASA-Goddard.

DESIGN RULES

While in general the application of anthropometric data is generally design specific, some rules are universally valid in the application of anthropometric data to any design.

The "Average Man" Fallacy

The statistically average man (or woman) does not exist. This is why off-the-rack suits must always be tailored. Ready-to-wear clothing is designed for an "average" person, but none of us is average, at the mean, in all our relevant dimensions. If we relax the average or the mean to encompass a small range on either side of the expected value, say five percent, the fact that bodily dimensions are only weakly covariant leads to the observation that the size of the population which is average along all of n dimensions is .05 raised to the nth power. Thus, retaining the example of the off-the-rack suit, consider that the relevant dimensions are torso length, shoulder width, torso circumference, and arm length, for a total of only four dimensions. In this example, then, there will only be .05 to the fourth, or .00000625 percent of the population fitted exactly be the "average" suit coat.

The Fifth and Ninety-fifth Percentile Specifications

Van Cott and Kinkade (1972) note that:

> the 'average man' fallacy is equally unfit for muscle strength and other biomechanical data. For example, in the design of an ejection seat, if trigger force requirements were set to the strength capabilities of the average or 50th-percentile pilot, the weaker 50 percent of pilots would be unable to escape.

These remarks lead us to the "MinMax" anthropometric design rules:

1) Any minimum dimension should be set to the maximum percentile.

2) Any maximum dimension should be set to the minimum percentile.

ORIGINAL PAGE IS
OF POOR QUALITY

Anthropometric data are typically stated in terms of cumulative percentiles. As anthropometry is an applied science with practical applications, distributional statistic data are seldom presented. Designers need to know the maximum and mimimum to design for within the target population. Because it is seldom practical to design a product for those on the extreme tails of a distribution, anthropometric data tend to ignore the tails of measurement distributions. Rather, the data are truncated and reported at some lower and at some higher percentile, typically the fifth and the ninety-fifth percentiles. Between these two percentiles will fall 90 percent of the studied population, a sufficient audience for most products.

Typically, within various cost tradeoffs, a product will be specified for an acceptable percentage of the studied population, centered around the fiftieth percentile. However, we have seen that the "average man" fallacy may lead us into potentially disastrous designs. The "MinMax" rules tell the designer how to apply the anthropometric data to sizing questions. If, for example, we employ the standard fifth and ninety-fifth percentile limits, the "MinMax" rules guide us in the following ways.

Having established that anyone falling within the fifth to ninety-fifth percentiles should be able to use the product safely and efficiently, the designer will use the anthropometric data for the ninety-fifth percentile to determine any minimum dimensions. Conversely, the designer will use the anthropometric data for the fifth percentile to determine any maximum dimension. For example, an access hatch should be designed so that a ninety-fifth percentile man will fit through the hatch. This ensures that ninety-five percent of the male population and virtually all of the female population will be able to fit through the hatch. On the other hand, a pressure operated control should be designed so that a fifth percentile woman can apply pressure sufficient to activate the control. This ensures that ninety-five percent of the female population and

virtually all of the male population will be able to activate the control.

In general, the quality of product design must be empirically demonstrated. Thus, guidance is given both by NASA and by Department of Defense (DOD) standards that products should be experimentally validated using mockups. Experimentation has two distinct but complementary functions in anthropometric product evaluation. On the one hand, a product of a design effort is tested to verify that it satisfies anthropometrically-derived performance criteria, i.e., that the intended users can actually use the product in the way that has been intended. On the other hand, the testing effort is used to gather further data that can be fed back into the current and future design processes. For these reasons, anthropometrically-based testing should begin early in the design process, long before the first hard prototype is produced. So that testing can commence early-on, mockups are used. Mockups are deliberately temporary, implemented to model the essential characteristics of a design. They are constructed so that no great or fixed investment is involved; having served their purpose, they may be discarded or recycled. As the design becomes increasingly firm, incorporating knowledge gained from earlier mockups, successive mockups may become more and more involved and lifelike. In the end, the mockup may actually possess all the characteristics of a prototype. In some cases, the mockup may pass out of the experimental laboratory into the training environment where it is used as a simulator.

ANTHROPOMETRY: SPECIAL TOPIC—STANDARDIZATION VERSUS EFFICIENCY

It serves this discussion to claim that the search for efficiency is a search for cost minimization in the short run, while standardization is a search for cost minimization in the long run. From an anthropometric standpoint, the most efficient tool is that which is designed for a specific user. Similarly, from this standpoint, the most standardized tool

is that which is designed for the greatest number of users.

These claims exemplify the more general debate between the utility of general purpose and specific purpose products. Clearly, the product designed for a specific purpose is most efficient at the task for which it was designed; the general purpose product is less efficient for any given task but can be applied to more than one task.

Unfortunately, the temporal aspects of this tradeoff have been largely ignored. Tasks succeed previous tasks, and users succeed previous users. The tool optimized for a specific task in the hands of a specific user can be justified only in terms of a short-range optimization. The product specific to a given user and a given task possesses little adaptability. As soon as the task and/or the user changes or is changed in any way, the optimization is lost. Within this design approach, succeeding tasks and/or users require new investments in optimized products. The product which previously optimized the user/task relationships becomes rapidly obsolescent, in short, a dead weight loss. The alternative is to continue to employ the product even though it is no longer optimized.

The argument here is that investment in specialized or task/user optimized products captures capital in a fixed form which inevitably is rendered obsolete. The capital thus frozen is incapable of being changed into a new form more adapted to the current task/user environment. Its costs cannot be amortized over more than one specific usage period.

Of course, products wear out over time. The classic argument has been that, since both special purpose and general purpose products have the same life expectancy, the extra cost of specialization is outweighed by the extra revenue generated by the efficiency of the product. This argument does not prevail, however, when the task/user environment alters within the lifetime of the product. In turbulent environments, this is actually to be expected, especially in high technology product areas. In other words, the

classic arguments for specialization, based upon a useful life which is less than the period taken to render the product obsolescent, are not valid in a number of high technology areas. The rate of change renders a product obsolete before its useful life has ended. In this case, to prevent the investment from being lost, the product must be designed to be able to adapt or adjust through technical stages, to be reconfigured. This requires a product which is general purpose rather than specially optimized. While performance will be reduced during one phase or technical stage, the entire investment need not be written off in subsequent stages.

With some reflection, it should be clear that these tenets are fundamental to philosophies of modular design. As a superior technical product becomes available, it can be used to upgrade a module of a total product without necessitating the rebuilding of the entire product. In commercial hardware and software design, it has also been recognized that modular construction also decreases repair and maintenance down-time and costs.

These same observations apply to the integration of user and machine on the basis of anthropometric data. Equipment optimized for a particular user population is of little residual use when the characteristics of the user population change. It is for this reason that we seldom use custom tailors to provide clothing for our growing children.

The current manned space program provides uniquely tailored suits for astronauts. As the population of people travelling into space increases and turnover in that population grows, this practice is one that will be rapidly discarded in favor of off-the-rack suits which can be reused by other or subsequent travellers.

These same rationales apply to control room products designed for Goddard use. This argument suggests that these products should be designed for the widest anthropometric utility, so that the widest class of users can appropriately and

ORIGINAL PAGE IS
OF POOR QUALITY

productively work with these products.

An example of this approach is in the packaging and siting of CRT displays. It has been traditional at Goddard to provide CRT displays as built-in components in rack-mounted configurations. This practice optimizes the interface between the CRT user and the CRT to a very narrow range. In contrast, anthropometric data would suggest that CRT devices be independently mounted on stands which are adjustable in several dimensions.

REFERENCES

Diffrient, N.A., Tilley, A.R., & Bardagjy, J.C. Humanscale 1/2/3, 4/5/6, 7/8/9. Cambridge, MA: The MIT Press, 1981.

Locke, E.A. Toward a theory of task motivation and incentives. Organizational Behavior and Human Performance, Vol. 3, 1968.

Van Cott, H.P., & Kinkade, R.G., Eds., Human Engineering Guide to Equipment Design. New York, NY: McGraw-Hill Co., 1972.

Webb Associates. Anthropometric Source Book, Volume I; Anthropometry for Designers, NASA Reference Publication 1024. Houston, TX: NASA/Johnson Space Center, July 1978.

Webb Associates. Anthropometric Source Book, Volume II; Anthropometry for Designers, NASA Reference Publication 1024. Houston, TX: NASA/Johnson Space Center, July 1978.

Webb Associates. Anthropometric Source Book, Volume III: Annotated Bibliography of Anthropometry. NASA Reference Publication 1024. Houston, TX: NASA/Johnson Space Center, July 1978.

CHAPTER THREE

ENVIRONMENTAL ISSUES

The human factors literature contains many documents specifically pertaining to environmental issues and corresponding design guidelines. Many appear agency specific; but, upon closer examination, they provide a wealth of information that generalizes to command and control environments. This chapter reports the established environmental concerns, suggests some new ones, provides source documentation, and fosters recognition of the importance of environmental issues in design.

GOALS OF ENVIRONMENTAL DESIGN

The purposes of considering the environment of a work area when designing the area are to ensure optimal working conditions and to achieve several goals. Bailey (1982) suggests four important goals of environmental design.

Performance Support

Work environments should support the user in his/her task performance. Basic safety needs (e.g., lighting, ventilation) as well as minimal workspace requirements must be met. Equipment must be designed to complement both the task-and-user and the surrounding environment. Equipment should also enhance the environment rather than detract from it, i.e., be available when necessary and not cause clutter. The user's psychological state affects performance and should be positively influenced by the environment.

Organization Support

The environmental design of a work area should support the organizational image and reinforce a sense of importance and membership in the user. Designers should be

aware of this and take steps to create an environment that projects a positive organizational image.

Normal Environments

Designs should support the existence of normal environmental conditions. Critical conditions such as temperature levels and air quality must be maintained within normal ranges and should not vary greatly over work shifts.

Assisting Learning

The fourth goal of environmental design is to assist the user in learning about the work area and the required tasks. Readily available documentation, clear, concise labeling, and facilitation of communication lead to achievement of this goal.

PHYSICAL ENVIRONMENT

Environmental factors of a work area can enhance or degrade the performance of the human/machine interface. Designers focus on physical environmental factors often to the exclusion of social environmental factors. However, social factors are important, and help to ensure safe, comfortable working conditions.

Temperature

The consensus regarding environmental temperature is that comfortable levels can be and should be maintained within a work area.

Heat and Performance. The experimental results on the effects of heat on performance are mixed. Bailey (1982) reports that heat levels of 90 degrees F can enhance performance for some tasks while degrading it for others. He suggests that, while the effects of heat differ from individual to individual and are task dependent, they nevertheless exist and must be compensated for by environmental design. Figure 3-1 suggests some recommended exposure times to heat.

Cold and Performance. The effects of cold temperatures on work performance have not been studied as extensively as those of heat. Individual differences in response to cold interact with differing task activity levels to produce a range of effects. Where colder environments are mandatory, designers should consider protective clothing, select out personnel who are unable to tolerate the temperatures, allow sufficient time for worker adaptation, and ensure reasonable activity schedules (Bailey, 1982).

Recommended Temperature Levels. The Department of Defense (1981) and the U.S. Nuclear Regulatory Commission (1981), along with other agencies and institutions, recommend the following guidelines for work environment temperatures:

- The heating levels should not fall below 65 degrees F.
- The air conditioning levels should not exceed 85 degrees F.
- Cold or hot air should not discharge directly onto personnel.
- Temperatures at floor level and at head level should not differ by more than 10 degrees F.

Air Quality

Another important physical environmental factor is air quality. Basic safety needs must be met under all circumstances. Comfort should also be provided for performance benefits and to reduce the likelihood of fatigue and stress.

Humidity Levels. Humidity and temperature levels interact to affect the air quality of a work area. MIL-STD-1472C (1981) and NUREG-0700 (1981) recommend that:

- Relative humidity levels should range from 45% to 50% when the temperature is 70 degrees F.
- As temperatures rise, humidity levels should decrease relatively. However, to ensure physical comfort, they should not fall below 15%.
- Humidity levels should not vary greatly over work shifts.

Figure 3-2 illustrates the comfort zone for humans as a function of humidity and temperature.

Ventilation. Proper ventilation reduces the likelihood of fatigue and provides a healthy work environment. MIL-STD-1472C (1981) recommends that:

- A minimum of 30 cubic feet of air per minute, per person, should be introduced to the work area.
- The intakes for ventilation systems should not be located near contaminated air sources (e.g., exhaust pipes).

NUREG-0700 (1981) suggests the air velocity of ventilation systems be considered. It recommends that:

- Air velocities should not exceed 45 feet per minute measured from head level.
- Noticeable drafts should not be present.

Illumination

In order for workers to best perform their tasks, they must be able to see adequately. Sufficient light must be provided, dependent upon the task being performed. Adjustable illumination levels should be available to the worker since individual needs vary for optimal performance (Bailey, 1982).

Recommended Levels. Figure 3-3 gives some recommended illumination levels relative to the task being performed. Farrell and Booth (1975), MIL-STD-1472C (1981), and NUREG-0700 (1981) all suggest the following guidelines for work area illumination:

- To reduce chance for worker eyestrain, fatigue, and reading errors, the level of illumination should not vary greatly over the work area.
- Supplemental lighting should be available if needed.
- Indirect or diffuse lighting should be used to prevent shadows.

ORIGINAL PAGE IS
OF POOR QUALITY

RECOMMENDED EXPOSURE TIME TO HEAT AS
A FUNCTION OF ACTIVITY AND TEMPERATURE

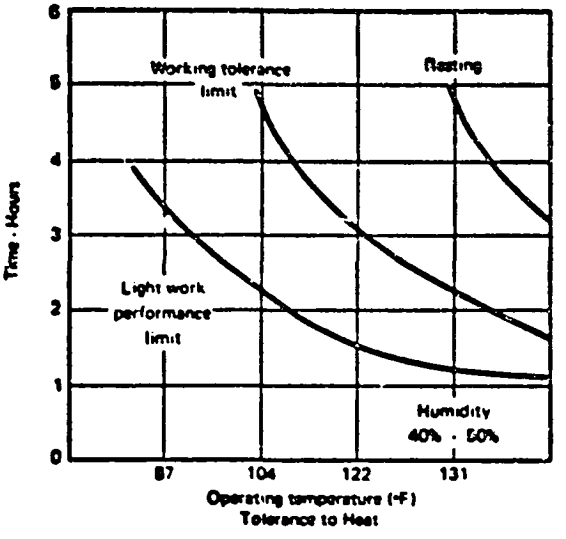


Figure 3-1, Bailey, p. 499, 1982.

COMFORT ZONE AS A FUNCTION OF RELATIVE
HUMIDITY VS. TEMPERATURE

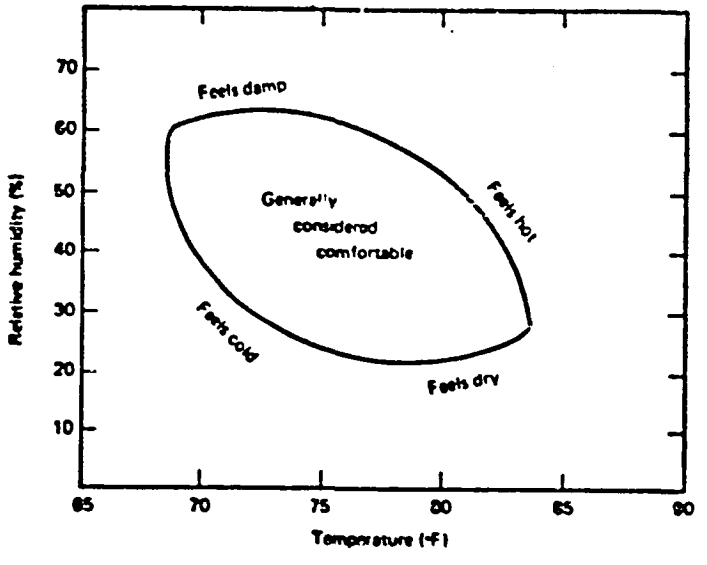


Figure 3-2, Bailey, p. 500, 1982.

Glare. An illumination related problem especially evident in work areas using video display terminals (VDTs) is glare. It increases the possibility for reading errors and encourages eyestrain. Therefore, designers should seek to eliminate both direct glare, i.e., glare due to actual light sources and reflected glare, i.e., glare from illuminated surfaces. Cakir, Hart and Stewart (1980) and Farrell and Booth (1975) suggest using indirect or diffuse lighting, eliminating distracting contrasts in work areas, and adjusting the VDT screen or covering it with a filter to eliminate glare.

Noise

Another important design issue involves auditory noise levels within work environments. Noise can be detrimental to the worker's performance, irritating, fatiguing, and unsafe if loud enough. Acceptable levels of background noise for effective communication are dependent upon the speaking voice being used and the distance between speaker and listener. Some reports even indicate that a complete absence of noise can be detrimental to worker performance (Bailey, 1982).

Effects on Communication. Figure 3-4 illustrates the effect of background noise on communication. As shown, effective communication rapidly becomes difficult as noise levels increase. Excess noise can be distracting and can lead to critical misunderstandings.

Effects on Safety. Noise can be detrimental to the worker's physiological well-being. Loud, low frequency noises produce the most serious hearing impairments, while high frequency noises are most annoying, and intermediate frequency noises interfere most in speech intelligibility (Bailey, 1982).

Recommended Levels. MIL-STD-1472C (1981) and NUREG-0700 (1981) state the following guidelines for noise levels in work environments:

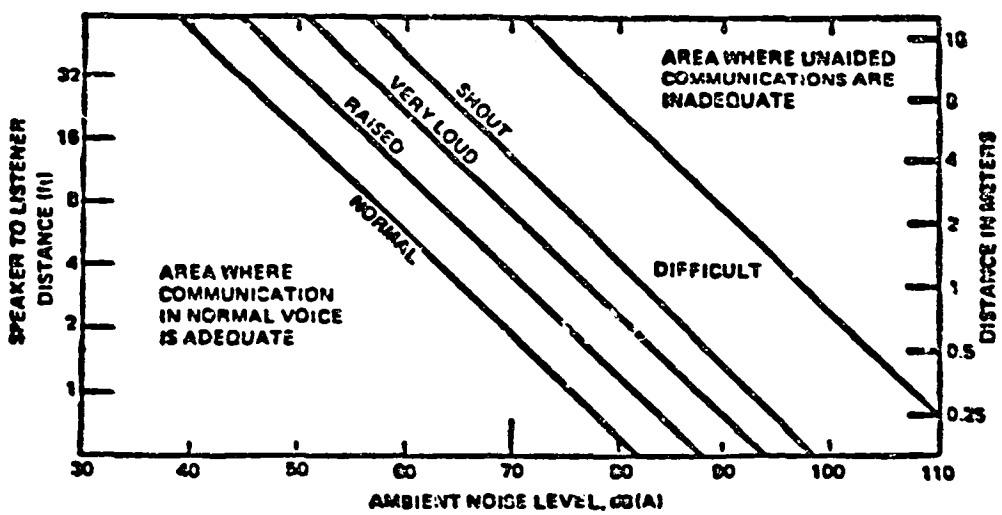
ORIGINAL PAGE IS
OF POOR QUALITY

RECOMMENDED ILLUMINATION LEVELS IN FOOTCANDLES

Work Area or Type of Task	Task Illuminance, footcandles		
	Minimum	Recommended	Maximum
Panels, primary operating area	20	30	50
Auxiliary panels	20	30	50
Scale indicator reading	20	30	50
Seated operator stations	50	75	100
Reading			
• Handwritten (pencil)	50	75	100
• Printed or typed	20	30	50
Writing and data recording	50	75	100
Maintenance and wiring areas	20	30	50
Emergency operating lighting	10	As above for area/task	

(Source: Illuminating Engineering Society of North America, *IES Lighting Handbook*, 1981 Application Volume.)

Figure 3-3. NUREG-0700, p. 6.1-46, 1981.



Voice level as a function of distance between speaker and listener and ambient noise level.

Figure 3-4, NUREG-0700, p. 6.1-50, 1981.

ORIGINAL PAGE IS
OF POOR QUALITY

- Background noise levels should not exceed 65 decibels.
- Noise distractions should be minimized.
- Acoustical materials should be used to limit reverberation time to one second or less.

Maneuvering Space

The physical environment should be spacious enough to allow workers to move around comfortably while performing tasks and undertaking routine maintenance. NUREG-0700 (1981) suggests the following:

- A minimum of 50 inches should separate the front edge of one equipment row and the back of the next.
- Each worker at a workstation should have a maneuvering space 30 inches wide and 36 inches deep, minimum.
- When two rows of equipment face one another with more than one individual working between, a minimum 8 foot separation is necessary.

Vibration

Both body and equipment vibration should be controlled for optimal task performance. MIL-STD-1472C (1981) suggests vibration levels acceptable for safety, proficiency, and comfort. Figure 3-5 provides the base values for the following guidelines:

- For safety, vibration levels should not exceed twice the acceleration values listed.
- For proficiency, vibration levels should not exceed the listed acceleration values.
- For comfort, acceptable vibration levels are determined by dividing the listed acceleration values by 3.15.

Ambience

An often neglected physical environmental factor is one which interacts with the social environment. The ambience of a work area affects the psychological state of the

ORIGINAL PAGE IS
OF POOR QUALITY

VIBRATION EXPOSURE CRITERIA FOR LONGITUDINAL (UPPER CURVE) AND TRANSVERSE (LOWER CURVE) DIRECTIONS WITH RESPECT TO BODY AXIS

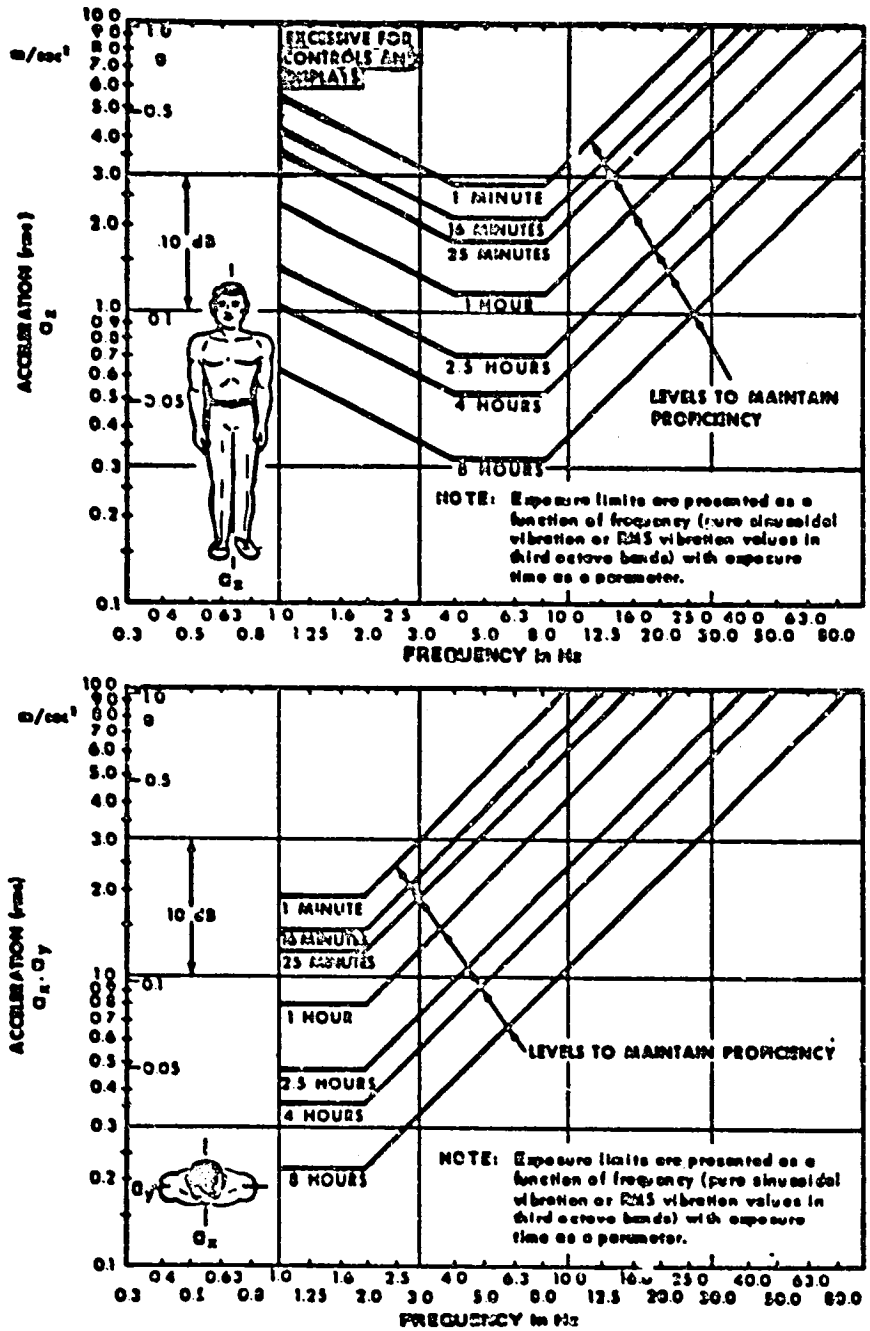


Figure 3-5, MIL-STD-1472C, p. 175, 1981.

ORIGINAL PAGE IS
OF POOR QUALITY

worker (Seminara, Gonzalez, & Parsons, 1977) and, in turn, influences his/her performance. Most existing guidelines do not address this issue clearly but do make several suggestions. NUERG-0700 (1981); Seminara, Eckert and Seidenstein (1979, 1980); Seminara, et al. (1977); and Seminara and Parsons (1979) suggest the following:

- The surrounding atmosphere should be visually pleasing; colors should be coordinated and cheerful, and visual relief from banks of instrumentation should be provided.
- The environment should look and smell clean.
- The user's needs and comfort should be provided for, e.g., restroom and eating facilities are necessary.

SOCIAL PSYCHOLOGICAL ENVIRONMENT

As suggested by Bailey (1982), any work environment is made up of two components: the physical and the social psychological. Physical aspects are concrete and easily lend themselves to a guideline format. The comparatively abstract social psychological factors are not always considered in design because of the inherent difficulty in quantifying them. Thus, they are difficult to place in guideline format. What follows are design considerations pertaining to the social psychological environment of work areas.

Shiftwork

The continuous staffing of most command and control rooms necessitates shiftwork. That the ramifications of this necessity are often not considered by the designer at all is a mistake since much research indicates stress generated by shiftwork can both directly and indirectly affect the worker's performance (Colquhoun & Rutenfranz, 1980). The effects of shiftwork should be understood by designers to benefit both the individual and task performance.

Physical Effects. The human body physically operates on a fixed twenty four hour schedule known as a circadian rhythm. Shiftwork interrupts this established pattern by changing eating, sleeping, and activity habits. The effect shiftwork has on physical variables such as body temperature and excretion of adrenaline and nor-adrenaline is called "re-entrainment." This process of adaptation to a new circadian rhythm is a slow and incomplete one because it is unnatural for the body to be operating in different rhythms. Sleep deprivation and inadequate digestive functions can result. In turn, the individual's health, psychological well being, and work performance can suffer.

Effects on Performance. Research indicates that the major effect shiftwork has on performance is a decline in alertness during night time hours (Colquhoun & Rutenfranz, 1980). Amount of sleep appears to interact with the type of tasks being performed in determining alertness during shifts. For command and control environments, these research findings suggest the need for a complete evaluation of task demands, careful time allocation of tasks between shifts, and a shift design that facilitates adequate sleep patterns.

Effects on Health. Mixed results have been obtained in experimental studies on health effects of shiftwork. Some report greater incidence of sickness for shiftworkers (Akerstedt & Torsvall, 1978; Angersbach et al., 1980; Koller, Kundi, & Cervinka, 1978), while others indicate no differences in health between shiftworkers and dayworkers (Taylor, 1967; Taylor & Pocock, 1972). Colquhoun and Rutenfranz (1980) distinguish between degrees of sickness reported due to shiftwork: actual physical disease and "psychosomatic" complaints. However, the existence of either type has negative effects on the individual and task performance.

Psycho-Social Effects. The psycho-social effects of shiftwork are difficult to quantify because they are individual and personal, but anyone who has worked different

shift schedules will attest to the importance of these effects. The small amount of experimental research done on this topic indicates that dislike of shiftwork is associated with reports of health effects and interruptions in social activities (Wedderburn, 1967). The same study also reports higher job satisfaction for those who like shift work and the one positive aspect of shiftwork, more time off and/or temporal flexibility. Banks (1956), in a study of wives of shiftworkers, found the most frequent complaint was the interruption of weekend activities. The social and interpersonal effects of shiftwork appear stressful, but more experimental work on the topic must be done before any firm conclusions are drawn.

Design of Shiftwork. There are several disadvantages associated with shiftwork as evidenced in the literature. However, since its necessity is irrefutable, a compromise must be reached. Shift systems should be designed to minimize the negative effects of shiftwork. Knauth, Rohmert, & Rutenfranz (1979) suggest the following criteria for shiftwork design:

- For strenuous tasks, shifts longer than 8 hours must be avoided; for monitoring tasks, 12 hour shifts are the limit.
- The number of consecutive night shifts must be limited; preferably only single night shifts should be interspersed in the shift plan.
- Each night shift must be followed by 24 hours of free time.
- Each shift plan should contain full weekends with at least two consecutive free shifts.
- The number of free days per year for night shift workers should be at least as large as for constant day shift workers.

Presence of Others

The social psychological work environment involves groups of people as well as individuals. Psychological theories pertaining to group processes and effects abound.

The documented "social facilitation effect," also known as the Hawthorne effect, illustrates how the presence of others increases arousal and performance. This effect levels off over time unless new variables are introduced into the social environment. Designers should be wary of placing individuals in continuously isolated situations; social interaction should be facilitated to increase its potentially positive effects.

Personal Space and Privacy

Social psychological research also suggests that human beings have a need for personal space and privacy as well as interaction with others. Too much open space in a work environment or the opposite, crowded conditions, leads to discontent with the layout. Workers should be provided adequate space to call their own, ensuring optimal satisfaction and performance.

Role Definition

Any work environment should facilitate optimal performance and worker satisfaction. Another important aspect of the psychological environment is sufficient role definition for the individual. The worker benefits from a sense of integration, a notion of fitting into the scheme of things. Verbal job and role explanations as well as examples given by management at all levels also help. These actions foster a sense of responsibility in individuals. If workers understand what they are doing beyond a superficial level and why they are doing it, better performance often results.

FURTHER RESEARCH

Currently, there are many environmental issues not fully understood that could benefit from further research. Little is known about the social and psychological effects of shiftwork. Shiftwork design for optimal task and personal schedules is not always considered. More experimental research on the effects of different schedules is

necessary to determine those optimal schedules. The effects of hot and cold temperatures on performance are not clear, also calling for more experimentation.

REFERENCES

Akerstedt, T., & Torsvall, L. Experimental Changes in Shift Schedules - Their Effects on Wellbeing. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Angersbach, D., Knauth, P., Loskant, H., Karvonen, M.J., Undeutsch, K., & Rutenfranz, J. A Retrospective Cohort Study Comparing Complaints and Diseases in Day and Shift Workers. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Bailey, R.W. Human Performance Engineering: A Guide for System Designers. Englewood Cliffs, NJ: Prentice Hall, 1982.

Banks, O. Continuous Shift Work: the Attitudes of Wives. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Cakir, A., Hart, D.J., & Stewart, T.F.M. Visual Display Terminals. New York, NY: John Wiley & Sons, 1980.

Colquhoun, W.P., & Rutenfranz, J. (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: Department of Defense, May 1981, MIL-STD-1472C.

Farrell, R.J., & Booth, J.M. Design Handbook for Imagery Interpretation Equipment. Seattle, WA: Boeing Aerospace Co., Dec. 1975.

Koller, M., Kundi, M., & Cervinka, R. Field Studies at an Austrian Oil Refinery. I: Health and Psychological Wellbeing of Workers Who Drop Out of Shiftwork. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Krauth, P., Rohmert, W., & Rutenfranz, J. Systematic Selection of Shift Plans for Continuous Production with the Aid of Work-Physiological Criteria. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Nuclear Regulatory Commission. Guidelines for Control Room Design Reviews. Washington, D.C.: Nuclear Regulatory Commission, Sept. 1981, NUREG-0700.

Seminara, J.L., Eckert, S.K., & Seidenstein, S. Human Factors Methods for Conventional Control Board Design. Palo Alto, CA: Electric Power Research Institute, Feb. 1980, EPRI NP-1118, Project 501-3.

Seminara, J.L., Eckert, S.K., & Seidenstein, S. Human Factors Methods for Nuclear Control Room Design. Vol. 1: Human Factors Enhancement of Existing Nuclear Control Rooms. Palo Alto, CA: Electric Power Research Institute, Nov. 1979, EPRI NP-1118, Project 501-3.

Seminara, J.L., Gonzalez, W.R., & Parsons, S.O. Human Factors Review of Nuclear Power Plant Control Room Design. Palo Alto, CA: Electric Power Research Institute, 1977, EPRI NP-309, Project 501.

Seminara, J.L., & Parsons, S.O. Human Factors Methods for Nuclear Control Room Design. Vol. 2: Human Factors Survey of Control Room Design Practices. Palo Alto, CA: Electric Power Research Institute, Nov. 1979, EPRI NP-1118, Project 501-3.

Taylor, P.J. Shift and Day Work: A Comparison of Sickness, Absence, Lateness and Other Absence Behavior at an Oil Refinery from 1962 - 1965. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Taylor, P.J., & Pocock, S.J. Mortality of Shift and Day Workers 1956 - 1968. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

Wedderburn, A.A.I. Social Factors in Satisfaction With Swiftly Rotating Shifts. In W.P. Colquhoun & J. Rutenfranz (Eds.). Studies of Shiftwork. London: Taylor and Francis, Ltd., 1980.

CHAPTER FOUR

WORKSTATION DESIGN

The anthropometric data and environmental guidelines provided in the two previous chapters form the foundation of many considerations within this chapter. Ergonomic aspects of workstation design and the corresponding guidelines are well documented within the human factors literature. Several source documents exist, and it is important for the system designer to be aware of their contents. This chapter presents workstation design issues and guidelines pertinent to the command and control environment at NASA-Goddard.

PRE-DESIGN CONSIDERATIONS

Before implementing any workstation design, system planners must have a thorough understanding of all components within the work area.

Review Documentation

The first step in the design process is to review all documentation specifically pertaining to whatever task the workstation is being designed for. A complete understanding of the task at hand will necessarily make the resulting workstation more effective. Functional requirements documents are good sources of task information and should be reviewed. Knowledge of all required tasks and their functions is important because designers are often responsible for planning several different workstations, and each should be individually tailored to the task. Documentation reviews help provide that necessary, specific understanding.

Hardware

The hardware, or equipment and physical facilities, comprises another workstation component. The capabilities and limitations of each piece of hardware are under

PRECEDING PAGE BLANK NOT FILMED

consideration for inclusion in the workstation must be clearly understood by the designer. Many pieces of equipment are task required (e.g., VDTs for monitoring tasks), and the designer must complement these pieces with a choice of other equipment that provides an integrated workstation (e.g., consoles and chairs for VDT monitoring tasks). Again, reviewing functional requirements documentation helps; vendor documentation and past user observations will also give the designer hardware knowledge. Thorough understanding of hardware limits and capabilities leads to better, more efficient workstations.

User Population

The other component designers must consider may be the most important. Workstations must be designed so that humans can use them and use them effectively. User population statistics, the basis of anthropometric data, should always be considered when planning workstations. Physical design should accomodate extremes, the 5th and 95th percentile user. In some situations it is necessary to have specific user population measurements for design purposes (e.g., manned spacecraft workstations), while in others existing general user population statistics are acceptable (e.g., data entry workstations). Designers should also be aware of physiological and psychological aspects of users. Human visual and auditory abilities should be recognized, as well as information processing capabilities and limitations. These considerations decrease the likelihood of fatigue, stress, and error and are most effective when part of the pre-design effort.

PHYSICAL LAYOUT

A successful workstation design (i.e. one that is easy to use and efficient) greatly depends upon the physical arrangement of all components. Existing guidelines tend to

focus on single person workstations, and the following guidelines have the same focus. Little experimental work has been done concerning multiperson workstations, but several related conceptual issues have been identified. A section of Chapter Seven in this document deals with these conceptual issues.

The guidelines presented here concerning physical layout are drawn from the following documents: McCormick (1976), MIL-STD-1472C (1981), NUREG-0700 (1981), Seminara, Eckert and Seidenstein (1979, 1980), and Van Cott and Kinkade (1972).

Accessibility

All equipment, displays, and controls should be easily accessible. Emergency or warning components should be located with direct access. The physical layout should also provide for maintenance access.

Coverage

The physical layout of equipment should facilitate and be consistent with staffing levels. If workstations are staffed by one or two persons, the critical operations controls and displays should not be spread out over a large area. The converse is also true; if large crews staff a workstation, adequate physical space for operations should be provided by the layout.

Furniture and Equipment

Furniture and equipment layout should facilitate ease and efficiency of use for the worker and the task. Several considerations are necessary for arranging furniture and equipment.

Visual Access. Workers need to view all critical task components easily and not have to physically strain to see them. This necessity implies size and distance considerations based upon specific user and task demands.

Communication Access. Workers should be able to communicate easily with others in the workstation. Excess noise should be avoided as should communication "barriers" created by equipment location.

Circulation. Flow of communication and physical movement should be facilitated, implying integrated and uncluttered workstation layouts. Both physical and verbal interference between users should be avoided.

Maneuvering Space. Users must have adequate space for moving in and out of the workstation. NUREG-0700 (1981) recommends,

- There should be a 36 inch minimum between the back of the workstation and any opposing surface.
- Users should have a lateral space of at least 30 inches.

In both cases, if more space is available, increased seperation is preferred. NUREG-0700 (1981) also makes some recommendations for equipment-to-opposing-surface distance.

- A minimum of 50 inches is necessary to separate the front edge of equipment rows from opposing surfaces when only one person attends the equipment.
- When more than one person attends a row of equipment, at least 8 feet must separate that row from another opposing surface.

Peripheral Concerns

Workstation designers should consider peripheral layout concerns as well as major, obvious ones. These concerns are often overlooked, yet they are important for a complete human factors approach to physical layout.

Documents. Documents necessary for reference purposes should be located within easy reach of the user. They should be clearly labeled and movable. Also, they should be easy to use, of a standard size that is not awkward to handle, in good condition, and bound so as to lie flat when opened.

Supervisor Access and Communications. The supervisor should be located with direct access and communication to the workstation, if not centrally located within it.

Other Personnel Access. Access to workstations for non-related personnel should be limited for security and task purposes, but available for emergencies and daily personnel interaction. A balance should be struck between the two, dependent upon the situation.

EQUIPMENT DESIGN

As stated earlier, one major component of a workstation is the equipment or hardware. There are several equipment dimensions for the designer's consideration, and the diversity of work environments necessitates a wide realm of choice. Goddard's command and control rooms consist mainly of control consoles with VDTs and seating. The following guidelines focus on console and chair design. Workstation planners should also be aware of existing guidelines for other types of equipment (e.g., desk dimensions and VDT data entry terminals).

Console Dimensions

It is assumed that workstation users are engaged in either seated, standing, or sit-stand operations. Console dimensions differ accordingly.

Standing Operations. Guidelines pertaining to console dimensions for standing operations found in MIL-STD-1472C (1981) and NUREG-0700 (1981), are summarized below:

- If the operator needs to see over the workstation console, the maximum height to accomodate the shortest user is 58 inches.
- The control height is determined by the functional reach radius of the operator, 25-35 inches for the 5th percentile female and 95th percentile male, respectively.

- Controls should be set back from the console edge a minimum of 3 inches to prevent accidental activation, and not more than 25 inches, ensuring reach by the shortest user.
- When other work surfaces are required, it is recommended they be 38 inches from the floor.
- Acceptable display height is between 41 and 70 inches above the standing surface.
- A kick space, 4 inches deep and 4 inches high, is recommended, allowing the user to get close to the console without leaning.

Seated Operations. The seated operator is typically found in NASA-Goddard's control rooms; this position is best suited for the requisite tasks as research shows the seated position is superior to a standing one in terms of fatigue. It appears that the arms can perform light work much longer when the operator is seated than when he/she is standing. Cakir, Hart and Stewart (1980), Farrell and Booth (1975), MIL-H-46855B (1979), MIL-STD-1472C (1981), NASA RP 1024 (1978), NUREG-0700 (1981), and Seminara, Eckert and Seidenstein (1980) suggest the following workstation design guidelines for the seated operator:

- If the operator needs to see over the workstation console, the maximum height to accomodate the shortest user is 45 inches.
- Control height should be within the functional reach of the 5th and 95th percentile user, a range of 8-34 inches above the sitting surface is suggested.
- Controls should be set back from the console edge a minimum of 3 inches, to prevent accidental activation, and not further than 25 inches, ensuring reach by the 5th percentile user.
- Acceptable display height is between 6 and 46 inches above the sitting surface.

- The optimal distance for viewing displays, especially VDT displays, is 20 inches.

- The console controls should be laterally spread within the functional reach of the operator, between 25 and 35 inches.

- When writing surfaces are required for the console, it is recommended they be a minimum of 16 inches deep, 24 inches wide, and 29-31 inches above the floor.

Sit-Stand Operations. When users need both mobility to monitor large areas and stability for precise tasks, sit-stand operations are recommended.

- Display height should be the same as that used for standing operations, between 41 and 70 inches above the floor. Recommended control height is also the same as for standing operations, between 34 and 70 inches above floor level.

- Chairs should have adjustable seat height, between 26 and 30 inches from the floor, with 18 inch diameter circular footrests, 18 inches below the top of the seats. These recommendations ensure that seated eye height is the same as standing eye height.

Seating Dimensions

When the focus shifts to the needs of a seated workstation operator, two aspects of design become very important. One is the provision of sufficient leg and foot room so the operator can remain comfortably seated. The other is the piece of equipment the operator is seated in - the chair. The chair should be designed to complement the task and the user's needs. If the operator is comfortably seated, chance for fatigue and stress is reduced. The likelihood of error due to awkward, uncomfortable positioning is also reduced. The following summarizes the guidelines pertaining to the seated operator from the above-mentioned source documents.

- The space needed for knee room should be a minimum of 18 inches deep.

- The minimum distance for knee clearance between the seat and table is 8 inches.
- Footrests for short users should be provided, and if a console that extends to the floor is being used, a kickspace 4 inches high and 4 inches deep should be provided.
- The chair should provide mobility for the operator; it should swivel and have casters.
- Because the optimum angle between chair seat and back for office tasks is 100 degrees, chairs should have adjustable backrests. It is further recommended that the seat bottom be adjustable to heights between 15 and 18 inches from the floor.
- The chair seat should be at least 17 inches wide and 15-17 inches deep and should have a downward sloping front edge so the backs of the operator's knees and thighs are not compressed.
- The seat and backrest should have at least 1 inch of cushioning.
- When the operator's task is data entry arm rests should not be used; when the task involves a long-term seated behavior like monitoring, arm rests should be provided.
- Operators should be made aware of the adjustable features of their equipment and how to use them.

COMMUNICATION SYSTEMS

The integration of several individual work areas and people is often necessary in command and control environments. Communication systems help achieve this integration and comprise an important workstation design element. There are different systems, each best suited for different tasks. NUREG-0700 (1981) reports on several and is the source of the following guidelines.

General Requirements

Operators should be provided with near by, clear instructions for each individual system. Contingency instructions should also be provided in case of system failure.

ORIGINAL PAGE IS
OF POOR QUALITY

Periodic maintenance checks are recommended; they reduce chance for system failure and ensure that the system is optimally effective in response to any new environmental changes.

Telephone Systems

Command and control environments require both internal and external telephone lines. The lines should have a standard frequency bandpass of 200-3300 Hz to ensure intelligibility. The telephones themselves (handsets) should be located close to the operator, be easy to use, have cords of sufficient length that do not tangle, and have clearly labeled switching mechanisms. The distinction between internal and external lines should be clear; labeling, color coding, and spatial grouping help achieve this. Headset telephones should be lightweight, comfortable, and have adequate storage space provided.

Radio Systems

Radio communications (e.g. walkie-talkie and UHF transceivers) should also provide a standard frequency response within the 200-3300 Hz range. Care should be taken that these communications do not interfere with the computerized equipment, each other, or other command operations.

Announcing Systems

Announcing systems consist of amplifiers, loudspeakers, and microphones. The integrated system should provide standard frequency response within the 200-3300 Hz range for adequate intelligibility; better communication is ensured using a 200-6100 Hz range. Microphones should be sensitive and of a quality commensurate with the rest of the system. Loudspeaker location should provide adequate coverage; intelligible sound levels should be found throughout the workstation. Loudspeaker volume should be adjustable. Designers should also be sensitive to priorities of the different communication systems, especially during warning or emergency situations.

Auditory Warning Systems

An auditory warning system is a function-specific communication system used in command and control environments. NUREG-0700 (1981) suggests the following guidelines:

- Each auditory signal should be clear, unambiguous, and distinctive in meaning; similar signals should not be contradictory in meaning.
- Signal coding must be distinctive: pulse coding should ensure adequate repetition; for frequency coding use no more than 5 separate frequencies within a 200-5000 Hz range.
- Signals should sound directly at the work area center.
- Signals should be audible throughout the workstation.
- The optimum frequency range for auditory warnings is within a 500-3000 Hz range.
- Signal intensity should be at least 10 decibels above average environmental noise, but total noise should not exceed 90 decibels.
- Auditory warning systems should be tested at adequate intervals, to ensure their proper working order and reduce chance for false alarm.

COMMAND PANEL DISPLAYS

In a command and control setting, the operator's focal point in the workstation is the command panel. The function of this workstation component makes it the most important piece of equipment there. Command panels have two major features - displays and controls. Displays are addressed first and command panel controls are discussed in the next section of this chapter.

Selection and Choice

Many types of displays are available, and the designer must make a choice based on function and task requirements. Figure 4-1 lists five common displays and shows what

RELATIVE EVALUATIONS OF BASIC SYMBOLIC INDICATOR TYPES (ADAPTED FROM VAN COTT AND KINKADE, HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN)

For	Counter is	Moving pointer is	Moving scale is	Chart Recorder is	Trend Recorder is
Quantitative reading.	Good (require minimum reading time with minimum reading error).	Fair	Fair	Poor (difficult to read and separate individual values)	Fair (supplemental scale has same drawbacks as moving pointer indicator)
Qualitative and check reading	Poor (position changes not easily detected).	Good (location of pointer and change in position is easily detected).	Poor (difficult to judge direction and magnitude of pointer deviation).	Fair (if all parameters are clustered, ok, otherwise not).	Good (if only comparing two or three parameters)
Setting	Good (most accurate method of monitoring numerical settings, but relation between pointer motion and motion of setting knob is less direct).	Good (has simple and direct relation between pointer motion and motion of setting knob, and pointer-position change aids monitoring).	Fair (has somewhat ambiguous relation between pointer motion and motion of setting knob).	N/A	N/A
Tracking	Poor (not readily monitored and has ambiguous relationship to manual-control motion).	Good (pointer position is readily monitored and controlled, provides simple relationship to manual-control motion, and provides some information about rate).	Fair (not readily monitored and has somewhat ambiguous relationship to manual-control motion).	Poor (not easy to differentiate individual parameters to monitor their changes over time)	Good (if only have two or three parameters which the operator is tracking).

Figure 4-1, Seminara, Eckert and Seidenstein, p. 3-12, 1980.

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

tasks they are best suited for. A good display will present the information to an operator in an easily understood form. When precise, real time information is needed, a digital counter display is best used. If the operator needs to make a relational judgment among a few discrete conditions, moving pointer and trend recorder displays are appropriate. When the task requires an input of some setpoint value, as might be needed in an automatic control system, digital counters and moving pointers best display the necessary information. If the operator is tracking the system over time while controlling it, moving pointer and trend recorder displays are best used to provide the needed information. Indicator status lights are best suited to display qualitative information (i.e., on/off, normal/abnormal).

When designers choose displays for the command panel, they should consider other factors that potentially influence display effectiveness. The surrounding environmental illumination will affect the illumination levels of the displays themselves. A proper contrast will be necessary for the operator to see the displayed information. The viewing angle of displays should be considered in order to minimize possibilities for glare. The viewing distance is another important factor, affecting the scale and numeral size of the displays.

Coding

When choosing a coding technique for displays, Bailey (1982) suggests that designers consider the following six factors.

- Kind of information to be displayed.
- Amount of information to be displayed.
- Space requirement for the code.
- Ease and accuracy of understanding the code.
- Interaction among displays at any given time.

- Code compatibility and the code discriminability.

Color. Several coding techniques are available. Color coding is often used, and often misused, but it is a valuable technique when used properly. The main problem with color coding is indiscriminate use. There must be a strong reason for using a specific color for a specific display. Bailey (1980), NUREG-0700 (1981), and Szoka (1982) suggest the following guidelines for color coding information:

- Color should be used to provide redundant information.
- The number of colors used should be kept to a minimum; for CRT graphic purposes three is the maximum.
- The meaning attached to a color should be clear and unambiguous.
- Red and green should be used only to indicate warning and normal/on/go conditions, respectively. Amber or yellow should be used to indicate caution.
- The meaning attached to a color should be consistent throughout the workstation.
- When color is used to code labels redundantly, the meanings should be consistent (e.g., if the label reads RUN the color should be green, not red,etc.). Figure 4-2 provides some common word-color associations that should not be violated.
- The colors used should contrast well with the background they appear against.

Figure 4-3 lists 22 colors of maximum contrast. Each successive color contrasts maximally with its preceeding color and satisfactorily with the other colors before it.

Other Coding Techniques. Shape and size coding, as well as numeric, and letter or word coding provide an even wider range for presenting additional information. Various categories are easily represented using these techniques. Again, overuse should be avoided, and clear and consistent meanings should be attached to the codes.

ORIGINAL PAGE IS
OF POOR QUALITY

RECOMMENDED COLORS FOR ALARM AND STATUS WORDS

Word	*Color*
active	green
alarm	red
clear	white
critical	red
disable	red
emergency	red
enable	green
failure	red
major	red
minor	yellow
normal	green
off	black
on	green
on-line	green
power	red
run	green
standby	yellow
stop	red

Figure 4-2, Bailey, p. 247, 1982.

TWENTY-TWO COLORS OF MAXIMUM CONTRASTS

Color Serial or selection number	General color name	ISCC-NBS centroid number	ISCC-NBS color-name (abbreviation)	Munsell renotation of ISCC-NBS Centroid Color
1	white	263	wh'te	2.5PB 9.5/0.2
2	black	267	black	N 0.8/
3	yellow	82	v.Y	3.3Y 8.0/14.3
4	purple	218	s.P	6.5P 4.3/9.2
5	orange	48	v.O	4.1YR 6.5/15.0
6	light blue	180	v.l.B	2.7PB 7.9/6.0
7	red	11	v.R	5.0R 3.9/15.4
8	buff	90	gy.Y	4.4Y 7.2/3.8
9	grey	265	med. Gy	3.3GY 5.4/0.1
10	green	139	v.G	3.2G 4.9/11.1
11	purplish pink	247	s.pPk	5.6RP 6.8/9.0
12	blue	178	s.B	2.9PB 4.1/10.4
13	yellowish pink	26	s.yPk	8.4R 7.0/9.5
14	violet	207	s.V	0.2P 3.7/10.1
15	orange yellow	66	v.OY	8.6YR 7.3/15.2
16	purplish red	255	s.pR	7.3RP 4.4/11.4
17	greenish yellow	97	v.gY	9.1Y 8.2/12.0
18	reddish brown	40	s.rBr	0.3YR 3.1/9.9
19	yellow green	115	v.YG	5.4GY 6.8/11.2
20	yellowish brown	75	deep yBr	8.8YR 3.1/5.0
21	reddish orange	34	v.rO	9.8R 5.4/14.5
22	olive green	126	d.OlG	8.0GY 2.2/3.6

Figure 4-3. NUREG-0700, p. 6.5-13, 1981.

COMMAND PANEL CONTROLS

The other major command panel feature is the controls.

Selection and Choice

The designer has a wide range of control choice; and, as in the case of display choice, task requirements help determine the best one. Figure 4-4 illustrates several control types and the functions for which they are best suited. When starting and stopping devices are required, push buttons and toggle switches should be used. If the operator needs to select one of several discrete options or to set the control along a continuous quantitative range, several controls can be appropriately used (as shown in Figure 4-4). When the operator is continuously controlling a simple system, knobs, thumbwheels, and levers are the best kinds of controls to use. If the task is to input large amounts of data to a system, keyboards should be used. In regard to selection and design, Bailey (1982) suggests:

- Critical and frequently used controls should be located within easy reach.
- The physical abilities required for control operation should not exceed the capability limits of the least capable user.
- The total number of controls should be kept to a minimum; there should be good reason for requiring a control.
- Control movements should be simple, easy, and as short as possible.
- Controls should be designed and located to prevent accidental activation.
- Controls should provide selection, verification, and feedback information to the user.

Compatibility

Controls should operate within population stereotypes. Figure 4-5 lists several functions and the corresponding actions that best achieve them. Related controls and

COMMON TYPES OF CONTROLS AND THEIR PREFERRED FUNCTIONS
(ADAPTED FROM McCORMICK, HUMAN FACTORS IN ENGINEERING AND DESIGN)

Control Device	Activation	Discrete Setting	Continuous Setting	Continuous Control	Data Entry	Comments
Pushbutton	X					Direct feedback if backlit
Toggle Switch	X	X				Good for 2 or 3 options
Rotary Selection Switch		X				Compact for multi-options
Banks of Pushbuttons		X	X			Direct feedback if backlit
Knobs		X	X	X		
Thumbwheels		X	X	X		
Levers			X	X		
Keyboards					X	

Figure 4-4, Seminara, Eckert and Seidenstein, p. 3-15, 1980.

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

U.S. POPULATION STEREOTYPES OF
CONTROL ACTIONS AND CORRESPONDING FUNCTIONS

	Function	Control Action
a.	On, Start Run, Open	Up, right, forward, clockwise, pull
b.	Off, Stop, Close	Down, left, backward, counterclockwise, push
c.	Right	Clockwise, right
d.	Left	Counterclockwise, left
e.	Raise	Up
f.	Lower	Down
g.	Increase	Forward, up, right, clockwise
h.	Decrease	Backward, down, left, counterclockwise

Figure 4-5, NUREG-0700, p. 6.4-6, 1981.

displays should be compatable in location, direction of movement, labeling, and coding. The operator should be required to perform a minimum of decoding and translation between related controls and displays. Likelihood for error and reaction time decrease with high control-display compatibility.

Coding Techniques

Several source documents identify and recommend different coding techniques (Bailey, 1982; MIL-STD-1472C, 1981; NUREG-0700, 1981), and each shall be considered with regard to command panel controls. Criteria for choosing a coding method include (Bailey, 1982):

- Total demands on the user when the control must be identified.
- Extent and methods of coding already in use.
- Illumination of the user's workplace.
- Speed and accuracy with which controls must be identified.
- Space available for the location of controls.
- Number of controls to be coded.

Color

Guidelines for color coding of controls are the same as those for displays. Consistent meaning and use of the color coding scheme is required.

Size. The use of controls coded by size alone implies:

- No more than three different sizes of controls (small, medium, and large) should be used.
- Controls used for performing the same function on different items of equipment should be the same size.
- When knob diameter is used as a coding parameter, differences between diameters should be at least 0.5 inch; for knob thickness, the differences should be at least 0.4 inch.

Shape. Shape coding is best used to identify controls requiring "blind" operation, where the operator must rely on tactile feedback only. Shapes suggesting the purpose of the control are recommended, making the control both visually and tactually identifiable, the main goal of shape coding. Other relevant points include the following:

- Coded features should not interfere with ease of control manipulation.
- Shapes should be hand-identifiable regardless of control position or orientation.
- A sufficient number of shapes should be provided to cover the number of controls requiring tactual identification.

Location. When controls are associated with similar functions from command panel to command panel (in the case of large, multiperson work areas), they should be in the same relative location. Within single command panels related controls should be located within functional groups.

Labeling. Labeling is a simple way of coding control functions that, when used properly, can aid initial learning and later performance. Guidelines for use of this technique follow (Bailey, 1980; MIL-STD-1472C, 1981; NUREG-0700, 1981).

- Locate labels in relation to the appropriate control (usually above it), consistently throughout the work station.
- Design labels to tell what is being controlled.
- Make labels brief, using only common abbreviations.
- Use standardized letter and number styles that are easily read.
- Identify groups of related controls by enclosing them within a border and labeling the groups by common function.
- Use horizontal labels where possible and vertical labels when space is limited; avoid curved labels.

Using each different coding technique has both advantages and disadvantages. Figure 4-6 lists the techniques discussed above and their respective advantages and disadvantages.

COMMAND PANEL LAYOUT

The physical layout of the command panel largely determines the effectiveness of its operational use. From an ergonomic standpoint, there are several guiding principles (NUREG-0700, 1981; Seminara, Eckert & Seidenstein, 1980) for arranging control and command panels, either in terms of several panels (e.g., nuclear power plant control rooms), or within one panel (e.g., satellite system control rooms).

Sequential Arrangement

When an operator has to act and react in a fixed sequence, panels can be arranged sequentially. Left-to-right and top-to-bottom sequences are most common since they conform to American population stereotypes. A sequential arrangement will minimize the movements required of the operator, an important consideration for time critical operations. It is also recommended that controls used in sequence be grouped together.

Frequency Arrangement

To minimize search time and reduce the likelihood of error, a frequency of use arrangement is recommended. Here the most frequently used controls and displays are placed in the center of the optimum visual and manual reach area of the panel, giving them a high level of availability.

Functional Arrangement

In a functional arrangement, all controls and displays used to perform a function are grouped together on a panel. This arrangement is the most common one found in practice. It is preferred when there are no consistent sequences of operations, because it allows for quick and accurate location of the displays and controls needed for any

ADVANTAGES AND DISADVANTAGES OF VARIOUS TYPES OF CODING

ADVANTAGES	TYPE OF CODING					
	LOCATION	SHAPE	SIZE	MODE OF OPERATION	LABELING	COLOR
Improves visual identification.	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic).	X	X	X	X		
Helps standardization.	X	X	X	X	X	X
Aids identification under low levels of illumination and colored lighting.	X	X	X	X	(When trans-illuminated)	(When trans-illuminated)
May aid in identifying control position (settings).		X		X	X	
Requires little (if any) training; is not subject to forgetting.					X	
DISADVANTAGES						
May require extra space.	X	X	X	X	X	
Affects manipulation of the control (ease of use).	X	X	X	X		
Limited in number of available coding categories.	X.	X	X	X		X
May be less effective if operator wears gloves.		X	X	X		
Controls must be viewed (i.e., must be within visual area and with adequate illumination present).					X	X

Figure 4-6, MIL-STD-1472C, p. 66, 1981.

ORIGINAL PAGE IS
OF POOR QUALITY

function. Labeling, lines of demarcation, shading, and spacing all serve to delineate functional groups.

Importance Arrangement

The controls and displays that are most important are placed within the operator's optimal visual and reach distance in this type of arrangement. It is best suited for small, one-operator work stations.

Graphic or Pictorial Arrangement

Another approach to layout is graphic or pictorial arrangements, more commonly called mimic panels. All related controls and displays are connected by visible lines drawn on the panel to show specific arrangements. This approach has two disadvantages; mimics require a lot of panel space and are difficult to modify once implemented.

FURTHER RESEARCH

At present, the focus of workstation design guidelines is on single person workstations. The multiperson workstation is usually not considered, leaving many specific questions unanswered. Further investigative and experimental research should be done to isolate the differences and similarities of single-person versus multiperson workstations. Questions pertaining to staffing levels, physical access to equipment, physical layout, changing personnel roles, and other theoretical and applied issues must be researched and specific guidelines generated, to complete the picture of human factors in workstation design.

REFERENCES

ANACAPA Sciences, Inc. Fundamentals of Human Factors for Engineering and Design. Santa Barbara, CA: ANACAPA Sciences, Inc., April, 1982.

Bailey, R.W. Human Performance Engineering: A Guide for System Designers. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.

Cakir, A., Hart, D.J., & Stewart, T.G.M. Visual Display Terminals. New York, NY: John Wiley & Sons, 1980.

Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: Department of Defense, Jan. 1979, MIL-H-46855B.

Farrell, R.J., & Booth, J.M. Design Handbook for Imagery Interpretation Equipment. Seattle, WA: Boeing Aerospace Co., Dec. 1975.

McCormick, E.J. Human Factors in Engineering and Design (4th Edition). New York, NY: McGraw-Hill Book Company, 1976.

Morgan, C.T., Cook, J.S., Chapanis, A., & Lund, M.W. Human Engineering Guide to Equipment Design. New York, NY: McGraw-Hill, 1963.

Seminara, J.L., Eckert, S.K., & Seidenstein, S. Human Factors Methods for Nuclear Control Room Design. Vol. 1: Human Factors Enhancement of Existing Nuclear Control Rooms. Palo Alto, CA: Electric Power Research Institute, Nov. 1979, EPRI NP-1118, Project 501-3.

Seminara, J.L., Eckert, S.K., & Seidenstein, S. Human Factors Methods for Nuclear Control Room Design. Vol. 3: Human Factors Methods for Conventional Control Board Design. Palo Alto, CA: Electric Power Research Institute, Feb. 1980, ERPI NP-1118, Project 501-3.

Seminara, J.L., Gonzalez, W.R., & Parsons, S.O. Human Factors Review of Nuclear Power Plant Control Room Design. Palo Alto, CA: Electric Power Research Institute, Mar. 1977, ERPI NP-309, Project 501.

Szoka, K. Practical considerations on the use of color. Silver Spring, MD: Computer Sciences Corporation, April 1982.

U.S. Nuclear Regulatory Commission. Guidelines for Control Room Design Reviews. Washington, D.C.: Nuclear Regulatory Commission, Sept. 1981. NUREG-0700.

Van Cott, H.P., & Kinkade, R.G. (Eds.). Human Engineering Guide to Equipment Design. New York, NY: McGraw-Hill, 1972.

Webb Associates. Anthropometric Source Book. Volume I: Anthropometry for Designers. Houston, TX: NASA/JSC, July 1978, NASA Reference Publication RP-1024.

Webb Associates. Anthropometric Source Book. Volume II: A Handbook of Anthropometric Data. Houston, TX: NASA/JSC, July 1978, NASA

ORIGINAL PAGE IS
OF POOR QUALITY

Reference Publication RP-1024.

Webb Associates. Anthropometric Source Book. Volume III: Annotated Bibiolgraphy of Anthropometry. Houston, TX: NASA/JSC, July 1978, NASA Reference Publication RP-1024.

Woodson, W.E. Human Factors Design Handbook. New York, NY: McGraw-Hill Inc., 1981.

CHAPTER FIVE

HUMAN FACTORS OF COMPUTER SYSTEMS: THE HARDWARE

INTRODUCTION

Over the past several years, human factors interest and research in issues related to computer hardware, software, and human-computer interaction has grown at an almost staggering rate. Due to the volume of interest and research as well as the limited time frame during which the research has been accumulating, some of the results tend to be ambiguous and, occasionally, directly contradictory. Nevertheless, as more research is conducted, evidence mounts up, and there are numerous areas where clear-cut standards exist. This report will synthesize the results from numerous documents which suggest design guidelines. Where possible, conclusions and design guidelines will be presented, and, where evidence is still inconclusive on significant issues, design considerations will be discussed. Taken together, the design guidelines and the design considerations define a set of parameters which must be carefully evaluated in the acquisition and configuration of computer systems.

Due to the volume of information, this report will be restricted to material related to computer system components which affect the human-computer interface, primarily, the visual or video display terminal (VDT) and interaction techniques and devices which support the human-computer dialogue. To organize this discussion further, the topics have been broken down into two categories: human factors issues of the physical properties or hardware components and the human factors issues of software. Hardware design issues include ergonomic consideration of visual display terminals (VDTs), color capabilities, and interaction tasks and techniques. These issues will be discussed in this chapter. The chapter which follows will consider software or informational

characteristics of VDTs, addressing topics which include coding techniques, dialogue types and properties, and display density.

ERGONOMICS OF VIDEO DISPLAY TERMINALS (VDTS)

Ergonomics, a European term for human factors, has been used primarily to refer to the physical and environmental aspects of the VDT and VDT use. This section will discuss three major ergonomic considerations: health and safety hazards and complaints for VDT operators, VDT environmental and workstation design, and visual properties of VDTs.

The growth of computer usage in the western world is staggering. In the past decade, total computer power available to U.S. business and industry has increased tenfold, and it is expected to double every two to four years (Gantz & Peacock, 1981). In 1980 there were five to ten million VDTs and more than 7 million operators in the U.S. (Center for Disease Control, 1980). Further, there are an estimated 15 million computers, terminals, and electronic office machines. By 1985 this number is expected to grow to 35 million, one computer-based machine for every three persons employed in the white-collar work force (U.S. Department of Commerce, 1979). Thus, the number of people using VDTs is large and growing rapidly; keeping pace with the proliferation of terminals is a growing concern about the health and safety aspects of VDT use. This concern has generated a great deal of public comment as well as substantial research on VDT aspects contributing to work health and safety. The next two sections will review some of these ergonomic issues and summarize some of the resulting guidelines and design considerations.

Health and Safety Hazards and Complaints

A review of recent articles and reports suggests that a host of problems may be caused or aggravated by the introduction of the VDT into the workplace. Complaints

include: eyestrain, visual fatigue, and related visual problems (Cold Type Organizing Committee, 1981; Grandjean & Vigliani, 1980; NIOSH Research Report, 1981; NYCOSH report on Health Protection for Operators of VDTs/CRTs, 1980; Tabor, 1982; Working Women Education Fund, 1981); postural problems (Grandjean & Vigliani, 1980; NYCOSH report on Health Protection for Operators of VDTs/CRTs, 1980); psychological stresses (NYCOSH report on Health Protection for Operators of VDTs/CRTs, 1980); radiation (Cold Type Organizing Committee, 1981; NIOSH Research Report, 1981; NYCOSH report on Health Protection for Operators of VDTs/CRTs, 1980); and industrial hygiene (NIOSH Research Report, 1981). Radl (1980) summarizes some of these problems as follows:

- Many of the screens and keyboards are badly designed. The most unsatisfactory points are: low luminescence level on the display, low contrast between characters and background, flicker of the display, reflections on the screen, and the design of the whole box in such a way that it is often impossible to use in a human-adapted position. In many cases keyboards are connected with the display box and are unnecessarily high and produce light reflections, mainly on the surfaces of the keys.

- Relatively poor workplace design and bad positioning, including mistakes in the illumination, can also be found at many of the present workplaces.

- Illumination conditions at most VDT workplaces are unsatisfactory. There are only general recommendations to avoid glare. Information on how to avoid glare and reflections on the screen is not disseminated. The existing illumination problems are caused by daylight as well as by artificial lighting.

- Eye defects often result in an increased workloads for many persons working with VDTs. These eye defects are not caused by VDT use. Field studies have shown that more than 50% of all German adults have non-corrected eye defects, and this is an important loading factor, when these persons work with VDTs.

ORIGINAL PAGE IS
OF POOR QUALITY

- In many cases the use of VDTs has forced an increase in information transmission rates between man and the technical information-processing systems. Normally a new technical and more computerized system with VDT workplaces is installed for economic reasons. Most manufacturers promise in their advertisements to reduce costs by an increase in performance of the human-computer system. Therefore all activities during the introduction phase, as well as later, are concentrated on bringing a higher output (meaning an increase of symbols per minute, data per hour or other number of working units per day and employee). It is difficult to explain that the main effect of the use of computer and VDT technologies should be to increase not primarily the quantity of information rates at the human-technical information-processing system interface, but the quality of the whole system performance, e.g. through better information selection and handling, through more flexibility of the organization, through better written output and through better and more adaptive reactions of the offices—and last but not least through more humanity at the workplace in the office.

- Many arguments in the discussions about VDT workplaces are emotional. This is understandable because the VDT has become a negative symbol for anxieties of the employee in the office: anxiety about the technical and organizational changes in the white collar area, anxiety about mass unemployment, anxiety about dequalification, and anxiety over more control from the computer. It is important to know and to try to solve these social problems. But it is also important to separate the ergonomically caused and the socially caused problems in the discussion of the acceptance of VDTs, because each kind of problem needs different measures to be solved.

- VDTs have had very bad publicity in the media. If a problem of their use is discussed in a research report, the papers will generalize it for all sorts of VDT workplaces, and they will once again point out how unhealthy and dangerous work with VDTs is.

These concerns have prompted a great deal of discussion, research, and even some legislation. At the anecdotal level, there was a strike by clerical personnel at the United Nations when word processing equipment was installed. In a similar vein, the U.S. Department of Commerce is thinking of removing its word processing equipment due to

operator complaints and concerns that the automated equipment is lengthening task time (due one supposes to an increased number of drafts made possible by the word processing systems).

On a more serious note, a number of European governments have or are preparing to take some legislative or regulatory actions to ensure the health and safety of VDT operators. Sweden is the most advanced, having passed legislation which specifies some design aspects of visual display terminals. Germany has proposed standards and safety regulations in which various visual display parameters are specified. The French have gone one step further; a government decree placed operators of terminals in the hazardous occupation category. As a result, employers are required to provide additional rest breaks and enhanced medical care for those employees. European activity has been far greater than that in the U.S. The most active U.S. agencies are the National Institute of Occupational Safety (NIOSH) and the U.S. military services. NIOSH has just concluded a large study examining potential health effect of working with VDTs (Human Factors, Vol. 23, No. 4, August 1981). The military services have also extended their interest to include concern for operator stress, performance, and safety (MIL-STD-1472C, 1981). As more attention has been focused on VDT problems, some basic assumptions have evolved to guide ergonomic research on VDT design and use. These include (Radl, 1980):

- Eye discomfort and workload in VDT workplaces can be reduced to or below the level at workplaces without VDTs but with similar tasks. The condition: screen, presentation mode, VDT box, keyboard, the whole workplace, and the environmental factors have to be designed as well as possible by existing technologies and following existing recommendations which are the results of ergonomic research and practical experience.

- It is not generally in question whether to use a VDT or not. But there are many questions and also practical

ORIGINAL PAGE IS
OF POOR QUALITY

answers on how to design a specific VDT workplace and its environment with respect to man and his specific task at this workplace. Manufacturers and users do not only need our criticism on VDTs and workplaces, they need detailed information on how to make them better.

- Work-time limitations and special break-time regulations for VDT workers are not the optimal way to solve the existing problems. It should not be the main function of ergonomics to compensate for high workload, which is caused by poor working conditions, only by time limitations or by additional break-times. The better measure consists in avoiding the loading factors by human-adapted workplace design and by interesting, non-monotonous tasks.

The basic ergonomic issues have thus far focused on health and safety of the operator. In particular, there has been a good deal of investigation into the possibility of VDT-induced radiation and negative aspects of VDT use with respect to both vision and posture. One universal conclusion which is very encouraging is that there is not a radiation hazard associated with VDT use (Cakir et al., 1980; Murray et al., 1981). Rädl suggests that visual and postural problems can be greatly alleviated by human-engineered workstation and environmental design and the design of human-engineered VDTs, keyboards, and other interaction devices. Subsequent sections outline some specific guidelines for these aspects of the workplace. Industrial hygiene, one of the potential problems associated with VDT workplaces, was not found to be a problem in the extensive NIOSH study (Murray et al., 1981; NIOSH report, 1981). Walk-through surveys of VDT areas indicated few sources of airbourne chemical contaminants. The occupational sources identified were photographic darkrooms, photocopiers, and other photo-reproduction equipment. The one general source of indoor air pollution was cigarette and cigar smoking. The evidence supporting the conclusion that employees operating VDTs were not exposed to hazardous levels of airbourne contaminants was overwhelming.

Psychological stresses caused or intensified by the introduction of VDTs into the workplace are real and must be addressed by a sensitive and coordinated managerial response. The NIOSH study documents some of the psychological stresses which VDTs can cause, particularly among clerical workers (Smith et al., 1981). In a large sample of employees, a pattern appeared in which professionals using VDTs reported the lowest stress levels, while clerical VDT operators reported the highest stress levels, with control subjects in the middle. The report concludes that the use of VDTs is not the only factor contributing to operator stress levels and health complaints, but that job content also makes a contribution. The authors note that the clerical VDT operators were monitored closely by computer systems which provided up-to-the-minute performance reports on the rate of production and error levels. Sometimes, the automation of clerical and other related low skill activities results in automation "pacing" the human operator, rather than vice versa. The NIOSH study also indicates that clerical employees greatly feared that they were likely to be replaced by a computer at some time in the future. The basic conclusion is that a number of interacting factors contribute to psychological and physical stress. Job redesign and workplaces redesign will alleviate some of the problems, but a positive and sensitive managerial policy is essential to ensure the efficiency and effectiveness of the "people component" of the human-computer system.

Environmental and Workstation Design

Environmental and workstation design issues are critical determinants of the effectiveness and efficiency of the workplace. Over the past forty to fifty years a great deal of information has been gathered defining standards for appropriate working environments for humans. Chapter three of this document reviews these issues and standards in general; this section will describe those which are particularly relevant to VDT workplaces. As indicated in the previous section, a consensus is emerging that

attributes a good deal of the problems and complaints concerning the introduction and widespread use of VDTs in the workplace to poor environmental and workstation design; often the introduction of a VDT merely aggravates existing problems of poor workstation design.

General Considerations for Workstation Design. Cakir et al. (1980) suggest several preliminary considerations in planning the workplace:

- Ensure that the user can reach and operate the controls. Major controls on the VDT are the keyboard, power on/off, brightness, contrast, and modem. These and other workstation equipment items should be easily and safely available.

- Ensure that the user can see and read the displays. Different displays (e.g., keyboard, screen, documents) should be positioned favorably for the user's standard position as well as any frequently used alternative positions.

- Ensure that the user is comfortably positioned and can get in and out of the workplace easily. Basic principles of workstation design should be closely adhered to; basic clearances should be observed, suitably sized equipment and office furniture provided, and sufficient amounts of workspace be made easily available. Environmental aspects of the workstation should be considered in the initial layout and periodically evaluated to ensure that deterioration does not occur over time.

Cakir et al. (1980) strongly recommend using model workstation or mockups (see Chapter 8 for futher discussion) to ensure human-engineered workstations. Mockups can be used to solicit valuable input from users, particularly junior levels of personnel who are typically not consulted but can be an invaluable source of practical design information.

Over and above these general considerations there are a number of specific workstation design and environmental factors to be considered. Cakir et al. (1980) summarize the issues in Figure 5-1. Equipment is vitally important to the comfort of users. Poorly designed or positioned equipment results in inefficient posture, potentially

ORIGINAL PAGE IS
OF POOR QUALITY

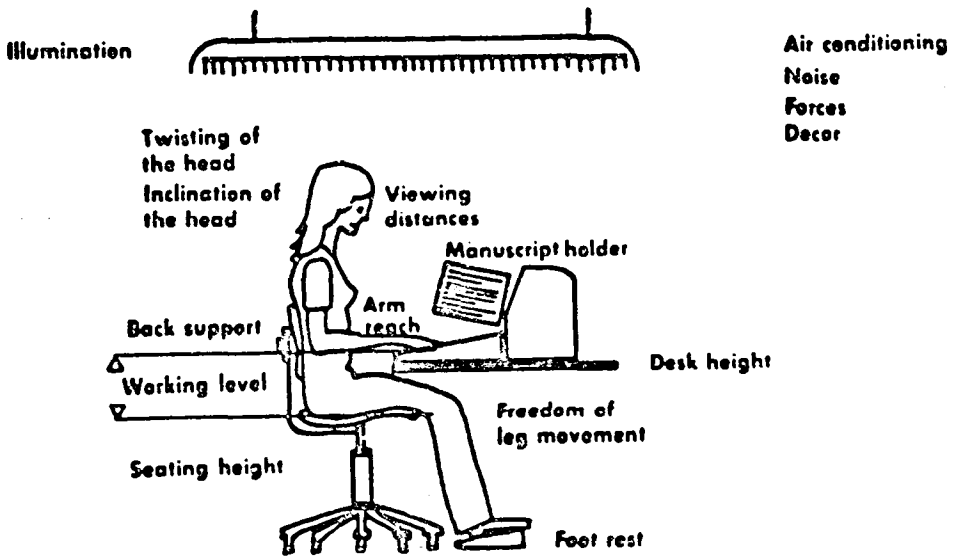


Figure 5-1 The most important aspects in the design of VDT workplaces. (Cakir, Hart, and Stewart 1980)

causing spinal disorders and fatigue in the back muscles. Moreover, design which ensures the freedom and ability to change posture is preferred, as even an optimal posture becomes fatiguing over long periods of time.

Working level

Cakir et al. (1980) define working level as the distance between the underside of the thighs and the palms of the hands. A common standard is that working level should range from 220 to 250 mm, corresponding to the lower 5% percentile limit for females and upper 95% percentile for males. Desk top, desk frame, and keyboard should be as thin as possible in order to ensure an appropriate working level. Detached keyboards with a height of more than 30 mm should be set in the desktop.

Desk Height

Desks for VDT workplaces should have a desktop height of 720 - 750 mm with a minimum free height of 650 - 690 mm. On detachable keyboards, the height of the home rows above the floor boards should be between 700 and 750 mm.

Chair, Seating Height, and Back Support

Chair height should be adjustable in order to enable key entry with arms and thighs in an approximately horizontal position and feet flat on the floor. Foot rests may help if the chair/desk height makes it impossible for the operator's feet to rest comfortably. Management should ensure that users are aware of the adjustability of office equipment and are reminded to make suitable adjustments periodically.

Foot Rests

Adjustable footrests should be provided which are large enough to cover the entire usable leg area and be anchored to the floor; well-designed foot rests help to provide postural support.

Document Holders

Document holders can help to reduce fatiguing body movements. Document holders should be portable, allow angle adjustments, and be equipped with an optional row marker. A correctly positioned document holder allows reduction of movement or transfer of movement to less loaded parts of the body.

ORIGINAL PAGE IS
OF POOR QUALITY

Arm Reach and Working Level

The keyboard should be positioned within easy reach of the user; the back row of keys should be within 400 mm of the front edge of the desk, and 60 mm should be allowed in front of the keyboard.

Display Height

In general the top edge of the screen should be at or below eye height. The line-of-sight should intersect the center of the screen.

Viewing Distance

The recommended range for eyes to manuscript, display screen, and key board is in the range of 450 to 500 mm.

Environmental Design Consideration for Computer Workstations. Cakir et al. (1980) note that of all the environmental factors - lighting, temperature, and noise - lighting is the most significant in VDT workplaces. This section addresses the issues of lighting the workplace; issues such as screen luminance and contrast illumination will be taken up in the section on visual properties of VDTs.

Illumination or ambient light level

VDT working areas should be illuminated with 300 to 500 Lux illuminance with the best possible glare shielding to safeguard against both direct and reflection glare.

Luminance Ratios

Visual fatigue can be caused by differential luminances of CRT screen, keyboard and screen, and the desk and the room; recommended ratios are 1:3:10. Keyboards can be designed so that luminance ratios between the keyboard and screen and between the keyboard and paper do not exceed 1:3. It should be noted that the ideal is 1:1.

Glare and Reflection

Glare is gross disturbance of the adaption process of the eyes caused by large differences in illumination. Direct glare can be avoided by appropriate positioning of light fixtures.

Indirect glare, caused by reflection from glassy surfaces, is also very undesirable and a likely cause of visual fatigue. Desks, floors, and other work surfaces should be selected to minimize glare and reflection.

Light bulb or fluorescent lights should be in warm, light, and uniform colors. Glare shielding of lights is usually desirable; prismatic or glow shields are preferred. Workstations should be positioned so that glare sources are out of the user's field of vision; lighting fixtures should be positioned parallel to the user's field of vision. Windows and curtains are also helpful in reducing glare. VDT screens should be fitted with anti-glare devices or come equipped with coatings or antiglare displays.

Temperature

Thermal emission from the VDTs should be taken into account when determining the heat and air conditioning needs of the workplace. Temperature should be controlled to a range between 72^{o} and 76^{o} with humidity at about 50%. Care should be taken in the acquisition of equipment to ensure that the equipment does not require excessive temperature conditions which result in discomfort for human users.

Noise

Generally VDT workstations are quiet as compared to conventional workstations. Nevertheless, normal ergonomic procedures for noise reduction should be taken. For example, other equipment in the room, such as impact printers, should be checked to ensure that the level of noise is not too great.

Visual Properties and Ergonomic Aspects of the Video Display Terminal Hardware

The discussion of the ergonomic aspects of VDT workstations in the previous section focused on general aspects of the workplace itself and, for the most part, is merely a reiteration of common standards for workplaces with or without VDTs. This section will focus on ergonomic aspects of the VDT itself. These standards are relatively new and, in some cases, clear-cut standards have yet to be developed. Nevertheless, these aspects are critically important and must be consciously addressed in the design of VDT workplaces.

The various physical attributes of a VDT should be considered in selecting one.

These properties are basically independent of information and content, but they are vitally important in determining the effectiveness of the human-computer interface. The section will review a spectrum of these characteristics together with recommended standards. Attributes are divided into the following categories: image and screen characteristics, attributes of character formation and display legibility, keyboard characteristics, and miscellaneous considerations including such items as response times and maintainability.

Image and Screen Attributes

The image and screen attributes considered here constitute the "basic visual properties" of VDTs. As indicated above, they are important and yet stand independent of information content and format.

Flicker

Flicker or image instability, if perceptible by the VDT operator, can be a source of annoyance and visual fatigue. Ideally, flicker should be imperceptible. In practice, it is usually sufficient to have a refresh rate on CRT-type displays of 50-60 Hz. Refresh rates under 20 Hz are very annoying, and screens with refresh rates under 50 Hz are not considered flicker free.

Luminance

Screen luminance is also a determinant of flicker. Screen or background luminance should be adjustable with a range of at least 15 and 20 cd/m^2 under normal lighting conditions. Character or symbol luminance is also important. Although there is variation in recommended standards, the consensus seems to be that a minimum character luminance of 30 cd/m^2 is desirable. Some guidelines (Cakir et al. 1980) suggest that as low as 45 cd/m^2 may be sufficient, but all agree that the range of 80 to 160 cd/m^2 is the most desirable.

Symbol Contrast

The contrast between characters and background is also important. Bank, Gertman, and Petersen (1980) in their review of relevant guidelines, conclude that a minimum contrast ratio of 3:1 or 4:1 is needed with as great as a 10:1 contrast specified as optimal.

Image Polarity

Image polarity is a physical attribute of VDTs which is being considered in Europe. It concerns the screen characteristic which determines whether the display has dark symbols on a light background or vice versa. The existing standards range from user's preference to conflicting recommended formats (Banks et al., 1980). The message for system designers is to keep image polarity in mind as a design consideration, realizing, however, that no generally accepted standard currently exists.

Phosphor

Phosphor properties of the screen may also determine the preceptibility of flicker. The general recommendation is that screens with medium to low persistence phosphor are the best compromise (Banks et al., 1980).

Color

Another important consideration in VDT selection and screen design is color. Due to the volume of material in this area, a separate section is devoted to this topic in a later portion of this chapter.

Adjustability of the Screen

In keeping with the notion of flexible workstations, it is recommended that VDT screens be flexible both on their horizontal and vertical axes. If the VDT is fixed the vertical angle should be 90^{o}.

Character Formation and Display Legibility Attributes. The characteristics reviewed below address what is displayed on the screen and how. They are also fairly independent of information content. The major references for the guidelines suggested in this section are: Cakir, et al. (1980), Bailey (1982), Shurtleff (1980), Ramsey et al. (1979), and Banks et al. (1980).

Resolution

Display resolution concerns the number of scan lines per inch as well as the dots per character. The recommended standard for scan lines is a minimum of 50 per inch (Bailey, 1982) and 12 to 18 lines per symbol height (Shurtleff, 1980). The number of dots per character for dot matrix characters is a minimum of 5 X 7 to 7 X 11.

Symbol Dimension

Several attributes must be considered. Stroke width measured in stroke width-to-height ratio is recommended in the range of 1:4 to 1:8. Recommended symbol width as a percent of upper case character height is in the range of 75 to 100%. Horizontal spacing, measured as a percent of symbol height, should be in the range of 10 to 65%. Row spacing should be between 100 and 150% of character height. More detailed information on these attributes can be found in Bailey (1982), Shurtleff (1980), and Cakir, et al. (1980).

Character Font

The character set chosen is also important in determining the overall readability of the display. The character set should contain upper and lower case characters, with lower case characters having descenders which come below the line where appropriate. The characters should be displayed in an upright, rather than slanted manner. Cakir, et al. (1980) suggest a review of the following pairs of characters as a quick check on the legibility of the character set: X/K, O/0, T/Y, S/5, I/L, U/V, I/1. The difference between each pair should be easily apparent in a well designed character set.

Cursor

In evaluating a candidate VDT, the cursor and its properties should be examined. A visible cursor, easily distinguishable from the elements of the character set, is highly desirable. One consideration which is usually application-dependent is the specific format of the cursor — an underline or a reverse video box. As yet no recommended standard exists, but the cursor is an important user consideration.

Backspace Capability

Another design consideration that is typically application-dependent is the backspace capability. Users should be queried to see if backspacing is necessary for physical as well as logical deletion of characters on the screen.

Cursor Control

The need for cursor control, horizontal as well as vertical, is another design consideration. Applications which require screen editing may be facilitated greatly by a VDT with both horizontal and vertical cursor control.

Screen Memory and Scrolling

Other application-dependent design considerations are the existence and amount of screen or local memory as well as how the memory is accessed, e.g., scrolling. Screen memory is an expensive yet very useful feature in VDTs. To the extent that the budget will support it, screen memory is a desirable attribute; two to four screen pages of memory is the normal range. Screen memory is usually accessed by scrolling, i.e., line by line, though for some application, page scrolling may be desirable.

Display Enhancement Features

Again depending on the application, display enhancement features may be a required for the VDT. Such capabilities as reverse video, dual intensity, and blinking may help facilitate tasks such as data entry and monitoring. Blink rates should be between 2 and 4 Hz, and it should be possible to blink portions of the display as well as portions of individual lines of the display. Another feature which should be considered is audio capability; a bell or electronic noise may be a desirable enhancement for some applications. The range of sounds which the VDT is capable of making should be explored to ensure that it meets acceptable auditory criteria and yet is not offensive to the user.

Keyboard Attributes. Characteristics of keyboards include some general criteria, characteristics of the keys, and the keyboard layout. The primary references for keyboard design considerations are: Cakir et al. (1980), Bailey (1982), Banks et al. (1980), MIL-STD-1472C (1981), and Ramsey et al. (1979).

General Criteria

The most important criterion is the detachability of the keyboard; this is a very desirable attribute in ameliorating the effects of operator fatigue. Keyboard slope appears to be an important user consideration; however, there is still

considerable disagreement about recommended standards (Banks et al., 1980). The keyboard should also be considered in eliminating luminance and glare problems of the workplace.

Key Characteristics

Tactile keystroke feedback is a generally desirable attribute, with a key activation in the range of .26 to 1.5N. Key travel in the range of approximately 1 to 8 mm is recommended. Keys should be spaced at intervals of approximately 20 mm between key centers. Key-top dimensions are recommended in the range of 12 to 15 mm. Key legends should be examined to ensure that they are moulded to the key to help prevent wear and abrasion. Key-top surfaces should be concave and treated to minimize glare. Important design considerations are failure rate for keys, and the type of error which results at failure. If special keys are needed, they should be integrated into the keyboard and not separated from the alphanumeric section by more than one inch.

Keyboard Layout

The layout of the alphabetic block should conform to standards for conventional typewriters. A separate numberic key pad is desirable; however, there is no current consensus on the most desirable format. Typical choices are calculator vs. telephone formats. The space bar should be at the bottom. All keys for which unintentional or accidental operation may have serious consequences should be secured by either position, additional required key pressure, key lock, or two-handed key operation. A task-dependent design consideration is the need for programmable function keys or color coded function keys.

Miscellaneous considerations. Several miscellaneous considerations are recommended in evaluating a candidate VDT. One, which will be addressed more fully in the next chapter, is response time. In consideration of VDT hardware, it is important to be sure that the VDT selected is not an undesirable and limiting feature of the overall response time in the human-computer interface.

A second design consideration which is particularly encouraged by the military (MIL-STD-1472C) is the maintainability of VDT equipment. Before acquiring a VDT, the designer should ensure that replacement parts are widely available and that diagnostic

procedures are in place. It is important for overall system effectiveness to invest in equipment which is reliable and speedily fixed when it malfunctions.

THE ERGONOMICS OF COLOR ATTRIBUTES

During the last decade, CRTs and other display monitors capable of presenting material in color have become relatively inexpensive. This newly available capability to use color in addition to monochromatic displays has been seized upon with great enthusiasm by programmers and other designers of the interface between computers and machines. Of course, the graphic arts community has for centuries worked with color in presenting material to viewers. Unfortunately, with the exception of a small community of artists who have adopted the computer as their medium, few people with the requisite technical training in computing have developed the appropriate skills in the graphics arts to use color effectively.

Further, computers and their displays in a control environment are applied to the communication of substantive information and data. Color displays represent technologically, a new medium of communication; the application of this new medium to unprecendented tasks has required the application of whatever knowledge that can be gleaned from older and different media which use color intrinsically, without really being able to assess the appropriateness or the effectiveness of these efforts. It is only very recently that studies of color in computer-generated displays have begun to appear. Even fewer of these studies have addressed the ordinary human factors questions of the effect of the tool upon the performance of the task.

In short, there is no well-ordered body of knowledge to guide us in the design of computer-generated displays using color for communications within a control environment. Some guidance can be taken from traditional color media, such as the

graphic arts and motion pictures, but without assurance that these principles are truly appropriate for the CRT display. Other principles can be derived from the human factors literature, which has considered color in other contexts, such as the color coding of controls and the selection of wall or background colors in a task-oriented enclosure. Still other principles can be taken from the empirical experience of those who have explored the use of color graphics for computerized generation of graphs, charts, and other types of management-oriented information display.

Thus, most of the guidelines suggested in this section on color attributes should be taken as tentative. These points contain more DON'T than DO guidelines; as human factors research contributes more thorough knowledge of the use of color in computer-generated displays in specific task environments, this situation will reverse.

Technical Definition

Color is a subjective phenomenon derived from the sensory perception of electromagnetic radiation with differing wavelengths within the visible range. Physicists model color along a wavelength spectrum, from 380 to 780 nanometers. Table 5-1 identifies the colors associated with ranges within this spectrum. The intensity of a color is associated with the energy or amplitude of the wavelength. The purity of a color is associated with the ambient energy at other surrounding wavelengths. A color darkens to black as the amplitude decreases to zero; a color fades to white as the surrounding amplitudes rise to match it.

A uniform spectral energy distribution through the range 380 to 780 nanometers is perceived as a grey, shading from black at the lowest energy level to white at the highest. The different colors arise from this greyness as the energy at a particular wavelength increases relative to the surrounding spectral energies. This dominant wavelength is called the "hue" of the color. The energy or amplitude of the wavelength is

ORIGINAL PAGE IS
OF POOR QUALITY

Table 5-1

Wavelength	Hue	Psychological Aspect
630-760	Red	warm (advance)
590-630	Orange	
560-590	Yellow	
490-560	Green	neutral
450-490	Blue	cool (retreat)
380-450	Purple	

called the "brightness" of the color. The ratio of the energy or amplitude of the wavelength to surrounding uniform energy density is called the "saturation" of the color, i.e., how close it is to white.

Physiologically, the human eye seems to be sensitive to three colors. The retina contains three kinds of light-sensitive cones, each of which is most sensitive to wavelengths for blue, red, or green hues. Figures 5-2 and 5-3 (Foley, 1981) illustrate the response characteristics of the eye for these three kinds of cones and the overall luminosity response of the eye.

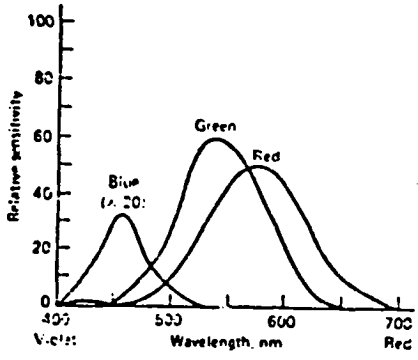
Clearly, we perceive more than these simple colors. The color that we perceive is a sum of the dominant wavelengths (those emerging from the surrounding white noise) weighted by their relative brightnesses. The distribution of the individual wavelength or hue brightnesses coalesce into relative saturation. Thus, the three visual primaries, red, green, and blue, combine to white at equal brightness to produce zero saturation.

We see in red, blue, and green; visual colors are various combinations of these primaries. This fact has been taken advantage of in the Red/Green/Blue (RGB) and Cyan/Magenta/Yellow (CMY) color models.

Several such schemata or models of the interrelations among hue, saturation, and brightness which have been devised to allow the selection of a specific color by the specification of a set of coordinates in a "color space." This type of color model has obvious appeal in computer graphics for it allows color to be specified quantitatively.

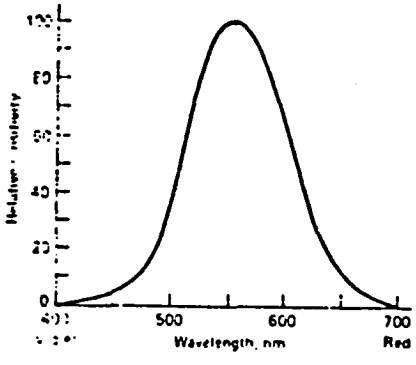
The RGB model (Figure 5-4) conceives the color space as a cube with red, green, and blue as vertices of a unit cube. The vertex which joins the RGB vertices is black while the vertex opposite the black vertex is white. Between the RGB color pairs are vertices for the combines color; hence, opposite each RGB vertex is the complementary color for that vertex. Grey is defined as shading the diagonal joining the black and the

ORIGINAL PAGE IS
OF POOR QUALITY



Response characteristics of the eye.

Figure 5-2. Foley & Van Dam, 1982, p. 605.



Luminosity response of the eye.

Figure 5-3. Foley & Van Dam, 1982, p. 605.

white vertices. The CMY model is represented by the same cube.

The RGB cube adds primary colors to black. The CMY cube subtracts colors from white. The CMY colors are the complements of the RGB colors. For example, Yellow is the sum of Green and Red which is White minus Blue. Hence, the RGB colors are termed additive primaries while the CMY colors are termed subtractive primaries.

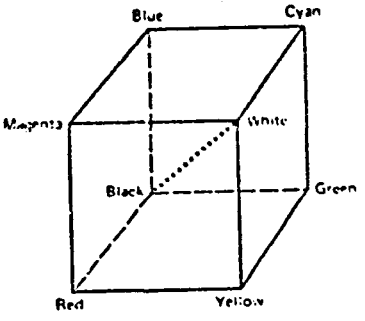
Any color within the cube may be specified as a set of RGB coordinates or conversely as a set of CMY coordinates. This specification can then be translated into hardware terms for color monitors which use red, green, and blue guns to produce a color picture. The RGB coordinates become directly the proportional excitation of each gun for each folor point on the display. Black is produced by not firing any of the color guns; and, at the other extreme, white is produced by firing all guns at maximum intensity.

Unfortunately, while the RGB or CMY model is very convenient from a hardware point of view, it is difficult to relate the three-dimensional mapping of intensities of red, green, and blue to the three-dimensional mapping of brightness, saturation, and hue. For example, in RGB, different levels of greyness are achieved by adding equal amounts of red, green, and blue to black. However, intuitively, we think of greys as different admixtures of white and black.

To accomodate this intuitive perception, other color models have derived. Two will be mentioned here, the HSV (Hue, Lightness, Saturation) models. These models may be specified by three coordinates along the dimensions of brightness, saturation, and hue.

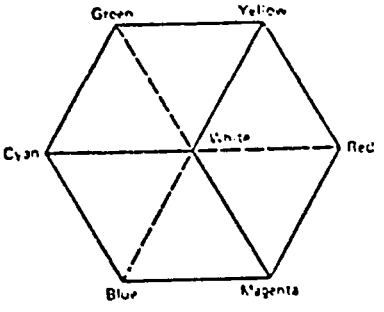
The HSV color model, often called the cone or artist's model of color, incorporates the intuitive painter's notions of hue, adding white to decrease saturation and adding black to reduce brightness. Figures 5-5 and 5-6 from Foley (1981) illustrate the transformation from RGB to HSV. The three-dimensional HSV space is defined by angular rotation to obtain hue, by vertical movement to obtain brightness, and horizontal

ORIGINAL PAGE IS
OF POOR QUALITY



RGB color cube. Grays are on the dotted main diagonal.

Figure 5-4. Foley & Van Dam, 1982, p. 611.



RGB color cube viewed along principal diagonal. Visible edges of cube are solid, while the invisible ones are dashed.

Figure 5-5. Foley & Van Dam, 1982, p. 615.

C-2

movement or displacement from the central axis to obtain saturation.* "Adding white" decreases the displacement from the central axis. "Adding black" decreases the vertical location, the height coordinate. The central axis of the NSV model defines the full range of greys, from black at the bottom to white at the top. White appears at the center of the plane defining the top of the inverted cone. The color white is at the "origin" of the plane. Hence, vector additions of vectors defined from this origin in hue saturation coordinates, the chroma, defines an additive color. From this, it is easy to see that equal vectors for the three primaries map to white, as expected.

The HLS color model, the double-cone model, is also frequently encountered. Foley's illustration is given in Figure 5-7. Although similar to the HSC model, it is somewhat less easy to use. It is not so intuitively obvious as the HSV model, because the HLS representation of the color vectors available in the HSC model cannot be performed in the HLS color space. The advantage of the HLS model is a great expansion of the desaturated colors which may be represented in the upper cone volume.

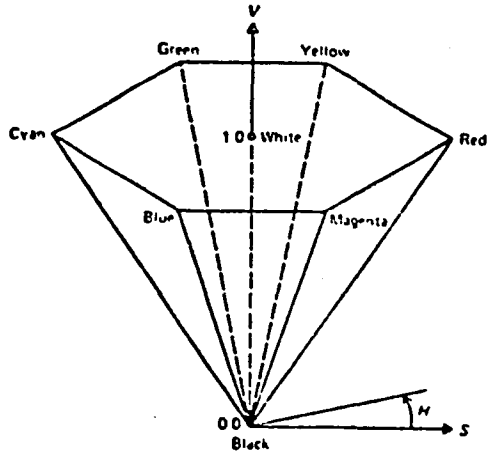
Both the HSV and the HSL models share with the RGB and CMY models the capability given to their users to specify any color with three quantitative and hence computable coordinates. They enhance the usefulness of the RGB and CMY models by using coordinates which are closer to a naive understanding of color and color making. This is extremely useful because it allows the user to specify functional definitions of color sets and ranges to be used in colored graphical presentations. More on this capability can be found in a later section.

Color Perception

The perception of color is a physiological process. As such, the perception of color

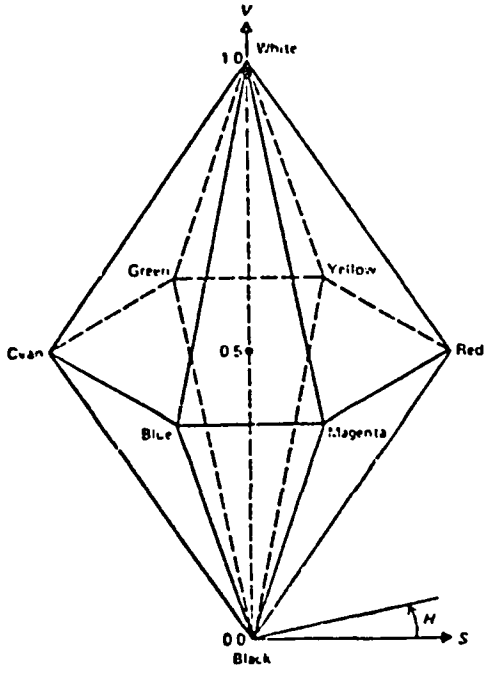
*This is essentially the same coordinate system as used by computer disk storage.

ORIGINAL PAGE IS
OF POOR QUALITY



Single hexcone HSV color model.

Figure 5-6. Foley & Van Dam, 1982, p. 614.



Double hexcone HLS color model.

Figure 5-7. Foley & Van Dam, 1982, p. 614.

differs from one individual to another. The ability to discriminate among colors is normally distributed through the population. Typically, when viewers are presented with colors defined by a three-dimensional model like the RGB or HSV models, they are able to relatively discriminate many more than 100,000 different colors. However, as might be expected from the 7 ± 2 rule, far fewer colors can be reliably discriminated absolutely. Indeed, various forms of colorblindness affect as many as five percent of the male population. (Only an extremely small proportion of females are colorblind.)

Color perception also carries with it an emotional or psychological "feel". Various colors are seen on psychometric ranges between hot and cool, near and far, relaxation and excitation, emphasis and deemphasis. Coupled with this are the conventional cultural meanings associated with different colors, for example, that red means stop or danger while green means go or OK.

Information Contents

In the control environment, design employing color must be instrumental. Color here is not used because it is pretty but because it conveys information to reduce error and improve performance. This, of course, does not imply that aesthetic values may be disregarded. Ugliness is a distraction. An ugly use of color will interfere with the conveyance of meaning (unless the jarring impact of ugliness is used itself as an informative measure, i.e., to gain specific attention.)

The designer using color in a control environment must use color for specific effect, bearing in mind the constraints of physiological, perception, emotional content, and accepted cultural meanings. The designer must make these aspects of color work for him.

Guidelines for the Use of Color.

The following guidelines are proffered for the user of color (Christ, 1975; Durrett & Trezona, 1982; Szoka, 1982; Williges & Williges, 1981):

1. Do not convey any meaning by color alone. Color should be used as redundant information, to "highlight" or confirm an informational message. The physiological perception of color is not uniform enough to rely on the absolute discrimination of color to convey information reliably. This is particularly true with reference to colorblindness.

2. Color can be used in coding, but an upper limit of a dozen color codes should be respected.

3. Color coding should conform to accepted cultural standards. For Americans, these are:

red	—	danger, halt, stop, prohibited, fire
yellow	—	look out, risk involved, caution, hazards
green	—	go, OK, normal, desirable, safety
blue	—	inactive, status out of service
orange	—	dangerous, beware
purple	—	radiation hazards
white	—	inactive, status ready

4. In general, no more than three to five colors should be used in a single display. The colors, when used for information coding, should be separate from one another to the extent feasible. Leebeek (1974) offers the following:

2 colors	—green, red
3 colors	—green, red, white
4 colors	—green, red, white, blue
5 colors	—green, red, white, blue, yellow

5. Do not place complimentary colors side by side. These colors clash and can produce a "jiggle":

red/green
blue/yellow
green/blue
red/blue
yellow/magenta

6. The following are mentioned as colors which may be used side by side:

blue/magenta

cyan/magenta
blue/cyan
yellow/green
yellow/red
magenta/red
cyan/yellow

7. Confine lighter blues to background areas or outline the color shape in white.

8. On a dark background, alphanumeric data may be displayed in white, cyan, yellow, yellow-green, or red.

   On a light background, alphanumeric data may be displayed in high contrast blue, black, or green. In short, use high color contrast for character/background (figure/ground) relations.

9. Since red and green are not easily visible at the periphery of the eye, use white for signals to be perceived in this area.

10. Red tends to excite the eye and eventually cause eyestrain. Red should be used judiciously to cause excitement, e.g., alert to danger.

11. Kaleidoscope color clutter should be avoided. This causes confusion and eyestrain. Try to use a given color in a given region of the display.

12. As the number of colors used increases, increase the size of color coded objects.

13. Color coding in general speeds up search tasks.

14. Material presented in color is assimilated somewhat faster than monochromatic data, but it is not assimilated more accurately.

15. Critical information displays using color should be designed so that they can be printed or displayed on a monochromatic backup device without loss of information.

16. Be consistent in the use of color codes. Once defined, a color code should be used thereafter with the same meaning.

17. Outline in white.

18. Use background color to differentiate functionally different areas of the display.

19. On displays with only primary colors, for bar and pie charts, use one color with different shading patterns and highlight with a solid color.

For the best shading patterns, use one angle and vary the density.

20. On displays with large palettes, for bar and pie charts and for maps, use a single hue and vary the brightness.

21. On displays with only primary colors, for curves, just two or three colors may be used by using different line textures and weights. Do not use blue to draw curves. Use color to key axes to curves, especially with double labelled axes.

22. Color can be used to downplay information—to make something less important use blue or cyan.

23. Above all, always use color for a specific purpose. Never use a color without a reason.

The advice given above concludes that in general no more than three colors should be used in coding and that no more than ten colors should be displayed at any one time. Typical low cost color graphics devices provide an active palette of about eight colors, including black and white. At first glance, then, it might appear that such devices are completely adequate for color usage. However, an inexpensive eight color palette provides, as a rule, just the RBG and CMY colors at full saturation. The exclusive use of fully saturated color tends to produce eyestrain in the user and a loss of detail focusing and to create a subjective feeling that the display is unattractively garish. The effect on the eye is like that of viewing a television with the contrast control turned high. For easy and accurate long term viewing, these fully saturated colors need to be "toned down."

Further, these simple palettes are unable to provide a "family" of colors. A color family is obtained by holding the hue dimension constant while varying the coordinates of saturation and/or brightness. The ability to define the coordinates of saturation and/or brightness allows the fully saturated colors to be toned down. In addition, it is often possible to substitute a family of colors for a fully saturated color when designing within the three-on-the-screen limitation. For example, this is the difference between the

guidelines (19) and (20). It also leads to the capability to provide three-dimensional representations using shading colors from within a single color family.

24. This leads to the practical observation that the active palette of a display device need not be very extensive, say 8 to 16 colors for most work. However, the entire color palette should be definable in terms of a color coordinate system, either of the color cube variety or of a color cone model.

25. Imaging refers to the display of scenes captured by sensors, such as cameras, and converted to digital data or to the computer generation of simulations of such scenes. In contrast to other categories of information display which present abstractions of an object, imaging attempts to reproduce the object with full fidelity. Thus, imaging has two characteric requirements: very high resolution and a large active palette. Resolution for effective imaging is typically on the order of 1024^2 and the active palette is typically at least 256 colors. These characteristics give a requirement for several millions of bits to completely specify an imaging display. As a consequence, little real-time imaging with this quality of reproduction has yet been done. For the next few years, imaging capabilities will likely remain in the domain of expensive hardware which is only cost-effective in specialized applications, such as video special effects.

    Because imaging is the only graphics technique devoted to reproduction of high-fidelity images, it also is the only technique which can legitimately justify a large active palette.

26. When displaying text, a single character color should be chosen for use within a single background field. This figure/ground relation should be chosen to maximize the figure/ground contrast per (8). Emphasis within the field should be displayed by a figure/ground color reversal ("inverse video") rather than by introducing another color.

27. A practice to be explicitly warned against is the coding of characters by color to indicate different classes of messages against a single background. This practice generates unreadable displays and user headaches. If coding of message content is required, prefix the message string by an iconic symbol or by a solid block of color.

    Suffixing or end-delimitting the message string with a similar redundant color block should be avoided. Such suffixing can take either of two forms. In the one, the suffix immediately follows the message string. In this case, the color block will interfere with the messages immediately above and below. In the other, the color block suffix is placed at the right hand border of the message field. The intervening blank space effectively disassociates the suffix from the message and renders it useless as a redundant code.

28. Typically, CRTs capable of generating color may also be used as a standard monochrome monitor. This default monochrome figure/ground relation should be used throughout to identify that region or field of the display through which normal communications will take place. Other specifically color-coded fields should indicate something about the specific application in progress.

29. Some inexpensive color displays resolve in color only to the area of a single character rather than to a single pixel. This type of display should be avoided because this limitation severely limits the amount and the location of text which may be displayed. Resolution should be sufficient to define color for any pixel on the display as opposed to character cells. However, in general, resolution does not need to be greater than that available on standard KCRT's.

    The accuracy of color electron gun alignment should be precise enough that any color may be defined for any pixel on the display without color distortion. This is of particular importance on the periphery of the display field where "pincushion" effects may arise. With inaccurate RGB gun alignments, characters appear as varigated colors rather than as a single color.

Interaction Techniques and Tasks

In an automated environment, primary control is exercised by computers. The human, in the role of a system supervisor, interacts with the mediating computer much more actively and intensely than with the actual system being controlled. For this reason a great deal of attention is now being directed to the tools and techniques for interacting with computers. Special reference in this regard should be made to Newman and Sproull (1979), Foley and Van Dam (1982), and Foley, Wallace, and Chan (1981).

In this section, guidelines for the use and application of several tools and techniques for interacting with a computer will be given. An "interaction technique" is a hardware/software assembly which allows a user to send data to a computer while the computer is running a user process. An interaction technique is typically used in the context of an information or data exchange between the computer and the user. It is thus a very special type of input device. Interaction techniques for input are generally

used with a VDT or graphics output device. Table 5-2 lists several common interaction techniques. Power region control keys and sensors are included but as yet are in the experimental stage.

Foley, Wallace, and Chan (1981) identify six interaction tasks and four controlling tasks. They differentiate between interaction and controlling tasks in the following way: Interaction tasks do not directly modify the displayed image while controlling tasks do directly modify the displayed image.

For the purposes of these guidelines, controlling tasks will be included as interaction tasks. Table 5-3 lists the tasks identified by Foley, Wallace, and Chan (1981).

In brief, the nine tasks are described by the following summary:

- o selection—the user makes a selection from a set of displayed alternatives.
- o position—the user indicates a position on the interactive display.
- o orientation—the user orients an entity in two-dimensional or three-dimensional space.
- o pathing—the user indicates a series of positions or orientations on the interactive display through time.
- o quantification—the user specifies a value to quantify a measure.
- o text—the user specifies a string of characters to be used as data
- o stretch—the user moves a particular feature of a displayed entity to a new position, while the remaining features are unaltered.
- o manipulate—the user moves an entity about on the display in two-dimensional or three-dimensional space.
- o shape—the user changes the shape of a two-dimensional or three-dimensional displayed entity.

A variety of hardware/software configurations, as illustrated in Table 5-2, may be adapted to the execution of these tasks. Foley, Wallace, and Chan (1981) analyze the application of these interaction techniques to these interaction tasks. Their conclusions

ORIGINAL PAGE IS
OF POOR QUALITY

Interaction Techniques

touch panel	direct interaction with display	
light pen		
tablet and stylus	indirect interaction with display	
mouse		
joysticks		
trackball		
cursor control keys	keyboard based	command and data entry
power region control keys		
alphanumeric keyboard		
functional keyboard		
soft keys		
chord	nondirect interaction with display	
voice		
sensors		

Table 5-2

ORIGINAL PAGE IS
OF POOR QUALITY

Interaction Tasks	
Select	interacting
Position	
Orient	
Path	
Quantify	
Text	
Stretch	controlling
Sketch	
Manipulate	
Shape	

Table 5-3: Foley, Wallace & Chan (1981)

will be summarized here as they apply to typical control room activities.

A note must be made regarding current use of displays for control purposes and potential usages. At the present time, virtually all NASA/GSFC display interactions involve text and numeric data with which the human operator/supervisor interacts by entering command strings with parameters. These applications are essentially modelled on teletypewriter devices which have been available since the 1950's.

Recently, new approaches have been suggested to implement both interactive graphics and color. The graphical representation of data in real time has the potential to allow the system operator/supervisor to exercise control by the pictorial manipulation of representation(s) of the controlled system. Implementation of this approach is, as yet, sometime in the future. These guidelines will reflect what is the best of current knowledge with regard to these future applications.

The basic interaction techniques listed in Table 5-2 may be briefly described as follows:

Touch Panel. A touch panel is based on a frame surrounding the display screen itself. Within the frame the presence of an object, typically a finger, may be sensed and its position determined. Such touch panels have been used in applications where a keyboard cannot be provided and/or where designers have determined that a keyboard is inappropriate for the intended user. Its use has often been urged on the basis of its extreme simplicity in use—the user merely places his finger at the desired location on the display within the frame.

This ease of use obtains, however, only under stringent conditions. The display must be within an easy arm's reach of the user. Due to the relatively large size of the human finger in relation to a graphics display, only a relatively low resolution can be obtained. This low resolution is forced by the requirement to compensate for human

motor inaccuracies in rapid finger positioning. A major component of such inaccuracies is the so-called "sweep error" and its aggravation by the physical geometry of the display in some touch panel implementations.

To obtain the highest resolution, the finger needs to be positioned at some distance from the display and then moved in a single straight line perpendicular to the visual surface of the display, somewhat like the old military academy custom of "eating a square meal." In actual practice, a person "sweeps" a finger toward the selected point and the tip of the finger traverses some arc during approach and again during departure. As a result, "extra" room must be provided around each target position to provide space for the finger arcing in and out. Without this room, the touch panel will spuriously register "selections" which are in actuality only the finger on its way to the desired location. The activation of such spurious selections is termed "sweep" error."

There are two generic types of touch panel, the "surface" and the "frontal plane." The surface touch panel is constructed so that its sensing elements (primarily capacitance) are embedded in or lay directly on the surface of the display screen. The frontal plane touch panel is placed in front of the display screen. Since most VDT screens are in fact not flat but curved, i.e., a sector of the surface of a sphere, the frontal plane touch panel is closer to the center of the display screen than to the periphery of the display screen. Hence, sweep error becomes worse as the finger is positioned further from the center of the display.

When surface touch panels are employed, this sweep error can be largely avoided. However, while frontal plane touch panels do not obscure the view of the curved display, ordinary surface touch panels use sensing filaments that "wrap around" the curved surface. Unfortunately, these sensing filaments are visible elements. The result is that higher resolution can be obtained but a greater obscuration of the displayed image occurs.

The consequences of these considerations are that touch panels become restricted to use in selection tasks and that the number of alternatives must be quite low, on the order of a 4 x 4 matrix on the face of a display within easy reach of the controller. These restrictions may be quite acceptable in some situations, for example, information retrieval. In the environment of real time control exercised by multi-person teams, the limitations and inflexibility of these restrictions argue strongly against the use of touch panels.

Light Pen. With a light pen, a light-sensing element is coordinated to the display of a specific light-emitting image on the display screen. The light-sensing element is typically housed in a tubular object resembling a pen (albeit vaguely), hence the name.

The resolution of a light pen is much greater than that of a touch panel, but the user is required to wield the device. When used with a keypad, a continued change between grasping and positioning the light pen and positioning the hands on the keypad is required. Because the light pen must be held for activation nearly perpendicular to the display screen, an unnatural position in most VDT configurations, users tend to report arm and hand fatigue after lengthy sessions. As with the touch panel, obviously, the display screen must be within easy reach of the user.

The alternation between using a keypad and using a lightpen is referred to as a change in "modality." While many interaction techniques require a change in modality, the change with a lightpen is most drastic because the plane of the hand's movement is changed from the horizontal to the vertical, i.e., a complete muscular reorientation is required.

While the lightpen remains a very powerful technique due to its high resolution, other techniques obtain even higher resolution with less change in modality, thus with less muscle fatigue and lower error in precise tasks.

Tablet and Stylus. The tablet is a flat worksurface equipped with sensors to detect the location of a stylus (pen) point on its surface. It may be used much like a sketch pad and is frequently the input technique used for sketching. As the stylus point is detected on the worksurface, a cursor or other pictorial element is displayed at the corresponding location on the display screen. The tablet and stylus has been successfully used in a wide variety of interaction tasks. However, because the tablet-and-stylus works best when the tablet is the same size as the display screen, it is a large piece of equipment. Since the operating feedback comes from the visual display, a large degree of motor skill is involved to move the hand holding the stylus while the eyes remain on the visual display.

Mouse. The mouse is a handheld device whose underside is equipped with wheel-like rotating elements. The mouse is used to move a cursor displayed on the screen. In contrast to the tablet-and-stylus which determines absolute locations on the display, the mouse generates relative movement of the cursor. A consequence is that the mouse may be used on any convenient surface and that long cursor movements may be generated by repeating short movements of the mouse. For tasks requiring cursor movement, the mouse has consistently been determined to be the most practical interaction technique.

Joystick. The joystick is a mounted rod which the user pushes in the direction the displayed cursor should go. It may work on the basis of angular displacement or pressure. While conceptually quite appealing in its analogy to a pilot's control stick, practical implementations have routinely suffered from non-linear response characteristics. It is difficult for the user to determine beforehand just exactly the angles and pressures required to bring the cursor to a desired position. As a result, an extended period of trial-and-error is typically needed to obtain a given result; time to complete tasks and error rates are relatively high.

Trackball. The trackball is used to control relative cursor movement by rotation of

the exposed surface of a ball element in the desired direction. A trackball is conceptually a joystick without the stick. Trackballs exhibit the same problems of non-linear response as joysticks do.

Cursor Control Keys. This is a set of keys on a keypad. Each key controls cursor movement in a separate direction. Typically right, left, up, and down cursor control keys are possible. Thus, only right angle movements, horizontally or vertically, are provided. Cursor control keys are used predominantly with the display of textual information to locate a particular character on the display, i.e., movement is from one character cell to another rather than from one pixel to another.

Some systems allow the terminal user to switch back and forth between different modes of interpretation of the cursor control keys. In the text mode, the cursor movements controlled by the cursor control keys define row and column coordinates. In the graphics mode, the cursor movements define X and Y display coordinates. In such a graphic mode, an object such as a crosschair is displayed to indicate the current location of the graphics cursor. Resolution to one pixel is easily obtained in this mode. However, the penalty of Fitt's Law is quite high when movements are constrained to the vertical and the horizontal. Fitt's Law asserts that

$$T = Q + K \log_2 A/(B/2)$$

where T is the time of the positioning move;

A is the length of the positioning move;

B is the size of the target;

Q and K are empirically determined constants.

Thus, for satisfactory use of cursor control keys, targets should be relatively large (i.e., of low resolution) and ample time should be allowed.

A major attraction of cursor control keys is that they may be built into the

standard keypad, requiring no separate equipment or changes in the hand modality. The preferred configuration of cursor control keys is illustrated in Figure 5-8. This arrangement maps the intuitive relations of up-and-down and left-and-right. The central key is often implemented as the Home key. Any key used to designate selection should be removed from this immediate arrangement to avoid erroneous selections caused by missplaced keystrokes.

Power Region Control Keys. This is a set of keys on a keypad. Each key controls selection of a subregion of the display (Bocast, 1982). Figures 5-9 and 5-10 illustrate the keypad arrangement and a typical selection sequence. Regions selected are indicated by altering the background color of the display. Like cursor control keys, power region control keys share the same hand modality with the keypad and require no extra equipment.

The principle functional difference is the speed of indicating a high resolution subregion of the display. The power region technique, for example, can resolve to any 2 x 2 pixel subregion on a 512 x 512 display in 5 keystrokes. However, the nature of the recursive reorientation of the meaning of the control keys may make it difficult to exercise this technique.

Alphanumeric Keyboard. The standard input device, providing keys similar to a typewriter keyboard. Using the alphanumeric keypad, the user enters strings of characters as commands or directives and data. As with ordinary typewriters, effective use of alphanumeric keyboards requires the development of reasonably sophisticated motor skills resembling those of touch typing. In one way or another, all interaction tasks may be carried out using the alphanumeric keypad, and it is found whenever command-control computers are actively used. The interaction tasks are specified by strings of characters entered by the user. Generally, the echo of the command itself as

ORIGINAL PAGE IS
OF POOR QUALITY

PREFERRLD CONFIGURATION
OF CURSOR CONTROL KEYS

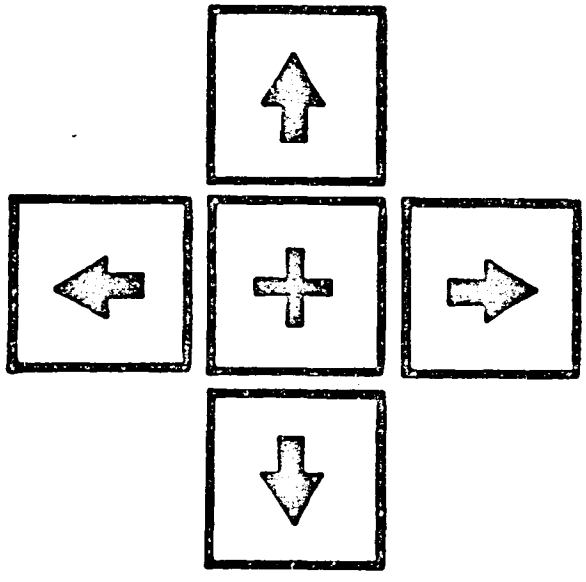


Figure 5-8.

ORIGINAL PAGE IS
OF POOR QUALITY

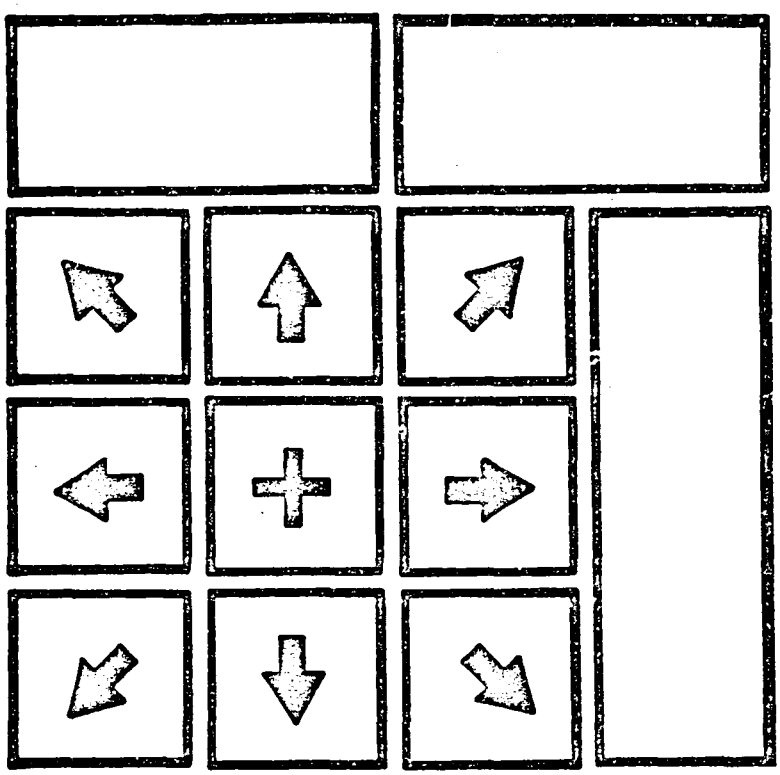
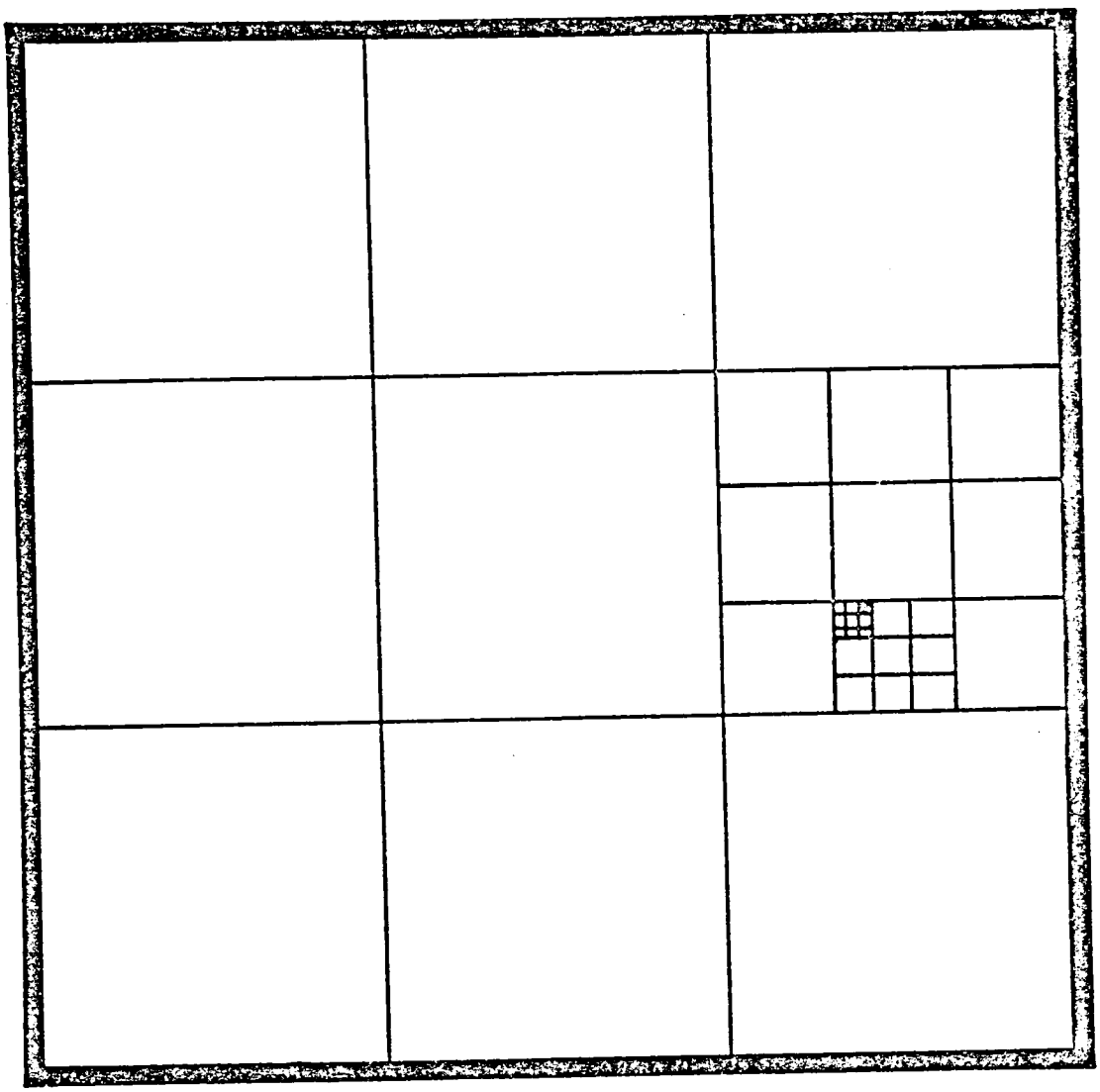


Figure 5-9.

ORIGINAL PAGE IS
OF POOR QUALITY



POWER REGION RESOLUTION

Figure 5-10.

typed in and the effect of the command must be displayed. Depending upon the complexity and number of the available directives and the resolution required, lengthy strings may be needed to fully identify and qualify a given command. As the number of characters typed increases, so does the time taken and the error rate.

Function Keyboard. The function keyboard is a special purpose keypad. The keys of the function keypad represent unique functions or procedures to be carried out when the key is pressed, rather than alphanumeric characters. The function keyboard can greatly reduce the number of required keystrokes (as is demonstrated, for example, by their widespread adoption as input to cash registers in fast food stores). Further, the keypad itself acts as a physical menu of the possible control commands. Many terminals incorporate function keys in the same unit as the alphanumeric keypad.

Soft Keys. Soft keys refers to a keyboard technique in which the definition of the meaning of a keystroke is under software control. Typically, the current definitions are displayed on the screen. When a key is depressed, the indicated function is carried out. On some systems an area of the display may be reserved for the soft key definitions and certain designated keypad keys are permanently associated with these definitions. At the other end of the spectrum are menu-driven interaction routines. In these, a menu of choices is displayed on the screen, and each menu choice identifies the alphanumeric key to use to select the choice. With menu-driven techniques of this type, the entire alphanumeric keypad becomes a set of soft keys. Intrinsic to the use of soft keys is the need to set aside at least some portion of the display for the definitions of the key. Thus, soft key applications may restrict the controller's view of the system under supervision.

Chord. The chord is a unit containing a set of keys pressed in combinations rather than one at a time. Thus, several keys are played at once to produce a chord as on a

piano. The need to remember the different chord combinations and then to finger the chord accurately has proven to be a severe drawback to acceptance of chord devices. As a device, it is essentially an effort to reduce the number of function keys required to the log to the base 2 of the number of function keys. While this may greatly reduce the size of the hardware, the use of more than 3 keys (8 chords) leads to rapid memory overload and rather slow human response times.

Voice. While all of the preceding techniques are based upon hand and finger manipulations, voice techniques rely instead on the electronic interpretation of spoken words. Systems capable of this task are rapidly becoming more sophisticated, capable of understanding larger vocabularies at higher speeds. At this point, voice systems are trained to specific voices. Voice input must be clearly enunciated, forcing a calm and measured speech pattern. Words spoken hurriedly, while under stress, or even while suffering from a cold, may not be understood.

For any given word (token), voice input may be faster than corresponding alphanumeric input. Quite clearly, major attractions of voice input are that it leaves the hands free for other uses and that commands may be spoken into a neck microphone while the user physically moves about. Functionally, voice input is an alternative to keyboard based techniques.

Sensors. Sensors refer to ongoing experimentation with currently exotic techniques based upon whole body sensing. These techniques do not provide the user with a specific tool like a lightpen. Rather, they place the user in an instrumented environment which senses the physical movements of the body and interprets these in meaningful ways for the computer. Techniques such as those under development in the Spatial Data Management System by the Architecture Machine Group at MIT will need to be considered carefully for future use, particularly in multi-person environments.

Guidelines

It should be evident from these brief descriptions that the applicability of a specific interaction tool or technique depends upon the task to be performed, the physical environment of the task, and the characteristics of the user. This section's guidelines would apply, assuming the following conditions:

- o that the environment is one of real time command and control. This requires a minimization of response time and error rates.
- o that the flow of data and commands is potentially complex in its structure, requiring the ability to select quickly and accurately from among many alternatives and thus requiring high resolution techniques.
- o that control and supervision will be exercised by a team of appropriately trained individuals.
- o that voice communications will be used to coordinate and pass information among teams of controllers.
- o that data and system states will increasingly be presented graphically and that three-dimensional physical or symbolic animation will be incorporated into the repertoire of data display techniques.

1. An alphanumeric keyboard should be provided as the fundamental interaction technique. No matter what other interaction technique(s) is (are) employed, the user should be able to simulate the technique using the keypad.

   Corollary: The standard keypad should be capable of generating a full 256 character set to support such simulation, using (CTRL) and (CTRL)(SHIFT) combinations as well as special function keys.

2. Cursor control keys should be incorporated into the standard keyboard in the preferred configuration of Figure 5-8. Ideally, the configuration of Figure 5-8 may be adopted; this configuration allows then implementation of standard text, standard graphics, and power region cursor control.

   Corollary 1: The display device should have addressing resolution to one pixel.

   Corollary 2: The display device should support figure/ground

reversals, like "inverse video."

3. Additional interaction facility should be provided by a mouse.

4. Touch panels are not appropriate for the real-time control environment because of their lack of resolution and their requirement for physical touching proximity to the display. Touch panels are appropriate for untrained individual users making simple selections from a fixed user position and outside of realtime, especially in confined quarters where no provision for a keyboard can be made. A touch panel would be excellent for a personnel officer working in a submarine.

5. Light pens are not recommended in the control room environment because of the requirement for physical touching proximity to the display. For example, a light pen could not be used for interaction with a large screen area display while a mouse may be used in such an application.

6. The tablet and stylus are not recommended in the control room environment because of the working surface they require and due to the difficulties of eye/hand coordination in their use. The tablet and stylus are highly recommended for digitizing analog data, such as sketching and maps.

7. Joysticks and trackballs are not recommended. Due to their non-linear operating characteristics, they are invariably outperformed by the mouse with its linear operating characteristics.

8. Chord input devices are not recommended.

9. Voice input devices are in general cautioned against in the multiperson control room environment. In this environment, the level of voice communications within the team and with other groups argues against adding to the general noise level. Indeed, in this environment the "hands free" attraction of voice input is counterbalanced by the need for the controller to keep his mouth free for communications with team members and other groups.

   Further, the present requirements to "train" a voice input device argues against the emergency interchange or replacement of controllers. At the current state-of-the-art in voice input technologies, multiple training over several operators quickly becomes very resource demanding. Voice input is appropriate for a single well-defined task, such as security recognition or inventory monitoring. In the first case, we have many users but a very small vocabulary; in the second, we have a large vocabulary but typically a single user.

10. Soft keys should be used with caution in the control-room environment because the key definitions can greatly reduce the display needed to monitor the system under control and supervision. When one can leisurely consider the data and then turn to consideration of action alternatives, soft keys, particularly in the form of menus, have proven to be very effective, even though time consuming.

    Corollary: Interaction techniques should be chosen and implemented to preserve as much as possible of the view of the system provided by the display. The guidelines suggested here will support personnel inter-operability, support control workstation inter-operability, support interaction with both individual and large-screen displays, and minimize the workspace and the hardware required at each control workstation.

ISSUES FOR FURTHER RESEARCH

A great deal of research has been conducted on the human factors of VDT devices in the workplace. Almost exclusively this research, has taken place in the environment of the office. Many of these findings, for example, those concerning health hazards, are generalizable to any environment. However, the validity of an extension of all findings from an office environment to NASA's control room environment remains to be verified.

The first part of this chapter covered the ergonomics of VDTs in office environments. An important qualification of these studies is that they have, in the main, been concerned with monochromatic displays used exclusively for text processing by single autonomous operators. A great deal of useful information has been developed within this context. Unfortunately, little information is readily available on the topics of color and graphics, which are of ever increasing importance in the control room environment. These technologies and their applications are still so new that only bits and pieces with a human factors impact have entered the literature. This is not to say that there is not a wealth of material available on graphics, per se. However, nothing speaks directly or indirectly to the human factors issues of computer hardware for graphics

generation which is not subsumed under the other sections of this chapter.

The conclusions of the ergonomics sections need to be verified and extended for the NASA/GSFC environment. But the realms of color and graphics for the NASA/GSFC control room environment, particularly in a multi-person team context, are almost completely unexplored. Those in the field barely know yet how to phrase the correct questions relating physical hardware capabilities for color and graphics to speed and reliability in human performance.

The following are some examples of such basic questions which need to be examined from the human factors perspective of human performance efficiency:

- What is the optimum display resolution for graphics tasks?
- Does the use of vector or of raster graphics technology impact performance?
- Does color used in pictoral representation interact with the use of color for coding?
- Is there an optimum or a threshhold for update intervals on real-time animation?
- For information display in a real time control room, is there any optimum subset of a 3-dimensional color space?
- Can multidimensional interaction techniques be developed?

REFERENCES

Bailey, R.W. Human Performance Engineering: A Guide for System Designers. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.

Banks, W.W., Gertman, D.I., & Petersen, R.J. Human Engineering Design Considerations for CRT-Generated Displays. Idaho National Engineering Laboratory, ID: U.S. Department of Energy, October, 1981.

Bergman,. T. Health Protection for Operators of VDTs/CRTs. New York, NY: NYCOSH VDT/Work Group, 1980.

Bocast, A.K. Information Display and Interaction in Real-Time Environments. Proceedings of the Human Factors Considerations in System Design Symposium,

NASA/GSFC, 1982, 319-358.

Cakir, A., Hart, D.J., & Stewart, T.G.M. Visual Display Terminals. New York, NY: John Wiley and Sons, 1980.

Center for Disease Control. Working with Video Display Terminals. New York, NY: John Wiley and Sons, 1980.

Christ, R.E. Color Research for Visual Displays. Proceedings of the 18th Annual Human Factors Society Conference, October 1974, 542-546.

Cold Type Organizing Committee. Don't Sit Too Close to the TV: VDTs/CRTs and Radiation. Bronx, NY: Cold Type Organizing Committee, September, 1980.

Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: Department of Defense, May, 1981. MIL-STD-1472C.

Durrett, J., & Trezona, J. How to Use Color Displays Effectively. BYTE. April, 1982.

Fitts, P.M., & Radford, B. Information capacity of discrete motor responses under different cognitive sets. Journal of Experimental Psychology, Vol. 71, 1966, 475-482.

Foley, J.D., & Van Dam, A. Fundamentals of Interactive Graphics, Reading, MA: Addison-Wesley Publishing Co., 1982.

Foley, J.D., Wallace, V.L., & Chan, P. The Human Factors of Graphic Interaction Tasks and Techniques. Washington, D.C.: George Washington University, Institute for Information Science and Technology, GWU-IIST81-3, January, 1981.

Gantz, J., & Peacock, J. Computer Systems and Services for Business and Industry. Fortune, Vol. 103, No. 8, 1981.

Grandjean, E., & Vigliani, E. (Eds). Ergonomic Aspects of Visual Display Terminals. London: Taylor and Francis, Ltd., 1980.

Human Factors. Special Issue, CRT Viewing I, V.D. Bhuse and E.J. Rinalducci (Eds.). Volume 23, No. 4, August, 1981.

Leebeck, H.J. Ergonomics for Command and Control Rooms. Instituut voor Zintuigfysiologie, Soesterberg, the Netherlands, IZF 1974-17, 1974, NTIS75-14458.

Murray, W.E., Moss, E., Parr, W.H., & Cox, C. A Radiation and Industrial Hygiene Survey of Video Display Terminal Operations. Human Factors, Vol. 23, No. 4, August, 1981.

Newman, W.M., & Sproull, R.F. Principles of Interactive Graphics (2nd Edition). New York, NY: McGraw-Hill Book Co., 1979.

NIOSH. Potential Health Hazards of Video Display Terminals. Cincinnati, OH: U.S. Department of Health and Human Services, DHHS 81-129, June, 1981.

Radl, G.W. Visual Display Units: Present Status in Ergonomic Research and Applications in the Federal Republic of Germany. In E. Grandjian and E. Vigliani (Eds.). Ergonomic Aspects of Visual Display Terminals. London: Taylor and Francis, Ltd., 1980.

Ramsey, H.R., & Atwood, M.E. Human Factors in Computer Systems: A Review of the Literature. Englewood, CO: Science Applications, Inc., Sept., 1979 NTIS-AD-075-679.

Shurtleff, D.A. How to Make Displays Legible. La Mirada, CA: Human Interface Design, 1980.

Smith, M.J., Cohen, B.G., & Stammerjohn, L.W. An Investigation of Health Complaints and Job Stress in Video Display Operations. Human Factors, Vol. 23, No. 4, August, 1981.

Szoka, K. Practical Considerations on the Use of Color. Silver Spring, MD: Computer Sciences Corp., April, 1982.

Tabor, M. Video Display Terminals: The Eyes Have Had It! Guild Notes. May, 1982. U.S. Department of Commerce. Statistical Abstracts of the United States: 1979 (100th Ed.). Washington, D.C., 1979. (Table No. 685)

Williges, B.H., & Williges, R.C. User Considerations in Computer-based Information Systems. Blacksburg, VA: VPI Industrial Engineering and Operations Research Department, 1981, NTIS-ADA-106194.

Working Women Education Fund. Warning: Health Hazards for Office Workers. Cleveland, OH: Working Women Education Fund, April, 1981.

CHAPTER SIX

HUMAN FACTORS OF COMPUTER SYSTEMS: THE SOFTWARE

INTRODUCTION

The previous chapter surveyed human factors considerations of the hardware or physical characteristics of computer systems in general, emphasizing VDTs in particular. This chapter will address the software or informational attributes of computer-based systems.

Software or informational attributes are fundamentally design issues; that is, given a piece of hardware and its associated capabilities and limitations, the software design issues concern how best to use the hardware capabilities to enhance the user-computer interface. These are issues which are highly discretionary, giving a good deal of flexibility to system designers. Moreover, these issues are critical determinants of the effectiveness and efficiency of the human-computer system. Poorly designed displays lead to operator annoyance, stress and strain, and in the worse case, operator error. Unfortunately, the software design issues are not nearly as well understood as the issues dealing with VDT hardware. Partly, it is a matter of time. Over the next several years, as the research evidence accumulates, many useful guidelines can be expected. On the other hand, some of the issues are difficult issues; they are often poorly defined and dependent on an understanding of human information processing which is far from complete.

As in the previous chapter, this chapter will present synthesized results from published guidelines and, for those issues for which the evidence is still inconclusive, user considerations. Topics include some general guidelines for the design of interactive systems, properties and types of interactive dialogue, coding techniques, informational

properties of displays, system-generated messages, and system response times. These topics will be preceeded by a short discussion of the design problems created by the introduction of computer-based displays into the command and control environment. The chapter concludes with a discussion of the needs for further research.

DESIGN ISSUES FOR COMPUTER-BASED INFORMATION DISPLAYS

In traditional command and control environments, information is displayed using banks of information displays, often called dedicated displays. Dedicated displays are typically unimodal or single-function and hardwired to the console. Dedicated displays present information in parallel, showing all the information they are designed to display all of the time, with no potential for selectivity. The operator, therefore, is required to assimilate the full set of displayed data, mentally and visually culling out that which is pertinent to the situation at hand. For a complex system, dedicated display control rooms have vast expanses of displayed data, inevitably leading to information processing problems for operators and space problems for designers.

An integrated information display is one in which many signals or pieces of data are presented in an interrelated form in a small area, usually on a CRT screen. Computer-generated information displays permit reconfigurable data screen formats in which not all of the data are displayed all of the time.

Given the technology for integrated displays, the possibilities are exciting. Integrated displays permit a selective presentation of information, providing a window into the system so that only a small portion of the system variables are displayed at any given time. Integrated displays centralize data, reducing the time the operator must spend searching for relevant pieces. Such displays afford the possibility of combining, summarizing, and abstracting primitive or low level status information in order to

present it to the operator in a form more compatible with the operator's high level information needs. Integrated displays permit designs which allow the operator to control the displayed data, the level of detail, and the level of abstraction.

The advent of minicomputers, microcomputers, and CRTs makes the computer-based control room an attractive alternative to conventional designs. Human factors research and emerging technology have continually improved the hardware aspects. The design problem of what to display on the screen has received little attention, however. This is basically a design problem, and the design problems for computer-generated displays are complex. In a dedicated display configuration, the primary design issue consists of a determination of the total information needs of the operator and, given those information needs, determination of how best to display the information. The key point, however, is that the designer of a dedicated information display system must decide these issues only once, whereas the designer of an integrated information display must make these decisions over and over again, for a multitude of system states and user needs.

Integrated display design must include three additional considerations. The first is the dynamic capability of integrated displays. In a dedicated environment, information is always present in the same form, regardless of the current information requirements or system state. Integrated displays afford the designer the opportunity to create dynamic rather than passive displays. Thus, a major design issue for integrated displays is not only what to display, but also when to display it.

The second issue concerns the capability of computer-generated displays to vary the level of detail of the displayed information. Integrated displays have the potential to change the mode of the displayed data, to summarize or aggregate lower level sources, and to abstract or present the states of multiple system components in a form more

useful to a human operator. By relieving the human operator of some of the more tedious information processing tasks required in monitoring and interpreting multiple information sources, integrated displays can be very helpful in reducing the information overload problems typical of data-intensive control stations. Integrated displays can selectively display data, suppress less important pieces, and prioritize others.

The third major design challenge for integrated display stations is the need for development of schemes to enable the operator to access required information effectively and efficiently. The goal in designing an integrated information display is to make it as easy and natural for an operator to extract information from the computer-based display as it was to scan the displays of a conventional control room.

These design issues are critical in real time environments but relevant in almost every setting in which a VDT is used for decision making. Some of the design guidelines and user considerations which follow begin to address these issues. However, for the most part, there has been very little comprehensive research on fundamental design principles for information displays. Except for some preliminary work on such properties as coding techniques and some general guidelines on formatting and labelling, little has been done to determine how best to exploit the power of computer-based displays.

GENERAL PRINCIPLES FOR EFFECTIVE DESIGN

Pew and Rollins (1975) suggest that a fundamental requirement for effective design of the human-computer interface is knowledge of the user population for whom the system is being designed. This includes an understanding of user backgrounds and knowledge, level of training, turnover in their jobs, and level of computer expertise.

At a deeper level, it is important to have an understanding of those psychological issues which motivate users and those which limit user capability. A primary factor

which limits or degrades human performance is the set of limitations on human memory and human information processing. Both Martin (1973) and Shneiderman (1980) provide brief reviews of psychological models of human memory and information processing strategies. A more thorough treatment is presented in Chapter Seven of this document. Although psychologists have not reached a consensus on the processes of information storage, retrival, and synthesis, there is a good deal of information which the designer can use to avoid configurations which are likely to tax the human component of the human-computer interface.

The attitude of the system designer towards the intended user is also critically important. Pew and Rollins (1975) suggest that systems should actively promote the personal worth of the individual user by respecting the intelligence, capabilities, and professionalism of the users. On an obvious level, this suggests the complete elimination of computer-generated jokes, ridicule, or praise. The computer-to-human dialogue should be concise, professional, and clear; this includes system prompts, command acknowledgments, and error messages.

Another generally agreed upon principle is that the user should be granted as much control as possible (Shneiderman, 1980). Good system design matches the level of control to the expertise of the user. Novice users will rely heavily on the system which tends to control the human-computer interaction; intermediate and expert users prefer systems in which the user has much more extensive control. A careful match of user to level of control will help to reduce user anxiety and frustration.

Computer-to-human communication should always be characterized by consistency and clarity. Error messages and other system-generated messages should be simple, direct, and unambiguous. When reporting errors, wording which does not imply fault should be used. Displays with variable format screens should strive to maintain

consistency across display screens. The same coding techniques should be used across screens. Position should be used as an information parameter whenever possible i.e., one portion of the screen should be reserved for error messages and warning messages.

Pew and Rollins (1975) suggest two final general guidelines. The system should, to the extent possible, carry forward a representation of the user's knowledge base. Whenever possible and useful, the system should keep track of previously made user choices and previously entered data so that the user is not required to reenter the data at a later time. To the extent possible, the computer should be an active decision aid, relieving the user of taxing bookkeeping. Finally, systems should be designed to allow users every opportunity to correct their own errors. Immediate feedback to users and the opportunity to correct errors quickly are major advantages of interactive systems and should be exploited in every way possible to minimize errors. Both are very rewarding to the user and, at the same time, contribute directly to system effectiveness.

THE DESIGN OF INTERACTIVE DIALOGUES

A fundamental design issue for the human-computer interface is the determination of the nature of the interactive dialogue. There are several types or modes of interactive dialogue. Choice of a particular dialogue strategy is typically both task-dependent and user-dependent. Before embarking on a comparison of specific dialogue types, an excellent presentation of dialogue properties provided by Ramsey and Atwood (1979) will be summarized.

Basic Properties of Interactive Dialogues

The dialogue properties discussed in this section are particularly important because they apply to all dialogue types and have some empirical data which supports the

conclusion. Figure 6-1 summarizes these properties and has been abstracted from the Ramsey and Atwood study.

In designing a human-computer dialogue, the issue of initiative must be addressed. It is important to focus on characteristics of the user who initiates an exchange. Research shows that computer-initiated dialogue is best for naive or casual users who require few exchanges with the system. More sophisticated users prefer the user control that user-initiated dialogues provide. Although there are design costs associated with it, a mixed mode system which allows the user to select the type of dialogue is probably preferred to a single mode system.

Flexibility is a measure of the number of ways the user can accomplish a given function. Some evidence suggests that flexibility is helpful for expert users. This is not the case for beginner or intermediate users who tend to adopt a satisficing strategy, learning only enough commands to accomplish exactly what they need.

Complexity and power are concepts related to flexibility. Complexity is a measure of the number of options available to the user at a given time. There has been little research in this area. Some evidence suggests that too much complexity, particularly when it is due to a large amount of irrelevant data, is detrimental to performance. At the opposite extreme is evidence that deep but sparse hierarchic structuring, though reducing complexity, is also a detriment to performance. Display complexity is an important issue and merits additional research.

The final property related to flexibility and complexity is power. Power is defined as the amount of work accomplished by one user command. A powerful human-computer dialogue allows users to accomplish a great deal with one or two "high level" commands. There is a feeling among managers that a powerful system tends to confuse users. Because power is often confounded with high complexity or a lack of generality, the issue

PROPERTIES OF HUMAN - COMPUTER DIALOGUES

(Ramsey and Atwood, 1979)

Dialogue Property	Description	Comments
Initiative	Initiative is concerned with whether the user or the computer initiates the individual information transactions within the dialogue. If the computer asks questions, presents alternatives, etc., and the user responds, the dialogue is 'computer-initiated". If the user inputs commands without such computer 'prompting", the dialogue is "user-initiated". "Mixed initiative" and 'variable-initiative" dialogues are also possible.	Computer-initiated dialogues are preferable for naive users or trainees, and for casual users. Computer-initiated dialogue allows reliance on passive, rather than active, vocabulary, implicitly teaches the user a "system model", and allows use of the system by a user who has not yet internalized such a model. Computer-initiated dialogue is also satisfactory for experienced users if use involves few transactions or system response is very fast. The latter usually implies a "smart"terminal. A slow, computer-initiated dialogue is very disruptive to the frequent, experienced user. See the later section on "response time". For most systems, designers should consider allowing the user to select either dialogue mode.
Flexibility	Flexibility is a measure of the number of ways in which a user can accomplish a given function. High flexibility can be achieved by providing a large number of commands, by allowing the user to define or redefine commands, etc.	There is evidence that nonprogrammer users adopt a "satisficing" strategy with respect to flexible dialogues. That is, they tend to utilize known methods for solving a problem even when the system provides less cumbersome methods, known but not yet learned by the users. There is also evidence that more flexible dialogues degrade performance (especially by increasing error rates) of relatively inexperienced users. Thus, highly flexible dialogues may be undesirable except for experienced and/or sophisticated users.
Complexity	Complexity is a measure of the number of options available to the user at a given point in the dialogue. Low complexity can be achieved by using few commands, or by partitioning the commands so that the user selects from a small set at any given time.	The effects of dialogue complexity on performance are unclear. It seems reasonable to expect that there is some optimal level of complexity for a particular task and user type, with degraded performance resulting from significantly more or less complex dialogue structure. There is evidence which suggests that a large number of redundant or irrelevant commands impairs user performance, and that extreme simplification" of the dialogue by hierarchic structuring is also detrimental.

Figure 6-1

ORIGINAL PAGE IS
OF POOR QUALITY

Dialogue Property	Description	Comments
Power	Power is the amount of work accomplished by the system in response to a single user command. In a dialogue with *powerful commands*, the user may accomplish, with a single command, an operation which would require several commands in a system with less powerful commands.	Obviously, the power of the commands must somewhat correspond to the user's needs, which may vary over time and users. In some application areas, a large range of command power is possible and use of relatively high-power commands can be very effective (e.g., matrix operators in a mathematical system). If power is achieved by using powerful commands and facilities instead of less powerful, but more basic commands, the result is a reduction in generality of the system. The MICA study found this to be a significant factor in system rejection by both managers and technical personnel. On the other hand, provision of powerful commands in addition to a more basic set tends to increase dialogue complexity. One possible solution is to partition the dialogue so the less sophisticated user is exposed to a sub-set of commands.
Information load	Information load is a measure of the degree to which the interaction absorbs the memory and/or processing resources of the user.	In most tasks, user performance is adversely affected by information loads which are either too high or too low.

Figure 6-1 (cont'd)

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

of power may not be so easily resolved. As with initiative, the best system is probably one which has a mix of commands: some low level and some quite powerful.

Ramsey and Atwood (1979) quote the design folklore which says "flexibility is good, complexity is bad, power is good." They note that this rule of thumb is simplistic and that a good deal of additional research is needed on these issues, especially for specific user types and specific task domains.

The final characteristic on which a human-computer dialogue may be evaluated is information load. This is a measure of the cognitive load that the dialogue imposes on the user. Ramsey and Atwood (1979) note that there is no evidence that existing knowledge about the measurement and effects of information load is being applied to system design. In fact, information overload is one of the most common problems cited in conjunction with information displays, particularly in control rooms (Seminara et al., 1979). The evidence is that user performance is affected by either too much or too little information. There are numerous techniques for reducing information load. They include use of displays, more powerful commands, more natural languages, and less operator input.

Types of Interactive Dialogue

The selection of a dialogue mode is one of the most critical decisions in the design of the human-computer dialogue. This section will review five major types: form-filling, question-and-answer, menu selection, command languages, query languages, and natural language. In addition to these, many other varieties and possible combinations provide a spectrum of modes. Several sets of design guidelines for the selection of dialogue type exist; reliable sources include: Martin (1973), Pew and Rollins (1975), Engel and Granda (1975), Ramsey and Atwood (1979), Shneiderman (1980), and Williges and Williges (1981).

Form-Filling. Form-filling dialogue is appropriate when data entry consists

primarily of parametric values. This kind of dialogue requires only a moderate amount of user training and efficiently replaces its hard copy analog; it is particularly appropriate when there are multiple forms to process. Ramsey and Atwood (1979) report that form-filling dialogue was found to decrease data entry time forty percent when compared to unaided input.

There are several guidelines for the design of form-filling dialogue sessions. Input frames should consist of fixed, protected background fields and variable foreground fields. Background fields should always contain the same information and the cursor should skip over them when a space or tab is executed. Variable fields should appear as underlined blanks or a reverse video field which are to be filled in by the user during data entry. An exception is made for default values, which should be automatically displayed in the appropriate fields. User acceptance of defaults should be signified by means of a carriage return when the cursor is positioned at the field. Easy cursor movement should allow the user to proceed from field to field. Error messages should clearly indicate a failure to provide a required entry.

Question-and-Answer. A question-and-answer dialogue is one in which the user responds to computer-generated questions. For the novice user, this is the simplist type of dialogue; it is not particularly desirable for frequent or experienced users. General format should be brief and concise with an obvious indication of the range and syntax of the desired response.

Menu Selection. Ramsey and Atwood (1979) describe menu selection as the archetype of interactive dialogue modes. The range of choices or candidate user options is presented directly on the screen. This dialogue mode depends only on a passive vocabulary and on memory recognition. The user need only recognize the desired action, whereas both form-filling and question-and-answer dialogues usually require that the user

recall needed input. In addition, menu selection dialogue typically requires minimal user action to communicate a choice, one or two keystrokes, rather than the series of keystrokes required to type words, phrases, or sentences. As a result, menu selection is an attractive technique for non-skilled typists.

Existing guidelines for menu dialogues suggest that menu items should be ordered on the basis of a logical structure or, failing that, in order of expected frequency of use. If multiple menu screens are used, the screens should be sequenced based on the flow of the user's analysis.

There are a number of ways to designate choices; the most common is by typing a return when the cursor is positioned on the desired option. If a selection code is used, it should be short, preferably one character. Numbers, beginning with 1 and continuing in a normal sequence, and alphabetics, beginning with A, are the most common. Typically, codes are left-justified and the number of menu choices is limited to no more than ten to fifteen items. Larger menus should be restructured and broken into logical hierarchies. A general guideline for all hierarchic displays suggests that the user should be given some indication of his current position in the hierarchy and a means of quickly moving around within it.

Additional guidelines on menu design can be found in Williges and Williges (1981); however, as Ramsey and Atwood (1979) point out, few of these are supported by hard, empirical facts. Most are the result of expert opinion.

Command Languages. Command languages constitute the most common interactive dialogue mode. This mode is the most hardware-efficient and minimizes user waiting time. However, it is the mode which provides the least assistance to users, and, except for extremely simplified systems, requires highly trained users.

There has been little research suggesting guidelines for the design of command

languages. Ramsey and Atwood (1979) provide a review of existing literature. They suggest that future work in this area is necessary and should include topics such as command language structure and complexity; statement syntax including keywords and positional forms, separators and terminators, and abbreviations; default values; command choice; command strategy, and overall dialogue style.

Query Languages. Query languages can be considered as a subset of the command language dialogue mode. In a query language, the user interacts with a system which has access to a data base. The query language is used to retrieve information from the data base. Ramsey and Atwood (1979) note that there has been little generic research on query languages; rather, research has focused on specific query languages. The general consensus, however, is that both computer-naive and computer-experienced users can be taught to use query languages. One study summarized by Ramsey and Atwood (1979) indicated that a layered or partitioned approach to query language design is most appropriate. This strategy would facilitate use by both experts and novices. Beyond this, however, there are few generally agreed upon guidelines. One fairly recent study described by Ramsey and Atwood (1979) found that users are flexible and can learn to work with data bases having various structures so long as the structure matches the user's perception of the underlying problem structure.

Natural Language Dialogue. Of all the dialogue modes, the natural dialogue mode is the most recent and thus, experimental, and yet it is the most appealing. The ultimate goal is to allow the user to interact with the computer in as natural a way as one would interact with another person. This goal, the unconstrained use of natural language dialogue, is not yet feasible. Present strategies require that the dialogue be restricted, creating a quasi or restricted natural language dialogue mode.

The major restrictions are on syntactic and semantic structures. Syntactic

constraints include structure, spelling, grammatical errors, and ambiguities. One area which is receiving research attention is the development of languages in which the computer system detects problems such as spelling errors or ambiguities and initiates corrective action.

The semantic or vocabulary restrictions typically require that the user's choice of words be severely restricted. In problem-solving contexts, several studies have shown that a restricted vocabulary does not seriously affect performance.

Ramsey and Atwood (1979) note that progress toward the total elimination of both syntactic and semantic restrictions is being made in the artificial intelligence area. It is, however, unlikely that results will be available in the near future or, if available, cost-efficient for nonexperimental systems.

CODING TECHNIQUES

Information coding is intended to assist the user in rapidly and effectively processing displayed information. Some of the existing guidelines were developed specifically for computer-based displays; the remainder are derived from traditional human factors sources and were developed primarily for electromechanical displays. The majority of the empirical studies compare two or more techniques, often in a task-specific context. Ramsey and Atwood (1979) point out that though this research is helpful in selecting a particular technique, there is little research which a designer can use to assist in applying a particular coding technique.

Several overall guidelines should be kept in mind when designing displays that use codes. Codes should be meaningful when possible and, at a minimum, be clear and consistent with the user's expectations. Color coding with red, for example, should be used sparingly and reserved for emergency or critical events or information. Coding

should be used only if it increases legibility and discrimility; it should not be employed if it seriously affects response time or otherwise degrades the informational environment of the human-computer interface. A review of specific coding techniques follows:

Alphanumeric Coding

Alphanumeric coding, the most prevalent type of display coding, is the most accurate technique for identification tasks and is often used in search tasks. Its primary advantage is its unlimited number of coding categories. Problems with alphanumeric codes include space on the screen for the symbols, cognitive load due to the need to recall, and meanings associated with symbols.

Shape Coding

Shape coding, the use of such things as geometric symbols to convey information, is very appealing and is a natural application for computer graphics displays. There has been, however, little empirical study on the utility of this coding technique. Research is underway to evaluate the feasibility of using shape coding to represent multi-attribute data where the shapes vary according to the data values. This research is still very speculative, and no final evaluation of the merits of the technique has been made.

Research does indicate that shape coding is useful for visual search and identification tasks (Ramsey and Atwood, 1979). A key issue in shape coding is discriminability. The use of no more than fifteen different symbols is recommended; and, when possible, meaningful shapes should be used to help maximize the user's ability to discriminate among symbols.

Color Coding

Research suggesting appropriate guidelines for the use of color in information displays began to occur following the advent of color displays and color graphics terminals. Research suggests that color coding—both redundant and nonredundant—

yields better performance than other static achromatic coding techniques in visual search and identification tasks. Research also suggests that color coding must be "relevant" in order to produce the performance advantage; that is, the color choice should be logical, and the user should have prior knowledge of the color of the target item.

There is some disagreement about whether color should be a redundant or nonredundant attribute in the information display. Problems with user colorblindness or color-weakness suggest that color coding as a redundant attribute may be preferred for a large, nebulous user population. If color is used redundantly, there may be some question as to the merits of using color at all. Research suggests that users have a strong preference for color displays, even when the use of color results in no measurable performance benefits (Ramsey and Atwood, 1979). Hence, color may be a component which enhances the "comfort level" of the workplace and, thus, may be an important aspect of a human-engineered workstation.

There are numerous guidelines on the use of color (Durrett and Trezona, 1982; Ramsey and Atwood, 1979; Szoka, 1982; Willeges & Willeges, 1981). Most, however, fall into the category of expert opinion rather than empirical evidence. Future research needs to evaluate such recommendations carefully. Existing guidelines include the following recommendations:

- Color coding should be used (1) to highlight related data spread about the screen; (2) to locate and flag headings, out-of-tolerance data, newly entered data, or data requiring immediate attention.
- Color coding should be used cautiously to avoid clutter and unpleasant visual effects for the user. Bombarding the user with many brilliant colors will cause eye strain and cognitive load.

- o Limit the number of colors (fewer than eleven are preferred) and number of hues. The use of different hues is often an effective alternative to using different colors.

- o In selecting colors, choice should be in keeping with the user's cultural expectations, e.g., red is for danger or emergency, green for normal.

- o In text displays with dark backgounds, red and magenta cause eyestrain and should be used sparingly. White, yellow, and cyan are easiest to read. If a light background is used, high contrast colors such as blue, black, and green should be used.

- o Compatible color combinations should be employed. Recommended combinations are blue/magenta, cyan/magenta, blue/cyan, yellow/green, yellow/red, magenta/red. Authors note that white works well with almost everything. Adjacent colors should be pleasing, and care should be taken to avoid bleeding. Outlining in white helps to distinguish adjacent colors and limit distortion.

Highlighting

Highlighting, like other coding techniques, permits the emphasis of some portion or portions of an information display. Although, generically speaking, highlighting can be extended to include color coding and blink coding, the highlighting discussion here will be limited to the technique of adjusting the brightness of displayed information or of presenting it in reverse video. Highlighting is typically used to attract user attention and to give feedback. For example, if a user is working on some field, the field should be highlighted so that the user knows precisely what is being manipulated.

Highlighting, just as color and shape coding, should be used cautiously. Some guidelines recommend that effective highlighting requires that no more than ten percent of the display should be highlighted at a given time. As with shape coding, maximum contrast is desired to enable the user to quickly and accurately distinguish between those items which are highlighted and those which are not. If there are two levels, normal and reverse video are recommended (i.e., if the normal mode is light character on a dark

field, reverse video implies dark characters on a light field). At any given time, a maximum of three level of brightness is recommended in order to ensure discriminability.

Blink Coding

Hardware requirements for blink coding were reviewed in Chapter Five. In particular, the blink rate must be within specified tolerances in order to enable the user to match his/her scan rate with the blink rate.

Blink coding should be used to attract the user's attention and is particularly helpful in high density displays. One empirical study found a 50% improvement in search times when target class items were blinked.

As with other "attention demanding" coding techniques, blinking should be used conservatively. Only a few items should be blinking at a given time. Although users can distinguish up to four different blink rates (one nonblinking), restricting the categories to two is recommended, with an absolute maximum of three. Multiple blink rates and/or persistently blinking items can be very irritating, potentially causing eyestrain and user fatigue. The user should always be able to stop the blinking of a displayed data item.

Miscellaneous Codes

A number of other techniques for coding have been tried, though few with empirical evaluations. These include size, depth, motion, focus or distortion, and sound. Sound, as a coding technique, should be used very conservatively. Although it can be used successfully to attract attention and to present information in parallel sensory channels, it is a technique which, if overused, can quickly overload and impair the user's information processing capabilities.

COMPUTER-GENERATED MESSAGES

Communication from computer to human is a critical component in the human-computer interface and is accomplished by computer-generated messages which appear on the CRT screen. These messages include prompts for more information, status messages, and help messages. In providing general rules which guide the design of all computer-generated messages, Engel and Granda (1975) recommend that messages be concise but clearly understandable to the user. Cryptic codes are not useful and often disfunctional for nontechnical users. In order to try to match the level of the message with the level of the user, more detailed messages can be provided upon user request. Messages should provide the user only necessary information which is immediately usable. Moreover, the message should be self-contained and not require the use of an off-line reference manual. Jargon should not be used, and abbreviations should be used very conservatively. When used, abbreviations must be consistent throughout.

In formatting messages, information for immediate recall or information which is difficult to remember should be placed at the beginning of the message; in contrast, easy to recall and less importart information may be placed at the middle or end. Items which must be recalled only for immediate entry are also placed at the end of message text.

Error messages must be designed with the user's level of expertise in mind. This is a case-in-point of the general rule, but is critical in the design of an effective and "user friendly" system. Error messages should always reflect a respect for the user's intelligence and professionalism. No attempt at humor or punishment is acceptable. Messages should be available upon user request.

INFORMATIONAL PROPERTIES OF VDTS

Informational properties of VDTs are the collected attributes which define how data is arranged or presented on a screen in order to convey meaningful information to the user. Using the convention that information is the meaningful part of data arrangement, this section addresses some of the guidelines and user considerations which may be incorporated into the design process in order to reduce the amount of information processing required of the user.

Information overload is a problem for all designers of command and control information displays. The introduction of computers into control rooms, however, has the potential to aggrevate the problem further. In conventional, dedicated-display control rooms, there was a limit on the number of electro-mechanical displays . . could be packed into a workstation which was typically highly constrained. Computers permit the almost limitless display of different pieces of data by allowing the human operator to call up various display pages. This capability is often linked with the design and operations prejudice that too much information/data is preferrable to too little. From a human factors perspective, this trend has potentially adverse consequences. One overwhelming conclusion substantiated by recent research is that the human information processor is very limited. He/she is slow, can handle only a few pieces of information simultaneously, and is tremendously burdened by the need to perform extensive data selection and integration. Displays with too much low level data, requiring continuous monitoring and periodic selection and integration of specific data items, risk information overload for the operator. Computers offer one compensation to offset the volume of data they are capable of displaying in that the computers may be programmed to display the data in integrated, aggregated forms more compatible with the user's needs; that is, computers can be programmed in such a way as to perform some of the user's

information retrived and synthesis tasks. Such displays function as user decision aids and are at the very edge of current research. As a result, research in this area is far from complete. This section will summarize the relevant results and indicate directions for further research. It is important to note that many of the guidelines and user considerations previously discussed are also helpful in converting low level data into useful information. A review of specific information properties of displays follows:

Display Density

Ramsey and Atwood (1979) note that display density or the amount of information contained on one display page involves both perceptual and cognitive issues. As indicated above, information overload is a serious problem in designing displays for real time environments. It has been shown repeatedly that increasing the number of data items displayed on the screen increases the time it takes to make decisions as well as increasing the number of operator errors. This is true whether the displayed data is relevant or irrelevant to the user's immediate decision making needs. Research, however, has not specified an "optimal" number of display elements. Ramsey and Atwood (1979) suggest that this number is task-specific.

The guidelines which have emerged suggest that the number of simultaneously displayed items should be minimized. Moreover, irrelevant displayed data should be reduced or eliminated. Monitoring, examination, and rejection of irrelevant data requires a portion of the user's cognitive resources that could be better employed in processing data relevant to the decision at hand.

User control of displayed data is an attractive attribute. By providing users with the capability to eliminate irrelevant items and also the ability to reverse such decisions, display designers are permitting displays which are sensitive to the user's subjective preference. Research has shown that there is a great deal of variation in the desired

amount of displayed data (Ramsey and Atwood, 1979).

Programming low level data into a form more compatible with the user's high level information needs has also been shown to decrease errors and improve operator performance on command and control tasks (Mitchell, 1980). Methods for preprocessing do not exist, except for task-specific applicat. . A generalized methodology is needed.

Finally, density may be reduced by appropriate data organization and display. Techniques such as spacing and highlighting may be used to relate and group data, helping the user to turn data into information.

Formatting Computer-Based Displays

A major portion of human factors research addresses the issue of display design and layout. Unfortunately little of it is applicable to computer-based displays; the majority was developed for analog, electro-mechanical, dedicated displays. Of the material developed specifically for computer-based displays, the best is the presentation by Engel and Granda (1975). They recommend the use of perceptual organization of displayed data. Such organization can be accomplished in a variety of ways. One recommendation is to reserve certain portions of each display page for certain types of information, e.g., one area for error messages, another for user input. Ways of increasing the user's perception of structure include separation of a fairly uncluttered screen into windows by the use of blanks and the use of lines, colors, or intensities to distinguish windows of information in cluttered screens. The designer is warned against breaking up the screen into too many small windows; this practice also contributes to display clutter.

Lists of items should be kept fairly short, with seven items the typically recommended maximum. Lists should be organized logically, either by frequency of use or, if there is no logical pattern, alphabetically. Individual items should be put on individual lines.

A variety of other user considerations are presented by Williges and Williges (1981); however, there is a great deal of debate as to the merits of most of them. The entire area of cognitive/perceptual organization and display layout is critically important and requires a good deal of serious research.

Graphical vs. Nongraphical Displays

With the advent of the technology of computer graphics, display designers have a choice between alphanumeric and graphical display formats. Ramsey and Atwood (1979) found a disappointing shortage of literature dealing with this question. Currently, the major determinants of the effectiveness of these two strategies are the relative importance of speed vs. accuracy, i.e., whether or not the user is required to recall information after the display is gone, and the type of information displayed. Although there is still some conflict in research results, information displayed graphically can be processed with more speed, yet alphanumeric displays permit greater accuracy. Some research indicates that alphanumeric displays, while slow to process, are more conducive to memorization.

In general, users react favorably to the suggestion of graphical displays. Perhaps based upon the conventional wisdom that "a picture is worth a thousand words", there is an increasing trend to use graphical displays, even though they often require expensive hardware and software. A clear priority in future research is the need to explore the appropriate uses and applications of graphics displays.

Formatting Tabular Data

For both tabular and graphical displays the best source of guidelines may be the existing graphic design guidelines used by artists and publishers.

General rules suggest that data to be scanned and compared should be presented in tabular form with each item starting on a new line. The arrangement should have some

useful order, e.g., frequency of use, importance, functional groupings. For ease of scanning, lists should be left-justified with indentation for subitems. Lists should be kept short, preferably within one screen.

Formatting Graphical Data

Most research in the display of graphical data is for noncomputer-based displays, is out-of-date, and does not form a cohesive, integrated collection useful in specifying comprehensive guidelines. Some general ideas can be drawn from this research, however. In general, it is better to integrate multiple graphs, i.e., multiple lines on a single graph are better than multiple graphs, particularly for the comparison of trend lines. Axes should always be labelled. Symbols should draw on the cultural background of the user.

Formatting Alphanumeric Data

Numeric fields should be grouped for readability. Punctuation can be handled with commas, spaces, or hyphens. Lists of numbers should use decimal point alignment and nondecimal numbers should be right-justified.

Alphabetic or textural data should use simple, concise sentences which are active in voice and affirmative in tone. Text should be left-justified and displayed in both upper and lower case. Paragraphs should be double spaced. Hyphenation and unnecessary punctuation should be avoided.

Labelling

Labelling is the act of placing a descriptive title, phrase, or word adjacent to a group of related objects or data. Labels can provide a quick source of information to the user. Every column and variable should have a label in order to facilitate user scanning and comprehension. Generally, upper case labels are preferred. An acceptable alternative is highlighting. Labels should be composed of distinct, meaningful names

which are easily discriminated from surrounding labels and data.

Further Research

Many issues on the informational properties of computer-based displays require further research. This area, more than any other, has received the least attention and yet, because of the flexibility made possible by the computer driving the displays, has the most design possibility and related concerns. The most difficult questions are raised by attempts to specify guidelines based on a cognitive or perceptual view of the user. Displays which take into account the user's strenths and limitations and are firmly grounded in good psychological theory are frequently described as "user friendly" displays.

SYSTEM RESPONSE TIME

Although system response time is not a property of a display, it is a critical determinant of the success or failure of an information display system. An interactive display which is too slow will aggrevate users and detract from the overall effectiveness of the human-computer interface. An interesting case in point is Multisatellite-2 at NASA/Goddard. Although the human factors of the display system were very well engineered, the overall system response time was so poor because of the needs of the color, graphical displays, that users preferred the more primitive yet responsive display and control environment of Multisatellite-1. R. B. Miller (1968) has presented a list of recommended response times. This list, though not completely substantiated by research, is widely quoted and provides rough estimates for designers. Miller's list is reproduced in Figure 6-2. Whether or not these exact times are met, a critical component of a system evaluation should be the examination of the system to ensure that the operation is not too sluggish and that the users feel comfortable with the response times.

ORIGINAL PAGE IS
OF POOR QUALITY

User Activity	Reasonable Response Time
Control activation (for example, keyboard entry).	0.1 SECOND
System activation (system initialization).	3.0
Request for given service:	
simple	2
complex	5
loading and restart	15 - 60
Error feedback (following completion of input).	2 - 4
Response to ID.	2
Information on next procedure.	5
Response to simple inquiry from list.	2
Response to simple status inquiry.	2
Response to complex inquiry in table form.	2 - 4
Request for next page.	0.5 - 1
Response to "execute problem."	15
Light pen entries.	1.0
Drawing with light pens.	0.1
Response to complex inquire in graphic form.	2 - 10
Response to dynamic modeling.	---
Response to graphic manipulation.	2
Response to user intervention in automatic process.	4

Figure 6-2. System response time as a function of user activity. (R.B. Miller, 1968)

REFERENCES

Durrett, J., & Trezona; J. How to use color effectively. BYTE, April 1982.

Engel, S.E., & Granda, R.E. Guidelines for Man/Display Interfaces. Poughkeepsie, NY: IBM Poughkeepsie Laboratory, December 1975.

Martin, J. Design of Man-Computer Dialogues. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1973.

Miller, R.B. Response time in man-computer conversational transactions. Proceedings Spring Joint Computer Conference 1968, Montvale, NJ: AFIPS Press, 1968.

Mitchell, C.M. The Design of Computer-Based Integrated Information Displays. Columbus, OH: The Ohio State University Doctoral Dissertation, 1980.

Pew, R.W., & Rollins, A.M. Dialog Specifications Procedures. Cambridge, MA: Bolt, Beranek and Newman, September 1975.

Ramsey, H.R., & Atwood, M.E. Human Factors in Computer Systems: A Review of the Literature. Englewood, CO: Science Applications, Inc., September 1979, NTIS-AD-075-679.

Seminara, J.L., & Parsons, S.O. Human Factors Methods for Nuclear Control Room Design. Vol. 2: Human Factors Surveys of Control Room Design Practices. Palo Alto, CA: Electric Power Research Institute, November 1979, EPRI NP-1118.

Shneiderman, B. Software Psychology: Human Factors in Computer Information Systems. Cambridge, MA: Winthrop Publishers, Inc., 1980.

Szoka, K. Practical Considerations on the Use of Color, Silver Spring, MD: Computer Sciences Corporation, April 1982.

Williges, B.H., & Williges, R.C. User Considerations in Computer-Based Information Systems. Blacksburg, VA: VPI Industrial Engineering and Operations Research Department, September 1981, NTIS-ADA-106194.

CHAPTER SEVEN

CONCEPTUAL ISSUES IN HUMAN FACTORS CONSIDERATIONS FOR CONTROL ROOM DESIGN

INTRODUCTION

In the spectrum of human factors considerations for control room design, there are many areas which have well-defined issues and thorough, well-formulated design guidelines based on many years of practical experience, theoretical development, and empirical research. Particularly in areas related to the use of computers in the command and control environment, effective design guidelines become more sparse and there seem to be many more questions than answers. Even in these areas, though, most of the issues are fairly clear-cut and the questions well-defined. Some human factors considerations are so new, however, that even the questions are hard to articulate. This chapter presents some of these issues and demonstrates their importance in system design. In addition, the chapter begins with an overview of information processing models of the human operator. This collection of psychological theory is neither clear-cut nor easily converted into useful design guidelines. Yet, it represents what is known and/or hypothesized about human beings and how they process information. This is the bedrock on which all past, current, and future system design guidelines must be based in order to be effective. As such, it forms a fitting bridge from the guidelines material in previous chapters to the more speculative and conceptual materials in this and subsequent chapters.

PRECEDING PAGE BLANK-NOT FILMED

CONCEPTUAL MODELS OF INFORMATION PROCESSING

The study of human information processing has received much attention in response to the increased use of computer systems and the increased recognition of need for better human-machine interfaces. Understanding the conceptual basis of human information processing is important for any student of human behavior and is especially necessary for those who utilize humans as system components. Kantowitz (1982) argues persuasively for a human factors approach to human information processing, which would integrate theoretical research results within applied settings. The benefits of this approach include a valid and reliable foundation for specific system design guidelines and a more effective human component in a system, with greater productivity and less margin for error. However, no framework exists for taking this approach. The following discussion attempts to construct a framework for a human factors approach by presenting an overview of several conceptual models of information processing and integrating specific guidelines where they exist.

Definitions

Human information processing can be defined as an active cognitive process that is analogous to a system. It is a flow and transformation of information within a human (Kantowitz, 1982). The human is viewed as an active information seeker who is constantly receiving, processing, and acting upon the surrounding environmental stimuli. Human information processing models are conceptual representations of cognitive behaviors. They attempt to delineate what cognitive processes occur and when and how these activities interact. Models of information processing are useful in representing the different theoretical positions and in attempting to define the limits and capabilities of human memory.

To place limits on the human's information processing abilities, an objective measure of information must be used. Psychologists measure information in bits (the term is a shortened version of binary units); a bit is the amount of information available to the human when one of two equally likely alternatives is chosen. The exponential relationship between bits and amount of information is expressed mathematically as:

$$H = \text{Log}_2 K$$

where K is the number of equal alternatives and probabilities, and H is equal to the amount of information received. If the human is presented with eight equally likely alternatives, a choice will yield three bits of information; sixteen alternatives, four bits, and so forth. The relationship is also expressed as the number of bits increasing as the amount of uncertainty decreases. It is estimated that the human memory can store between 100 million and 1 million billion bits of information (McCormick, 1976), a greater storage than any existing computer storage. Figure 7-1 illustrates the bits of information a human receives when processing familiar items like digits and letters. The system designer would seek to measure information objectively in bits, to provide a criterion for applied issues. When the amount of information received is considered in conjunction with human processing capabilities, affected design issues include number of displays for one task, number of coded colors on a command panel, or number of auditory codes.

Human vs. Computer Information Processing

Many human information processing models are analogous to computer information processing systems. The underlying flow or structure appears to be the same. Figure 7-2 represents a simplified flow diagram that applies to both human and computer information processing systems. Humans input data from the senses while the computer system receives it from interactive devices. Both systems recognize, attend to, process,

ORIGINAL PAGE IS
OF POOR QUALITY

ITEM	BITS OF INFORMATION
BINARY DIGIT	1.00
DECIMAL DIGIT	3.32
LETTERS	4.70
ALPHA-NUMERICS	5.17

Figure 7-1. Martin, 1973, p. 337.

FLOW DIAGRAM OF HUMAN/COMPUTER INFORMATION PROCESSING SYSTEM

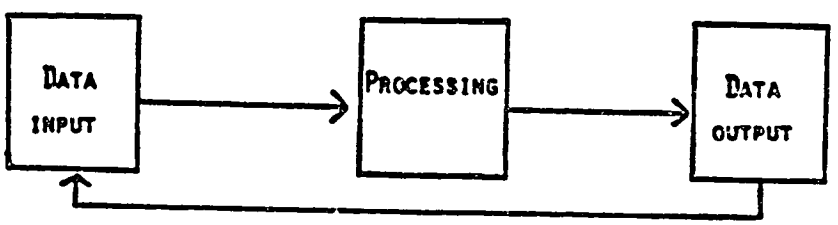


Figure 7-2.

and store information, and both output some kind of information or action. The data output often becomes the data input for the next thought or task, creating a continuous loop process in both human and computer information processing.

When a human is placed within a computer system, it is important for the designer to recognize that the human processing system interfaces directly with the computer processing system. Figure 7-3 is a simplified flow diagram illustrating this interface. The output of one system provides input for the other, and to ensure optimal operations the computer processing loop should interface smoothly with the human processing loop, i.e., overload or ambiguous messages should be avoided.

Short Term Memory/Long Term Memory Store Model

The traditional conceptual information processing model is the short term memory (STM)/long term memory (LTM) store model. Proponents of this model conceptualize information processing as occurring in three distinct memory stores: sensory, short term memory, and long term memory. The stores are not physical entities existing in the human's mind, but rather, useful theoretical structures delineating the ongoing cognitive activities. A flow chart representation of this model can be found in Figure 7-4.

The initial memory store for information processing is the sensory store. It is a perceptual store thought to have two major sensory channels and to operate on a subconscious level. The visual or iconic store receives information from the eyes while the auditory or echoic store receives through the ears. Sperling (1960), and Darwin, Turvey, and Crowder (1972) offer some experimental evidence for the existence and differentiation of these two sensory stores. Both are considered brief repositories for perceptual information capable of holding up to four or five items known as the span of apprehension, for 10 to 200 milliseconds (Loftus & Loftus, 1976).

It is an accepted fact that a large portion of the visual and auditory information in

ORIGINAL PAGE IS
OF POOR QUALITY

FLOW DIAGRAM OF HUMAN PROCESSING/COMPUTER PROCESSING LOOP

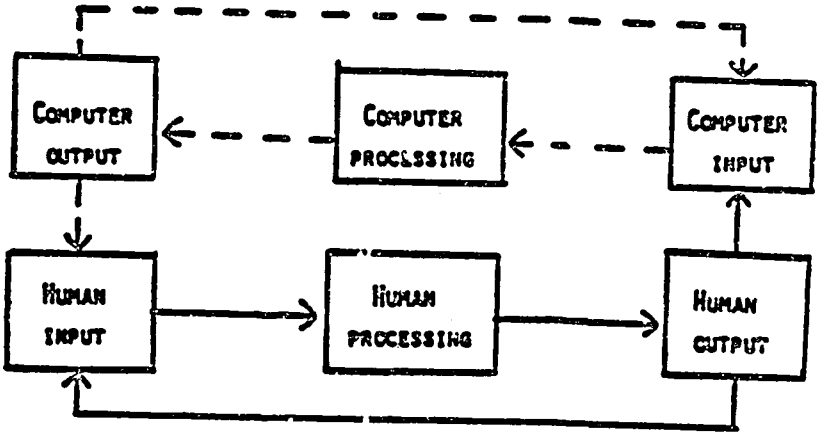


Figure 7-3.

SHORT TERM STORE/LONG TERM STORE MODEL

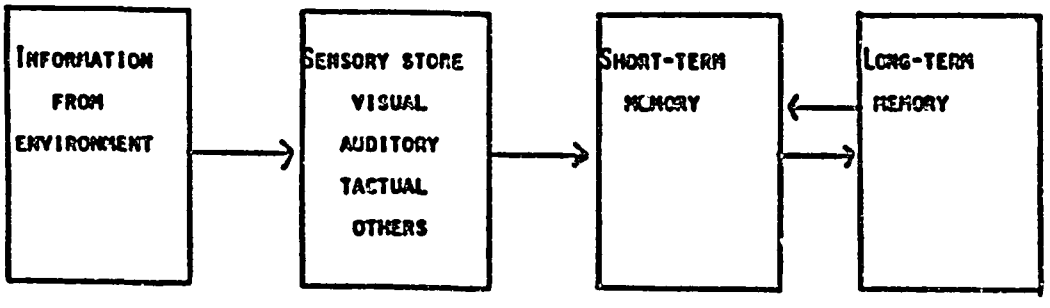


Figure 7-4. Bransford, 1979, p. 37.

an environment is perceived by the human. The cocktail party phenomenon illustrates this. When in a situation where several conversations are occurring at once, the human is able to perceive many of them. However, the raw sensory information is useless until some *meaning* is attached to it. The processes of pattern recognition and attention accomplish this and in doing so, transfer the selected information into the next store—short term memory. Otherwise, the sensory store has a very rapid decay rate. The human attends to one cocktail party conversation and excludes all of the surrounding perceptual noise from consciousness; the perceptual stimuli from lighting, music and other voices decay.

The second phase of the STM/LTM model is the short term memory store, which has limited capacity and contains information being currently processed by the human. Experimental research, using free recall paradigms and resulting in serial position curve evidence (subjects are given a list of nonsense syllables to learn and when asked to recall them, remember more items from the beginning and end of the list, rather than in the middle), supports the existence of a short term memory along with a long term memory (Loftus & Loftus, 1976). The short term store receives information from both sensory and long term stores (Figure 7-4) and is capable of holding information up to 15 seconds. However, it is a transient store, and its contents continuously change unless rehearsed. Rehearsal, either verbal or mental, allows the human to hold information in short term store for longer periods of time, e.g., repeating a phone number as you walk from the directory to the phone, or to transfer it to long term store, e.g., individual's personal phone numbers become ingrained after repeating them often enough. Miller (1956) determined short term store capacity to be seven plus or minus two (7 ± 2) items. The information content of the short term store is independent of item number because it is possible to increase content through the process of chunking. Chunking is a subjective

organization that incorporates information from several items into one chunk, e.g., when trying to recall a list of 12 letters, c nking them into four familiar acronyms, IBM-FBI-PHD-TWA, facilitates retention (ANACAPA Sciences, Inc., 1981). The information content per chunk can be objectively measured by determining the number of bits needed to encode or understand the chunk. When incoming information exceeds the human's short term store capacity, a breakdown in the ability to learn and understand occurs. Chunking information will help avoid this and give the person a greater available store, increasing the capacity to process information. There are individual differences in the short term memory store capacity, i.e., some are able to incorporate greater amounts of information into one chunk than others, but the number of items remains at 7 ± 2.

The rehearsal and organization of information transfers it to the final phase of the STM/LTM processing model—long term memory store. Long term store is a permanent memory holding all sensory and semantic information necessary for thinking. It is conventional memory that holds all the human's knowledge of the world. Information is encoded and held here and can be retrieved through the processes of recognition and recall. The strength of a memory "trace" and the associative pathways of memory facilitate these retrieval processes, respectively (Bransford, 1979). Decay from long term store, or forgetting, takes place due to interference and retrieval failure. Two types of interference are suggested: proactive, when information processed before receiving an item to remember affects the recall of that item, and retroactive, when information processed after receiving an item to remember affects its recall.

Semantic/Episodic Long Term Memory Model

One body of research suggests two types of long term memory (Tulving, 1972). Both types are permanent memory stores, but they differ in content. Like the STM/LTM model, this model makes a conceptual, rather than physical, distinction between stores.

Episodic long term memory is context specific and stores temporally coded information. How and when things occur, as they affect the individual, make up the content of episodic memory. The information within this store is considered autobiographical and changes quickly and continuously (Klatzky, 1980). Episodic long term store is quite susceptible to forgetting because the very act of retrieving or remembering information becomes a temporal event to be stored. This, plus the constant flow of new events as they are experienced and stored by the human, leads to a greater likelihood for forgetting.

Semantic long term store, the other memory store proposed by this model, is not as susceptible to forgetting and is not context specific. Semantic memory contains all the human's general knowledge of concepts, principles, and meanings. It holds information that is independent of time and place occurrence, e.g., spelling rules, multiplication tables, and does not change very rapidly. The act of retrieval does not affect the store; and, as it is highly organized, retrieval is not random (Klatzky, 1980).

The semantic/episodic long term memory model is an extension of the STM/LTM model. However, the STM/LTM conceptual model remains a dominant theory representing human information processing.

Design Implications of the STM/LTM Model

Two dimensions are used by humans to discriminate information within the sensory store. One is an absolute discrimination, the other, relative discrimination. When humans are presented with a single stimulus and have to discriminate it from all others, they must go to long term memory store to do so. The human information capacity is limited for making these absolute discriminations, and Figure 7-5 shows the capacity range for this kind of activity. As illustrated, the capacity for making absolute discriminations is 7 ± 2 items. However, when humans are presented with two stimuli at

once and must make a relative discrimination between the two, their capacity for making discriminations is greatly increased. This implies that relative discriminations are much more efficient for human information processing and should be relied upon for quicker and less error prone judgments. Relative discriminations greatly increase the short term store capacity.

As stated earlier, the short term store capacity is limited. Figure 7-6 lists five different types of items humans process and the corresponding short term memory span of each. Memory span is defined as the longest list of items that can be recalled without error immediately after presentation (ANACAPA Sciences, Inc., 1981). Memory span differs according to item type but hovers around 7 $\pm$ 2 items. For quick and effective human processing of the information these example items represent, the capacities for each should not be exceeded.

One of the main contributions a human makes to a system is the ability to recognize patterns. Taking small chunks of information and encoding them into larger chunks is a major human information processing skill. This ability can be highly utilized through the graphic representation of information. Graphic displays encode large amounts of information into one chunk or item, increasing the short term memory capacity greatly and making the human a more effective information processor.

Strategies for Information Processing Model

Some experimental research criticizes the STM/LTM model as being too structured when considering the cognitive activities involved in information processing (Moray, 1978; Underwood, 1978a). The "flow chart" approach of the STM/LTM model does not consider the individual variability of processing sequences; it implies a structurally limited response process. The strategies model accounts for these variable individual processing sequences (i.e., strategies) within the structured limitations suggested by the

ORIGINAL PAGE IS
OF POOR QUALITY

RANGE OF ABSOLUTE DISCRIMINATIONS

STIMULUS DIMENSIONS	AVERAGE DISCRIMINATIONS
PURE TONES	5
LOUDNESS	5
BRIGHTNESS	5
SIZE OF VIEWED OBJECTS	7
COLORS	9

Figure 7-5. ANACAPA Sciences, Inc., 1981, Session 13.

TYPE OF ITEM	MEMORY SPAN
DIGITS	8
COLORS	7
LETTERS	6
WORDS	5
SHAPES	5

Figure 7-6. ANACAPA Sciences, Inc., 1981, Session 13.

STM/LTM model. Human information processing is thus viewed as an individualistic and dynamic activity due to the wide range of available strategies.

Moray (1978) defines a strategy as "subtle striving of a rather rational agent in a fairly orderly universe, implying the goal-directed, purposeful use of resources" (p. 302). Strategies manipulate incoming information dependent upon the individual's goals and expectations. The same stimulus offers different information to different individuals. One may process information using the sentence structure of some text while another may use the spatial location of items within the same text. Subjective organizations of information, e.g., chunking, are considered strategies.

Proponents of this conceptual model stress the assumption that strategies are individually determined, yet work within cognitive structural limits. This assumption precedes others; the limits of one cognitive structure necessarily affect processing in other structures; past success with one strategy leads to its recurrent use, as well as lack of awareness for alternative strategies, and experimental assessment of strategies is inherently difficult.

Strategies for human information processing are important elements of systems that involve ongoing human control. The operators of systems providing status information will develop monitoring strategies that can be positive or negative depending on the situation (Moray, 1978). While they may not be aware they are using strategies, their behavior reflects this. Strategy use by operators in complex systems is somewhat beyond the scope of this paper; the reader is directed to Moray (1978) and Underwood (1978b) for an in-depth treatment of the topic.

The use of strategies for any human behavior is being researched by experimental psychologists. Strategies for information processing is the current model under investigation; therefore, all experimental results are not in. As it is, the model leaves

several unanswered questions. However, it is perhaps the most inclusive model of information processing available and an exciting alternative to the STM/LTM model.

Levels of Processing Model

The fourth conceptual information processing model for review is the levels of processing model (Bransford, 1979; Craik & Lockhart, 1972). It is similar to the STM/LTM model, proposing three stages of memory called levels. It differs from the STM/LTM model by defining the levels as processes rather than structured stages. The model assumes that information is processed by the human at different levels varying in depth. The first level is the physical or perceptual level where processing occurs in terms of the physical appearance of stimuli. The next level is acoustic where processing occurs in terms of how stimulus information sounds. The semantic level is last, and processing here is in accordance with stimuli meaning. It is suggested that these processing levels are ordered by depth, with physical attributes being processed at the most superficial level and semantic attributes at the deepest level. Information need not be processed at one level before going to the next; rather, any of the three can be directly accessed in any order. The levels are ordered by depth only. The major assumption this model makes is that deeper processing leads to better memory. Briefly, supporting theory states that processing of information leaves traces upon memory; the deeper the processing, the deeper the traces, thus leading to better memory (Bransford, 1979).

There are criticisms of this model. The assumption that deeper processing leads to better memory must be qualified by the type of experimental task used to measure retention. There is no objective measure of depth in this model. The experimental results show only that semantic processing is more effective for retention tasks than physical processing, not that one level is deeper and thus more effective for information

processing. Without an objective measure of depth, the major assumption of the model can be challenged. The model does have preliminary support, and it provides another useful conceptual alternative.

Serial vs. Parallel Processing

The last conceptual information processing model, to be addressed briefly, is a dichotomous model focusing on pattern recognition. Items of information are processed or recognized one at a time sequentially in serial processing. In parallel processing several information items are processed simultaneously. Experimental evidence for this model supports the existence of both processing types, rather than one as opposed to the other (Klatzky, 1980). Also, both appear to operate within all information processing mechanisms, especially the sensory store.

Although both serial and parallel processing are thought to occur in humans, most display designs are based on the assumption that humans are parallel processors. Parallel processing best detects threshold changes; but, where specific event changes need to be detected, serial processing is better. Real time control situations call for parallel processing of information; however, there are limits to the parallel processing capabilities. When information is presented too rapidly, human performance suffers. Speed stress taxes human capacities, and performance on time shared tasks suffers (McCormick, 1976). Therefore, display designers are cautioned against presenting information at a rate greater than the human's parallel processing capabilities.

Design Guidelines

There are other conceptual information processing models, both similar and dissimilar to those outlined above. The five addressed here have one common premise: human information processing is a system. When the human component is interfaced with a machine system, designers must consider human information processing system

limits and capabilities. Figure 7-7 provides a flow chart illustrating the human information processing/machine interface. The productivity of the entire system will be increased by attention to this interface. It is a simple proposal; but, as Kantowitz (1982) suggests, it is not always implemented due to the philosophical differences between theoretical and applied scientists. Both basic and applied research can benefit one another, resulting in design suggestions for better human-machine interfaces.

Several guidelines resulting from experimental research using reaction time as a dependent variable can be found in ANACAPA Sciences, Inc. (1981), Pew (1971), and Van Cott and Warrick (1972). The following summarizes these source document guidelines:

- To achieve rapid response rates to displayed information decrease the cognitive task load of the information, i.e., simplify the display.
- Use of eye, finger, and tongue movements give the fastest reaction times, while head and foot movements take longer.
- When an array of signals is required, each should be easily detectable from the others to ensure rapid response rates.
- Direct stimulus-response compatibility, achieved through adherence to population stereotypes, decreases error rate and reaction time, e.g., use red for stop or warning, use meters that show increases with clockwise motions, etc.

When presenting information to the human, designers should consider several criteria leading to more effective human-machine interfaces. These criteria for information suggested by ANACAPA Sciences, Inc. (1981), are:

- detectability
- discriminability
- compatibility
- redundancy
- meaning
- standardization

ORIGINAL PAGE IS
OF POOR QUALITY

FLOW CHART OF INFORMATION PROCESSING
WITHIN A SYSTEM

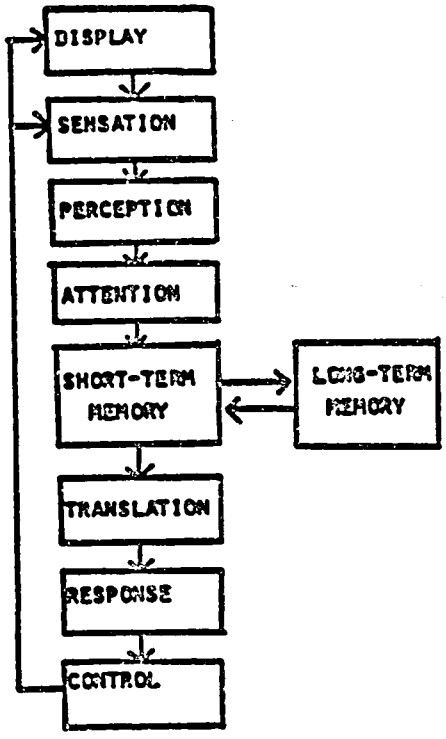


Figure 7-7. Durrett & Stimmel, 1982, p. 399.

Research on the use of different sensory channels for information processing and their effects points to the following conclusions (McCormick, 1976; Van Cott & Warrick, 1972):

- Auditory stimuli capture the human's attention better than other sensory channel stimuli, implying their use for warning or special events.
- Added sensory channels providing redundant (i.e., identical and simultaneously presented) information increase the probability of reception.
- The number of channel-competing sources should be minimized.
- Sensory channel capacity is limited. Figure 7-3 illustrates the capacities for unidimensional stimuli, and Figure 7-9 shows capacities for multidimensional stimuli.

One effect of stress on the human is a narrowing of attention. In emergency or time-critical situations, information overload should be avoided; displays and tasks for those situations should be designed as simply as possible. It was suggested above that the presentation rate for effective information processing is limited. Van Cott and Warrick (1972) report that humans cope with excessive information presentation rates by using one or several counterproductive measures. They fail to respond to stimuli, respond less accurately, give incorrect responses, or respond as time permits. It appears that the optimal presentation rate of information is task dependent. One experiment reported by Van Cott and Warrick (1972) gives an upper limit of 43 bits/sec. for a reading task. Optimal rates for other tasks need to be experimentally determined within specific situations.

Summary

A human factors approach to human information processing necessitates a conceptual, as well as applied understanding of the topic. Currently, design guidelines

ORIGINAL PAGE IS
OF POOR QUALITY

THE CHANNEL CAPACITY OF SENSES FOR DIFFERENT UNIDIMENSIONAL STIMULI

SENSE	STIMULI DIMENSION	CHANNEL CAPACITY (BITS)	DISCRIMINABLE CATEGORIES
VISION	DOT POSITION (IN SPACE)	3.25	10
	DOT POSITION (IN SPACE)	3.2	10
	SIZE OF SQUARES	2.2	5
	DOMINANT WAVELENGTH	3.1	9
	LUMINANCE	2.3	5
	AREA	2.6	6
	LINE LENGTH	2.6-3.0	7-8
	DIRECTION OF LINE INCLINATION	2.8-3.3	7-11
	LINE CURVATURE	1.6-2.2	4-5
TASTE	SALT CONCENTRATIONS	1.9	4
AUDITION	INTENSITY	2.3	5
	PITCH	2.5	7
VIBRATION (ON CHEST)	INTENSITY	2.0	4
	DURATION	2.3	5
	LOCATION	2.8	7
ELECTRICAL SHOCK (SKIN)	INTENSITY	1.7	3
	DURATIONS	1.8	3

Figure 7-8. Van Cott & Warrick, 1972, p. 28.

ORIGINAL PAGE IS
OF POOR QUALITY

THE CHANNEL CAPACITY OF SENSES FOR MULTIDIMENSIONAL STIMULI

STIMULI DIMENSION	CHANNEL CAPACITY (BITS)	DISCRIMINABLE CATEGORIES
SIZE, BRIGHTNESS, AND HUE (VARIED TOGETHER)	4.1	18
FREQUENCY, INTENSITY, RATE OF INTERRUPTION, ON-TIME FRACTION, TOTAL DURATION, AND SPATIAL LOCATION	7.2	150
COLORS OF EQUAL LUMINANCE	3.6	13
LOUDNESS AND PITCH	3.1	9
POSITION OF POINTS IN A SQUARE (NO GRID)	4.6	24

Figure 7-9. Van Cott & Warrick, 1972, p. 29.

concerning human information processing and the human-machine interface are sparse. Much more applied and theoretical experimental research needs to be done. However, an awareness of the conceptual issues in human information processing, to this point, can only benefit Goddard system designers and, in turn, command and control environments.

References

ANACAPA Sciences, Inc. Human Information Processing, Session 13. In Fundamentals of Human Factors for Engineering and Design. Santa Barbara, CA: ANACAPA Sciences, Inc., 1981.

Baron, S., & Levison, W.H. Display analysis with the optimal control model of the human operator. Human Factors, Vol. 19, No. 5, 1977, 437-457.

Bloomfield, J.R., & Modrick, J.A. Cognitive processes in visual search. Proceedings of the 6th Congress of the International Ergonomics Association, July 1976, 204-209.

Bransford, J.D. Human Cognition, Learning, Understanding and Remembering. Belmont, CA: Wadsworth Publishing Co., 1979.

Carbonell, J. On man-computer interaction: A model and some related issues. IEEE Transactions on Systems, Science and Cybernetics, Vol. SSC-5, No. 1, Jan. 1969, 16.

Conrad, R. Short-term memory factor in the design of data-entry keyboards: An interface between short-term memory and S-R compatability. Journal of Applied Psychology, Vol. 50, No. 5, Oct. 1966, 553-556.

Craik, F.I.M., & Lockhart, R.S. Levels of processing: A framework for memory research. Journal of Verbal Learning & Verbal Behavior, Vol. 11, 1972, 671-684.

Darwin, C.J., Turvey, M.T., & Crowder, R.G. An auditory analogue of the Sperling partial-report procedure: Evidence for brief auditory storage. Cognitive Psychology, Vol. 3, 1972, 255-267.

Durding, B.M., Becker, C.A., & Gould, J.D. Data organization. Human Factors, Vol. 19, No. 1, 1977, 1-14.

Durrett, J., & Stimmel, T. A production-system model of human-computer interaction. Proceedings of Human Factors in Computer Systems, March 1982, 393-399.

Estes, W.K. Is human memory obsolete? American Scientist, Vol. 68, Jan.-Feb. 1980, 62-69.

Fisk, A.D., & Schneider, W. Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. Human Factors, Vol. 23, No. 6, 1981, 737-750.

Howell, W.C., & Fleishman, E.A. (Eds.). Human Performance and Productivity, Volume 2: Information Processing and Decision Making. Hillsdale, NJ: Lerence Erlbaum Associates, Inc., 1982.

Kantowitz, B.H. Interfacing human information processing and engineering psychology. In W.C. Howell and E.A. Fleishman (Eds.), Human Performance and Productivity, Volume 2: Information Processing and Decision Making. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 1982.

Klatzky, R. Human Memory: Structures and Processes. San Francisco, CA: W.H. Freeman and Co., 1980.

Loftus, G.R., Dark, V.J., & Williams, D. Short term memory factors in ground controller/pilot communication. Human Factors, Vol. 21, No. 2, 1976, 169-181.

Loftus, G.R., & Loftus, E.F. Human Memory: The Processing of Information. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 1976.

McCormick, E.J. Human Factors in Engineering and Design (4th Edition). New York, NY: McGraw- Hill Publishing Co., 1976.

Martin, J. Design of Man-Computer Dialogues. Englewood Cliffs, NJ: Prentice- Hall, Inc., 1973.

Miller, G.A. The magical number seven, plus or minus two: Some limits on our capacity to process information. Psychological Review, Vol. 63, 1956, 81-97.

Moray, N. The strategic control of information processing. In G. Underwood (Ed.), Strategies of Information Processing. New York, NY: Academic Press, 1978.

Navon, D., & Gopher, D. On the economy of the human-processing system. Psychological Review, Vol. 86, No. 3, 1979, 214-255.

Pew, R.W. Human Information Processing and Reaction Time. Cambridge, MA: Bolt Beranek and Newman, Inc. Report No. 2111, March 1971.

Sheridan, T.B., & Ferrell, W.R. Man-Machine Systems; Information, Control, and Decision Models of Human Performance. Cambridge, MA: The MIT Press, 1974.

Sperling, G. The information available in brief visual presentations. Psychological Monographs, Vol. 74, 1960, 1-29.

Teichner, W.H., & Krebs, M.J. Laws of the simple visual reaction time. Psychological Review, Vol. 79, No. 4, 1972, 344-358.

Tulving, E. Episodic and semantic memory. In E. Tulving and W. Donaldson (Eds.), Organization of Memory. New York, NY: Academic Press, 1972.

Umbers, I.G. Models of the process operator. International Journal of Man Machine Studies, Vol. 11, 1979, 263-284.

Underwood, G. Concepts in information processing theory. In G. Underwood (Ed.), Strategies of Information Processing. New York, NY: Academic Press, 1978a.

Underwood, G. (Ed.). Strategies of Information Processing. New York, NY: Academic Press, 1978b.

Van Cott, H.P., & Kinkade, R.G. (Eds.). Human Engineering Guide to Equipment Design. New York, NY: McGraw-Hill Publishing Co., 1972.

Van Cott, H.P., & Warrick, M.J. Man as a system component. In H.P. Van Cott & R.G. Kinkade (Eds.), Human Engineering Guide to Equipment Design. New York, NY: McGraw-Hill Publishing Co., 1972.

Welford, A.T. Perceptual selection and integration. Ergonomics, Vol. 13, No. 1, 1970, 5-23.

Williges, R.C. Applying the human information processing approach to human/computer interactions. In W.C. Howell and E.A. Fleishman (Eds.), Human Performance and Productivity, Volume 2: Information Processing and Decision Making. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 1982.

THE HUMAN AS SYSTEM SUPERVISOR

As automation is introduced into command and control environments, the role of the human is unquestionably changing (Sheridan & Johannsen, 1976). Traditionally, the human in a complex system functioned as a manual controller, interacting with the controlled process in a direct, moment to moment manner. The human carefully monitored displayed data, gave commands to change the current system state in order to bring it more in line with a desired objective, and evaluated the resulting output to ensure that the sequence of commands brought the system to the desired state (Figure 7-10a). In increasingly automated systems, these manual control functions have, for the most part, been allocated to the computer. Although the full or partial automation of a system or specific functions within a complex system may replace individual operators, the general trend is that automation does not usually result in a decrease in the overall staff for a system; rather, a redefinition of tasks and reallocation of responsibilities is taking place as a result of increased automation (Rouse, 1981) A major new function which is emerging as the primary task of the human in automated systems is that of a monitor and supervisor of the banks of micro, mini, and large scale computers that do the direct controlling (Figure 7-10b) (Sheridan and Johannsen, 1976). Although the trend is very clear, there are a number of problems caused by this new supervisory role, problems which must be addressed in order to ensure an efficient and effective human-computer interface and overall system performance. The two major issues concern: (1) the allocation of responsibilities between the human and computer, and (2) the creation of adequate mechanisms to affect the human-computer interface.

Allocation of Responsibilities

Historically, the human in a control system was conceptualized as the flexible component. Tasks and responsibilities which the mechanical and electrical components

ORIGINAL PAGE IS
OF POOR QUALITY

Advanced Control System

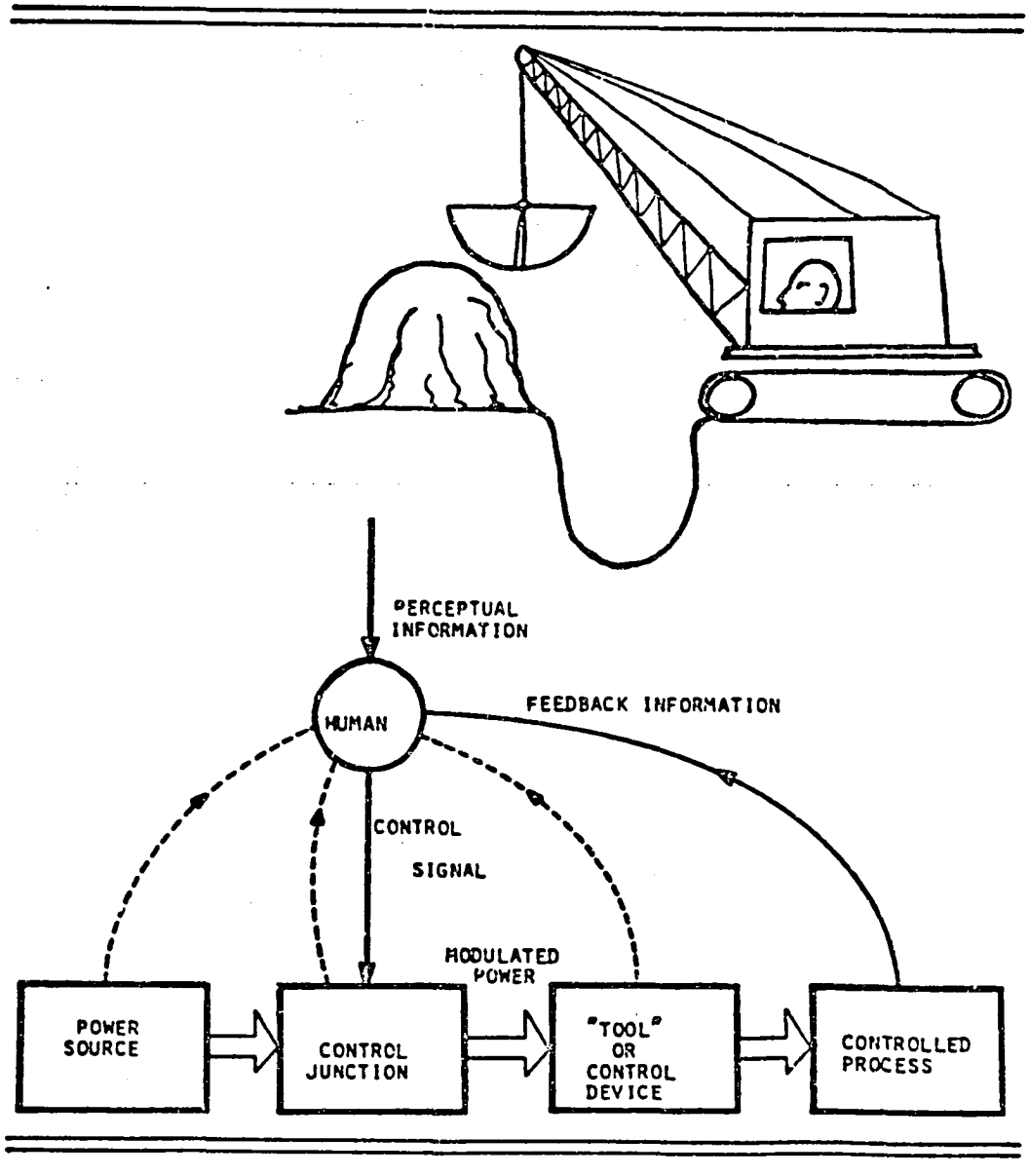


Figure 7-10a

ORIGINAL PAGE IS
OF POOR QUALITY

Automated Control System with a Human Supervisor

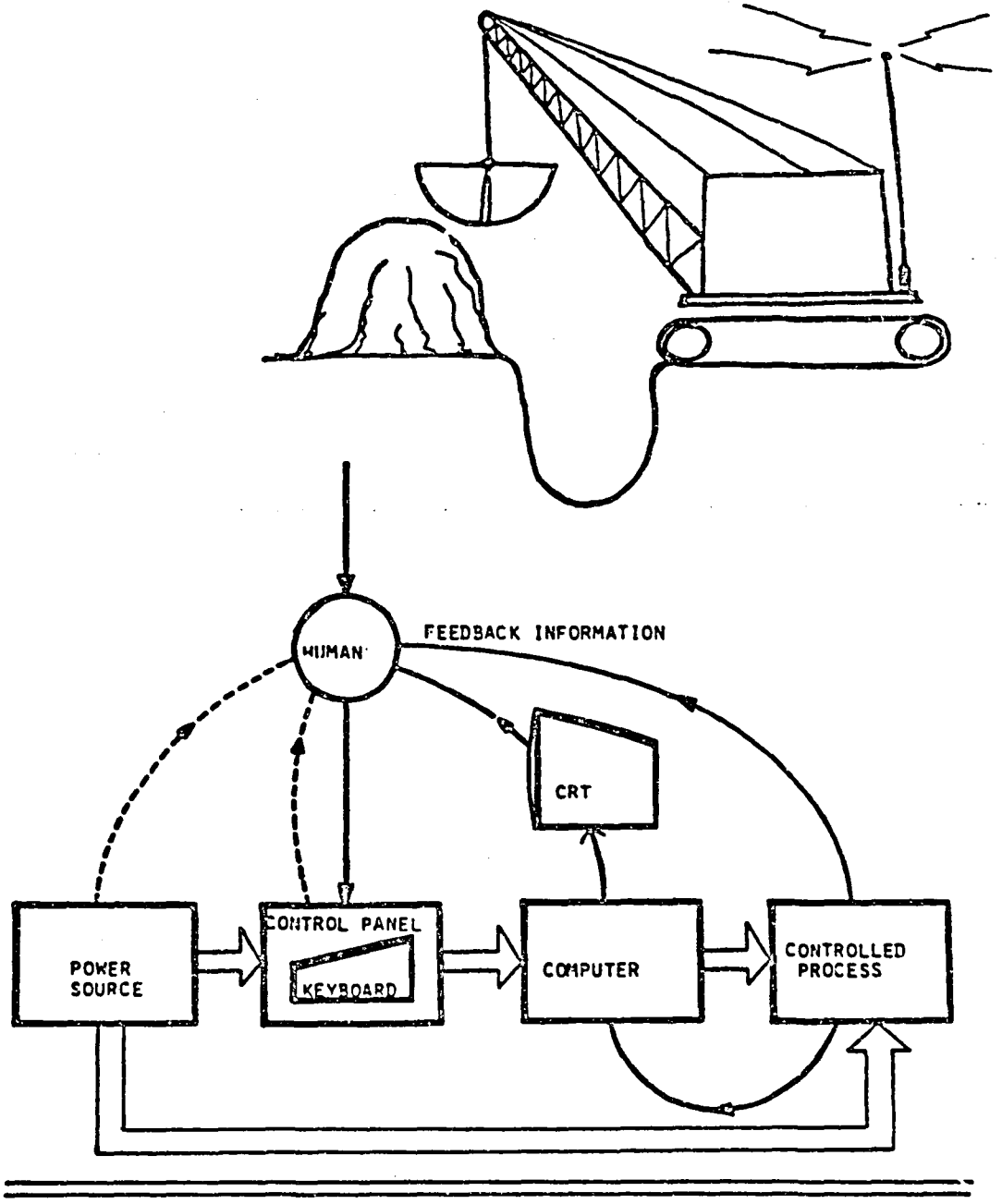


Figure 7-10b

could not be trusted to handle were assigned to the human. This process of task allocation resulted in the human operator sometimes being over utilized and at other times being underutilized. The procedure of "job allocation by default" continues to be used in automated systems with insidious and potentially serious repercussions. The problems of task definition and allocation are very serious in the design of automated systems.

Before addressing the major issues involved in task allocation for an automated command and control environment, it might be wise to review why a human is retained in the control loop at all. Rouse (1982) sums up the reasons very succinctly. The possibility of failure is the reason for having the human involved in automatic control processes. If hardware and software failures could not occur and if automation were capable of handling all contingencies, then human operators would not be necessary. Failures, however, do occur; design limitations frequently manifest themselves even after meticulous and thorough system tests and simulations. Thus, the primary task of the human in an automated control system is to detect failures and anomalies and to deal with them appropriately. In fact, it is likely, as the trend toward increasing automation continues, that the tasks of system monitoring, failure detection, and diagnosis will dominate the human's responsibilities in complex systems (Rasmussen & Rouse, 1981).

The consensus seems to be that the human must be retained in most systems, even those with high levels of automation, in order to detect unexpected and undesirable system states and to "take control of the system" in order to ensure its continued and safe operation. The system design must specify the allocation of tasks and responsibilities in such a way that the human is able to carry out these functions to the best of his/her ability and that the system will operate in at least a minimally safe manner under degraded or failure conditions.

Recent research suggests that care must be taken in introducing automation into a system. The thoughtless automation of particular functions may degrade the overall efficiency and effectiveness of the system as a whole and make the human's position in the system so ineffective as to be negligible.

These issues were raised very pointedly by a NASA sponsored workshop entitled "Human Factors of Flight-Deck Automation—NASA/Industry Workshop" (Boehm-Davis, Curry, Weiner, & Harrison, 1981). Participants representing the NASA-Ames Man-Vehicle Systems Research Division, the Federal Aviation Administration, the Royal Air Force, airline companies, aircraft manufacturers, universities, and consulting firms began with the premise that although technology has now reached the level where it is possible to automate many control functions, the more serious question is whether control function should be automated, taking into consideration various human factors issues. Though the issues were discussed in the context of flight deck automation, they are relevant to many control environments.

The two issues most relevant to Goddard's control rooms concern the effects of automation on the human operator. The first concerns the role of the human operator when the automated system is operating under normal conditions; at such times, the human operator is reduced almost exclusively to a system monitor. This passive role may leave the human, particularly a highly skilled operator, bored and/or complacent and/or unhappy with a seemingly inessential position in the system. The second issue is a direct corollary. Personnel in automated systems are expected to function in two roles; the operator acts as a system supervisor and monitor when the system is functioning automatically and as a direct or manual controller during emergency or degraded conditions. The passive role of supervisor or monitor may cause him/her difficulty in making the transition to an active controller's activities. The workshop participants felt

that the roles of supervisor and manual controller were not necessarily compatible nor complementary; the roles may require two very different sets of skills and two types of knowledge or conceptual models of the system, making it very difficult to make a quick and effective transition from monitor or supervisor to active controller and back.

An experiment recently conducted at NASA-Langley gave support to these concerns. A study comparing the relative benefits versus complexity/cost of various levels of state-of-the-art autopilots was performed on a Langley general aviation simulator (Bergeron, 1981). Several disturbing trends were observed in this experiment. As the level of automation increased, pilots were taken out of the aircraft control loop and made managers of the autopilot functions. The result was a greater likelihood of a pilot's losing track of where he/she was in a landing approach, often leading to errors or blunders. The report noted that

> pilots can be lulled into a false sense of security or complacency with too many automatic features... the problem appears to be almost as if the pilot thinks of the autopilot as a copilot and expects it to think for itself. He allows himself to become completely engrossed in other tasks once the autopilot is set. Hence, he is frequently late in resetting new functions or confused as to exactly where he is in the approach. (Bergeron, 1981, p. 706)

The report concludes that perhaps an intermediate level of automation may be preferable to the most automated device possible. In addition, the author states that more effective human/machine interface could alleviate some of the observed problems.

A case in point using one of Goddard's own systems may also help to illustrate the potential problems in highly automated systems. In the process of reviewing human-machine interface issues for the current and proposed Multisatellite Operation-1 (MSOCC-1) systems, several questions were raised about the appropriateness of the functions allocated to the human component in the next two proposed generations of

MSOCC (Mitchell, 1981). The proposed configuration for NASA-Goddard's MSOCC system is an exciting use of technology and will drastically reduce the amount of direct manual intervention in the DOC (Data Operations Control) and computer operations areas. The staffing plan, however, calls for maintaining or possibly increasing the current staff. It is unclear, however, what the eight to ten people per shift will do because the majority of their current functions will be automated. Currently, computer operators transport, mount, and dismount mission-specific software resident on disks and tapes. Under the proposed automation plan, this activity will be fully automated. The responsibilities of the DOC operator are also unclear. Figure 7-11 depicts a scenario which was given in an MSOCC-1 Operations Requirements Study (TM-81-6098). The scenario represents the anticipated human-computer dialogue during the preparation for a satellite contact. Examination of the scenario reveals that the only active human input is to type the word "GO" as the second to last step in the sequence. An alternative version of this scenario eliminates even this step, assigning the operator to a completely passive, monitoring role.

Analysis of this scenario from a human factors perspective raises a number of questions about the reasonableness of the role assigned to the human. Currently, MSOCC personnel feel, and in actuality are, underutilized. Because of the nature of their responsibilities, personnel are skilled and highly trained, yet they spend most of their time engaged in relatively insignificant tasks. With the introduction of additional automation, MSOCC personnel are likely to have their tasks further reduced and, under the current plan, not augmented by any additional tasks.

The NASA-Ames Workshop, the Langley autopilot automation research, and the MSOCC scenario jointly suggest a set of principles to guide the design of automated systems.

HUMAN - COMPUTER DIALOGUE FRAGMENT

FROM THE PROPOSED AUTOMATED MSOCC-1

Statement Source	Time Tag	Item Number	Control Statements	Comments
SCHEDULE	185:20:16:10	1	DI SAMA	Display PROC SAMA
SCHEDULE		1.1	CO LN1 TO TAC6	These items displayed from PROC
SCHEDULE		1.2	CO TAC6 TO AP5	
SCHEDULE		1.3	CO AP5 TO KCRT (MOR1)	
SCHEDULE		1.4	CO AP5 TO SCR (MOR1)	
SCHEDULE		1.5	DLL SAMASYS TO AP5	Downline load SAM-A software to AP5
SCHEDULE		2	WAIT	Wait for operator intervention
KEYBOARD		3	CO	Operator key-in
SCHEDULE		4	S SAMA	EXEC SAMA

DOCS Operator–Computer Interaction Scenario for Automated MSOCC-1 Operations

Figure 7-11

- Even though it is possible to fully automate a function, it may not be desirable to do so either from an overall systems point of view or from a human factors perspective.
- A primary goal in system design and specification is to ensure that the human component of the system has a reasonable and responsible role.
- Assign tasks to the human and computer components in such a way that optimal use is made of the resources of each.

The question then arises: What should the human do in an automated system? How should tasks be allocated to make optimal use of both the system's human and computer resources? The answer is neither perfunctory nor simple. Essentially, the role of the human component must be redefined to include a cross-section of meaningful tasks which enable the humans to function as responsible and important components of the system. This redefinition may require the rethinking of the overall system design, reallocation of tasks, and the expansion of the human's responsibilities. In MSOCC, for example, some thought might be given to expanding the controller's responsibility to include software development/maintenance as well as supervisory and occasional manual control activities. Augmenting the role definition in this way is a fairly novel approach but may be a satisfactory solution to the problem of assigning skilled personnel to important but tedious supervisory tasks.

Task allocation requires evaluation of the strengths and weaknesses of both human and system components (Crawford et al., 1977). Current hardware and software technology will supply the answers for the computer components. Information about the human is not so easily found. Current theories of human performance, particularly in the area of information processing, must be used to determine what tasks the human performs well and what human-computer interfaces or decision aids might facilitate

his/her performance. In order to ensure a reasonable role for the human component, tasks which are done relatively equally well by both humans and computers may well be assigned to the human. It is not unreasonable to assign tasks to the human which can be done equally well by the computer in order to ensure that the human is a functioning and vital part of the control process — humans get bored and/or complacent, computers do not. One interesting possibility receiving some attention is a dynamic, rather than static, task allocation scheme wherein tasks are allocated between the human and computer by determining who has the most available resources at the time that the need for the task arises (Rouse, 1981).

Whether a static or dynamic allocation is used, however, it is essential that one step of the design process detail operations scenarios for human operators specifiying what they are to do, when they are to do it, what fraction of their time is likely to be idle, and where they are under utilized. It is only by taking an explicitly operator-centered perspective that system design will ensure that the system has been adequately human-engineered as well as hardware-engineered.

Interface for the Human-Computer Dialogue

In addition to defining a reasonable role for the human component, the design process in automated systems must address the problem of providing interfaces between the human and computer which facilitate the human's ability to interact with the system in a rapid and effective manner, with as little effort as possible.

Information display is the primary interface which can help or hinder the human-computer dialogue in a control environment. One of the human's primary tasks, in an automated system, is monitoring displayed information. The human's information processing skills, however, are very limited. The human's short term memory can hold only a limited amount of information, and he/she is easily overloaded by too much

information, relevant or irrelevant (Miller, 1956). The human is very slow at scanning displayed information, and the amount of information which can be gathered is limited by the short term memory capacity. Furthermore, humans have limited capability and speed in integrating pieces of displayed information (Rouse, 1975).

Traditional information displays tended to further burden human information processing limitations rather than to compensate for them. The reason was not intentional, but rather due to the limitations of the current technology. In traditional, hardwired dedicated displays, there was little choice about information display design. Each hardware device, data channel, or sensor generated a data item which was individually displayed to the operator (e.g., the battery, the voltage regulator). Control room designers could choose how to display the data (dials, bar graphs, needles, etc.) and could arrange the position of displays on control panels but had no opportunity to display data selectively, to group or aggregate it into higher level summaries. In essence, the displays, due to limitations of technology, were directly tied to the lowest level hardware subsystems. Traditional displays placed a tremendous burden on the human operator. The human was responsible for monitoring sometimes vast amounts of displayed data, selecting out relevent items, and combining and integrating the low level data into meaningful forms compatible with high level decision making needs. These displays further degraded information processing capabilities related to display scanning, information selection, and integration of information.

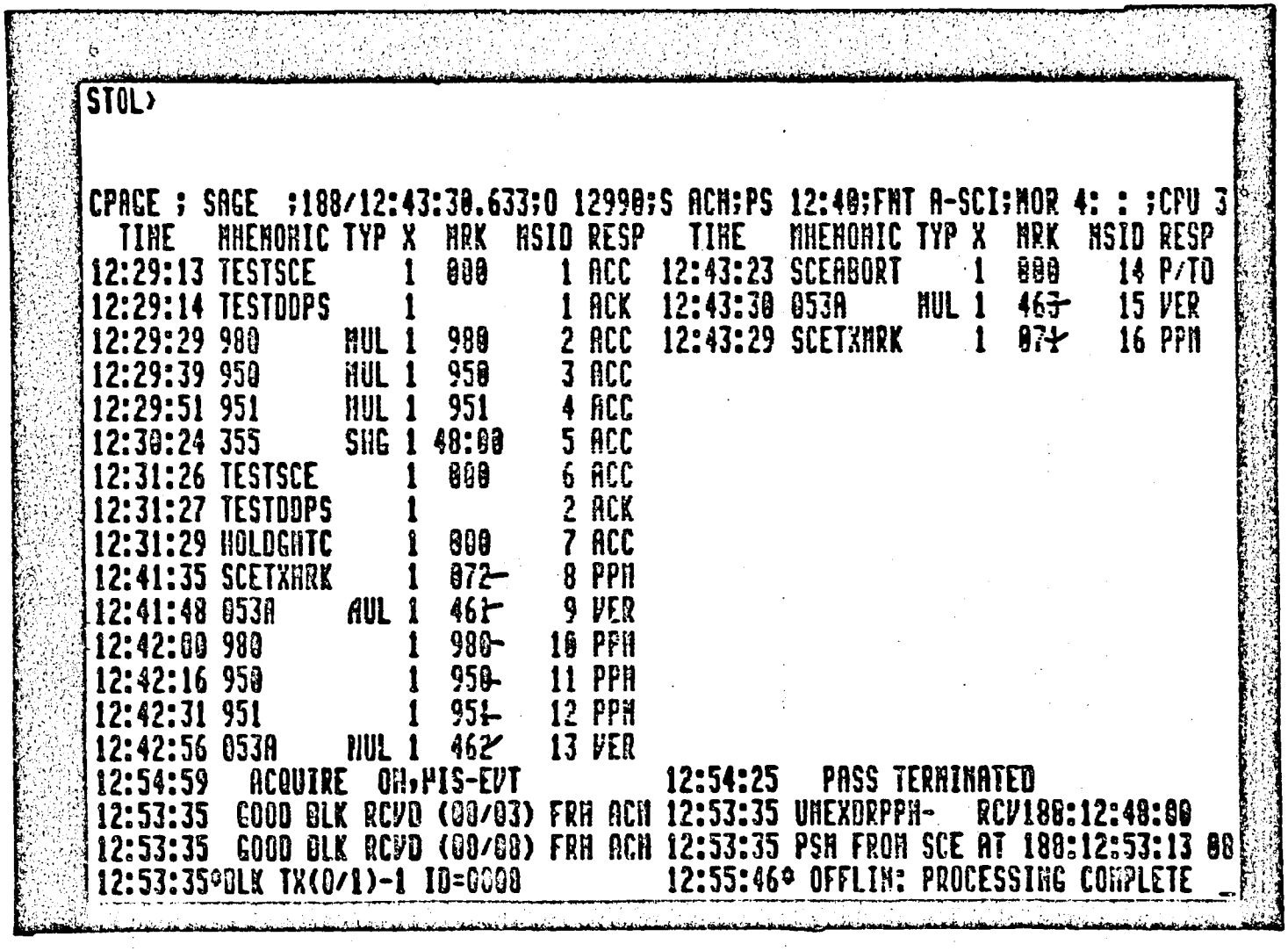
The advent of computer-based displays eliminated the need for this type of display but not necessarily the practice. Computer-based displays allow data to be filtered, summarized or aggregated, and displayed in forms only limited by the imagination of the designer. Unfortunately, perhaps because it is easier, many computer-based displays simply use the CRT as a new medium on which to display "the same old data in the same

old mode." As early as 1975, Braid warned, "there is an alarming tendency...to propose replacement of the dedicated conventional instruments by a few dedicated electronic displays ... Such proposals ignore the flexibility that electronic displays offer."

This is a problem with MSOCC in which multiple display pages are used to display great amounts of low level, hardware specific data (see, for example, Figure 7-12). The controller must monitor these displays, abstract out relevant data, and integrate them into forms necessary for high level decision making. The current displays are very detailed and completely lack any decision aiding features.

Automated systems will further aggrevate the problems in displaying low level, hardware-oriented data. In the role as system supervisor and monitor, the human requires a high level, system overview and must have the ability to quickly detect and diagnose system anomalies or failures. Vast arrays of low level displayed data will require continuous scanning of displayed data, most of which is not relevant to his/her needs at any given moment, selection of the pertinent items, and integration of these items into a form which meets supervisory decision making needs. This process of scanning, selecting, integrating, and problem solving is slow and taxes known limitations of human information processing skills. In automated systems, complexity is generally increased and, thus, a corresponding increase may be expected in the amount of displayed information. The level of much decision making is raised: The computer is responsible for low level decisions and control functions; the human is responsible for high level decisions and control functions. Thus, it may be expected that even more integration of low level data may be expected in order to synthesize information useful to high level decision making needs.

In addition, automated systems typically require the human to interact with the system in two capacities: as a supervisor when the system is behaving normally and as a



MSOCC DISPLAY FOR SAGE

Figure 7-12

ORIGINAL PAGE IS
OF POOR QUALITY

manual controller in emergency or degraded conditions. One problem created by the dual role of the human in automated systems is that the human now has two different and perhaps quite disparate functions, potentially requiring two different set of skills and two different views of the system. In automatic mode, the human needs a high level, integrated overview of the system, whereas, in manual mode, the human needs to have an understanding of the system which is detailed, thorough, and "nitty-gritty".

One of the difficulties of the multiple functions of the human in complex systems is that the varying sets of responsibilities suggest that the operator needs to build up multiple internal models of the system in order to integrate his knowledge of the system and to guide his control actions. A skilled operator in a highly automated system must build up a hierarchy of internal models which encompass a set of system views varying from a very general and broad system overview to a variety of very specific and detailed models of particular sybsystems. Experimental and theoretical research suggests that human understanding of a complex system is guided by an internal or "mental" model of the system built up by the operator over time. Internal models guide the selection and integration of displayed information. The adequacy of the internal model will govern the timeliness and appropriateness of an operator's responses. Research has shown that exploiting the internal model can improve operator efficiency (Rouse, 1975). One way to facilitate the development of appropriate internal models is through information displays which assist in organizing information and presenting it in modes which facilitate assimilation and integration, thereby reducing the cognitive load on the human operator.

A primary human-computer dialogue issue for MSOCC and other automated systems is really one of design: How do you use the flexibility to present information in forms which are compatible with the user's mental model of the system and current role? In

highly automated systems, assuming that the operator has at least two sets of internal models, one which allows him/her to function as a monitor and system supervisor and a second which allows him/ her to function as a manual controller, a reasonable suggestion is that perhaps, at the very least, the control room of an automated system ought to have two sets of displays which the operator can choose between: one set giving a high level system overview, the other providing detailed views of individual subsystems. When acting in a supervisory capacity, the high level, overview displays would be used. If more detail is desired, if some problems are suspected, lower level, detailed displays may be accessed. Moreover, there is a need for information displays which explicitly support the decision making and problem solving role of the human as system supervisor. Computer-based displays have provided designers with the required hardware. It is a design problem to exploit computer hardware in a manner which supports and facilitates the human-computer dialogue.

Summary and Conclusions

Using the human as a system supervisor raises a number of design issues concerning the allocation of tasks in automated systems and the design of the information displays which enhance the human-computer dialogue. Fundamentally, the design issues point to a need for the addition of a human-centered perspective in the design process. The human role must be as carefully and as thoughtfully engineered as the hardware, even if this means a modification or reduction in the overall level of automation.

Moreover, the technology of automation must be used to facilitate the human-computer interface. Information displays are needed which explicitly support the human's decision making tasks in the system. One possibility is a hierarchic set of information displays which change depending on the human's current role (supervisor or controller).

A hierarchical approach to information display has several advantages. It explicitly forces system designers to develop a set of human-oriented system models which will guide the design of displays. If they are designed around the operator's decision making needs, the displays are likely to become more human-oriented and less hardware-oriented. If an attempt is made to provide the appropriate information at the appropriate time, there is likely to be less information displayed at any given time, and the quality of the displayed information will require less operator effort to integrate into an assimilatable form. A very pressing problem with contemporary control rooms is that there is just too much information for an operator to be able to assimilate it quickly, easily, and accurately. Humans are easily overloaded, particularly by the displays of great amounts of irrelevant information (Ackoff, 1967; Seminara et al., 1979). Moreover, human ability to integrate multiple pieces of displayed data into meaningful information is very limited (Rouse, 1975). As a result, a reasonable and perhaps vitally necessary direction for research in the area of automated control room design is to develop displays which provide active decision aiding for the modern controller, displays which provide information compatible with the operators' current internal model, which filter out irrelevant information, and which summarize and condense lower level information into a form suitable for the operator's high level information needs.

References

Ackoff, R.L. Management misinformation systems. Management Science, Vol. 14, No. 4, December 1967.

Bergeron, H.P. Single pilot IFR autopilot complexity/benefit tradeoff study. Journal of Aircraft, Vol. 18, No. 9, September 1981, 705-706.

Boehm-Davis, D., Curry, R.E., & Wienir, E.L. Human Factors of Flight Deck Automation—NASA/Industry Workshop. Moffett Field, CA: NASA/Ames Research Center, January 1981, NASA-TM-81-260.

Braid, J.M. Integrated multi-function cockpit display systems. AGARD Conference Proceedings No. 167 on Electronic Airborne Displays, NATO Advisory Group for Aerospace Research and Development, April 1975, AGARD-CP-167.

Miller, G.A. The magical number seven, plus or minus two: Some literature on our capacity for processing information, Psychological Review, Vol. 63, 1956, 81-97.

Mitchell, C.M. Human-Machine Interface Issues in the Multisatellite Operations Control Center (MSOCC). NASA Technical Memorandum, Greenbelt, MD:NASA/GSFC, 1981, NASA-TM-83826.

NASA/GSFC. Operational Requirements Study for the Automated Multisatellite Operations Control Center-1 (MSOCC-1) Data Operations Control System (DOCS). Silver Spring, MD: Computer Sciences Corporation, 1981, NAS5-24300: TM-81-6093.

Rasmussen, J., & Rouse, W.B. (Eds.). Human Detection and Diagnosis of System Failures. New York, NY: Plenum Press, 1981.

Rouse, W.B. Design of man-computer interfaces for on-line interactive systems. Proceedings of the IEEE, Vol. 63, No. 6, June 1975.

Rouse, W.B. Human-computer interaction in the control of dynamic systems, Computing Surveys. Vol. 13, No. 1, March 1981, 71-99.

Rouse, W.B. Models of human problem solving: Detection, diagnosis, and compensation for system failures. Submitted for publication to IFAC Journal of AUTOMATICA.

Seminara, J.L., Eckert, S., Seidenstein, S., Gonzalez, W., Stempson, R., & Parsons, S. Human Factors Methods for Nuclear Control Room Design. June 1979, EPRI NP-1118-SY.

Sheridan, T.B., & Johannsen, G. (Eds.). Monitoring Behavior and Supervisory Control. New York, NY: Plenum Press, 1976.

ISSUES IN MULTIPERSON CONTROL TEAMS AND MULTIPERSON SUPERVISORY TEAMS

The customary approach to human factors engineering considers the relationships between a single person and a machine. In highly automated environments, it is increasingly the expectation that many people will be involved in the control and guidance of complex systems. Little has entered the literature to guide us in the design of multiperson control and/or supervisory interfaces.

The working together of people in groups has been extensively considered from the perspectives of management, human relations, and decision making. A number of studies and experiments provide a body of knowledge on team organization, leadership roles, intra- and intergroup communication structures, and other aspects of people working in small groups. The major thrust behind these studies has been the improvement of group productivity, whether on the production line or in managerial policy setting.

Unfortunately, just as the traditional human factors approach has not been used to scrutinize, from an engineering or design standpoint, the productivity of interacting groups via their technical systems, the study of workteams and small groups has not expressly included the technical systems with which these groups carry out their work. As a result, the issue of multiperson control teams has been largely ignored. Those who have looked at the control and supervision of technical systems have concentrated on individuals, while those who have looked at multiperson processes have concentrated on the human dynamics of these processes.

The object of this section will be to present an organized approach to the issue of multiperson control and/or supervisory teams. Because it is a region of human factors which is relatively unexplored, the first concern will be with offering some conceptual

categories with which the problem may be handled. A set of helpful working terms is the first requirement.

First, we need to reiterate the distinction between "control" and "supervision." Control refers to the human participant's role as being one which completes the control loops of the system. Supervision refers to the human participant's role as being one which is separated from the physical control of the system, allocating to the individual the tasks of monitoring the behavior of a system and of providing information and guidance to the system as it performs its task. Typically, the supervisory role is carried out through the mediation of computers.

These roles are not exclusive. An individual may both control and supervise a system. An automobile driver or a pilot, for example, may complete the control structure of the vehicle and provide higher level guidance, such as mission definition, strategy, and tactics. The supervisor of a computer-controlled system may be required to intervene with manual control under certain circumstances. In systems designed to maintain a constant operator work load, the computer may handle tactical decisions during periods requiring extensive strategic decision making, while the human may handle these tactical decisions during periods of low strategic activity.

Typically, the literature treats the single operator in relation to the system under control. While there are many exceptions to this, these exceptions tend to be in the areas of command and control. In these studies, there is little distinction between multiperson control of a single system and multiple single control of coordinated subsystems.

To sort out these relations, the following terminology and categorization is suggested:

- o Discrete Functions — tasks whose successful completion depends only minimally if at all upon the successful operation of other processes.
- o Coordinated Functions — tasks whose successful completion depends upon the successful operation of other processes. Coordinated functions exchange information on their states. There is typically some sort of precedence relation among a set of coordinated functions.
- o Systemic Functions — tasks whose successful completion depends simultaneously upon the successful operation of all on-going processes.

Discrete functions differ from coordinated functions in that they possess no precedence relations and hence require little or any information exchange. The work of a race crew on a race car during a pit stop illustrates crudely the notion of discrete functions. Several different tasks must be completed while the car is in the pit. The fuel tank is topped off; the tires are changed; oil is added; water is added; the driver is given something to drink; the windshield is cleaned. These "subsystem maintenance operations" may all be undertaken with essentially no communication among the various tasks. They begin with the arrival of the car; the car departs when all tasks are completed. The initiation of all tasks is under one central precedence rule: the arrival of the race car in the pit. Once the car is in the pit, these tasks are carried out independently in any convenient temporal order. If different time constraints were applied, a single operator could randomly and sequentially complete all tasks. Under compressed time constraints, such as a race condition, a multiperson team may be used, one individual to each task, so that the set of tasks can be carried out simultaneously.

On the other hand, a common way to describe the set of tasks required by coordinated functions is by using network flowcharts. For example, PERT charts describe coordinated functions. The interactions among air traffic controllers may also be described as coordinated functions. Each controller is responsible for a given air

C-3

space. As aircraft move from one region into another, the air control tasks are coordinated by the exchange of information concerning the aircraft from one controller to the next.

Systemic functions are superordinate to coordinated and discrete functions. The systemic task of driving coordinates the coordinated functions of accelerating and braking and such discrete functions as tuning the radio.

Multiperson control and/or supervisory teams may be classified according to the types of tasks the individuals in the team are working on. The work team is a multiperson team whose members each deal with a discrete function. The tactical team is a multiperson team whose members are responsible for coordinated tasks. The strategic team is a multiperson team whose members are responsible for systemic tasks. Organizational diagrams for these types of teams are given in Figure 7-13.

For the work team, the team members are linked together through a hierarchically superior controller/supervisor. Lines of communication are not required among the members of the work team. It is sufficient that overall coordination of task initiation be imposed by the higher level controller/supervisor.

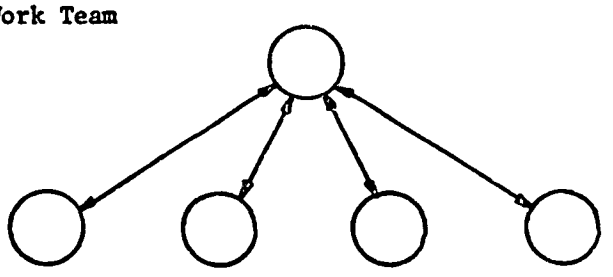
For the tactical team, the members require lines of communication among themselves as well as lines of communication to and through a hierarchically superior controller/supervisor. For the strategic team, communications occur among the team members without the mediation of a hierarchically superior controller/supervisor.

If the symbolism for the individual members in these groups is interpretted as nodes on a graph, each node can in turn be recursively defined as a work team, a tactical team, or a strategic team. Various graphs can then be built up which can be roughly classified into three classes.

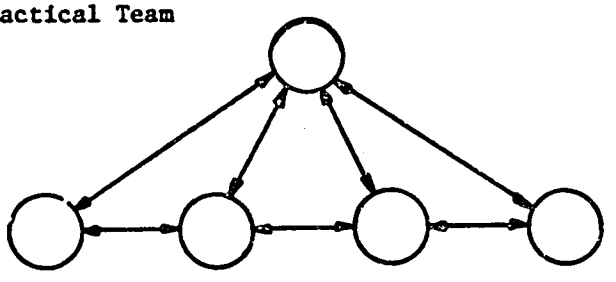
Hierarchic organizations in pure form begin with the work team and build

ORIGINAL PAGE IS
OF POOR QUALITY

(a) Work Team



(b) Tactical Team



(c) Strategic Team

Figure 7-13. Team Organizations

recursively a hierarchic tree. Heterarchic organizations in pure form begin with the tactical team and build recursively a network. Anarchic organizations in pure form begin with the strategic team and build recursively a network characterized by strictly lateral communications.

This classification is not intended to describe any particular real world organizations. Many different organizations may be constructed through the analytic use of these structures, recursively defining any dependent node. Thus, a typical assembly line organization might begin with a strategic team, define each of the nodes of the strategic teams as a tactical team, and then define each of the nodes of the tactical teams as work teams.

The communication lines depicted in the team structure diagrams signify formal communications. Formal communications are task specific communications authorized and sanctioned by the organization. Another way of conceiving formal communications is that formal communications are those which are expressly designed into the system. Informal communications consist of all other communications, whether task related or not. Many observers will claim that, in fact, it is these informal communications upon which the actual work and production of an organization depend. These workers will suggest that informal communications are used to plan and to execute the work of an organization while formal communications are used to document the conclusions of informal communications.

Multiperson control and/or supervisory teams are almost invariably linked both internally and externally by informal communications. These informal links exist regardless of the structure of formal communications. The importance of these communications pattern lies in tying the study of technical systems which integrate human controllers and/or supervisors to the overall organization(s) responsible for the

operations of these systems. As noted earlier, the examination of multiperson teams of controllers and/or supervisors has been lost in a peculiar limbo. The study of group processes from an organizational perspective and the development of social technologies for the construction and operation of human groups has focused on the formal and informal communications among human team members. The study of technical systems integrating humans has focused on the formal communications between individuals and their machines.

At the boundary of these two approaches, between organizational development (OD) technologies and human factors engineering technologies, we find human groups interacting to control and/or supervise a technical system. From a human factors perspective, this issue introduces a new problem: how are the members of a controlling and/or supervising team themselves to be controlled and/or supervised? How can the integration, coordination, and synchronization of these team members working simultaneously (or at least concurrently) on a task(s) be designed into the technical system?

At this point, the discussion will be limited to the types of systems typically deployed for real time satellite control at NASA Goddard and under consideration for future Goddard missions. For the purposes of the remainder of this discussion, the tasks of real time satellite control will be assumed to be highly automated with a reliance upon computational devices to mediate between the human elements and the technical elements to be controlled within the system. Using the previously defined terminology, this places the human into the role of a system supervisor. Goddard supervisors work now and will increasingly work as team members, making the issue of multiperson supervisory teams an increasingly critical one for the success of the Goddard mission. The structuring of operational responsibilities at NASA Goddard entails a heterarchic

approach, which verges on anarchic, to interteam communications.

Within teams, ranging from software development to scientific users, from contractor groups to DOC controllers, a variety of team structures can be observed to have evolved from the interplay of the task at hand, the technology available to perform the task, and the skills and training required of the human supervisor within the constraints of Civil Service and contractor personnel procedures. Rather than attend to this heterogenous assembly in all its variation, this discussion will consider the supervisory team according to a single simplified model. In this model, a team interacts with a given system in its entirety through the mediation of computers. An example of this model might be the team of supervisors of a highly automated power generation plant.

The single multiperson supervisory team alters the classic "human/machine" relation of human factors engineering to a "human/system" relationship. While there has been much learned about the autonomous relation between a human and a machine, the multiperson supervisor introduces the problems of relations between individuals while they are relating to their technical system.

The members of a team are not necessarily co-located either in space or in time. This means that the problems of integration, coordination, and synchronization among team members involve questions of shift work, ergonomic adjustment of machines, personnel interoperability, and the design of communications channels. These problems bring to the fore questions of status and leadership within a team, suboptimization, workspace layout, and team training. Questions regarding the managerial, administrative, and social design of the team need to be addressed.

These guidelines are concerned with the hardware and software design of the interface between the automated system and its supervisors. Many of the issues raised

by multiperson supervisory teams, while quite important and so raised here, are beyond the scope of this report. However, communications is an element of many of these problems and can be addressed from the standpoint of design of control rooms. Communications can be categorized in two dimensions: between the system and the team and among the members of the team.

Communications Between System and Team.

In a highly automated control room, communications between the system and the human team is largely via displays from the system to the team and largely through various control instruments from the team to the system. Principal among the control instruments used in highly automated environments are keypads and other interaction devices attached to communications and KCRT terminals.

Displays. Typically, control room displays are designed for a single proximate viewer. This may be inappropriate for multiperson environments for a number of reasons:

- o requirements for several team members to process the same information at the same time;
- o requirements for team members to cover the absence of any single team member;
- o disruption of one channel of communication while the team member physically moves to another location to view another display.

The general principle here is that supervision of any part of a system should be possible from any station within a control room. Once located, any individual within a control room should be able to obtain all required information and to exercise all required control without moving from that station.

This principle suggests the following:

- o standardized and modular work stations

- o the use of large screen displays
- o team training for personnel interoperability
- o highly intelligent intervention of computer support in selection of the set of necessary and sufficient data to be displayed and the inclusion of real time look-ahead software capabilities
- o a tiered or theatre architecture for the control room
- o adaptive allocation of tasks between the computer and the team
- o sophisticated design and control of ambient illumination
- o ergonomic adjustment of seating, work surfaces, and working tools, such as local CRT or graphics displays
- o the use of high resolution local or personal displays supported by "messy-desk" software such as articulated by the I-space concept (Rieger, Wood, & Allen, 1981)

Control Instruments. In keeping with the principle stated above, control instruments in the team environment should be standardized and modular, and be capable of ergonomic adjustment. The relation between display and control suggests further geometry-related considerations.

- o Control instruments should be low profile to avoid interference with the field of view. Similarly, in the suggested tiered environment, the control instruments should be relatively shallow.
- o The working environment should be pulled around the individual rather than raised and/or extended in front of him.
- o The use of horizontally mounted rather than vertically mounted displays in the primary work area should be encouraged. High resolution displays can compensate for perspective distortion by increasing the size of images the farther they are from the eye of the individual.
- o Interaction devices which do not depend on the actual location of the display device should be used. This rules out touch panels and light pens, but rules in keypads and mice.

Figure 7-14 illustrates this design geometry. The narrowness and low profile of the workspace directly in front of the operator provides a deeper field of view and thus both closer location to the primary large display and a denser packing of stations. The side module of each station are kept well below shoulder height to allow an uninterrupted lateral field of view for communications with other team members. This geometry is radically different from the workstation geometry indicated by the dashed line in Figure 7-14, normally proposed for single controllers. The difference is driven by the use of central large screen displays which are visible to all team members. Figure 7-15 illustrates the wrap-around geometry of the multiperson team workstation with the individual in a standard reach diagram position. (A flat writing surface is provided on the right hand side of this right-handed individual.)

Communications Between and Among Team Members

Attention was given in the above sketch of an individual workstation to geometries enabling person-to-person communications among team members. Important design requirements for an environment in which group processes are facilitated is unimpeded visual and physical access among team members. An ideal design would place the team members in a circle, facing inward so that all team members will be simultaneously visible.

It is difficult to conceive of any single alphanumeric display which could service all team members arranged in such a circle. Further, as the team becomes larger, the diameter of the circle becomes large enough to overwhelm the psychological perception of a natural proximity for communications.

However, the geometry of the circle for smaller teams allows the placement of displays both within a central pit and around the control room circumference, above the heads of the team members. This of course requires multiple copies of the same

ORIGINAL PAGE IS
OF POOR QUALITY

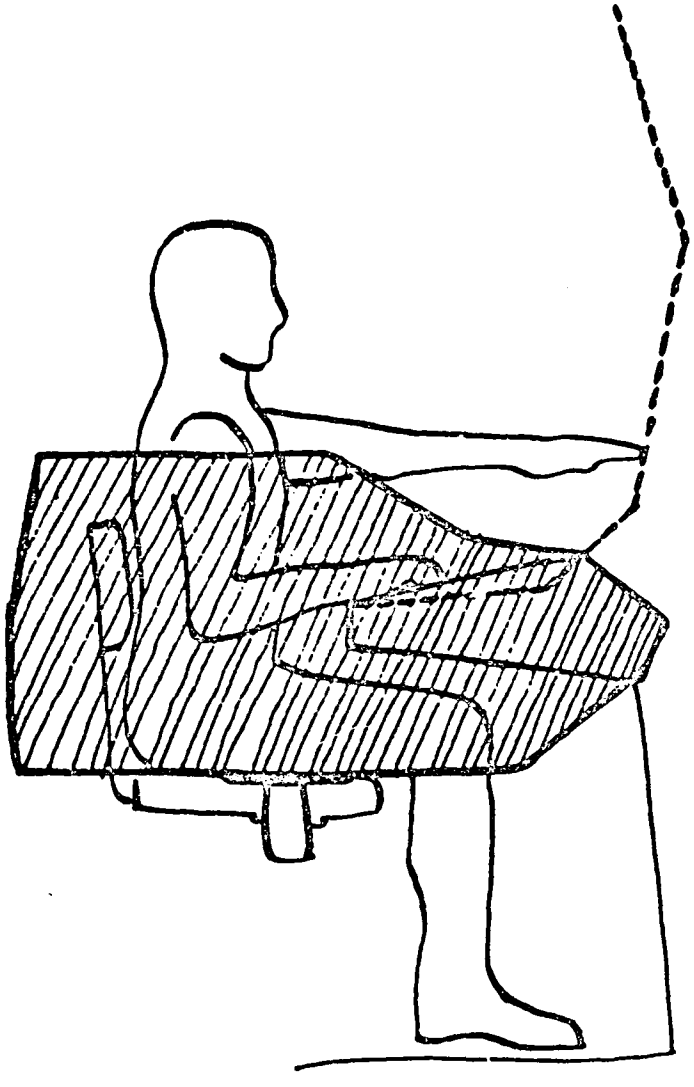


Figure 7-14

ORIGINAL PAGE IS
OF POOR QUALITY

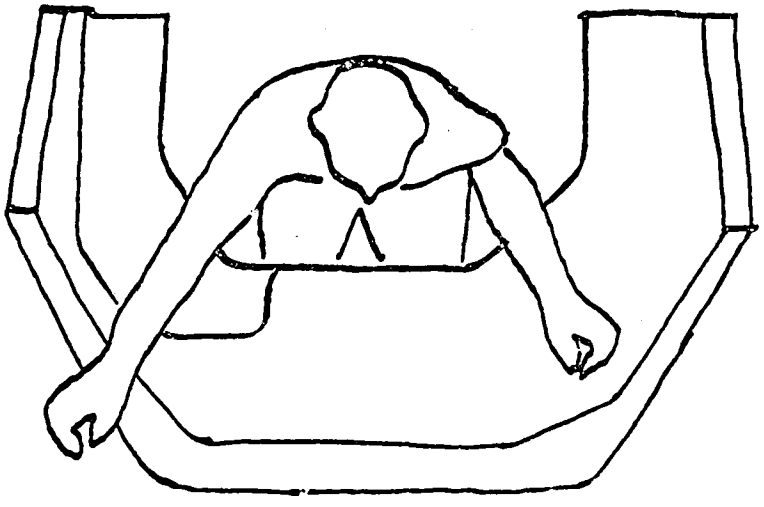


Figure 7-15.

information display and introduces problems with field of view for any given team member, both for the pit display and for the circumference display.

At present, thus, it is not clear how such a circle arrangement can be effectively and efficiently used. In the future, the central pit may make an ideal stage for real time holographic display of an operating system, but that technology is not yet fully available.

In contemporary control rooms, face-to-face speech and various forms of telephonic communications are relied upon to pass formal and informal information among team members. While this has proven useful, these oral communications suffer from several disadvantages, which include:

- o susceptability to interference and other noise, both internal and external to the communications channel;
- o requirement that both sender and receiver(s) be available for communication at the same time;
- o lack of integral means to save the communication for later recall;
- o status deference in decision making.

To date, the application of computers in highly automated environments has been limited to formal communications between humans and machines. Little attention has been given to the application of computers to supporting and managing the formal and informal communications among the members of a supervisory team. As communications among team members and from the team to the external world undergird the integration, coordination, and synchronization of team members in their tasks, and since computerized systems can provide effective communications channels, it appears reasonable to suggest that the design of control rooms include facilities and support for computer-based intrateam communications from one station to another.

Hiltz and Turoff (1978) have explored the technical design and social impact of

computerized conferencing. Their work suggests that such computer-based communications have unique advantages that may be very useful in the control room environment. Among the various advantages of computer-based communications are the removal of the problems associated with oral communications.

Communications for Teams Separated Spatially and Temporally

The argument for the integration of computer-based message and conferencing systems in control room design becomes quite persuasive when communication among team members who are separated in space or in time (e.g., shift workers) is required. It is, of course, only a small step to recognize the potential of computerized messaging and conferencing among different teams within heterarchic or anarchic organizations.

Summary

The ideas presented in this section are speculative and tentative at best. They are presented here not as firm dicta but rather to suggest that designs and procedures for multiperson supervisory teams may in fact be radically different from those of traditional single-person workstations. There is little firm guidance available yet in the literature and even less that can be currently considered applicable to strategic teams carrying out systematic (and coordinated) functions in an heterarchic organization such as NASA/Goddard. A great deal of research is needed in this area to confirm or challenge the propositions presented here.

References

Hiltz, S.R., & Turoff, M. The Network Nation: Human Communication Via Computer. Reading, MA: Addison-Wesley Publishing Co., 1978.

Rieger, C.J., Wood, R., & Allen, E. Large Human-Machine Information Spaces. College Park, MD: University of Maryland, Artificial Intelligence Group, March 1981, RP1024 (NASA-25764).

ORIGINAL PAGE IS
OF POOR QUALITY

MANAGEMENT PHILOSOPHY

The emphasis of the material presented in these guidelines has been on the human-machine interface as a whole. A human factors approach views this interface from the human's perspective, attempting an optimal integration of his/her capabilities and the machine's capabilities. It is suggested that this approach be taken a step further, to focus clearly on the social-psychological environment (Chapter 3) and the human interaction that takes place within it when analyzing, evaluating, or designing work organizations. By doing this the human component of the work environment takes on increased value and becomes an asset or resource to be utilized accordingly. Management use of the human-as-a-resource approach results in both quantitative and qualitative benefits to the organization. Job satisfaction, morale, absentee and turnover rates, performance (e.g., error rates), and productivity can all be affected constructively.

If the human-as-a-resource is the accepted, underlying premise, then the designer or leader of any work group needs to consider carefully the choice of possible management style. Many different philosophies for managing people exist, each profoundly influencing worker communication, goal setting, conflict resolution, motivation and decision making which in turn affects overall organization performance. Management exists as such to bear this heavy responsibility and as Costley and Todd (1978) suggest, one of management's primary functions is to create conditions that will maximize the productivity of the employee and, in doing so, enhance the organization.

The human-as-a-resource approach to effective management has been used successfully in various types of organizations. Before illustrating this approach to management in a satellite command and control environment, a brief examination of different management styles is necessary.

Management theory and the ensuing applied research has centered on a categorization of types: leader or manager traits, leader behaviors, and organizational situations. The notion that managers possess certain personality traits that make them managers has not been strongly supported (Hampton, Summer & Webber, 1978). Thus, the approach of looking for certain personality traits in an individual to determine whether or not he/she is a leader has largely been abandoned.

Categorizing manager behaviors has proved more fruitful in terms of identifying management styles and in determining what one is most effective. The Ohio State studies, as described by Hampton et al., 1978, defined two kinds of manager behavior: initiation of structure and consideration. The manager classified as the initiating structure type places an emphasis on getting the work out. He/she plans, directs, and controls the work within the organization he/she manages. In contrast, the consideration-style manager is concerned with the human needs of subordinates and helps them to satisfy those needs. The experimental results of this model show initiating structure behavior resulting in productivity with consideration behavior resulting in more satisfied subordinates. It appears that the technological stability of the organizational environment interacts with the manager behavior to produce these results, making the distinction not quite so clear.

Another dichotomous theory of manager or leader behavior is McGregor's Theory X and Theory Y (in Costley & Todd, 1978; French & Bell, 1978; Hampton, et al.; and Huse, 1980). McGregor suggests that managers hold assumptions about the nature of human behavior regarding work. Theory X individuals do not like to work, lack ambition, avoid responsibility, and must be forced to do good work. Theory Y people seek out responsibility, like to work, find work a source of satisfaction, and are capable of making positive contributions to the organization. Managers who believe workers are Theory X

types are themselves authoritarian and retain tight control over the work and the employees, believing this is the only way to motivate that type of person. Communication in this kind of work group tends to flow in a downward direction only. The manager who views employees as Theory Y types is considered egalitarian and encourages employee initiative, self-fulfillment, and participation in decision making and task accomplishment. The flow of communication here is both upwards and downwards, and side to side. Some experimental results suggest the Theory Y view of employee work behavior leads to success; but, again, situational aspects of the organization and individual characteristics interact to influence the results.

Rensis Likert developed a management system theory based on a continuum of management style as cited by French and Bell (1978). He characterized four management styles ranging from task-centered to employee-centered. They are: 1) exploitive-authoritative, 2) benevolent-authoritative, 3) consultive, and 4) participative group. His experimental results consistently show that the most effective organizations are characterized by the fourth type of management—participative group.

Blake and Mouton also place management style or behavior into a dichotomous framework (cited in French & Bell, 1978). They have identified a "concern for people" style and a "concern for production" style. However, their experimental results indicate that the most effective manager is one who places great emphasis on both styles.

The third aspect considered by management theory is the organizational situation. Theorists and researchers with this focus point to contingencies; the most effective management style in terms of production and employee satisfaction is contingent upon both management style and organizational environment. In discussing their contingency theory, Lawrence and Lorsch suggest that the "fit" between organizational structure and environment is essential for effective organizations. The degree of fit is determined by

management actions called differentiation and integration. Lawrence and Lorsh state that stable, homogeneous environments need less differentiation and integration while diverse, uncertain environments need more differentiation and integration (cited in French & Bell, 1978). Fiedler's contingency theory identifies two management styles: relationship-motivated and task-motivated and three types of situations that can be either favorable or unfavorable: leader-member relations, task structure, and leader position power. The experimental results on this model suggest that task-motivated leaders perform best when the situation is very favorable or very unfavorable for the manager to exert influence; relationship-motivated managers tend to perform better when the situation is either moderately favorable or moderately unfavorable (cited in Hampton et al., 1978).

Other management theories exist, e.g., path-goal theory, expectancy theory, and leadership pattern choice models, and many are quite complex. What is important to consider is that the potential for more effective managment is unlimited (Cootley & Todd, 1973), implying the need for careful prior thought about the organization or work group being formed, its task goals and objectives, its staff (size and make-up) and its mangement philosophy. The command and control environments of the different projects currently in place and being planned for the future at Goddard could only benefit from a thorough analysis and evaluation of these factors.

Case Study

The literature generally points to the human-as-a-resource approach for effective management in terms of productivity and employee satisfaction with the underlying assumption that employee satisfaction is positively linked to productivity. A useful and relevant illustration of this approach to management was seen at the University of Colorado's Laboratory of Atmospheric and Space Physics (LASP) within the Solar

Mesophere Explorer (SME) mission. Several Goddard and contractor personnel visited LASP recently and listened as the staff outlined the management approach to the SME project.

Upper level management set out to accomplish several things with the project besides guaranteeing the health and safety of the spacecraft and collecting data. They wanted everyone on the staff to have a thorough understanding of what was going on from all points of view. By doing this, they sought to achieve common goals. In achieving common goals, they eliminated adversary positions. The director felt these were the key assumptions within his philosophy: to achieve common goals and to eliminate adversary positions, thus leading to productive, satisfied employees and smooth, effective operations.

Several actions were taken to achieve these objectives. The user was visibly considered at all levels. The mission operations manager communicated closely with the scientists to better serve their needs and was also closely tied to the operations people. Upper level management also kept in close contact with the hardware designers incorporating ergonomic aspects into the physical environment, e.g., recessed ceiling spotlights over workstations to decrease glare on CRT screens. All decisions were made by consensus within the appropriate groups rather than by edicts being passed down from upper level management. The consensus decision-making process led to a thrashing out of common goals, with everyone working towards the same outcome, thereby channeling motivation to the project as a whole as opposed to territorial or political ends. This philosophy also led to the development of a unique shift design for operations. The flight controllers and operators participated in the design of the twenty-four hour staffing plan. A two, twelve hour shift schedule (3:30 a.m. to 3:30 p.m.) was adopted. This was based on a staff consensus which concluded that there are morning and evening types of

people and that shift hours should coincide with those personal preferences. Once a controller chooses a shift, he/she remains on that shift, allowing for the establishment of to establish daily routines, including the important biological process of re-entrainment (Chapter 3). The shift design also made both shifts equally attractive, i.e., neither operated during entirely popular or unpopular hours.

Another key assumption of the SME management was the importance of accurate assessment of, and feedback on, individual work performance. A computerized performance assessment tool was used to provide clear direction and feedback to the worker. Each individual's tasks were broken down into easily handled components, with the break down determined by consensus, and monthly print-outs tracking progress towards each goal were provided. Thus, employees had concrete evidence of their past effort and present status. Most workers displayed their progress reports for all to see turning the exercise into a game-like activity. Management indicated that quantifying performance effectively motivated workers and supported morale and satisfaction.

The management philosophy at the SME project included a positive perspective towards accomplishment. The focus was strictly on what could possibly be done at all levels, including the human ones, given the resources, rather than on limitations. There appeared to be a great deal of flexibility in dealing with potential problems and compromise situations. The result was that successful, efficient operations were maintained and that motivation and morale were high.

The SME project can be considered a small project by Goddard standards with the project director and mission operations manager comprising upper level management. The size was advantageous to the management approach and allowed many things to happen that might be difficult in larger projects. However, the success of the project on several different levels and its application to Goddard projects should not be disregarded

because of the "smallness" of the operation.

The SME project was successful from several perspectives. It was completed ahead of schedule and under budget, had a successful launch, and has continued to have successful operations. Unique to the project is the fact that one-third (equivalent) of the operators in the control room are undergraduate students from the University of Colorado at Boulder who work part-time to support the staff flight controllers, e.g. most worked as flight controllers and software programmers. Also unique to the project was the combination of roles for the flight controllers. These interesting aspects of the SME project are beyond the scope of this document; for further information the reader is directed to Moe (1982). The central point, however, is that the project succeeded in implementing human factors in the design of the command and control room to the delight of those working within that environment. Informal conversations with the operations staff yielded enthusiastic responses to what had been done. A video tape detailing the physical aspects of the control room is available through Code 500 and the NASA/GSFC Human Factors Group (1982). The successful use of the human-as-a-resource management philosophy enlarged the application of human factors to the project. It should be pointed out that no one theory of management is best; several factors influence what approach is best suited to what organization or group. However, the choice of a management philosophy should be a conscious decision made after serious consideration of the group's goals, tasks, and staff, and the choice should be made early in the existence of group.

References

Costley, D.L., & Todd, R. Human Relations in Organizations. St. Paul, MN: West Publishing, 1978.

French, W.L., & Bell, C.H. Organization Development (Second Edition). Englewood Cliffs, NJ: Prentice-Hall, 1978.

Hampton, D.R., Summer, C.E., & Webber, R.A. Organizational Behavior and the Practice of Management (Third Edition). Glenview, IL: Scott, Foresman and Company, 1978.

Huse, E.F. Organization Development (Second Edition). St. Paul, MN: West Publishing, 1980.

Moe, K.L. Trip Report of the Visit to Solar Mesophere Explorer (SME) Operations Center in Boulder, Colorado. NASA/GSFC memoranda from Code 502, August, 1982.

NASA/GSFC Human Factors Group. Tour of the SME Mission Operations Room—Video Tape. August, 1982.

CHAPTER EIGHT

TOOLS FOR HUMAN FACTORS DESIGN AND EVALUATION

INTRODUCTION

This chapter provides a brief overview and introduction to some of the commonly used tools in human factors analysis. A number of these tools are very simple both to learn and to use, and often result in very valuable information about the human factors aspects of the system design process. The techniques discussed here include task analysis, link analysis, and operational or onsite observation, and audits. Another technique reviewed here is the use of situational mockups as a formal part of the design and evaluation process for workstations, information displays, and system control panels. The mockup technique is a required step in the military design process (MIL-STD-1472C) and frequently has a very high payoff. In addition, this chapter describes a range of more sophisticated tools used in human factors design and evaluation, grouped under the general rubric of mathematical or engineering models of human-machine interaction. Finally, a number of human factors methodologies will be reviewed. Recently, methodological approaches to design have been receiving a great deal of attention. Although frequently application-specific, they show a great deal of promise as design tools.

TASK ANALYSIS

One of the more useful tools employed in human factors design and evaluation is task analysis. It is a prerequisite to any type of top-down analysis and provides valuable design and job description information. Fundamentally, a task analysis defines what the human does in a man/machine interface and what he/she needs to do, resulting in a role definition of the human component in a system.

A task analysis is a structured method for describing work behavior in terms of tasks (McCormick, 1979). Tasks are basic units of human activity; several tasks together comprise functions. A task analysis breaks functions down into tasks and analyzes the informational requirements and control feedback necessary for task accomplishment.

Tasks have several characteristics, and these help the designer determine what behavior is a task, as opposed to a subtask or function. The following are task characteristics, as suggested by ANACAPA Sciences, Inc. (1981):

- Independent - one task can be performed independently of another. The level of activity is meaningful in itself.
- Observable - an observer can determine whether or not a task has been performed.
- Measurable - an observer can assess whether or not a task is performed properly.
- Time-Ratable - a task has an identifiable beginning and end.

Several formats can be used to conduct a task analysis; and the decision to use one format over another depends upon the activities making up the tasks. Figure 8-1 lists the available formats and the activities best suited to each. As shown, for complex decision or problem-solving activities, decision table or flow charts and outline formats are best; for continuous or sequential activities, outline or time-line formats are best; and for step-by-step and identifiable activities, column formats are best utilized. An in-depth description of each format type can be found in McCormick (1979).

Task analysis, as a human factors tool for design and evaluation, yields valuable information and is currently used as such by agencies as the U.S. Nuclear Regulatory Commission (NUREG-0700, 1981; NUREG/CR-2254, 1981) and the Department of Defense (MIL-STD-1472C, 1981). NASA-Goddard's command and control room environments would benefit greatly from a task analysis applied in the design phase of

GUIDELINE FOR SELECTING APPROPRIATE METHODS AND FORMATS FOR ANALYZING VARIOUS TYPES OF TASKS AND ACTIVITIES

TASKS WHICH INVOLVE	ARE BEST DESCRIBED IN
•Complex decision making •Problem solving	Decision Table/Flow Chart or Outline Format
•Continuous activities (for example, driving a car) •Activities which must be performed in a specific sequence, within a definite time frame	Outline or Time-Line Format
•Step-by-step activities •Identifiable procedures	Column Format*

*The column format will be satisfactory for the vast majority of technical tasks.

Figure 8-1, McCormick, 1979, p. 97.

ORIGINAL PAGE IS
OF POOR QUALITY

new systems. A number of benefits of task analysis which appear relevant to NASA-Goddard are proposed by ANACAPA Sciences, Inc. (1981). Task analysis can:

- o serve as a basis for other analyses
- o provide design requirements and reflect design impacts
- o ensure that a task is within human performance capabilities
- o ensure human safety
- o minimize error by identifying what could go wrong and when
- o serve as a basis for procedural and system support development

As defined, the benefits of a task analysis are wide ranging. The cost of utilizing this human factors tool is minimal; therefore, it behooves system designers to apply it frequently.

LINK ANALYSIS

Another human factors tool used in design is link analysis, a method used to determine layout of workspaces, control and display panels, and communication networks. It determines optimal arrangements by calculating appropriate criterion measures of the "links" or connections between entities and by analyzing the relationships found.

There is an informal structure for conducting a link analysis. The designer first determines what link type best demonstrates the relationships between entities. McCormick (1976) defines three link types: visual, auditory or tactile communication; control; and eye, hand, foot, or body movement links. Each analysis measures one type of link. In a command and control environment, link analysis could be applied to

command panel design. For example, an operator's hand movements could be the appropriate link chosen for measurement.

The next step is to determine the most appropriate criterion of link measurement to use. There are several available, and the choice of one or more is operation-dependent. The following are criterion measures suggested by ANACAPA Sciences, Inc. (1981):

- o Probability
- o Time
- o Strength
- o Importance
- o Frequency
- o Sequence
- o Distance

Some criteria are qualitative and require subjective value judgments by the person conducting the analysis. That person necessarily needs to be well informed regarding the procedures and tasks being performed. In the example scenario where operator hand movements are links, frequency could be an appropriate criterion. A movement from one entity to another on a command panel would have a frequency measurement of one. Design of command panels requiring minimal operator hand movements would justify using frequency as a criterion.

To conduct an effective link analysis, a representation of the activity being analyzed is needed. Graphic or schematic diagrams provide this and assist in measuring the links. Matrices should be set up to categorize the criterion measures and to provide sum totals of the links within the activity. Matrices can be of two types: directional, where element A links to element B in that order only; and nondirectional, where

direction of link is not important, i.e., A to B or B to A (ANACAPA Sciences, Inc., 1981). For purposes of the scenario, a nondirectional matrix could be used.

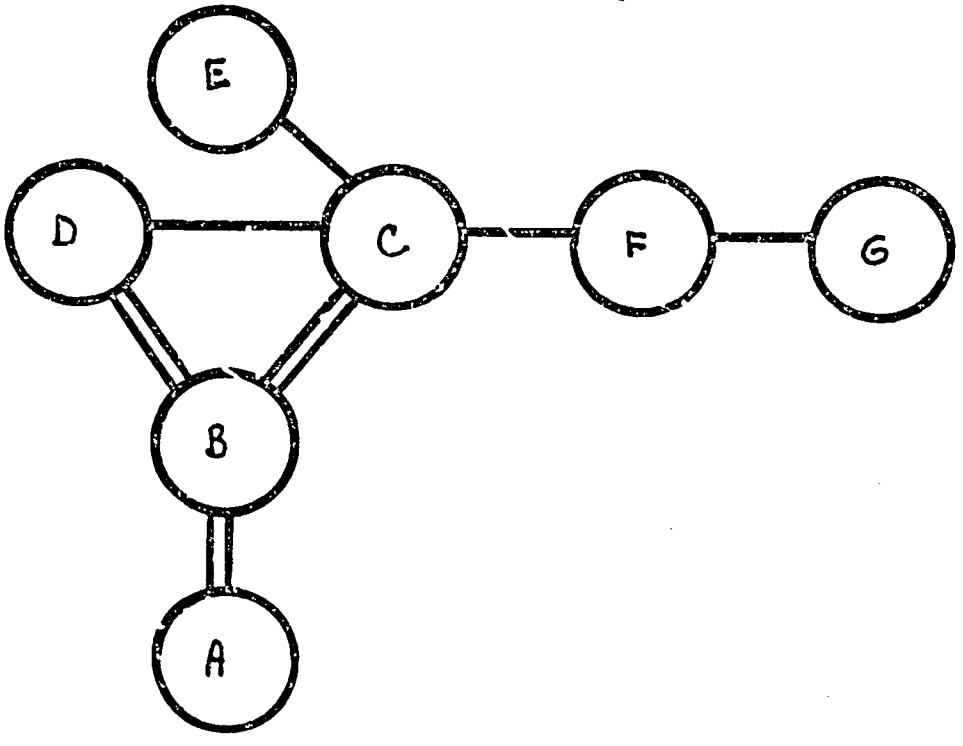
Next, the totals within the matrix are ranked according to frequency intervals: most, next most, and least frequent. This helps determine the link strength in preparation for drawing the link diagram. Figure 8-2 is a nondirectional link diagram. The strength of the links is represented by the type of line connecting the entities. When drawing the diagram, eliminate crossed lines, put the strongest links closest together, and have all links represented. Several iterations of this drawing may be necessary to produce an accurate diagram.

When directional matrices are used, drawing the link diagram differs slightly. After the links are drawn in corresponding strength representations, a principal path must be determined. Figure 8-3 shows a simple directional link diagram with the principal path corresponding to the alphabetized entities; i.e., move from A through F. To determine the path, start at any entity and follow the strongest link coming into that point. It is a "backwards" process that always produces the same principal path result.

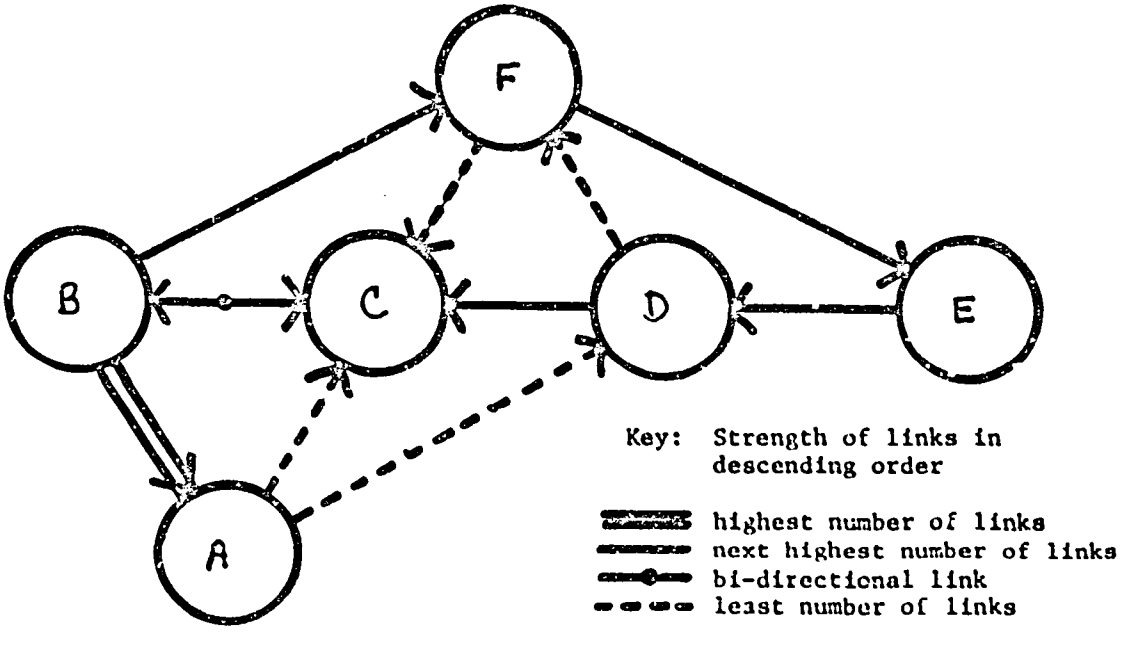
The last step in a link analysis is applying the link diagram to a layout. In the example scenario, the controls and displays used in conjunction most frequently, as evidenced by the link diagram, are grouped together and in the center of the operator's reach envelope

As a tool for design, link analysis offers a structured approach to layout. When used during the design phase of a system (rather than after the fact), it can be very powerful, forcing the designer to think about what actions will occur and to determine what ones are most important. Better layouts and arrangements, benefiting both human and machine performance, are likely to result.

ORIGINAL PAGE IS
OF POOR QUALITY



8-2 Non-directional link diagram



8-3 Simple directional link diagram

ONSITE OBSERVATION

One very useful tool for conducting a human factor analysis is onsite observation. Particularly for the modification or the development of newer generations of existing systems, onsite observation or operational audit of the current system can be a vital diagnostic tool in identifying existing or potential human factors problems which can be corrected in newer systems.

Site visits are a required procedure in licensing nuclear power plants (Bell & Swain, 1981; NUREG-0801, 1981; Seminara & Parsons, 1979). The purpose of such visits is to allow the human factors analyst to become familiar with the operations-relevant charactertistics of the system. The intent is not to make design recommendations or criticisms, but rather to identify aspects of the control room, the general layout, and administrative control procedures that effect generic human performance.

A site visit may include the review of scenarios or sequences of events to identify human actions that directly affect the system-critical components. Another aspect of a review may be talk-through or walk-throughs of control procedures to identify and examine critical human factors aspects. This procedure allows the analyst to fully understand the activities of the operator in various control functions. Performance specifics are identified along with any time requirements, personnel assignments, skill-of-the-craft requirements, alerting cues, and recovery factors. Subsequently, a task analysis may be performed.

Onsite observation consisting of passive observation, critical event reviews, talk-or-walk-throughs, or task analyses is a powerful tool for human factors design reviews. It takes advantage of the wealth of knowledge and experience accumulated by skilled operators and allows the analyst to augment his/her "text book" knowledge of the system with invaluable, real time experience. As a tool used in the preliminary stages of human

factors analysis, site visitation probably is the tool with the lowest cost/benefit ratio and should be included whenever possible.

MOCKUPS

Introduction

The following guidelines are an extensive overview of mockups and models in the general design process that can be found in Woodson (1981). A recommendation, consistent with good human factors principles, is that Goddard consider the establishment of a mockup test facility. The section which follows suggests some guidelines for operation and staffing of a GSFC mockup test facility.

Mockup Test Facility

The application of advanced technologies and diverse operational teams at GSFC to problems of real time satellite control makes imperative the minimization of error originating in any system component. In support of the highly visible manned space program, NASA has already mandated the use of mockups in the design process. The Department of Defense has mandated the incorporation of human factors engineering in large scale systems design. The implementing specification, MIL-H-46855B, explicitly calls for the use of mockups in Par.3.2.2.1.1 (1981). The reasons for this are clear: system designs must incorporate their human elements at the earliest possible stages, and human factors guidelines must be validated by testing the designs through the use of mockups.

Any physical product can be mocked up or physically modelled. Procedures using these physical products can be tested before the design becomes final. The products used by GSFC fall basically into two classes: communications products and work station products. The communications category includes all devices for conveying data from one

place to another. These devices include KCRTs, phone sets, time displays, graphics interactive devices, and the computing hardware and software which support them. Workstation products include luminaires, desks, seats, and other items not necessarily specifically configured for GSFC missions. In general, GSFC communications products or their interfaces (displays, etc.) are embedded in workstation products.

GSFC operations are typified by the coordinated effort of multiperson teams. These types of operations are seldom found in the purely commercial sector but are frequent in defense systems and in high-technology regulated sectors, such as nuclear power and air traffic control. Mockups are required to ensure that multiperson operations communicate and function smoothly within a given designed environment.

This, of course, does not slight the need for testing and evaluation of one-on-one communications, particularly at GSFC, between a controller and the system being controlled. In this area, we think primarily about interactive communications with computers. The need to mock up environments in which complex team interactions can be observed does, however, suggest certain recommendations for a GSFC mockup facility.

The facility should be large enough that complete control rooms can be mocked up at a 1:1 scale. The facility should be linked to operational facilities so that test and evaluation can be conducted by dual operation in real time. The facility should be serviced by computers of sufficient power that realistic data environments can be simulated.

The mockup facility should be treated as an experimental laboratory. In this laboratory, at least four distinct sets of personnel will interact: designers, mockup specialists, evaluation specialists, and subjects. (For another perspective, see NUREG-0700, 1981).

Designers of hardware and/or software and/or procedures will submit candidate designs to the facility. Mockup specialists ("set designers") will construct the appropriate environment. Evaluation specialists will develop a test plan and conduct the evaluation experiments, including selection of appropriate subjects. It is crucial that designers be divorced from the evaluation process.

The facility will possess instrumentation tools and equipment, both hardware and software. Such tools include anthropometric measuring devices, videotape, software monitors, and other sensors.

Administratively, the facility must be supported by GSFC top management. It should operate under a formal management charter ensuring its independence. The use of the facility to evaluate both in-house and contractor designs must be mandated.

The facility should be a resource to designers as well as a tool to evaluate their designs. Conference and video rooms should be part of the facility. Overhead catwalks in the mockup area would be desirable.

The mockup facility should be chartered to develop an independent experimental and data acquisition program. For example, the facility should be charged to monitor the anthropometric user populations of GSFC and any variations in these populations over time.

Designers of products to be evaluated by the facility should provide only the design specifications to the facility. It is the role of the evaluation personnel independently to define a test and experimentation plan given the functional specifications of the product(s). Indeed, the functional specifications should go to the mockup facility at the same time as they go to the design team. As is well known but seldom practiced evaluation criteria should accompany the functional specifications.

The mockup facility should cooperate with and support design teams and design review teams by providing evolutionary mockups throughout the design cycle. This means that the mockup facility will be involved from first concept layout through final prototype. This includes the potential concretization of the mockup into a training simulator.

Designers should view the facility as a helpmate in the design process. If the facility is drawn in only to make a summary judgment on a designer's creation, this assistance will be resented and, if possible, rejected, no matter how justified, warranted, or needed any criticism may be. In terms from "egoless" programming approaches to software development, the mockup facility should provide a structural environment for "structured walkthroughs." The facility should be seen as "validating" rather than as "evaluating" candidate designs. This places a substantial educational burden on the facility and its staff.

The evaluation staff should be extremely competent in experimental design and statistical evaluation. The concept underlying the operation of the facility should be one of careful and controlled experimentation. This must be so that experimental results from the literature can be validated (or rejected) for GSFC populations and applications; so that the facility can publish GSFC findings on their own merits in the field to garner both internal and external credibility, and so that the facility can attract and retain top caliber human factors professionals.

Mockup Techniques

Chapanis (1958) covers the basics of experimental design for human factors engineering. Woodson (1981) covers the basics of mockup design and of subject selection. The following discussion is based upon Woodson, pp. 993-1003.

Mockups are developed throughout the development process to validate proposed designs. There are two basic types of mockups, differentiated by scale. The miniature-scale mockup is essentially a model used to examine gross or over-all structural or 3-dimensional relationships. The full-scale mockup is used to test the relationships between the system and its user or maintainer.

At the beginning of the design process, mockups are tentative, cheap, and temporary. As the design process unfolds, mockups become increasingly substantial, closer to the physical reality implied by a design. By the conclusion of the design process, a mockup takes the form of a prototype. If the prototype is sufficiently advanced, the mockup may graduate to a training simulator during the deployment stage of the system life-cycle. Different stages in the design process require different levels of complexity. The following mockup approaches are suggested to provide these different complexity levels.

Paper Mockup. This kind of mockup is inexpensive and relatively quick to provide. The working medium is paper and/or cardboard. The paper is coordinate scaled (line quadrille paper), and design elements may be cut out and moved around on a backing surface, or they may simply be drawn on a working surface. This provides a very good first-cut examination of miniature-scale workplace or facilities layouts or for initial review of full-scale relationships like those of a control panel and its elements to operator reach. Woodson notes:

> It should be emphasized that the paper mockup is not to be regarded as a plaything that is beneath the dignity of the practicing professional . . . a paper mockup will provide important criteria for developing more sophisticated mockups later on during the design program. (p. 993)

Soft 3-Dimensional Mockup. This type of mockup is somewhat more durable than a paper mockup. It is constructed from wood, cardboard, and rigid foams. It is termed

"soft" because the materials are easy to work and assemble, in contrast to "hard" metal.

A wooden frame provides structural support for cardboard or foam board representations of a control or work environment. The cardboard or foam board "skins" may be used as the mounting surface for paper mockups of controls and displays. Such a full-scale 3-dimensional soft mockup gives the ability to evaluate the spatial interrelations between an operator and his working environment.

A miniature-scale soft mockup is typically made from a soft wood like balsa. The elements of the scene (chairs, panel racks, etc.) may have a magnet attached to their undersides so that they can be secured on a metal mounting plate.

A soft mockup can be made more realistic once the basic patterns have been validated by replacing the paper mockpups of instruments with their actual counterparts, mounting them in the mockup skin. From there, the instruments may be wired to simulate active instruments.

Soft mockups can also be used to examine maintainability problems, such as location and size of access hatches. Because of the ease of construction many alternative designs may be tried out via soft mockups. The appearance and operator/maintainer relationships exhibited can be captured photographically for all trials. This can lead to increased communications among those involved in multi-specialist design teams and provides both documentation and a comparison among designs for design reviews.

Hard Mockups. The hard mockup serves to define the detailed assembled aspects of a completed design; at the extreme it is a full prototype. The hard mockup is made with metal and exhibits the details of internal structure as well as external appearance. This is the working laboratory for finalizing design decisions, like the running of wires and the selection of hinges. It provides a device for working out assembly sequences and

maintenance operations. Hard mockups are used to evaluate specific human-machine interface problems, including maintenance and repair as well as operation.

Other Mockups. Styling bucks and models consist of clays or molded plastics providing just the external appearance and dimensionality of a product. Portability models add dynamic characteristics, like the center of mass, to evaluate products such as hand tools which are expected to be manipulated, carried, or positioned by their users. Portability models are used to examine the weight and balance effects of the product in use. Accessibility mockups are concerned with optimizing access to internal components. They can examine the physical arrangement of components from the view of the efficiency of maintenance.

Determining Type and Level of Mockup

While there are no absolute rules, the available time and the criticality of the human-machine interactions are key considerations. A mockup cannot be useful if it cannot be ready at the appropriate design stage; the type and level of mockup should be planned into the design schedule.

Woodson notes the following as critical interactions—

- The working space is limited due to external confining constraints.
- An escape envelope or path must be defined.
- Visibility adequacy and/or constraints need to be verified.
- Reach adequacy and/or constraints need to be verified.
- Lighting parameters need to be established.
- Entrance and exit for non-standard users needs to be provided.
- Control and display arrangements for ease of location, identification, and speed of use need to be studied in real time.

- Component-rack interactions may present mobility problems for the maintenance technician.

Making a mockup insufficiently realistic or detailed may prevent finding reliable answers; on the other hand, any effort expended beyond that required to answer questions like those above is not cost-effective. To be as useful as possible as a design evaluation tool, a mockup should be as flexible, adaptable, and changeable as possible, allowing alternatives to be quickly and inexpensively considered. A mockup is not an investment but a tool.

Miniature-Scale Mockups and Models. Scale should be selected to fit the overall number of items to be evaluated in the miniature scene. The model and its elements do not need to be detailed, but they do need to be scaled accurately. One-sixth scaled models are suggested for interior room arrangments. As long as a flat floor is involved, the metal base plate to which magnets will stick should be inscribed in a grid of the appropriate scale. These models provide a vantage point to observe total arrangement proposals. Among other objectives, miniature-scale can be used to evaluate sightlines, route utilities, arrange workstations, and evaluate traffic flows.

Use of Drawings and Paste-Ups. Panel composition and layout can be initially evaluated by simply pinning a drawing on a wall. Better yet, attach a metal, felt, or cork surface to the wall to which panel element paper mockups can be attached. Both sitting and standing relationships can be observed. This technique can be used to analyze reach problems, sequencing and grouping, spacing and layout, and height for visual displays. Free standing walls with different plane surfaces can be simply constructed from a wooden frame and foam board.

Erector Set Mockups. Optimum positioning of controls and displays can be established by placing the user in a 3-dimensional framework constructed from "erector

set" beams. Control and display elements can then be mounted on adjustable supports bolted to crossbars on the frame. The elements can be adjusted in 3-dimensional space until the best location is determined.

Experimenting with Alternative Panel Layouts

Woodson puts it most clearly:

> In experimenting with alternative panel layouts, one should make a checklist of the principal human engineering features that should be kept in mind, i.e., functional organization, sequence of use, frequency of use, and primacy or importance. In addition, however, one can also examine a number of factors that are not in the typical human engineering guides. For example, although there are criteria for spacing to prevent inadvertent activation and criteria for size of label letters, and so forth, spacing is often a matter of general appearance, e.g., balance, symmetry, and absolute clarity. One can "see" these characteristics only when experimenting with several different arrangements and spacings. For example, it may become obvious that, because the panel has to be very small, crowding obviously creates confusion. By making slight alterations and/or adding separator lines around certain related functions, one can alleviate the confusion. One can also tell rather quickly when the size variation among labels is not sufficient to provide an immediately clear indication of function levels. Even though criteria have been established by human engineers, these sometimes need to be adjusted. (p. 998)

Human-Machine System and Environment Simulation

While all models and mockups are to some extent simulations, the use of computers to provide a dynamic interaction between human and system is perhaps the ultimate mockup. The extent of realism depends on several things including how important a variable may be to human performance, how well it can be simulated, the time available, and the cost. Woodson cautions: "Avoid the temptation to create an exotic simulation because it is a design challenge." However, it should be kept in mind that a successful simulation may be advanced into a training device for the operational system.

Choosing Subjects for Mockup Evaluations

Designers tend to be unsatisfactory subjects. They tend to be biased toward their own designs. They are not generally representative of the user population. In addition, designers typically assume that all users will react to a design in the same way that they do. Things about the design that seem straightforward, clear, and desirable to the designer may be completely strange, foreign, and undesirable to actual users.

Subjects should be chosen directly from the expected user population. They should exhibit the range of anthropometric distribution for that population, particularly in size and strength. Those chosen should have the appropriate range of intelligence, experience, and training.

Determining the Number of Evaluators

To evaluate reach and clearance, five subjects from each of the extreme design percentiles (e.g., the 5th and 95th percentiles) should be adequate. To evaluate weight characteristics of a portable package, 10 small subjects should suffice. To evaluate control manipulability, at least 20 subjects are required. For mockup and simulation evaluations of team procedures, a minimum of three complete teams should be used. To evaluate comfort and convenience, at least 50 evaluators should be used.

Establishing the Basis for Test Subject Selection

When the mockup is testing dimensional physical relations, test subjects should be chosen to represent the critical dimensional limits of expected users. This situation requires subjects who represent the largest people, to test clearance, and who represent the smallest people, to test reach. In-between size subjects need to be included to ensure that some in-between dimensional problem is not overlooked. It is standard practice to fit the 90% of a population who fall between the 5th and 95th percentiles. However, note that if a product is to be used by both sexes, the range should be from the

5th percentile woman to the 95th percentile man.

For human engineering factors other than dimensional physical relations, a more random sample from the user population should be used, of sufficient size to obtain reasonably reliable measures.

Evaluation Design

Mockup evaluation design should follow standard experimental design. This recommendation implies statistically honest and reliable procedures and appropriately trained personnel to run them. Chapanis's (1958) text, as noted previously, is a standard adaptation of experimental design applied to human engineering questions.

Co. slusion

Mockups are an invaluable aid to the design process because they provide feedback to the designer and early detection of human factors problems in an experimental setting. The most widely used human engineering methodologies incorporate the use of mockups and their evaluation into the design process. It would be beneficial if NASA/GSFC regularly used mockups and in the design process and considered the establishment of a Mockups Test Facility. This facility would provide design evaluation for the GSFC community and serve as an ongoing experimental resource in developing human engineered control rooms.

MATHEMATICAL MODELLING TECHNIQUES USED IN HUMAN FACTORS ANALYSIS

Designers of machines pursue the design process in a predominantly quantitative manner. In response to the desire to describe the human-machine interaction in somewhat similar terms, a wide variety of mathematical models of human-machine interaction have been developed.

In the past, much of the design of complex human-machine systems was accomplished using principles of "conventional wisdom" or by trial and error techniques. As a result, the human in the system was frequently confronted with a non-human-engineered system and left to cope as well as he/she could. Quantitative design methods which model the human-machine interaction permit the prediction of design choices in terms of system performance criteria. This ability rests on the ability to model the way that the human behaves as a component of the overall human-machine system.

There are many questions about the validity of such models — how can one predict human behavior? The use of such models over time has shown that they have a great deal of validity for narrow and well-defined application domains. Often, the utility of a model does not depend on its ability to predict accurately and in detail. A model which provides roughly accurate or approximate behavioral data is often useful in design decisions. Moreover, the process of modelling may help to facilitate the design process by assisting the designer in organizing and clarifing his/her thinking on the human-machine interactions involved in the system.

This section will survey a number of models and modelling methodologies which have been found useful in either conceptual or detailed design and analysis and modelling of human-machine systems. Two excellent sources for further reference are the recently reprinted classic text by Sheridan and Ferrell (1981), Man-Machine Systems: Information, Control, and Decision Models of Human Performance, and the excellent

tutorial text by Rouse (1980), Systems Engineering Models of Human-Machine Interaction.

This review will follow the organization which Sheridan and Ferrell (1981) present in their text.

Information Processing Models

This class of models and modelling methodologies represents the human component of the human-machine system as an information processor limited in its capacity both to attend to multiple inputs and to match stimuli with suitable responses. The models described in this section rest on the various theories of human information processing presented in the previous chapter.

Sheridan and Ferrell (1981) divide models of information processing into two major classes: those concerned with probability estimation and revision and those concerned with information measurement.

Probability estimation, both objective and subjective, is used to capture the capacity of people to express their perceptions of relative frequency and proportion. Probability theory may be used as a normative tool to describe or characterize optimal human behavior. Rules of probability may be used to form subjective estimates to assess the probabilities of hypotheses, and Bayesian probability theory may be used to update the estimates on the basis of new evidence.

Models of information measurement are based on the principles of information theory which were developed in communication analysis as a way of quantifying and describing the behavior of communications channels. Sheridan and Ferrell provide an introduction to principles of bivariate and multivariate information analysis. Information measures are interpreted in terms of coding, redundancy, and sequential constraints. The text includes a review of experiments in which human performance has been successfully

interpreted using information measures. Such measures have been most successfully used in control tasks in which human performance can be characterized simply as stimulus/response behavior. They begin to lose power for more complex tasks.

Manual Control Models

The next broad class of models used to describe, characterize, and predict human performance are control theory models. Sheridan and Ferrell (1981), Kelley (1968), and Rouse (1980) all provide extensive treatments of this subject. Manual control models seek to minimize error or system deviation from the norm. Often referred to as engineering models, manual control models have been quite useful for describing continuous control of systems having a limited number of degrees of freedom, i.e., variables which need control. This class of systems includes vehicles of all kinds including aircraft, automobiles, bicycles, and ships. These models have not been as useful in systems in which control is predominantly discrete rather than continuous. Unfortunately discrete control is characteristic of many of the modern complex systems having various levels of automation.

Rouse (1980) provides an interesting overview of discrete-time "modern" control theory formulations. He notes that although optimal control theory has been applied to modelling supervisory control situations in an effort to cope with the changing role of the operator in the face of increasing automation, the analogy of the human operator to a servomechanism has some inherent limitations which may also define the limits of the applicability of control theory and its models.

Models of Decision Making

One criticism of engineering or manual control models of the human operator is that although, for specific applications, such models are very accurate at matching human behavior, i.e., descriptively valid, they have little intuitive validity. Using

sophisticated mathematical techniques, control theory models assume the human behaves as if he/she were engaged in a series of calculations which include integral and differential calculus, differential equations, Laplace and Fourier transforms. Models based on these assumptions lack intuitive validity because users often doubt that the human operator engages in such sophisticated computations in the decision making process.

Decision theory was developed as a methodology to explain economic choice behavior in certain (i.e., deterministic) and uncertain (i.e., probablistic) environments. Over the years, decision theory and models based on decision theory have been widely applied to many decision situations and decision makers, including the human operator in complex control systems. Decision theory models assume that the decision maker optimizes some specified criterion or set of criteria (e.g., minimize cost, maximize profit) by selecting the alternative from a well-defined and exhaustive set of decision alternatives which yields an optimal value of the criterion function.

Utility theory provides an enhancement to decision models by attempting to modify the optimization process based on the preferences and values of individual decision makers in decision environments. Thus, optimal choice is computed by determining which decision outcome is worth the most to the decision maker. For example, although an outcome resulting in a gain of $80 yields twice as much monetary reward as one resulting in $40, the value or utility of the first outcome to the decision maker may only be an increase of 50% rather 100%. The addition of a decision maker's utility function for outcomes is a refinement of decision making models which enhances their intuitive appeal and strengthens their structural utility. The primary difficulty with utility theory models of decision making is that the decision maker's utility function must be assessed, a task which is neither straightforward nor trivial.

In addition to being either deterministic or probabilistic in nature, decision models exist for both single objective and multiobjective decision situations. The theory is more advanced and computations are much better defined and defined for the single objective or criterion case; multiattribute decision models are at the cutting edge of current research in decision theory.

Another variation in decision theory models is time. Some models are static, representing one time, "one shot" decisions. Other models are dynamic and allow modelling of sequential decision making processes. Applications to human behavior in control systems include signal detection models of static behavior, dynamic models of behaviors including optimal stopping and data taking time, reaction time and discrimination, and instrument scanning and sampling.

Newer Modelling Approaches

As the quest for more faithful and accurate models continues and as the need for models which reflect complex decision making behavior in automated systems grows, a number of new modelling approaches have been tried, some with a good deal of promise.

Queueing Theory. Rouse (1980) contrasts manual control models with queueing theory models by stating that the former are concerned with system performance as defined by deviations of the system's state from some desired trajectory, as opposed to queueing models which measure length of time required to perform tasks, for example, waiting and service times.

Queueing models are very applicable to situations where task completion time is important. Applications have included models of visual sampling behavior for instruments on a console as well as monitoring behavior. One very succesful application is in air traffic control environments, where queueing theory models have been used to assist in scheduling take-offs and arrivals and in staffing. One novel application is the

use of queueing models to assist in dynamic task allocation in automated and semiautomated cockpits; queueing models have also been used successfully to model multitask pilot decision making.

Fuzzy Set Theory. An even more recent approach to modelling discrete human decision making is the use of fuzzy set theory. Its use in modelling human-computer interaction in complex systems is even newer and there is, as yet, only limited experience. Rouse and his colleagues (1980), however, have tried several applications and concluded that fuzzy set theory may be very useful for situations where the human must cope with inexact knowledge of the process being observed and/or controlled. This research team has used fuzzy set models in both process control and fault diagnosis tasks.

Production Systems, Markov Chains and Pattern Recognition. Rouse (1980) presents three modelling methodologies which have not yet been applied to human-machine interaction situations, but show a great deal of promise, particularly for automated systems in which the human functions as a system supervisor.

Production systems have been widely used in computer applications, particularly in artificial intelligence. They have also been successfully used to model decision making and policy making behavior in social science applications. Production systems permit modelling of discrete, sequential decision making in which a pattern of events evokes actions.

Probabilistic sequences of events can be modelled as Markov Chains. Markov Chains allow the description of aggregate human behavior, not just individual behavior. Aggregate behavior is often more useful in engineering design as opposed to statements or descriptions about individual behaviors.

Another technique being developed in artificial intelligence is pattern recognition.

Theories and models of pattern recognition may be quite useful for describing human behavior in display scanning and sampling as well as fault diagnosis. Furthermore, if the pattern recognition models are robust enough, they may be quite helpful in designing decision aids to assist humans in pattern recognition tasks.

Summary

This section provides a broad and general overview of modelling techniques used in human factors design and analysis and in the description of human-computer interaction. Some of the models and modelling strategies, such as manual control models and decision theory models, are well-defined and tested, with proven and accepted domains of applicability. Some of the techniques are much newer and more speculative. There is a need, however, to explore strategies and techniques beyond the conventional models. Modern systems, with increased automation, are bringing about a change in the role and responsibilities of the human operator. New tasks are discrete rather than continuous and frequently involve a higher level of decision making. Conventional tools and approaches have not been able to represent supervisory behavior adequately and, thus, must be augmented. Several of the modelling approaches show great promise in describing human-machine interaction in automated systems.

HUMAN FACTORS ENGINEERING METHODOLOGIES

Introduction

It is truly pointless to argue whether human factors engineering methodologies are a discretely separable set of methods or whether they fall generically within some other classification, such as systems engineering. Human factors engineering methodologies are discussed here not to claim a separate discipline but to ensure that consideration of the human system component receive explicit attention.

While superior design has always considered human capabilities and limitations, industrial design, architecture, and other activities devoted to producing goods for human use have traditionally proceeded in the craft tradition. This craft tradition, founded on good sense, intuition, and serendipity as well as a weeding out of clearly inappropriate designs, proceeded by building up a body of craft lore concerning what does and does not work when humans use material products. This lore, while not precise, sufficed even for the relatively uncomplicated products of the Industrial Revolution and through the nineteenth century. Whether handmade or machine-made, most items were still individually made, individually used, and individually designed.

The technologies of the twentieth century introduced new complexities and new scales to design, manufacture, and use. Our machines became systems, too large and too complex to be understood in their totality by a single individual. The craft skills no longer were sufficient for design, manufacture, or use. Scientific and analytic techniques were developed as required to surmount the inadequacy of the individual designer, who could no longer operate on the basis of the "feel of the thing."

Design became a cooperative effort across many specialties, manufacture became the work of diverse groups, and use became the responsibility of specialized team members. Integration and configuration management arose as their own specializations, with subspecialties concentrating on particular types of interfaces. Systems management itself became an administrative specialty, attempting to maintain order amidst incipient chaos. The prospect of an individual possessing an all-encompassing comprehensive overview became nearly meaningless. As the technologies became more sophisticated, gaps arose in design areas where specialists remained ignorant. And as the specialists were increasingly oriented to engineering and analytic technique and as the ultimate system user faded into anonymity, the system user and operator all too often

fell through the cracks of the interfaces.

A dominant sector of human factors research has revolved around a figure in American folklore who attains near heroic stature and, in his rugged and daring individualism, has never quite faded into faceless anonymity in the eyes of those designing for him—the fighter pilot. Aviation-related research has been a mainstay of support for American human factors work in complex high-technology systems. Indeed, some of the most wide ranging applied human factors work has been done in support of the quintessential American Hero, the NASA astronaut.

Within the last two decades it has become abundantly clear that the human system component is the a weak link when the system fails to build in human capabili and limitations. In the complexity of contemporary systems, the old craft approaches to ensuring usability simply have been superceded. The "squishy" performance o. .. human organism now needs to be integrated into the system design as much as the engineering performance of a computer chip or a bearing; and the integration needs to be as technically based as other older engineering techniques to ensure compatibility among the components of the design effort.

As expected, the major impetus for formal human factors engineering came from organizations with experience in operating large and complex systems which depended critically upon people for safe and effective performance. Significantly, the impetus did not arise on the part of the manufacturers of the products and systems being used by these organizations, except as an adjunct to traditional industrial design and marketing activities. The major systems operators have had to impress their concerns for human factors engineering on their suppliers. For the major systems operators, human factors engineering is not a factor in marginal sales but in institutional and organizational survival.

Department of Defense

Of course, the major supporters of human factors engineering are the Department of Defense, and the Nuclear Regulatory Commission, NASA, and the Federal Aviation Administration. The Department of Defense has been actively programmatic in insisting upon human factors engineering, promulgating the Military Standard MIL-STD-1472C, Human Engineering Design Critria for Military Systems, Equipment and Facilities and the Military Specification MIL-H-46855B, Human Engineering Requirements for Military Systems, Equipment and Facilities. The NRC has issued many volumes of human factors related techniques and standards.

MIL-H-46855B:

> "establishes and defines the requirements for applying human engineering to the development and acquisition of military systems, equipment and facilities. These requirements are the basis for including human engineering during proposal preparation, system analysis, task analysis, system design (including computer software design), equipment and facilities design, testing, and documentation and reporting . . . human engineering shall be applied . . . to achieve the effective integration of personnel into the design of the system . . . to develop or improve the crew-equipment/software interface and to achieve required effectiveness of human performance during system operation/maintenance/control and to make economical demands upon personnel resources, skills, training and costs." (p. 1)

The Specification requires human engineering efforts in analysis, design and development, and in test and evaluation.

Proceeding from a baseline mission scenario, analysis includes defining and allocating system functions between personnel and machines, applying human factors standards to equipment selection, analysis of tasks, and evaluation from a human factors perspective of preliminary system and subsystem design. To define and allocate system functions, the Specification requires that the information flow and processing needed to

accomplish the system objective be analyzed. Then estimates of the processing capabilities of potential human roles, such as operator or maintainer, in the system must be made in terms of load, accuracy, rate, and time delay. The allocation of functions is then made from projected performance data, estimated cost data, and other known constraints. This allocation of functions determines which functions will be assigned to machines and which to personnel.

With regard to the selection of equipment, the Specification requires that "human engineering principles and criteria" be applied to identify and select the equipment to be operated, maintained, and/or controlled by personnel. Equipment selected "will meet the applicable criteria contained in MIL-STD-1472C."

To determine components of tasks, human activities within the system are submitted to task analysis. This analysis is used in making design decisions, for example, to determine whether system performance requirements can actually be met by the envisioned combinations of men and machines. Further, the task analysis is used to develop personnel requirements and procedures for operating and maintaining equipment. These requirements and procedures will also reflect needed training and skill levels for system personnel.

This "gross" analysis will identify "critical" tasks to be analyzed further. A critical task is a task in which human performance which does not accomplish system requirements "will most likely have adverse effects on cost, system reliability, efficiency, effectiveness, or safety" (p. 12). Thus, a task is critical whenever characteristics of the equipment in use "demand performance which exceeds human capabilities or approaches (human) limitations" (p. 12).

The further analyses of critical tasks identify important parameters of human performance:

- information required by the operator or maintainer, including those cues which alert the personnel to begin the task
- available information
- process of evaluating the information known to the operator or maintainer
- possible decisions as a consequence of evaluation
- actions taken to carry out a decision
- the body movements required by the actions taken
- workspace envelope required by the actions taken
- available workspace
- location and condition of the work environment
- frequencies and tolerances of possible actions
- time base or profile of the entire sequences
- feedback provided to the operator or maintainer to inform of the adequacy or effectiveness of the actions taken
- required tools and equipment
- required number of personnel, their skills and experience
- required job aids or references
- required communications, including types and media of the communications
- any special hazards that may be involved
- interactions among personnel engaged in the task
- operational or performance limits of the personnel
- operational limits of machines and software involved.

Significantly, the Specification requires this analysis of critical tasks "for all affected missions and phases <u>including degraded modes of operation</u>" (p. 5). The "gross" analyses

and the further critical task analyses then are used to determine individual and team or "crew" workloads which are compared with and evaluated against the performance criteria for the system.

To evaluate preliminary system and subsystem design, as in the selection of equipment, "human engineering principles and criteria" are applied to system and subsystem designs. These designs must satisfy the criteria of MIL-STD-1472C.

Human engineering in detail design requires participation of personnel who are assigned human engineering responsibilities in design reviews and engineering change proposals. Equally as important, the Specification requires "studies, experiments and laboratory tests to resolve human engineering . . . problems" (p. 5). Two approaches are spelled out by the Specification: mockups and models, and dynamic simulation. Concerning mockups and models, the Specification directs that

> "at the earliest practical point in the development program and well before fabrication of system prototypes, full-scale three-dimensional mockups of equipment involving critical human performance shall be constructed. In those design areas where systems/equipment involve critical human performance and where human performance measurements are necessary, functional mockups shall be provided" (p. 6).

Concerning dynamic simulation, the Specification directs its use as a design tool, giving consideration to different models of the human operator. Considerations should be given as well to "man-in-the-loop" simulation and its possible development and use as training equipment.

To ensure that human engineering is truly applied, the Specification requires that it be reflected in the equipment-detail-design drawings, in the appropriate design documents for the work environments, workstations, and facilities, and for performance and design specifications. Among the items explicitly enumerated for analysis under "normal, unusual, and emergency" conditions, the following are generally applicable for

NASA/Goddard consideration:

- o atmospheric conditions, such as composition, volume, pressure, temperature, humidity, and air flow
- o acoustic noise, both steady state and impulse
- o adequate space for personnel, their movement, and their equipment
- o adequate physical, visual, and auditory links among personnel and between personnel and their equipment, including eye position in relation to display surfaces, control, and external areas
- o safe and efficient walkways, stairways, platforms
- o provisions for minimizing psychophysiological stresses
- o provisions to minimize physical or emotional fatigue, or fatigue due to work-rest cycles
- o protection from chemical, biological, toxicological, radiological, electrical, and electro-magnetic hazards
- o optimum illumination for the visual task

Finally under equipment detail design, the Specification requires that "the development of procedures for operating, maintaining, or otherwise using the system equipment" be "based upon the human performance functions and tasks identified by human engineering analysis. This is done to assure that personnel behaviors are "organized and sequenced for efficiency, safety and reliability . ." and that "the development of operational, training, and technical publications" (p. 8), reflect this human engineering.

The Specification requires a hmman factors test and evaluation (T and E) program:

- o to assure fulfillment of the Specification's requirements
- o to demonstrate that the system, equipment, and facility design conforms to human engineering design criteria

- to confirm compliance with performance requirements where personnel are a performance determinant
- to obtain quantitative measures of system performance as a function of human interaction with equipment
- to determine any undesirable design or procedural features that have been introduced

This human engineering test program is to be incorporated into the system Test and Evaluation (T and E) program. The Specification directs that the human engineering portions of all tests include particular components:

- a simulation or, if possible, actual conduct of the mission or work cycle
- specific tests of the critical tasks
- a representative sample on non-critical scheduled and unscheduled maintenance tasks
- proposed job aids, training equipment, and special support equipment
- test subjects representative of the range of the intended user population
- collection of data on task performance in operational environments
- identification of discrepancies between required and observed task performance
- criteria for acceptable performance of the test

Further, all failures occurring during T and E are to be subjected to a human engineering review to differentiate between failures due to equipment alone, personnel-equipment incompatability, and those due to human error" (p. 10).

To ensure that human factors or human engineering is incorporated in all phases and all parts of system analysis, design and development, and test and evaluation, the Specification requires the human engineering program to be coordinated with other

program areas and integrated into the total system program. The mechanism to encourage this coordination and integration is the requirement that personnel assigned human engineering responsibility must "approve all layouts and drawings having potential impact on human interface with the system, equipment, or facility" and that " the human engineering portion of any analysis, design, or test and evaluation program shall be directed under the direct cognizance of" these personnel (p. 10).

Several aspects of the human engineering methodology laid out by MIL-H-46855B deserve special attention. The emphasis on the application of "human engineering principles and criteria" extends in time throughout the entire process and through all components of the process of analysis, design and development, and test and evaluation. To ensure that serious attention is paid to human engineering problems, human engineering specialists are required to sign off on designs, plans, and drawings with potential effects on the human/machine interface at each stage.

The MIL-H-46855B human engineering program emphasizes the conduct of studies, tests, and experimentation, both in the design and the evaluation stages. Notably, it encourages the early use of mockups as an evolutionary design tool which may, with the incorporation of dynamic simulation of system behavior and functions, lead to training simulators. There is a stress upon the ongoing collection of data concerning human performance in the operational context of a given system.

The Specification recognizes that working hardware is not sufficient for a working system. The human engineering program ensures not only well-designed hadware, but, from analysis of the role of the human in the system, develops the data needed to address problems of staffing levels, personnel selection and training, and procedures for the operation, maintenance, and other use of the system.

In addition, the Specification invokes the technical authority of established human

engineering standards, specifically the MIL-STD-1472C supplemented by Human Engineering Guide to Equipment Design (Van Cott & Kinkade, 1972) and 41 other specifications, standards, handbooks, and publications which treat specific topics in greater detail. MIL-STD-1472C provides guidance for visual and audio displays, controls and their labelling, application of anthropometric data, workspace and environmental conditions, maintainability, remote handling equipment, vehicle and vehicle cabs, avoiding hazards and promoting safety, aerospace vehicle compartments, and the personnel-computer interfaces. Standards for the personnel-computer interface largely incorporate the recommendations contained in Guidelines for Man/Display Interfaces (Engel & Granda, 1975).

The Nuclear Regulatory Commission

Together, MIL-H-46855B and MIL-STD-1472C present a coherent approach to human engineering practice and application as well as a very useful and proven set of human engineering guidelines. Much of the Nuclear Regulatory Commission's human factors program has been derived from these DOD guidelines.

The Nuclear Regulatory Commission, as an "in loco parentis" operator of nuclear power plants, has a strong interest in the application of human factors knowledge to nuclear power plants. As might be expected, the NRC's major interest here is with the control rooms of nuclear power plants, particularly in the aftermath of Three Mile Island. The bibliography for this report contains a selection of NRC and NRC supported work in this area (Banks & Boone, 1981; Banks, et al., 1981; Bell & Swain, 1981; Finlayson, Hussman, & Smith, 1977; Mallory, Flieger, & Johnson, 1980; NUREG-0700, 1981; Swain, 1980; Swain & Guttman, 1980).

As a regulator of private power production using nuclear fuel, the NRC's role as the manufacturer is different from that of the Department of Defense, which itself directly

uses the manufactured product. Rather than mandate the manufacturer's process of developing designs, the NRC relies upon review of proposed designs and evaluation of these designs with regard to published standards. Discrepancies that are discovered are reported to the manufacturer who then must correct the situation.

NRC documents NUREG-0700, Guidelines for Control Room Design Reviews, and NUREG-0801, Evaluation Criteria for Detailed Control Room Design Review, are the primary sources of material with relevence for NASA/Goddard. NUREG-0700 contains a description of the NRC's Control Room Design Review Process and the Control Room Engineering Guidelines which form the bulk of the report. NUREG-0801 contains the procedural prescriptions to determine whether a design meets the functional requirements of NUREG-0700.

> "The licensee and applicant for operating license is required to perform a comprehensive review using NRC human factors design guidelines and evaluation. To aid the licensee in performing the review, NUREG-0700 . . . was developed and published. To aid the NRC staff and the licensee/applicant in judging the accepability of the review performed and the design modifications implemented, NUREG-0801 was developed" (p. ix).

The usefulness of MIL-H-46855B has not been lost on the NRC. Appendix B of NUREG-0700 focusses on the design of new control rooms. The appendix follows through the analysis and design and development phases of MIL-H-46855B. In the light of human performance errors at Three Mile Island, the NRC began its program of test and evaluation of existing control rooms from a human engineering standpoint. In the MIL-H-46855B framework, NUREG-0700 and NUREG-0801 address the test and evaluation phase in great detail as guidelines for the review of existing control room designs, which is NRC's immediate project. However, the NRC notes that "these guidelines should also be of use during the design process for new control rooms," and NUREG-0801 provides the

test and evaluation criteria to be used.

The Control Room Human Engineering Guidelines (CRHEG) of NUREG-0700 largely extend MIL-STD-1472C in those areas particularly pertinent to control room design and serve the same purpose as MIL-STD-1472C. The major topics covered in the CRHEG include: control room workspace, communications, annunciator warning systems, controls, visual displays, labels and location aids, process computers, panel layout, and control-display integration.

The nuclear power industry, through the Electric Power Research Institute (EPRI), has needed to come to grips with the human factors issues in control room design and to react to NRC regulation in this area. Thus, it is quite useful to consider along with NUREG-0700 and CHREG two publications produced by EPRI. The first, Human Factors Review of Nuclear Power Plant Control Room Design, provides a survey of current industry practice up to 1977. It is a marvelous tutorial on what NOT to do in control room design. The second, Human Factors Methods for Nuclear Control Room Design, published in four volumes through 1979 and 1980, provides detailed guidance, to the industry from within the industry, on how to remove and/or avoid the deficiencies and errors catalogued in the 1977 EPRI study. These recommendations too are largely based on the framework established by MIL-H-46855B.

The Control Room Design Review (CRDR) test and evaluation process is defined as having four phases: planning, review, assessment and implementation, and reporting. These phases are to be carried out by the licensee/applicant according to NUREG-0700 and are coordinated with NRC activities according to NUREG-0801: evaluation of the licensee/applicant's program plan report, scheduled site visits during the review phase, evaluation of the submitted CRDR report, and verification of the implemented changes. The objectives of the CRDR are clearly stated with relation to these phases:

- to determine whether the control room provides the system status information, control capabilities, feedback, and analytic aids necessary for control room operators to accomplish their functions effectively. (review)

- to identify characteristics of the existing control room instrumentation, controls, other equipment, and physical arrangements that may detract from operator performance. (review)

- to analyze and evaluate the problems that could arise from discrepancies of the above kinds, and to analyze means of correcting those discrepancies which could lead to substantial problems. (assessment)

- to define and put into effect a plan of action that applies human factors principles to improve control room design and enhance operator effectiveness. Particular emphasis should be placed on improvements affecting control room design and operator performance under abnormal or emergency conditions. (implementation)

- to integrate the (CRDR) with other areas of human factors inquiry (reporting) (p. 1)

The planning phase described by NRC in NUREG-0700 in general simply reflects sound project management principles and practices. However, extraordinary emphasis is placed upon the selection of the review team and its composition. NUREG-0801 expands this guidance almost to the level of position classification statements for the different required specialists, including both formal education and professional experience qualifications.

The review process itself is broken down into several areas of review: operating experience review, review of system functions and analysis of control room operator tasks, control room inventory, and control room survey. It culminates in verification of task performance capabilities and validation of control room functions. Any and all problems or discrepancies from the CRDR are compiled.

These discrepancies are then the focus of the assessment and implementation

phase. The discrepancies are assessed first for potential safety consequences. Any that have such safety consequences will be corrected. Any remaining discrepancies are further analyzed for effects on operator or plant performance, availability, or efficiency. The discrepancies judged significant in light of the criteria will also be corrected. Discrepancies to be corrected are then subject to analysis and to design improvement. During implementation, the discrepancies are physically corrected in the control room.

Reporting requirements are rigid throughout. In part, this rigidity is due to NRC's nature as a regulatory agency. More importantly, it echoes the concern of MIL-H-46855B that human factors engineering be based on appropriate data and that human factors engineering programs must produce reliable data to provide a basis for further human factors design and evaluation.

While based upon MIL-H-46855B, NUREG-0700 is quite useful in the context of these guidelines because it demonstrates the successful adaptation of the military specification to a non-military environment and because it focuses on the application of these specifications to the control room environment. In addition, NUREG-0700 adds considerable meat to MIL-H-46855B's treatment of the test and evaluation process and is specific to control room environments generically similar to those at NASA/GSFC.

National Aeronautics and Space Administration

Unfortunately, a similar programmatic effort has not yet materialized at NASA. While NASA projects have contributed to our human factors knowledge (Bohan & Wendhausen, 1973; Kubokawa, Woodson & Selby, 1969), NASA human factors studies have traditionally had the manned aerospace vehicle and its crew as their subjects. In support of the manned space program, NASA commissioned the Anthropometric Source Book (Webb Associates, 1978) which in Volume 1: Anthropometry for Designers, Chapter VIII,

Anthropometry in Sizing in Design, under Workstation Design, contains the clearest statement of NASA guidance for human engineering. Even this is posed merely as a method to be used in developing anthropometric design data. The approach can be outlined in a series of steps as follows:

- Determine the characteristics of the potential user population and select the appropriate anthropometric data base for analysis.
- Establish what the equipment must do for the user (form, function and interaction).
- Select the principal interface of the user with the equipment.
- Establish the anthropometric design values to be needed in fabrication.
- Design and evaluate a mock-up and revise the design as necessary.

Clearly, this outline captures with broad brush the more developed guidance of MIL-H-46855B and NUREG-0700. Again, emphasis is placed on the concept that human engineering cannot be performed without specific knowledge of the intended user population. Note the clear concern in the second step that equipment must be designed for the intended user rather than forcing the user to adapt to the equipment. Clear as well is the recognition that purely analytic studies will not suffice when designing for people. The design work must be evaluated through testing and experimentation, using representative users with a mock-up or simulation of the equipment. The authors of this report hope that these guidelines will be effective in assisting NASA/GSFC to develop a more comprehensive and more detailled program for the application of human factors engineering.

George Washington University

Woodson (1981) devotes Chapter 5 of the Human Factors Design Handbook to "Human Engineering Methods."

> The materials in this chapter (of over 100 pages) follow somewhat closely the human engineering program practices of the U.S. military services as they have been spelled out in human engineering specifications and standards . . . the purpose of this chapter is to provide a number of guidelines to assist designers in doing their own human engineering (p. 893),

when engineering specialists are unavailable. Woodson accomplishes this in a remarkably clear and straightforward fashion with numerous illustrations and examples. Given that MIL-H-46855B explains what to do, Woodson presents a very practical exposition of how to do it. As Woodson says,

> although these guidelines were originally developed for use in military systems development, they have been found to be equally applicable to any hardware development program, large or small. Because the methods are based on a logical and systematic process of
>
> (1) establishing the proper role of the human in the system,
>
> (2) designing the human-machine interfaces to fit the human's capabilities and limitations,
>
> (3) evaluating and testing to see that the design does fit, and
>
> (4) properly training the human to finally close the loop and thus assure reliable, total human-machine performance effectiveness, they should apply to all products that are used or operated by humans (p. 893).

The foregoing discussion has described global methodologies for human engineering in general. For the highly automated control room, an important human factors concern is the interaction between the computer and the controller or supervisor. The design of conversations between a computer and its user which is truly human engineered is the object of a local human engineering methodology under development by researchers at George Washington University (Bleser, Chan & Chu, 1981; Bleser & Foley, 1981; Foley, 1981; Foley, Wallace & Chan, 1981; Sibert, 1982).

Because the interface between the computer and the user can clearly be considered as a conversation, these researchers adopt linguistic design (Bocast, 1983) as their basic design approach. This is a modification of "traditional" top-down software design methodologies in which the high level problem is seen as constructing a language specific to the needs of the user. The language is designed to express the objects or data structures of the user's application and the necessary and sufficient ways in which these objects can be manipulated.

Analysis of the problem must produce a description of the process from which the objects of the application and the ways in which they can be manipulated and allowed to interact can be derived during the linguistic design process. To produce these descriptions, the George Washington University (GWU) researchers are suggesting the application of the human factors technique of task analysis. Task analysis itself is described elsewhere in these guidelines. From the task analysis, it is hoped that "a set of design constraints and objectives, a definition of user characteristics, and a set of functional requirements" may be produced (Sibert, 1982). Note that these functional requirements are for the conversation about the user's application, not for the user's application itself.

The functional requirements of the conversation at the interface must somehow reflect the functional requirements of what the conversation is about; otherwise there is no semantic content of relevence to the user application. A task is essentially defined as a group of independent but related activities diverted towards a goal; when performed a task results in a meaningful product. Before task analysis can be done, the goals and products must be known (McCormick, 1979). A task identified by the task analysis might be exemplified by: "Convey a request for selection of an action from a set of actions 'A' given state 'B'." The functional requirements might concern the allowable response time

or the permissible error rate. Thus, the GWU methodology presupposes that the application problem itself has already been completely analyzed.

With the human factors data gathered in the task analysis as the foundation, the GWU method proceeds in a standard linguistic approach through a four-step process of conceptual design, semantic design, syntactical design, and lexical design. The conceptual design is centered around the concepts needed by the user to work successfully with the system. It is the purpose of conceptual design to organize a set of language constructs, what the language is "talking" about. In brief, it identifies the objects to be talked about (data), the relations among the data (data structure), and the necessary and sufficient set of manipulations (operators) that are necessary to address the application problem from the perspective of the user at the interface.

The semantic design is centered around specifying a sparse vocabulary, the words of the language which will symbolize or convey the meaning of the conceptual constructs. The vocabulary then defines the units of meaning of the language. The vocabulary elements are called the "tokens" of the language. However, it is necessary to structure the vocabulary, to develop ordering rules so that the elementary units of meaning can be combined in ways from which sensible meanings can be built up, i.e., to produce complete thoughts. The syntactical design is centered on this creation of a grammar for the language.

The lexical design is centered on the problem of defining the means by which a language token will be specified. As Sibert (1982) notes, it is only at this stage that we begin to think systematically about hardware. For example, a token meaning "the sun" might be defined by the computer as a string of characters "SOL" or perhaps by an idiographic image or by ringing a bell. Referring to the functional requirements provided by the task analysis, the characteristics of different interaction techniques may be

evaluated to provide the lexical basis of the conversation to ensure naturalness for the user, efficiency in time and effort, and minimization of errors in forming and ordering the tokens of the language.

The proposed GWU approach departs from customary linguistic design at this point to consider the physical environment of the conversation as well as the "mental" environment of reference and user's manuals formalized from the work of the preceding steps. (It remains unclear at this time how this step affects the design of the man-machine conversation itself).

Finally, with the language completely designed at all levels—conceptual, semantic, syntactic, and lexical—and with all reference and user's material completely drafted, the language is subjected to a complete design review and evaluated against the functional requirements of the tasks to be talked about and against human engineering guidelines. Part of the GWU research effort is directed toward establishing these guidelines and to develop metrics that can be used to assess "such characteristics as goodness, efficiency, or user friendliness" (Sibert, 1982). On the basis of the design review, a new design iteration may be started or the conversation may proceed to implementation.

Figure 8-4 (Sibert, 1982) presents the sequence of steps being investigated by GWU researchers. In summary, the conceptual, semantic, syntactic, lexical design steps and the design review are proven components of linguistic design. Their methodology goes beyond ordinary linguistic design as a methodology in the application of the human engineering technique of task analysis to provide a well-structured foundation to the conceptual design and in the explicit consideration of the environment of the conversation. The GWU researchers are also active in investigating ways in which the linguistic design process may be more rigorously structured and formally expressed. In particular, they have made significant contributions to systematically lexical design and

providing a basis upon which selection of interaction techniques at the lexical level may be made using human factors criteria. The full development of their methodology for the design of the man-machine interface is eagerly awaited.

Figure 8-4

Top Down Design Methodology Outline

- o Task Analysis
- o Conceptual Design
- o Semantic Design
- o Syntactic Design
- o Lexical (interaction technique) Design
- o User Environment Design
- o Design Review
- o Implementation

SUMMARY

The DOD Specification, MIL-H-46855B, is the leading methodology for the integration of human factors engineering into the systems development process. The NRC has followed this approach, implementing the methodology in a civilian environment and focussing on control room applications. NASA's philosophy of a human factors methodology can easily be incorporated in the methodology developed by DOD and adapted by the NRC. It appears reasonable to recommend that NASA consider MIL-H-46855B for adoption, fashioning its implementation to the special characteristics of NASA activities, as the NRC has done.

The specific interface design methodologies under development at George Washington University deserve further support and encouragement. If proven in practice, these specific methodologies may be prime candidates for inclusion in a NASA version of MIL-STD-1472C for control room design.

References

ANACAPA Sciences, Inc. Fundamentals of Human Factors for Engineering and Design. Santa Barbara, CA: ANACAPA Sciences, Inc., April, 1982.

Banks, W.W., & Boone, M.P. Nuclear Control Room Annunciators: Problems and Recommendations. Idaho Falls, ID: EG & G Idaho Inc., September, 1981, NUREG/CR-2147.

Banks, W.W., Gertman, D.I., & Petersen, R.J. Human Engineering Design Considerations for CRT-Generated Displays. Idaho Falls, ID: EG & G Idaho Inc., October, 1981.

Behan, R.A., & Wendhausen, H.W. Some NASA Contributions to Human Factors Engineering: A Survey. Washington, D.C.: Government Printing Office, 1973.

Bell, B.J., & Swain, A.D. Procedure for Conducting a Human Reliability Analysis for Nuclear Power Plants. Washington, D.C.: Nuclear Regulatory Commission, December, 1981, NUREG/CR-2254.

Bleser, T., Chan, P., & Chu, M. A Critique of the SEEDIS User Interface. Washington, D.C.: George Washington University, Institute for Information Science and Technology, March, 1981, GWU-IIST-81-04.

Bleser, T., & Foley, J.D. Toward Specifying and Evaluating the Human Factors of User-Computer Interfaces. Washington, D.C.: George Washington University Institute for Information Science and Technology, August, 1981, GWU-IIST-81-22.

Bocast, A.K. Information Management. In W. B. Eddy (Ed.). Handbook of Organization Management. New York, NY: Marcel Dekker, forthcoming.

Chapanis, A. Research Techniques in Human Engineering. Baltimore, MD: John Hopkins Press, 1958.

Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: Department of Defense, May, 1981, MIL-STD-1472C.

Department of Defense. Human Engineering Requirements for Military Systems. Washington, D.C.: Department of Defense, January 1979, MIL-H-46855B.

Engel, S.E., & Granda, R.E. Guidelines for Man/Display Interfaces. Poughkeepsie, NY:

IBM Poughkeepsie Laboratory, TR00.2720, December 1975.

Finkelson, F.C., Hussman, T.A., & Smith, K.R. Human Engineering of Nuclear Power Plant Control Rooms and its Effects on Operations. El Segundo, CA: The Aerospace Corporation, February, 1977, ATR-77(2815)-1.

Foley, J.D. Tools for the Designers of User Interfaces. Washington, D.C.: George Washington University, Institute for Information Science and Technology, March, 1981, GWU-IIST-81-07.

Foley, J.D., Wallace, V.L., & Chan, P. The Human Factors of Graphic Interaction Tasks and Techniques. Washington D.C.: George Washington University, Institute for Information Science and Technology, January, 1981, GWU-IIST-81-3.

Kelley, C.R. Manual and Automatic Control. New York, NY: John Wiley and Sons, Inc., 1968.

Kubokawa, C., Woodson, W., & Selby, P. (Eds.). Databook for Human Factors Engineers. Moffett Field, CA: NASA Ames Research Center, November, 1969.

McCormick, E.J. Human Factors in Engineering and Design (4th Edition). New York, NY: McGraw-Hill, Inc., 1976.

McCormick, E.J. Job Analysis: Methods and Applications. New York, NY: The American Management Association, 1979.

Mallory, K., Flieger, S., & Johnson, I. Human Engineering Guide to Control Room Evaluation. Washington, D.C.: Essex Corporation, July, 1980, NUREG/CR 1580.

Rouse, W.B. Systems Engineering Models of Human-Machine Interaction. New York, NY: North Holland, 1980.

Seminara, J.L., & Eckert, S.K. Human Factors Methods for Nuclear Control Room Design, Vol. 4: Human Factors Considerations for Advanced Control Board Design. Palo Alto, CA: Electric Power Research Institute, February, 1980, EPRI-NP1118, 501-3.

Seminara, J.L., Eckert, S.K., & Seidenstein, S. Human Factors Methods for Nuclear Control Room Design, Vol. 1: Human Factors Enhancement of Existing Nuclear Control Rooms. Palo Alto, CA: Electric Power Research Institute, November 1979, EPRI NP 1118, 501-3.

Seminara, J.L., Eckert, S.K., & Seidenstein, S. Human Factors Methods for Nuclear Control Room Design, Vol. 3: Human Factors Methods for Conventional Control Board Design. Palo Alto, CA: Electric Power Research Institute, February, 1980, EPRI NP-1118, 501-3.

Seminara, J.L., Gonzalez, W.R., & Parsons, S.O. Human Factors Review of Nuclear Power Plant Control Room Design. Palo Alto, CA: Electric Power Research

Institute, EPRI NP-309, 501, March 1977.

Seminara, J.L., & Parsons, S.O. Human Factors Methods for Nuclear Control Room Design Volume 2: Human Factors Survey of Control Room Design Practices. Palo Alto, CA: Electric Power Research Institute, November, 1979, EPRI NP-1118, Project 501-3.

Sheridan, T.B., & Ferrell, W.R. Man-Machine Systems: Information, Control and Decision Models of Human Performance. Cambridge, MA: MIT Press, 1981.

Sibert, J. Top-Down Methodology for Human Factors Research. Proceedings of the Human Factors Considerations in System Design Symposium. NASA/GSFC, 1982, 239-256.

Swain, A.D. Human Factors in Nuclear Power Plant Operations. Alburquerque, NM: Sandia National Laboratory, August, 1980, SAND80-1837C.

Swain, A.D., & Guttman, A.E. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications. Albuquerque, NM: Sandia National Laboratory, October, 1980, NUREG/CR-1278.

U.S. Nuclear Regulatory Commission. Evaluation Criteria for Detailed Control Room Design Review. Washington, D.C.: U.S. Nuclear Regulatory Commission, October, 1981, NUREG-0801.

U.S. Nuclear Regulatory Commission. Guidelines for Control Room Design Reviews. Washington, D.C.: U.S. Nuclear Regulatory Commission, September, 1981, NUREG 0700.

Van Cott, H.P., & Kinkade, R.G. (Eds.). Human Engineering Guide to Equipment Design. New York, NY: McGraw-Hill Co., 1972.

Webb Associates. Anthropometric Source Book, Vol. 1: Anthropometry for Designers. Houston, TX: NASA/Johnson Space Center, NASA RP-1024, July, 1978, NTIS#N79-11734.

Woodson, W.E. Human Factors Design Handbook. New York, NY: McGraw-Hill, Inc., 1981.

CHAPTER NINE

THE CUTTING EDGE: DIRECTIONS FOR FUTURE RESEARCH

This report documents a broad research effort which surveyed all the major topics and associated guidelines, standards, and recent research related to human factors aspects of control room design. The activity spanned more than ten months and included the review of more than 300 documents and publications. Topics included those which are conventionally defined as "human factors" such as anthropometry and workstation design, those which are emerging due to the introduction of the computer into the workstation such as appropriate use of color and interaction techniques, and finally, those which form the cutting edge of current research such as displays which support the role of a human supervisor in an automated control environment. The guidelines constituting the body of this document provide a distillation of what is known. Design standards and guidelines as well as user considerations are summarized in a form usable by system designers. There are, however, many areas, particularly those related to computers, which are not well-defined, areas for which recommended standards are not available, and, sometimes, areas which are so nebulous or undefined that relevant human factors aspects and appropriate human factors questions cannot even be formulated. These areas define the nucleus of the future research agenda.

Just as in the current set of guidelines, the issues for further research consist of easy issues and difficult issues. "Easy" issues are areas in which there are still unanswered questions, but for which the required research strategies to address the questions are obvious and simple, requiring merely an expenditure of time and effort to carry out the needed tests and evaluation. "Easy" issues include the development of Goddard-specific anthropometric data, effects of environmental temperature on human

PRECEDING PAGE BLANK NOT FILMED

performance, and workstation design for multiperson workstations. Also included in the "easy" category are many of the questions concerning the hardware aspects of computer-based workstations. Although undertaking the needed experimentation to determine such things as preferred keyboard layout and useful color or graphics capabilities may be tedious, time consuming, and expensive, in comparison to research on the design and evaluation of strategies for information display, such topics look easy.

The most challenging human factors research over the next decade will be in the area of human-computer interface. For real time systems in particular, and for most human-computer systems in general, research will focus on the development of methods to exploit the potential of the computer in assisting and improving human performance. Particularly in the areas of information display and decision aiding, the computer is a new medium with no analog in previous generations of workstations and has enormous potential to improve the efficiency and effectiveness of the human-machine system.

Before the introduction of the computer into display technology, information displays were generally dedicated, status displays, often linked to low level hardware components. The human operator by necessity was forced to monitor banks of displays of low level status information, select out pertinent displays, and combine the displayed information into higher level forms compatible with his/her decision needs. Computers provide the opportunity to drastically change this mode of information display. Information provided by computer-based displays can be preprocessed by the computer, integrated and combined into a form more suitable to decision needs than low level displays reflecting the status of system hardware components. The computer can be used as an information filter to reduce the cognitive load of information processing. The design of such displays is not easy, however. At this point, it is still unclear what the important questions are. An understanding of how humans perceive and process

information is necessary. Given at least a rudimentary theory of human information processing, models which can be implemented on a computer are needed. These would be "as if" models which would take as input low level status information and, behaving "as if" they were human information processors, display higher level human-compatible information as output. In essence, the information displays would be designed with some level of "intelligence".

A related activity is the use of computers to replace the human in some tasks and the use of the computer as an active decision aid to the human in other tasks. Using the computer both to relieve the human of tedious or stressful tasks (automation) and to assist the human in decision making tasks (decision support systems) will be a major thrust of future research. The expanse and potential of computer systems require that strategies be found to use automation to enhance, rather than degrade, human performance and to use computers as a decision aid, rather than a decision hurdle.

Although the goals are clear, the implementation strategies are not. A great deal of basic research is needed to develop strategies for using the computer. Then, the resulting strategies need to be empirically evaluated and the results used to refine the strategies, which again must be evaluated. The road to the full utilization of the computer's potential in human-computer systems is long and uncertain; yet, the promise offered is staggering. The computer offers the human decision maker an unparalleled helpmate whose potential is at this point unbounded.

APPENDICES

PRECEDING PAGE BLANK NOT FILMED

APPENDIX A

ANNOTATED BIBLIOGRAPHY

A tangible result of the literature survey conducted by George Mason University is the annotated bibliography contained in this appendix. The literature survey was a multi-purpose activity. It served as a framework for the guidelines presented here; it generated the annotated bibliography; it provided an up-to-date assessment of human factors literature and research pertinent to Goddard's command and control environments, and it greatly contributed to the educational forum concerning human factors that George Mason University strove to achieve at Goddard.

The annotated bibliography is maintained in automated form on a Tandy-Radio Shack TRS-80 Model II microcomputer. Using the Profile II package, an alphabetical filing system was constructed. The system is capable of many tasks but is not without its limitations. It was occasionally necessary to make trade-offs regarding space versus information while constructing the files. For example, in some cases titles were abbreviated to fit the available space.

A valuable aspect of the system is the ability to sort the data base according to pre-assigned keywords. As each entry was annotated, up to 16 appropriate keywords were assigned, representing the content of the entry. The sixteen keywords are:

KW1 — Artificial intelligence

KW2 — Decision support systems

KW3 — Command and control

KW4 — Information processing

KW5 — Anthropometry

KW6 — VDT hardware

KW7 — VDT software

PRECEDING PAGE BLANK NOT FILMED

KW8 — Design guidelines

KW9 — Annotated bibliographies

KW10 — Human factors engineering

KW11 — Human factors tools

KW12 — Workstation and environmental design

KW13 — Supervisory control and monitoring behavior

KW14 — Human-computer interface

KW15 — Display design

KW16 — Effects of automation

The annotated data base contains several items for each bibliographic entry besides what is listed in this appendix. The assigned keywords are one example. From the first field on the screen it can be determined whether the GMU project (P) holds the document or whether it can be found in the library (L). The second field on the screen indicates what type of document the entry is, with the corresponding legend:

T — technical report or memorandum

B — book

J — journal article

D — dissertation

P — proceedings article

W — working paper

C — chapter from a book

M — media

The format of the printed bibliography is somewhat different from convention formats due to unavoidable space trade-offs. Only the first three authors of a document are listed, with the length of the last names limited to twelve characters. The length of

the title was also limited to no more than seventy-six characters. In cases where no author name was available, the sponsoring agency was inserted as the author, e.g., NASA/GSFC, Department of Defense, Human Factors Society, and so forth. The entries include standard information: author, title, publisher, and date. In an attempt to make the entries as complete as possible, additional information was included. Affiliations of the author were included where applicable as were page numbers. Where a National Technical Information Service number (NTIS) was available, it was included to assist those wishing to obtain the document. Applicable report numbers, such as those used by the Electric Power Research Institute (EPRI-XXX) and the U.S. Nuclear Regulatory Commission (NUREG-XXX), were also included. The system is capable only of sorting alphabetically according to the first letter of the primary author's last name. In instances where single authors have published multiple documents, entries were made randomly after the initial alphabetized placement of the author's last name because the system was not capable of more detailed alphabetizing.

The space available for each annotation was somewhat limited but quite adequate for the purpose of this document. The PROFILE II software limited the size of the bibliography to three hundred entries which was currently sufficient. However, actions are being taken to develop an expanded automated bibliography.

Immediately following is a list of abbreviations used within the bibliographic entries and annotations.

List of Abbreviations and Acronyms

ACM—Association for Computing Machinery

AFB—air force base

AIAA— American Institute of Aeronautics and Astronautics

AMRL—Aerospace Medical Research Laboratory

APA—American Psychological Association

ARI—Army Research Institute

BBN—Bolt Beranek and Newman

CRT—Cathode Ray Tube

CSC—Computer Sciences Corporation

CTA—Computer Technology Associates

Def. Doc. Ce.—Defense Documentation Center

Dept. of Def.—Department of Defense

DHHS—Department of Health and Human Services

DOC—Department of Commerce

DOCS—Data Operations Control System

EPRI—Electric Power Research Institute

ERBS—Earth Radiation Budget Satellite

GAO—General Accounting Office

GWU-IIST—George Washington University Institute for Information Science and Technology

HF—human factors

HFG—NASA/GSFC Human Factors Group

HFS—Human Factors Society

Hum RRO—Human Relations Research Organization

IEEE—Institute of Electrical and Electronics Engineers

KCRT—keyboard cathode ray tube

LAN—local area network

MDOD—Mission and Data Operations Directorate

MIL-H—Military Handbook

MIL-STD—Military Standard

MOD—Mission Operations Division

MOR—mission operations room

MSOCC—Mul Satellite Operations Control Center

NA GMSFC—NASA George Marshall Space Flight Center

NASA/GSFC—NASA Goddard Space Flight Center

NASA/JSC—NASA Johnson Space Center

Nat. Res. Coun.—National Research Council

NBS—National Bureau of Standards

NIOSH—National Institute for Occupational Safety and Health

NRC—U.S. Nuclear Regulatory Commission

NTIS—National Technical Information Service

NUREG—U.S. Nuclear Regulatory Commission document

NYCOSH—New York Committee for Occupational Safety and Health

SAI—Science Applications Inc.

SAND—Sandia National Lab. document

SMC—Systems, Man and Cybernetics Society

SRI—Stanford Research Institute

TDRSS—Tracking and Data Relay Satellite System

TIS—Technical Information Service

VDT—Visual Display Terminal

VPI—Virginia Polytechnic Institute

ORIGINAL PAGE IS
OF POOR QUALITY

ACM, The Psychology of Human-Computer Interaction, ACM Computing Surveys, Vol. 13. No. 1, Mar 1981.

Special issue. Includes: An Applied Psychology of the User; HF Studies of Database Query Language; Behavioral Aspects of Text Editors; The Psychological Study of Programming, and The Psychology of How Novices Learn Computer Programming. Specially notable for Rouse's article: Human-Computer Interaction in the Control of Dynamic Systems.

ANACAPA Scie, Fundamentals of Human Factors for Engineering and Design, ANACAPA Sciences, Inc., Santa Barbara, CA, 1981.

The supporting documentation from an intensive, practical three day seminar held in Washington, D.C. in March 1982. Topics covered include human factors models, human information processing, predesign analysis, task analysis, principles of display/control layout, human/computer interface design, methods of layout and arrangement and design test and evaluation. It provides an excellent overview of human factors considerations in system design.

Alluisi, E. A. & B. B. Morgan, Engineering Psychology and Human Performance, Annual Review of Psychology, Vol. 27, 1976, pp. 305-330.

A somewhat dated yet thorough literature review spanning ten years (1966 - 1976) of research in the human factors field. It contains an excellent bibliography through 1976 and provides an integrated framework for the literature survey.

Alter, S., Decision Support Systems: Current Practice And Continuing Challenges, Addison-Wesley Publishing Company, Reading MA, 1980.

Presents case studies, conclusions, and recommendations taken from a survey of 56 non-traditional information systems. While not all systems reported might be considered decision support they all are efforts to overcome the deficiencies of MIS. Provides a taxonomy of decision support systems and comparative patterns of usage by individuals with different organizational roles. Treats implementation in strategic and tactical detail, particularly ways to avoid known dangers. Very good bibliography.

Ammerman, H. L. & W. H. Melching, Man in Control of Highly Automated Systems, HumRRO, Alexandria, VA, NTIS# AD727658, May 1971.

This paper identifies what a person should do as a decision maker and controller in the newly evolving man-machine systems. Among the topics discussed are man's underlying basic functions in a complex system, task activities for individual jobs and their analyses, and training and the design of operational job positions.

ORIGINAL PAGE IS
OF POOR QUALITY

Apostolakis, G., S. Garribba & G. Volta, Ed., Synthesis and Analysis Methods for Safety and Reliability Studies, Plenum Press, New York, NY, 1980.

Selected papers from the NATO Advanced Study Institute on Synthesis and Analysis Methods for Safety and Reliability Studies, July 3-14, 1978. Divided into four sections: binary systems; multistate systems, logic diagrams; multistate system, other methods; and man-system interactions. Rasmussen's paper "Notes on Human Error Analysis and Prediction" is a good primer paper.

Atwood, M. E., H. R. Ramsey & J. N. Hooper, Annotated Bibliography on Human Factors in Software Development, NTIS# ADA071113, Englewood, CO, Science Applications, Inc., Jun 1979.

As part of a larger research effort on state of the art human factors, a literature survey was conducted by the Army Research Institute, resulting in this 478 entry annotated bibliography pertaining to the behavioral aspects of software design, programming, coding, debugging, testing, evaluation, and maintenance. The literature is covered through 1977.

Bailey, R. W., Human Performance Engineering:A Guide For System Designers, Prentice-Hall, Inc., Englewood CliffsNJ, 1982.

This recent text thoroughly covers human factors in regards to system design. It is divided into six major sections: the human user; the activity- basic design, interface design, facilitator design; the environmental context; and tests and studies. It contains both classic and newly emerging human factors topics and is a valuable source.

Banks, W. W. & M. P. Boone, Nuclear Control Room Annunciators: Problems and Recommendations NRC, EG&G Idaho, Inc., Idaho Falls, ID, NUREG/CR-2147, Sep 1981.

Identifies problem areas in nuclear control rooms associated with annunciator display systems and provides specific and generic solutions to these problems. Also provides recommendations and direction for future improvements and research focused on the man/display interface from a HF engineering perspective. MIL-STD-1472-B was used as a display evaluation criterion. Generally, annunciators were found to be inadequately organized and structured via importance, function, system impact, or response required.

Banks, W. W., D. L. Gertman & R. J. Petersen, Human Engineering Design Considerations for CRT-Generated Displays, NRC, EG & G Idaho, Inc., Idaho Falls, ID, Oct 1981.

Funded by the NRC, this work reviewed and summarized the findings of thirteen source documents detailing standards for the use of CRT generated displays. The focus is primarily on hardware characteristics (e.g., symbol contrast, luminance, refresh rate); there is some discussion of workstation design, use of color, and interactive devices.

ORIGINAL PAGE IS
OF POOR QUALITY

Banks, W. W. & M. P. Boone, A Method for Quantifying Control Accessibility, Human Factors, Vol. 23, No. 3, 1981, pp. 299-303.

A method of statistically quantifying the accessibility of controls was proposed, the index of accessibility, and validated. It considered three sources of variability; operator's reach envelope, frequency of use, and relative physical position of contro ls with respect to the operator. The need for valid and reliable measures is a point well taken and this index should be used again to replicate the results.

Baron, S. & W. H. Levison, Display Analysis with the Optimal Control Model of the Human Operator, Human Factors, Vol. 19, No. 5, 1977, pp. 437-457.

An interesting article that examines the optimal control model of the human operator, in particular, operator-display interface and human operator information processing. A simulation task was used, with the results being compared to model results.

Baron, S., C. Feehrer & R. Muralidharan, An Approach to Modeling Supervisory Control of a Nuclear Plant, Bolt Beranek and Newman, Inc., Cambridge,MA, NUREG/CD-2988, Nov 1982.

This report describes the results of a study aimed at determining the feasibility of applying a supervisory control modelling technology to the study of critical operator-machine problems in the operation of a nuclear power plant. Brief overviews of alternative approaches to the modelling of human performance, and different perspectives on the roles of operators in process control activities are included.

Bartlett, M. W. & L. A. Smith, Design of Control and Display Panels Using Computer Algorithms, Human Factors, Vol. 15, No. 1, 1973, pp. 1-7.

The CRAFT facilities-allocation algorithm was used to design an aircraft main instrument panel. The results suggest that this is a feasible activity for control and display panel design. It is an interesting idea, but needs further work as this experiment was not very rigorous.

Behan, R. A. & H. W. Wendhausen, Some NASA Contributions to Human Factors Engineering: A Survey, U.S. Government Printing Office, Washington, D.C., 1973.

This short paperback text reports some NASA contributions to human factors engineering the authors felt were applicable outside of their original aerospace settings. The contributions included cover the areas of measurement of physiological parameters, display techniques, underwater work, vibration and impact research, vision testing, and tools. It is not intended to be a comprehensive volume, but rather a review of several possibly helpful studies.

Bell, B. J. & A. D. Swain, A Procedure for Conducting a Human Reliability Analysis for Nuclear Power Pla, Sandia National Labs, NUREG/CR-2254, Dec 1981.

The report presents an overview of a procedure for conducting a human reliability analysis as part of a probabilistic risk assessment. In addition, detailed description of each step and an example of an actual analysis is included.

ORIGINAL PAGE IS
OF POOR QUALITY

Beltracchi, L., A Qualitative Operator-Process Interaction Model, U.S. Nuclear Regulatory Commission, Washington, D.C., 1981.

A short paper (10 pages) outlining a model of the interactions between the operator and nuclear plant process. A specific design concern discussed is the control-display operator/process interaction for abnormal modes of information. Display design concep ts for abnormal situations are developed.

Beltracchi, L., Trip Report Memo to V.A. Moore, U.S. Nuclear Regulatory Commission, Washington, D.C., May 1982.

This trip report contains viewgraphs for the talk "Potential Computer Based Functional Aids for Powerplant Operator" in which various schemas for control room operator decision support are presented.

Bergeron, H. P., Single Pilot IFR Autopilot Complexity/Benefit Tradeoff Study, Journal of Aircraft, AIAA80-1869R, Vol. 18, No. 9, Sep 1981, pp. 705-6.

This article is a summary of several experiments designed to evaluate the effects of increasing levels of automation for autopilots in the cockpit. The results suggest that simple low-cost partially automated autopilots may provide sufficient benefits to justify its use, but that a completely automated autopilot may be undesirable or unaffordable. In completely automated autopilot experiments, pilot performance was found to be degraded.

Bergeron, H. P., "General Aviation Single Pilot IFR Autopilot Study", NASA/Langley, Hampton,VA, NASA CP2170, Nov 1980.

This technical report summarizes experiments conducted at NASA-Langley examining desirable levels of automation for autopilots. The experiments suggested that some level of automation is useful in a high work environment, but that there are some disturbing trends associated with high level automation found in state of the art autopilots.

Bergman, T., Health Protection for Operators of VDTs/CRTs, NYCOSH VDT/WORK GROUP, NYCOSH, New York, NY, 1980.

A pamphlet describing the visual problems and health hazards associated with working with VDTs: eye strain, glare, contrast glare, the "flicker effect", screen and character size and color, machine maintenance , eyeglasses and contact lenses, posture, exercise programs, and stress. It makes several suggestions for controlling these hazards.

ORIGINAL PAGE IS
OF POOR QUALITY

Bleser, T. & J. D. Foley, Towards Specifying & Evaluating the Human Factors of User-Computer Interfaces, George Washington U., Inst. for Info. Science & Technology, Washington, DC, GWU-IIST-81-22, Aug 1981.

This is a brief paper details the development of a specification language to describe the human factors aspects of an interface. This specification language is intended to be consistent with the Foley methodology which examines the user interface at the conceptual, semantic, syntactic and lexical levels (Foley, 1981; Bleser, Chan, and Chu, 1981).

Bleser, T., P. Chan & M. Chu, A Critique of the SEEDIS User Interface, George Washington U., Inst. for Info. Science and Tech., Washington, DC, GWU-IIST-81-04, Mar 1981.

This report describes the evaluation and critique of the user interface of the SEEDIS (Socio-Economic Environmental Demographic Information System) using the Foley design methodology (Foley 1981). This top-down design methodology was used to examine the conceptual, semantic, systactic, and lexical levels of SEEDIS. It is an excellent case study of the application of this methodology.

Bloomfield, J. R. & J. A. Modrick, "Cognitive Processes in Visual Search", Proceedings - 6th Congress of the Inter. Ergonomics Assoc., Jul 1976, pp. 204-209.

This article suggests three processes for visual search; organization, variable field of view, and congratulation. The authors list several implications for human information processing.

Boehm-Davis, D. A., R. E. Curry & E. L. Wiener, Human Factors of Flight-Deck Automation — NASA/Industry Workshop, NASA/Ames Research Center, Moffett Field,CA, NASA TM81260, Jan 1981.

This technical report is a summary of a NASA-industry workshop held to identify human factors issues related to flight-deck automation which are likely to require further research for resolution. The scope of automation, the benefits of automation and automation-induced problems were discussed and a list of potential research topics was generated. Although the subject was flight deck automation, the results are very interesting and probably generalize to many command and control environments.

Bourne, L. E., B. R. Ekstrand & R. L. Dominowski, The Psychology of Thinking, Prentice-Hall, Englewood CliffsNJ, 1971.

A useful text covering the topics of problem solving, verbal learning, concept formation, and language, from a cognitive psychology viewpoint. Experimental evidence is presented to support theory where available.

Bransford, J. R., Human Cognition, Learning, Understanding and Remembering, Wadsworth Publishing Co., Belmont, CA, 1979.

This text provides an excellent overview of the field of cognitive psychology and human memory. It surveys several information processing models and offers existing evidence for each theory.

ORIGINAL PAGE IS
OF POOR QUALITY

Brown, R. V., C. R. Peterson & W. H. Shawcross, Decision Analysis as an Element in an Operational Decision Aiding System (DAS), Office of Naval Research, Decisions & Designs, Inc., McLean VA, NTIS# ADA018109, Nov 1975.

Reports on continuing decision analytic research and the initial development of several prototype decision aids for the tactical support of naval task force commanders. Focus is on the potential contribution of advanced techniques of decision analysis as decision aids in the development of operational plans and as an action selection tool in the mission execution phase of task force operations. Nine aids were developed to varying degrees and tested for use on interactive computer graphics terminals.

Brown, J. S., R. Burton & M. Miller, Steps Toward a Theoretical Foundation for Complex Knowledge-Based CAI, ARI & NPRDC, Bolt Beranek & Newman, Inc., Cambridge, MA, 3135, Aug 1975.

Describes research directed at designing and evaluating instructional systems which are able to use their knowledge to mimic some of the capabilities of a good tutor. These capabilities include construct or infer-structural models of a student's reasoning strategies, and identify his underlying misconceptions. Describes two paradigmatic instructional systems built around a decision making and gaming environment, issues of building intelligent instructional systems, and designing robust intelligent systems

Buckler, A. T., A Review of the Literature on the Legibility of Alphanumerics on Electronic D, U.S.Army Human Engineering Lab., Aberdeen, MD, NTIS# ADA 040625, May 1977.

This document is a brief (8 pages) review of selected highlights with a 56 item bibliography. Points touched upon: generation techniques, font, symbol subtense, resolution, percent active area, contrast, symbol width to height, stroke width to height, symbol spacing, viewing angle, size of symbols displayed at edge of screen, and symbol color.

CSC, Report of the Goal-Setting Workshop for the 1981 Computer Sciences Summer Stu, NASA/GSFC, Leesburg, VA, Jun 1981.

A preliminary report suggesting several broad study goals in reference to NASA. They include: identifying those NASA operations where computer-based information techniques and systems would, in the view of NASA management, fulfill the most critical set of currently unsatisfied needs, develop a plan for incorporating computer networks into those NASA operations most likely to benefit, and formulate the charter for a research and service NASA Computer Science and Technology Organization.

CTA, Progress Report-IC4 System Design Study, NASA/GSFC, Greenbelt, MD, NAS5-26689, Jan 1981.

Included in this summary progress report from Computer Technology Associates is a review of Data System Modernization documentation, a completed, documented analysis of Solar Maximum Mission(SMM) operations, and a description of the User Computer Interactive Demonstration System.

ORIGINAL PAGE IS
OF POOR QUALITY

Cakir, A., D. J. Hart & T. F. M. Stewart, Visual Display Terminals, John Wiley & Sons, New York, NY, 1980.

This book is a manual of design guidelines and user considerations for video display terminals (VDT) and VDT workplaces. It reflects the most current standards prevalent in Europe.

Carbonell, J. R., On Man-Computer Interaction: A Model & Some Related Issues, IEEE Trans on Sys, Science & Cyber, Vol. SSC-5, No. 1, Jan 1969, pp. 16.

A dated yet helpful literature survey focusing on man-computer interaction. The authors present on-line interaction from an information processing and decison analysis point of view where the operator seeks to minimize overall costs. Both applied and theoretical implications are included.

Carbonell, J. R., Artificial Intelligence & Large Interactive Man Computer Systems, ONR, Bolt Beranek & Newman, Inc., Cambridge, MA, Vol. SSC-5, No. 1, Jul 1969, pp. 16.

A report on SCHOLAR, an early prototype system capable of a true mixed-initiative man-computer dialogue on a given topic.

Card, S. K., W. K. English & B. J. Burr, Evaluation of Mouse, Rate-Controlled Isometric Joystick,Step Keys,& Text Keys, Ergonomics, Vol. 21, No. 8, 1978, pp. 601-13.

Four devices are evaluated with respect to how rapidly they can be used to select text on a CRT screen. The mouse is found to be faster on all counts and also to have the lowest error rates. It is shown that variations in positioning time with the joyst ick and mouse are accounted for by Fitt's Law. In the case of the mouse, the measured Fitt's Law slope constant is close to that found in other eye-hand tasks leading to the conclusion that positioning time with this device is almost the minimal.

Chapanis, A., On The Allocation of Functions Between Men and Machines, Occupational Psychology, NTIS AD626311, Vol. 39, No. 1, Jan 1965, pp. 1-11.

General guidelines or considerations for the man-machine interface make up this document. It is a helpful piece, including issues easily forgotten when designing systems. The author utilizes a behavioral approach for allocation of functions, and recommends a strategy for making allocation decisions.

Chapanis, A., Man-Machine Engineering, Wadsworth Publishing Co., Inc., Belmont, CA, 1965.

This is a classic text by a "lion" of the field; it provides an excellent introduction for human factors engineering and human factors psychology. Topics include discussion of the position of the human in man-machine systems, visual presentation of information, speech communication, and the design of controls.

ORIGINAL PAGE IS
OF POOR QUALITY

Christ, R. E., "Color Research for Visual Displays", Proceedings - 18th Annual HFS Conference, Oct 1974.

The experimental literature (1952-1973) on the effects of color on visual search and identification is reviewed. Quantitative analysis of the experimental results indicated that color may be a very effective performance factor under some conditions, but that it can be detrimental under others. A guide for design decisions is provided and needs for further research are identified.

Chu, Y. Y. & W. B. Rouse, Adaptive allocation of decision making responsibility between human & compute, IEEE Trans Syst Man Cybern, Vol. SMC-9, No. 12, Dec 1979, pp. 769-778.

A very interesting perspective for allocating decision making responsibilities between humans and computers in multitask situations, based on the current workload of both components in the interface. The resulting decision support system would be an adaptive one allowing for optimal interface performance.

Cicchinelli, L. F. & A. E. Lantz, The Elimination of Irrelevant Information in a Multidimensional Stimulus Clas, Human Factors, Vol. 20, No. 1, 1978, pp. 75-82.

Reports evidence for the facilitation of accurate decision making due to subjects filtering of visual CRT display information. The study implies humans can eliminate great amounts of information mechanically without reducing classification accuracy, by proper training. The authors suggest their methodology be used for providing objective measures of information in classification tasks, to examine individual differences in feature analysis and for training procedures.

Clapp, J. A. & M. Hazle, Building Blocks for C3 Systems, Air Force Systems Command, MITRE, Bedford MA, NTIS# ADA052568, Mar 1978.

Assesses the feasibility of constructing the information processing components of C3 systems from reusable building blocks. The objective is to reduce the time, cost, and risk of acquiring and modifying C3 computer systems. Three kinds of building blocks are identified: requirements, design, and software. A data flow architecture is proposed as a framework for partitioning a system into functional components with flexibility to adapt to changing requirements and different configurations.

ColdType Org, Don't Sit Too Close to the TV, VDTs/CRTs and Radiation, Cold Type Organizing Committee, Bronx, NY, Sep 1980.

This document package consists of a pamphlet and several loose articles pertaining to radiation and use of VDTs. VDT radiation is seen as a health hazard, with the author calling for more rigorous governmental standards and the technology to build radiat ion free terminals.

ORIGINAL PAGE IS
OF POOR QUALITY

Colquhoun, W. & J. Rutenfranz, Ed., Studies of Shiftwork, Taylor & Francis, Ltd., London, 1980.

This is a large collection (thirty nine) of articles relating to the ergonomics of shiftwork. It is organized into sections pertaining to biological adaptation, individual and environmental factors in adjustment, effects on performance efficiency, effects on social and family life, effects on health and well being, the design of shift systems and the economics of shiftwork. A complete and unique volume; it contains European as well as American work.

Conrad, R., Short-term Memory Factor in the Design of Data-Entry Keyboards: An Interface, J. of Applied Psychology, Vol. 50, No. 5, Oct 1966, pp. 553-556.

The experimental results of a data entry task using two keyboards (one having high stimulus-response compatibility, the other low), indicate an interface between short-term memory and stimulus-response compatibility. The limited-capacity channel model for information processing is supported.

Coombs, M. J. & J. L. Alty, Ed., Computing Skills and the User Interface, Academic Press, New York, NY, 1981.

A selection of papers around the idea that interfaces between a computational system and a user should be designed to accomodate the level of computational skill that the user brings to the interaction. The first group of papers discusses the issues involved in providing facilities for "naive" users. The second group deals with the nature of computational skills and techniques of instruction. The third group looks at philosophies for interface design and practical design work to improve user interfaces.

Cooper, R. G., P. T. Marston & J. Durrett, A Human-Factors Case Study Based on the IBM Personal Computer, BYTE, Apr 1982, pp. 56-72.

Human factors experts evaluate the IBM computer regarding keyboard,documentation, and functional operation. It illustrates the general procedure of applying human factors principles when deciding which personal computer fits one's needs. No specific tasks are evaluated.

Cox, J. T., Disturbance Detection Applied to the Space Shuttle, NASA/JSC, Houston, TX, 1982.

This paper provides a brief description of the process used and the key concepts developed to support disturbance detection in space flight operations. The nuclear industry's Disturbance Analysis Surveillance system is discussed with respect to its relative role in the space program and some suggestions for its implementation are made.

ORIGINAL PAGE IS
OF POOR QUALITY.

Craig, A., Monitoring for One Kind of Signal in the Presence of Another: The Effects of, Human Factors, Vol. 23, No. 2, 1981, pp. 191-197.

A visual vigilance task was used to investigate the effects of signal mix on detectability. The results suggest that signal detectability is impaired by the presence of another kind of signal, with the impairment tending to be greater the lower the detectability of the signal considered on its own.

Crawford, B. M., D. A. Topmiller & G. A. Kuck, Man-Machine Design Considerations in Satellite Data Management, A.F.Systems Command, Aerospace Medical Research Lab, Wright-Patterson, NTIS# ADA041287, Apr 1977.

This report contains an introduction to human information processing theory with implications for satellite data management, a section addressing human-computer relationships and decision aiding techniques, and some conceptual design guidelines for the Satellite Data Management system developed by AMRL.

Crawford, B. M., W. H. Pearson & R. F. Backert, Computer-Based Simulations for Man-Computer System Design, A.F.Systems Command, Aerospace Medical Research Lab., Wright-Pat.AFB, OH, TIS#A81-48374, 1981.

The Human Engineering Division of the Air Force Aerospace Medical Research Laboratory has used man-in-the-loop simulations to investigate human factors problems posed by man-computer interactions in proposed weapon system concepts. Two command and control experiments and one cockpit design experiment are summarized in this article.

Crawford, A. M. & K. S. Crawford, Simulation of Operational Equipment with a Computer-based Instructional Syste, Human Factors, Vol. 20, No. 2, 1978, pp. 215-224.

This article investigated the feasibility and effectiveness of teaching performance skills using computer-based training. It provides some interesting evidence for the effectiveness of computer-based training that can be applied to the use of simulators in command and control environments.

Curry, R. E., D. L. Kleinman & W. C. Hoffman, A Design Procedure for Control/Display Systems, Human Factors, Vol. 19, No. 5, 1977, pp. 421-36.

This article proposes a design procedure for control and display systems. The primary analysis tool is the Optimal Control Model of the Human Operator. This model is used at 3 levels: information, display-element, display-format. The model hypothesizes a human will mimic a good inanimate controller. Therefore, it is used as a framework for design. It is also an excellent predictor of performance. Results show the information level a good method of quantifying human requirements of the control task.

ORIGINAL PAGE IS
OF POOR QUALITY

Curtis, B., Ed., Tutorial: Human Factors in Software Development, IEEE Computer Society Press, New York, NY, 1981.

A large collection of 51 papers applying cognitive ergonomics, cognitive psychology, psycholinguistics, and industrial or organizational psychology to the study of software development. These papers are topically arranged by: models of problem solving in programming; software language characteristics; specification formats; faults and debugging; team performance; appraising individual programmer differences; and methodological guidance.

Dainoff, M. J., A. Happ & P. Crane, Visual Fatigue & Occupational Stress in VDT Operators, Human Factors, Vol. 23, No. 4, Aug 1981, pp. 421-438.

In this study, 121 office workers whose jobs required use of VDTs for varying proportion of their workdays were interviewed to determine the attitudes to their work and toward office automation. A subset was examined for one week during which time optometric and mood/physical measurements were taken. Results indicated high levels of eye fatigue, as well as complaints regarding glare and lighting. The pattern of complaints was independent of job pressure and hostility toward office automation.

Danaher, J. W., Human Error in ATC System Operations, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 535-546.

Several ATC-related aircraft accidents are summarized to illustrate the controller's changing role and the manner in which the controller interacts with pilots, other controllers, and the work environment. These cases also cite exemplary performance, as well as mistakes, by pilots and controllers, and the circumstances which fostered them, to illustrate the strengths and weaknesses of the human element in the present system. Implications for future ATC system design are discussed.

DeGreene, K. B., Ed., Systems Psychology, McGraw-Hill, Inc., New York NY, 1970.

Excellent collection of integrated papers. Authors include Chapanis, Sackman, Alluisi. Topics: systems and psychology; systems engineering; systems analysis techniques; accidents & safety; systems test & evaluation; information & uncertainty; estimation of workload in complex systems; behavioral decision theory; human operator in control systems; man-computer interrelationships; maintainability; staffing; training; psychophysiological stress; motivation and job performance factors; and applications.

DeMaio, J., S. R. Parkinson & J. V. Crosby, A Reaction Time Analysis of Instrument Scanning, Human Factors, Vol. 20, No. 4, 1978, pp. 467-471.

A reaction time task, instrument scanning, was used to compare performance of student and instructor pilots. The results indicate that experienced pilots rely on peripheral vision to a greater extent than inexperienced ones, suggesting the parallel processing of information due to experience.

ORIGINAL PAGE IS
OF POOR QUALITY

Def. Doc. Ce, Use of Computers in Human Factors Engineering, Defense Documentation Center, NTIS# AD/A-001400, Nov 1974.

The contents of this annotated bibliography cover documents pertinent to the application of techniques for computer handling of human factors data. The 170 items were drawn from the Defense Documentation Center's data bank covering the time period of January 1953 through August 1974.

Def. Doc. Ce, Man-Machine Interactions, Defense Documentation Center, NTIS# AD-752800, Nov 1978.

This annotated bibliography consists of 192 references pertaining to man-machine interaction. The items were drawn from the Defense Documentation Center's data bank covering the time period of January 1953 through August 1972. The literature concerns human factors involved in solving and learning man-machine interactions, as well as the effective use of men in system design.

Demb, A., Computer Systems for Human Systems, Pergamon Press, Oxford, 1979.

This text is a case study of the conversion of decentralized computation to centralized services in a 10-campus state college system.

Dept.of Def., Human Engineering Requirements for Military Systems, Military Specification, Department of Defense, Washington, D.C., MIL-H-46855B, Jan 1979.

This document establishes and defines the requirements for applying human engineering to the development and acquisition of military systems, equipment and facilities. It forms the basis for including human engineering in all phases of design and is approved for use by all Departments and Agencies of the Department of Defense. Topics covered include: system analysis, task analysis, system design, equipment and facilities design, testing, and documentation and reporting.

Dept.of Def., Human Engineering Design Criteria for Military Sytems, Equipment and Faciliti, Department of Defense, Washington, D.C., MIL-STD-1472C, May 1981.

This is the most recent military design guideline document that provides criteria for the design of any military facility. It represents state-of-the-art human factors for the Department of Defense. Areas addressed include: function allocation, fail safe design, visual display requirements, control and ground workspace requirements, maintenance and personnel-computer interface guidelines.

Dept.of Def., Data Item Description, Human Engineering Design Approach Document-Maintainer, U.S. Government Printing Office, Washington, D.C., DI-H-7057, Jun 1979.

A short document that provides design guideline considerations for the maintainer of a system. For further information the reader is directed to MIL-H-46855B and MIL-STD-1472C.

ORIGINAL PAGE IS
OF POOR QUALITY

Dept.of Def., Data Item Description, Human Engineering Design Approach Document-Operator, U.S. Government Printing Office, Washington, D.C., DI-H-7056, Jun 1979.

A short document that provides some guideline considerations for evaluation of man-machine interfaces. It contains many items that are addressed in MIL-H-46855B and MIL-STD-1472C, and the reader is directed to those documents for an in depth treatment of the subject matter.

Diffrient, N., A. R. Tilley & J. C. Bardagjy, Humanscale 1/2/3, 4/5/6, 7/8/9, The MIT Press, Cambridge MA, 1981.

A set of heavy plastic cards with data dials and accompanying explanatory brochures. Each Humanscale card is concerned with a different facet of human factors data. They include: body measurements; link measurements; seating guide; seat/table guide; wheelchair users; handicapped and elderly; safety; human strength; hand & foot controls; displays; head & vision; hands & feet; standing at work; seated at work; space planning; public space; body access; and light and color. A marvelous, compact reference.

Drury, C. G. & M. R. Clement, The Effect of Area, Density, & Number of Background Characters on Visual Sear, Human Factors, Vol. 20, No. 5, 1978, pp. 597-602.

Area of search field, density of background characters, and number of background characters were controlled in a search task experiment to determine which required the longest search time. The results showed that search time was most dependent on number of background characters.

Durding, B. M., C. A. Becker & J. D. Gould, Data Organization, Human Factors, Vol. 19, No. 1, 1977, pp. 1-14.

A series of three experiments examining human data organization. The results indicate that the subjects had existing organizational structures, could organize according to semantic structure, and had difficulties with inappropriate structures. Implicati ons for computer-based information retrieval systems are given.

Durrett, J. & J. Trezona, How To Use Color Effectively, BYTE, Apr 1982, pp. 50-3.

A brief but effective review of the uses of color in CRT displays. The visual process for color is reviewed, some guidelines for the use of color are given, the make-up of color is examined, and some information processing considerations are suggested.

Ehrenreich, S. L., Query Language: Design Recommendations Derived from the Human Factors Litera, Human Factors, Vol. 23, No. 6, 1981, pp. 709-725.

The human factors literature dealing with query languages is reviewed thoroughly. Both natural and formal query languages are discussed, and VDT software design guidelines are suggested. This is a very informative and complete paper.

ORIGINAL PAGE IS
OF POOR QUALITY

Einhorn, H. J. & R. M. Hogarth, Behavioral Decision Theory: Processes of Judgement and Choice, Annual Review of Psychology, Vol. 32, 1981, pp. 53-88.

An extensive review of behavioral decision theory. Optimal decision models, strategies and mechanisms of judgement and choice, and learning/feedback are discussed from a theoretical viewpoint. Methodological concerns were also addressed.

Embrey, D., "Human Reliability in Industrial Systems: An Overview", Proceedings - 6th Congress of Inter. Ergonomics Assoc., Jul 1976, pp. 12-16.

The field of human reliability is reviewed. The nature of system reliability assessment is described, and the importance of considering human reliability is emphasized. Human error, and techniques for its quantitative assessment are also discussed.

Engel, S. E. & R. E. Granda, Guidelines for Man/Display Interfaces, IBM Poughkeepsie Laboratory, Poughkeepsie,NY, TR 00.2720, Dec 1975.

This hard to find classic in the human factors field contains a wealth of guideline information pertaining to man/machine interfaces. It addresses the following issues: display formats, frame content, command language, recovery procedures, user entry techniques, principles, and response time. The report is highly recommended to those interested in the applicaiton of human factors.

Enstrom, K. D. & W. B. Rouse, Real time determination of how a human has allocated his attention between co, IEEE Trans Syst Man Cybern, Vol. SMC-7, No. 3, Mar 1977, pp. 153-161.

This experiment provides an interesting application of a computer algorithm for task allocation. The algorithm used fading-memory system identification and linear discriminant analysis for real-time detection of human shifts in attention in a contol and monitoring situation. A validation of the model is included, suggesting it may be situation specific.

Erickson, J. R. & M. R. Jones, Thinking, Annual Review of Psychology, Vol. 29, 1978, pp. 61-90.

An extensive theoretical overview of problem solving, concept learning, and reasoning from a psychological perspective. An excellent bibliography is included.

Estes, W. K., Is Human Memory Obsolete?, American Scientist, Vol. 68, Jan 1980, pp. 62-9.

A comparison is made between human memory and computer memory in this interesting article. Human retrieval times, organization of short term memory, and the nature of forgetting are examined. The author concludes that there is little likelihood of computer memory replacing human memory, or vice-versa, as both appear to have seperate functions they are best suited to. The article is written from a psychological perspective.

ORIGINAL PAGE IS
OF POOR QUALITY

Farrell, R. J. & J. M. Booth, Design Handbook for Imagery Interpretation Equipment, Boeing Aerospace Co., Seattle, WA, D180-19063-1, Dec 1975.

This document is a weighty collection of design guidelines, with a heavy emphasis on visual considerations. Topics include; optical imagery displays, electro-optical imagery displays, special imagery displays, workstation design, and facilities design. A helpful section comprised of checklists pertaining to specific displays is also included.

Fine, B. J. & J. L. Kobrick, Effects of Altitude & Heat on Complex Cognitive Tasks, Human Factors, Vol. 20, No. 1, 1978, pp. 115-122.

The affects of altitude and heat on complex cognitive tasks were tested using an artillery fire direction center operation. The results indicated that all tasks were affected by altitude and heat with individual differences. Errors of omission exceeded those of commission. The authors suggest their technique for analyzing stress-sensitive factors in complex cognitive performance.

Finkelman, J. M. & C. Kirschner, An Information Processing Interpretation of Air Traffic Control Stress, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 561-568.

Observes evidence of stress in ATC's. Suggests that a source may be the high information-processing demand which the job imposes. Proposes a method to assess individual differences in channel capacity by means of a subsidiary task measurement technique. This procedure can be used to assess reserve capacity which may permit prediction of performance decrements on stress-related disorders among individuals.

Finlayson, P. C., T. A. Hussman & K. R. Smith, Human Engineering of Nuclear Power Plant Control Rooms & Its Effects on Opera, The Aerospace Corp., El Segundo, CA, ATR-77(2315)-1, Feb 1977.

Presents the results of an evaluation of the effects of human engineering on operator performance in the control room. Covers control room design features, parameters influencing operator performance, control room design criteria and trends in development of advanced control centers, operator motion requirements in a control room, evaluation of the human engineering features of nuclear and non-nuclear control centers, and conclusions regarding operator characteristics, job performance, and control design.

Finley, D. L., F. A. Muckler & C. A. Gainer, An Analysis and Evaluation Methodology for Command and Control, Office of Naval Research, Manned Systems Sciences, Inc., Northridge CA, NTIS# ADA-23871, Nov 1975.

Discusses problems in assessing the status, potentials, and weaknesses of operational manned systems and of dealing analytically with that variance in system behavior attributable to its human members. Offers a methodological framework for dealing with C&C as an integral part of systems. Concepts of the methodology include: C&C definitions and taxonomies, a Systems Taxonomy Model, systems descriptors, the use of operator models, and analytic decision making.

ORIGINAL PAGE IS
OF POOR QUALITY

Fisk, A. D. & W. Schneider, Control & Automatic Processing During Tasks Requiring Sustained Attention: A, Human Factors, Vol. 23, No. 6, 1981, pp. 737-750.

Vigilance tasks, and the resulting decrements in performance were examined within the framework of the automatic/controlled information processing model. The results include system design implications.

Foley, J. D. & A. Van Dam, Fundamentals of Interactive Graphics, Addison-Wesley Publishing Company, Reading, MA, 1982.

Presents graphics concepts and recent advances in graphics hardware and software. A complete graphics application program is developed in Pascal, using the Core System of standard graphics subroutines proposed by ACM's SIGGRAPH. Emphasizes human factors. Includes treatment of color theory and practice as applied to computer graphics, including description of color models. Covers basics of graphics: 2D & 3D viewing, clipping, segmentation, interaction, device drivers, transformation, projection, etc.

Foley, J. D., V. L. Wallace & P. Chan, The Human Factors of Graphic Interaction Tasks & Techniques, George Washington U., Dept. of EE & CS, Washington, DC, GWU-IIST-81-3, Jan 1981.

A comprehensive review of current interaction techniques from a human factors perspective. The ergonomic issues are presented and graphics interaction tasks and techniques are defined. Several interaction techniques are assessed against the array of interaction tasks in terms of cognitive, perceptual, and motor load, visual and motor acquisition, learning, fatigue, and error. Provides a good review of the limited literature available.

Foley, J. D., Tools for the Designers of User Interfaces, George Washington U., Inst. for Info. Systems & Technology, Washington, DC, GWU-IIST-81-07, Mar 1981.

This is a preliminary report on the development of the Foley methodology for the design of a human-computer interface. The methodology attempts to impose a structure on the complex task of designing user-computer interfaces so that the design can be divided into manageable pieces, each which can be dealt with in a systematic, rigorous, and quantitative way. The four steps in the process are called the conceptual, semantic, syntactic, and lexical design steps.

Fowler, F. D., Air Traffic Control Problems: A Pilot's View, Human Factors, Vol. 22, No. 6, 1980, pp. 645-653.

Anecdotal evidence is used to identify existing and potential human error sources. System-induced human errors caused by radar and information processing limitations, inadequate communication capabilities, and FAA policies are discussed.

French, W. L. & C. H. Bell, Organization Development(2nd edition), Prentice-Hall, Inc., New York, NY, 1978.

This textbook outlines organization development, its theory and practice, and some key considerations and issues. It is valuable for those interested in management practice and philosophy.

ORIGINAL PAGE IS
OF POOR QUALITY

GAO, Effectiveness of U.S. Forces Can Be Increased Through Improved System Design, General Accounting Office, Washington, D.C., PSAD-81-17, Jan 1981.

In this report to the Congress of the United States the General Accounting Office states that Department of Defense military systems would benefit from greater consideration of logistic support, human factors, and quality assurance, during the design phase of acquisition processes. It is suggested that overall system effectiveness to defend the country can be increased by implementing these considerations.

Gaertner, K. P. & K. P. Holzhausen, Controlling Air Traffic with a Touch Sensitive Screen, Applied Ergonomics, Vol. 11, No. 1, 1980, pp. 17-22.

Modern air traffic control systems are increasingly using computer generated radar displays to present targets, target information and other general information to control personnel. A laboratory of a new touch sensitive control device in a simulated ATC system is described in some detail together with results. Ergonomic advantages and design problems are discussed.

Gerver, D. & H. W. Sinaiko, Ed., Language Interpretation and Communication, Plenum Press, New York NY, 1978.

Papers from the NATO Symposium on Language Interpretation and Communication, Sept.26 - Oct. 1, 1977. The Symposium explored both applied and theoretical aspects of conference interpretation and of sign language interpretation. These papers, particularly on the nature of simultaneous conference interpretation and sign language interpretation, are relevant to the design of man-machine interface, conceptualizing the computer-system and man-computer communications problems as language interpretation problems.

Gimmy, K. L. & E. Nomm, "Automatic Diagnosis of Multiplex Alarms for Reactor Control Rooms", ANS Annual Meeting, Los Angeles CA, Jun 1982.

Describes a system under development at the Savannah River nuclear reactor to help reactor operators to respond to multiple alarms in a developing incident situation. The system analyzes the patterns of alarms to determine if a known pattern is developing, advises the operator, and provides procedural guidance.

Gould, J. D., Visual Factors in the Design of Computer Controlled CRT Displays, Human Factors, Vol. 10, No. 4, 1968, pp. 359-376.

A somewhat dated report that provides comprehensive coverage of the important visual variables that determine image quality on computer-controlled CRT displays. For each variable, the recommended ranges of values based on experimental work are reported, and compared with the values presently used on displays.

ORIGINAL PAGE IS
OF POOR QUALITY

Grandjean, E. & E. Vigliani, Ed., Ergonomic Aspects of Visual Display Terminals: Proceedings of the Internatio, Taylor & Francis, Ltd., London, 1980.

The text contains numerous papers on such topics as: physical characteristics of VDTs, visual function, visual impairments, VDT performance, postural problems, psychological aspects of VDTs, practical experiences and case studies, and ergonomic design guidelines.

Grandjean, E., Fitting the Task to the Man: An Ergonomic Approach, Taylor & Francis, Ltd., London, 1980.

This text is designed to present the rudiments of human factors engineering or, from the European perspective, ergonomics in a simple and clear form to engineers, technical specialists, and managem. Topics include discussions of human factors considerations for: muscular work, nervous control of movements, improving efficiency, problems of body size, design of workplaces, heavy work, skilled work, fatigue, boredom, shift work, as well as evironmental factors and design issues.

Grignetti, M. C., D. C. Miller & R. S. Nickerson, Information Processing Models & Computer Aids for Human Performance, Semiannual Technical Report No. 1, Section 2, Task 2: Human-Co, Bolt Beranek & Newman, Inc., Cambridge, MA, BBN 2190, Jun 1971.

Reports on a measuring system implemented to obtain statistical parameters necessary to specify a queueing theory model of the dynamic behavior of a time-sharing computer system. Presents results on the statistics of use for one system. Concerned with session duration, resource loads, and the use of different computational facilities, like Editors.

HFS, CRT Viewing II, Human Factors, Vol. 23, No. 5, Oct 1981.

This is the second of a two issue series in the Human Factors Journal devoted to ergonomic aspects of video display terminals. Among other excellent articles, there is an extensive bibliography of articles on the effects of VDTs (1972 - 1980).

HFS, "Proceedings of the Human Factors Society 23rd Annual Meeting", Boston, MA, Human Factors Society, Santa Monica, CA, Oct 1979.

Papers presented at this conference were on topics which included: application of computer technology to interactive systems, computer aided modeling for interface design and evaluation, techniques for analyzing computer system interfaces, consumer products design, evironmental design, industrial ergonomics, work place design, safety, training, visual performance, and graphics.

HFS, CRT Viewing I, Human Factors, Vol. 23, No. 4, Aug 1981.

Two issues of the Human Factors Journal were devoted to ergonomic consideration of video display terminals. Three of the papers in this issue contain summaries of the NIOSH report examining a number of problems with VDTs. Both this issue and the next (October 1981) contain excellent material on the ergonomics of VDTs.

ORIGINAL PAGE IS
OF POOR QUALITY

HFS, "Proceedings of the Human Factors Society 19th Annual Meeting", Dallas,TX, Human Factors Society, Santa Monica, CA, Oct 1975.

Papers presented at this conference were on topics which included: training, safety, data inputting, learning, system design and testing, driver behavior, aids and training for decision making, human factors in an industrial setting, visual information display, and visual search and target acquisition.

HFS, Air Traffic Control I, Human Factors, Vol. 22, No. 5, Oct 1980.

A special issue of the Human Factors Journal devoted to the human factors problems of air traffic control from the perspective of controllers and of pilots. Individual articles are cited in this bibliography.

HFS, "Proceedings of the Human Factors Society 25th Annual Meeting", Rochester, NY, Human Factors Society, Santa Monica, CA, Oct 1981.

Papers presented at this conference were on topics which included: nuclear power plant operations, visual performance, aerospace operations, ergonomics, nuclear power plant safety, industrial design, displays, innovative human-computer interfaces, visual displays, control room design and evaluation, safety, information processing and decision making, workplace design, computer workplaces and equipment.

HFS, "Proceedings of the Human Factors Society 18th Annual Meeting", Huntsville, Human Factors Society, Santa Monica, CA, Oct 1974.

Papers presented at this conference were on topics which include: public transportation, health care delivery, man-computer interface, aviation research, safety, control/display design, driver behavior, target acquisition, defense systems, aerospace systems, handtools, employee motivation and job enlargement, and environmental psychology.

Hart, S. G. & T. E. Wempe, Cockpit Display of Traffic Information: Airline Pilots' Opinions about Conten, NASA, Ames Research Center, Moffett Field, CA, TM78601, Aug 1979.

The report summarizes research conducted at NASA-Ames on display formats for computer-generated cockpit displays of traffic information. The study defined the information that the potential user-population felt should be incorporated along with preferred symbology and format.

Hart, S. G. & L. L. Loomis, Evaluation of the Potential Format & Content of a Cockpit Display of Traffic, Human Factors, Vol. 22, No. 5, 1980, pp. 591-604.

An interesting look at the use of computer-generated displays for airplane cockpit traffic information purposes. User population preferences were collected and experimentation on the preferred features was conducted. The authors make a strong point for this evaluation method.

ORIGINAL PAGE IS
OF POOR QUALITY

Haskin, F. E., J. L. Darby & W. B. Murfin, Analysis of Hypothetical Severe Core Damage Accidents for the Zion Pressurize, Sandia National Laboratory, Albuquerque, NM, NUREG/CR-1939, Oct 1982.

This report describes analyses of the response of a Pressurized Water Reactor at the Zion Plant to hypothetical core meltdown sequences. The analyses consider the progression of core meltdown, containment response, and consequences to the public. Strategies for accident management and mitigation of consequences are suggested.

Hayes, R., J. Brownell & J. Hayes, Human Factors Problems of the Command Control & Communications Process in the, DARPA, CACI, Inc., Arlington, VA, NTIS ADA027420, Jul 1976.

"A set of HF activities in the C3 process is enumerated and the determining forces controlling these HF are elaborated. A list of variables constituting the set of relevant dimensions of future (1990) environments for C3 centers is developed, and, by analyzing the literature and exploring expert opinion, values for these variables are specified which in aggregate constitute meaningful alternative futures." Basically a superficial set of unexplained lists. Futures tend to either it will or it won't be.

Heglin, H. J., NAVSHIPS Display Illumination Design Guide, Section II: Human Factors, Naval Electronics Laboratory Center, San Diego, CA, NTIS AD 770478, Jul 1973.

Provides HF guidelines for use in design of shipboard visual displays, supported by research data, tables, graphs, and charts for general reference and followed by application specification materials that offer standards and tolerance limits. Covers human vision capabilities and limitations; illumination, layout, and visual displays; CRT displays; TV displays for single viewers and for group viewing; coding; projection devices; display legibility; specifications for displays, layouts, and illumination.

Helander, M. G. & J. M. Schurick, A Bibliography of the Literature Relating to the Human Factors Aspects of VDT, Canyon Research Group, Inc., Westlake Village CA, CRG-TR-82-003, Jul 1982.

This bibliography contains 493 human factors references on visual display terminals. The entries are classified into the following categories: character and display design; general review documents; health effects; lighting and reflectance; PTT research; standards for VDT design; visual discomfort; work organization and job satisfaction; and workstation design, postural discomfort, and biomechanics.

Hepler, S. P., Continuous Versus Intermittent Display of Information, Human Factors, Vol. 18, No. 2, 1976, pp. 183-188.

This article suggests that both continuous display and intermittent display of information are optimal for retention, dependent upon task situation. Three stages of processing for visually presented materials are supported; acquisition, consolidation, and retention.

ORIGINAL PAGE IS
OF POOR QUALITY

Hiltz, S. R. & M. Turoff, The Network Nation, Human Communication Via Computer, Addison-Wesley Publishing Co., Reading, MA, 1978.

An introduction to the technologies and social implications of computer-based conferencing systems. The history and development of conferencing systems and technologies is covered, along with social and psychological processesin computerized conferencing, impacts on managerial and staff functions, public use and access, design of the human-machine-communications interface, issues of public policy and regulation and forecasts of possible societal impacts.

Holt, R. W., Controlled & Automatic Processing in Person Perception, George Mason University, Mar 1982.

This is a paper being prepared for publication examining controlled and automatic information processing in person perception. The experimental results support the existence of both types of processing and suggest several interesting points on person perception.

Hopkin, V. D., The Measurement of the Air Traffic Controller, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 547-560.

Reviews and critically assesses measures of the ATC. Argues that there are many reasons for measuring the ATC and that no measure can yet be treated as either indispensible or useless. Notes an existing bias to measure the controller as part of the system than in the ATC's own right.

Howell, W. C. & I. L. Goldstein, Ed., Engineering Psychology: Current Perspectives in Research, Meredith Corporation, New York, NY, 1971.

Although ten years old, this book of readings contains many valuable, classic works that have greatly contributed to the human factors field. It contains fifty five articles, divided into five sections; introduction to engineering psychology, human performance, multiman-machine system performance, training , and environmental conditions. It is further broken down into chapters providing extensive organization. This volume is highly recommended as a source document.

Howell, W. C. & E. A. Fleishman, Ed., Human Performance and Productivity, Vol. 2: Information Processing and Decision, Lawrence Earlbaum Associates, Inc., Hillsdale NJ, 1982.

An excellent collection of timely human factors topics are presented in this book from a human information processing viewpoint. An effort was made to provide integrated chapters; both theoretical and applied research are addressed.

ORIGINAL PAGE IS
OF POOR QUALITY

Huchingson, R. D., R. D. Williams & T. G. Reid, Formatting, Message Load, Sequencing Method, & Presentation Rate for Computer, Human Factors, Vol. 23, No. 5, Oct 1981, pp. 551-560.

> Also a portion of the NIOSH study, this work examined four types of formatting (vertical, compact, chunk extended, and message extended), three levels of message load, four methods of sequencing, and three presentation rates. The first study looked at all combinations and one combination was selected from this for further study. The follow-on experiment examined the compact chunk presentation for three message levels and for three exposure rates. Optimal dynamic presentation rules are suggested.

Huchingson, R. D., New Horizons for Human Factors in Design, McGraw-Hill Book Company, New York, NY, 1981.

> This recent text includes topics such as, the human as a systems resource, aerospace systems, industrial systems and environment, surface transportation systems, and communications and data processing systems.

IBM Systems, Human Factors, IBM Systems Journal, Vol. 20, No. 2, 1981.

> This is a special issue devoted to a sampling of human factors work at IBM. Articles include: Procedures of the Human Factors Center at San Jose; Effects of Manual Style on Performance in Education and Machine Maintenance; Natural Language Programming: Styles, Strategies, & Contrasts; Human Factors in the Development of a Family of Plant Data Communication Terminals; and Human Factors in Communication.

Isreal, J. B., C. D. Wickens & G. L. Chesney, The Event-Related Brain Potential as an Index of Display-Monitoring Workload, Human Factors, Vol. 22, No. 2, 1980, pp. 211-24.

> An alternative measure of workload is presented; the event-related brain potential, and compared with a reaction time secondary task measure. The event-related brain potential measures were found to systematically reflect differences in task workload and to covary closely with the reaction time measure.

Jenkins, J. P., Models of Cognitive Behavior in Man-Machine Systems, Nuclear Regulatory Commission, Mar 1982.

> This document consists of an annotated outline for the author's doctoral dissertation. It reviews four models of cognitive behavior; the Rasmussen adaptation of the stimulus-operations response model, the Siegel-Wolf cognitive simulation model, the Sheridan supervisory control model, and artificial intelligence as a generic model. The resulting dissertation is eagerly awaited.

ORIGINAL PAGE IS
OF POOR QUALITY

Kantowitz, B. H., Interfacing Human Information Processing and Engineering Psychology, in W.C. Howell & E.A. Fleishman (Eds.) Human Performance and P, Lawrence Erlbaum Associates, Inc., Hillsdale, NJ, 1982.

This chapter is an excellent presentation of a human factors approach to information processing. The author makes several important distinctions between basic and applied research and suggests several integrated approaches for interfacing engineering psychology with human information processing theory.

Kelley, C. R., Manual and Automatic Control, John Wiley & Sons, Inc., New York, NY, 1968.

An overview and excellent introduction to the conceptual issues in manual and automatic control. This is a classic text that has lost little with age.

Kerwin, W. T., G. S. Blanchard & E. M. Atzinger, Army Material Systems Analysis Activity, Man-Machine Interface -A Growing Cri, U.S. Army, Washington, D.C., Discussion Paper #2, Aug 1980.

This report states that the US Army has man-machine interface problems; there are not enough qualified people to perform the tasks required by increasing weapon complexity, the large number of new systems being developed, recruiting and retention problems, and a declining manpower pool. The report calls for an integrated as opposed to fragmented effort towards solving the problem, and makes some recommendations.

Kolers, P. A., R. L. Duchnicky & D. C. Ferguson, Eye Movement Measurement of Readability of CRT Displays, Human Factors, Vol. 23, No. 5, Oct 1981, pp. 517-528.

This article is one of several in the same issues of Human Factors which summarizes the results of the NIOSH study on effect of visual display terminals. This portion studied the readability of CRTs and found character densities of 35 to 70 characters per line favored the smaller-size characters with respect to reading efficiency; comparison of scrolling rates suggested the static page was more efficient than continuous scrolling at the subject's preferred rate; faster rates were more efficient.

Kreifeldt, J. G., Cockpit Displayed Traffic Information & Distributed Management in Air Traffic, Human Factors, Vol. 22, No. 6, 1980, pp. 671-691.

This article is based on several years' experimental study of placing ground control information in the cockpit. Information such as surrounding aircraft, and navigation routes can improve safety and efficiency of the air traffic control system. Through this system, pilots have more information on board and reduce response delays.

Kulp, R. A., T. J. Rebbin & R. A. Sperling, "Human Factors Considerations in the Design of an On-Line, Real-Time Computer", Proceedings - 17th Annual Meeting of the Human Factors Society, Santa Monica, CA, 1973, pp. 425.

Human factors considerations are listed that should be covered when designing an on-line computer system.

ORIGINAL PAGE IS
OF POOR QUALITY

Ledgard, H., A. Singer & J. Whiteside, Directions in Human Factors for Interactive Systems, Springer-Verlag, New York NY, 1981.

Lecture Notes in Computer Science 103. This text is an illuminating look at the author's experiences in designing a human factors experiment. Beginning with general design issues, they illustrate their discussion with real world materials. An extremely interesting discussion of their own human factors experimentation is given. An excellent guide to anyone designing experiments concerning the human engineering of software, particularly for interactive systems.

Leebeek, H. J., Ergonomics for Command and Control Rooms, Institute voor Zintuigfysiologie, Soesterberg, NL, NTIS# N75-14458, 1974.

In Dutch with a short English summary. Dutch title: Technische Menskunde voor Commando- en Controlruimten. A brief review of the author's experience in control room design. Leebeek concentrates on illumination in general and on display boards in particular. He provides handy rules-of-thumb and cautions, such as display characters should be no smaller than 1/300 of the distance between the viewer and the display. He treats natural illumination and the relative costliness of alternatives.

Loftus, G. R. & E. F. Loftus, Human Memory: The Processing of Information, Lawrence Erlbaum Associates, Inc., Hillsdale, NJ, 1976.

A thorough examination of the short-term/long-term memory store model for information processing from a psychological perspective. All pertinent experimentation is referenced, making this a valuable source.

Loftus, G. R. & E. F. Loftus, Short-Term Memory Factors in Ground Controller/Pilot Communication, Human Factors, 1976.

Reasons for short-term memory error in pilot communication with ground controllers were investigated using a simulated short-term memory task. The results indicated that amount of information being processed at any time, and retention intervals, were the major determinants of error.

Mallory, K., S. Flieger & J. Johnson, Human Engineering Guide to Control Room Evaluation, NRC, Essex Corporation, Washington, DC, NUREG/CR-1580, Jul 1980.

Draft Report containing a Control Room Evaluation Process and Human Engineering Guidelines. Includes an assessment of control room layout, the adequacy of information provided, the arrangement & identification of controls and instrumentation displays, etc. The guidelines & procedures for evaluation are based on human factors evaluations of 9 nuclear control rooms. Very well done and reasonably extensive; the report is two and a half inches thick. Guidelines are arranged by specific, practical topics.

ORIGINAL PAGE IS
OF POOR QUALITY

Mandal, A. C., The Seated Man (Homo Sedens), The Seated Work Position. Theory and Practice, Applied Ergonomics, Vol. 12, No. 1, Mar 1981, pp. 19-26.

Demonstrates that contemporary design of seating is perverse in its insistence that the body hold unnatural right-angled limb articulations. Shows the ergonomic characteristics of natural seating and provides design recommendations for improved seat and work surface combinations.

Marcus, A., Designing the Face of an Interface, IEEE J. of Computer Graphics and Arts, Jan 1982, pp. 23-29.

Discusses guidelines for graphic design for human/machine interfaces. Reviews reference grid, typographic parameters (letter spacing & justification, space & structure, letter forms & capitalization, tables & lists). Applies this discussion to SEEDIS & changes its graphic design format somewhat. The initial implementation of these changes has been favorably received by users. In this case, more detailed evaluation remains to be done.

Martin, J., Design of Man-Computer Dialogues, Prentice-Hall, Inc., Englewood Cliffs NJ, 1973.

This book is based on a course given at IBM Systems Research Institute on man-computer dialogues. It is an easy to read text covering the following topics: alphanumeric dialogues, dialogues with sound and graphics, psychological considerations, operators without training, and implementation considerations.

Matula, R. A., Effects of Visual Display Units on the Eyes: A Bibliography (1972-1980), Human Factors, Vol. 23, No. 5, Oct 1981, pp. 581-586.

This bibliography contains 174 entries obtained from online searches of various data bases, including Excerpta Medica, INSPEC, Medline, NTIS, PIRA, Psychological Abstracts, SCISEARCH, and SOCIAL SCISEARCH.

McCormick, E. J., Human Factors in Engineering & Design(4th Edition), McGraw-Hill Inc, New York, NY, 1976.

An excellent systems-oriented textbook with good coverage of the various aspects of human factors, and a good source of basic human factors data. He covers information input and mediation processing, human output and control processes, workspace and its arrangement, environmental concerns, and methodologies for applications of human factors data. Specific topics include: visual, auditory, and tactile displays; speech communications; applied anthropometry; illumination; noise.

McCormick, E. J. & M. S. Sanders, Human Factors in Engineering and Design(Fifth edition), McGraw-Hill Book Company, New York, NY, 1982.

This, the fifth edition of a classic text on human factors, covers the following topics: the data base of human factors,information input, human output and control, workspace and arrangement, environment, and selected topics in human factors. This is a valuable overview and reference book.

ORIGINAL PAGE IS
OF POOR QUALITY

Meister, D., Human Factors: Theory and Practice, John Wiley & Sons, Inc., New York, NY, 1971.

A classic text dealing with the underlying concepts of human factors and with the realities of the human factors job. Intended as a practical guide to the daily performance of human factors tasks. Covers: the man-machine concept; human error; methods of analyses; research; human factors in predesign and in detail design activities; relations between the engineer and human factors specialist; procurement of research; and the organization of human factors work teams within an organization.

Miles, S. D., Man/Machine Interface Study for Command Applications, Bendix Field Engineering Corp., NASA/GSFC, Greenbelt, MD, NAS5-25025, Jun 1980.

This document identifies and evaluates various methods for handling spacecraft commanding in GSFC Control Centers. It discusses the operational advantages and disadvantages of the following systems: KCRT, Special Purpose Consoles, General Purpose Consoles, and Smart terminals or microprocessors. It is an informative overview of Goddard's past and present systems.

Mitchell, C. M., L. J. Stewart & A. R. Bocast, Human Factors Aspects of Control Room Design:Guidelines and Annotated Biblio, NASA/GSFC, George Mason University, Greenbelt, MD, TM 84942, Dec 1982.

This document reports the results of a literature survey and analysis conducted by George Mason University on human factors aspects of control room design. The focus was the command and control environment at NASA/GSFC. Topics range from the well-defined to the more speculative, such as the role of the human in an automated environment. Human factors of computer systems are emphasized, and tools and methodologies available for human factors analysis are included. An annotated bibliography is included.

Mitchell, C. M., "Human Factors Dimensions in the Evolution of Increasingly Automated Control", Proceedings of the 26th Annual Human Factors Society Meeting, Human Factors Society, Seattle,WA, Oct 1982.

This paper describes the human factors research effort at NASA/GSFC concerning the current and proposed command and control environments for near-earth satellites. Both current and proposed research is discussed. The author is a charter member of the NASA/GSFC Human Factors Group and has been directly involved in all phases of the NASA/GSFC human factors effort.

Mitchell, C. M., Human-machine Interface Issues in the MSOCC-1, NASA, Goddard Space Flight Center, Greenbelt, MD, TM83826, Aug 1981.

This technical memorandom presents the details and conclusions of a human factors review of current and proposed command and control environments for near-earth satellites. The report found that little attention had been devoted to fundamental human factors consideration in the current systems, and that the proposed systems, with increased levels of automation, are likely to further degrade the quality of the human-computer interface.

ORIGINAL PAGE IS
OF POOR QUALITY

Mitchell, C. M., P. Van Balen & K. Moe, Ed., "Proceedings of the Human Factors Considerations in System Design Symposium", NASA/GSFC Human Factors Group, Greenbelt, MD., May 1982.

The Proceedings of the NASA-Goddard Symposium held May 1982 in Greenbelt, MD and College Park, MD. Planary session topics include: general background and applicability of human factors as a tool in system design; human factors in nuclear power plant control rooms and in software design; and a critique of interaction devices and techniques. Workshop sessions focused on several topics. Complete papers and viewgraphs of the presentations are included.

Mocharnuk, J. B., D. F. Gaudio & C. L. Suwa, Imaging Infrared Ship Target Acquisition Studies, Human Factors, Vol. 23, No. 5, 1981, pp. 561-80.

Three studies are described which illustrate the iterative interaction of laboratory research in the system design process. They focused on operator performance in an imaging infrared ship target acquisition system. Ship type, display contrast, ship orientation and video bandwidth had significant effects on operator performance, whereas video frame rate yielded a flat function. Results are discussed in the context of a distinction between informational and image quality effects on target acquisition.

Mocharnuk, J. B., Visual Target Acquisition & Ocular Scanning Performance, Human Factors, Vol. 20, No. 5, 1978, pp. 611-631.

Three experiments, using a brief exposure technique investigated the effects of information and physical variables on visual search performance and the associated ocular activity. The results suggest that stimulus information had no effect on eye movement measures, physical restrictions imposed on the search task were responsible for changes in ocular behavior, and per item search rates increased as the total information in the display increased.

Moe, K., Trip Report of the Visit to Solar Mesosphere Explorer Operations Center, NASA/GSFC, Greenbelt,MD, Aug 1982.

This reports summarizes the activities covered on a trip to the Solar Mesosphere Explorer(SME) Operations Center housed in the University of Colorado's Laboratory for Atmospheric and Space Physics(LASP). Several Goddard, contractor, and human factors personnel attended. Topics covered included: a review of the systems engineering approach used for the SME mission, an exchange of human factors ideas with members of the GSFC Human Factors Group, and a review of ERBS human factors analysis milestones.

Monk, T. H., Target Uncertainty in Applied Visual Search, Human Factors, Vol. 18, No. 6, 1976, pp. 607-612.

The aim of this experiment was to determine if target uncertainty effects occur in applied visual search tasks. Targets varied from non-targets along a single dimension. There was a 9.5 % increase in search time when there was target uncertainty. Target position or difficulty was not a confounding factor.

ORIGINAL PAGE IS
OF POOR QUALITY

Moray, N., The Strategic Control of Information Processing, in G. Underwood (Ed.), Strategies of Information Processing, Academic Press, New York,NY, 1978, pp. 301-28.

This chapter, in the excellent book Strategies for Information Processing, applies the concept of variable strategies to a generic command and control environment. The author concludes that operators develop strategies adaptive to the task at hand, for optimal performance. The role of the human as controller and as supervisor is addressed.

Moray, N., Ed., Mental Workload, Its Theory and Measurement, Plenum Press, New York, NY, 1979.

This is the proceedings of the 1977 NATO conference on Mental Workload. There are a number of papers which are both theoretical and applied in nature. Topics include papers on: experimental psychology and mental workload, control engineering and workload measurement, mathematical models and mental workload, physiological psychology and mental workload, applied psychology and mental workload.

Morgan, C. T., J. S. Cook & A. Chapanis, Ed., Human Engineering Guide to Equipment Design, McGraw-Hill, New York, NY, 1963.

This text is somewhat dated, but does provide a traditional overview of the human factors field, especially equipment design. Chapter headings include the following: man-machine systems, visual and auditory presentation of information, speech communication, man-machine dynamics, control design, workplace layout, design for maintenance, effects of environment, and anthropometry.

Mourant, R. R., R. Lakshmanan & R. Chantadisai, Visual Fatigue & Cathode Ray Tube Display Terminals, Human Factors, Vol. 23, No. 5, Oct 1981, pp. 529-540.

This article reports the results of two experiments in the NIOSH study. Experiment I investigated the effects of display type, amount of information, and display contrast on the visual mechanism during a visual search task. CRT usage for three hours produced measurable visual fatigue in eye movement and visual mechanisms; such fatigue was not present in the hard copy visual search task. The second study had subjects engaged in the task for two 4 hour sessions;fatigue in both CRT and hard copy was found.

Mumford, E. & H. Sackman, Ed., Human Choice and Computers, American Elsevier Publishing Co.,Inc, New York NY, 1975.

Proceedings of the IFIP Conference on Human Choice and Computers, Vienna, April 1-5, 1974. Thematically arranged around: management choice, trade union choice, democratic choice, and social choice. The book and its papers are very widely cited.

ORIGINAL PAGE IS
OF POOR QUALITY

Mumford, E. & D. Henchall, A Participative Approach to Computer Systems Design, John Wiley and Sons, New York NY, 1979.

A case study of the successful implementation of a new computer system. Argues that office or shop-floor employees should have a major design role, particularly in creating work organization and task structures, and that both an increase in efficiency and in job satisfaction should be system objectives. Provides techniques to give users the skills to diagnose their own problems, set targets, and design work strategies.

Murray, W. E., E. M[illegible] & W. H. Parr, A Radiation & Industrial Hygiene Survey of Video Display Terminal Operations, Human Factors, Vol. 23, No. 4, Aug 1981, pp. 413-420.

Part of the NIOSH study, this article describes a radiation survey which included 136 terminals. The results of the tests demonstrated that the VDT operators included in this investigation were not exposed to hazardous levels of radiation or chemical agents.

NASA/Ames, Man-Vehicle Systems Research Division Bibliography 1976-1981, Moffett Field,CA, Oct 1981.

This technical report is an annotated bibliography providing a cross-referenced directory of publications written by the personnel of the Man-Vehicle Systems Research Division of NASA-Ames Research center and its contractors, 1976 to 1981. Subject areas included are: flight management systems, human factors in aviation safety, simulation technology for aeronautics, helicopter man-machine integration technology utilization, and space flight related research.

NASA/GMSFC, Spacelab Display Design and Command Usage Guidelines, NASA/GMSFC, GMSFC, AL, MSFC-PROC-711A, Apr 1980.

This document presents guidelines that attempt to standardize the crew/experiment interface among different payloads and result in lower crew training time and increased efficiency of the payload crew in onboard experiment operations.

NASA/GMSFC, Spacelab Experiment Computer Application Software Display Design and Command, NASA/GMSFC, GMSFC, AL, MSFC-PROC-711, Jan 1979.

This study contains specifications and guidelines for the design of spacelab displays. The report was conducted by the Essex Corporation. Many of the guidelines are based on the results of empirical investigations conducted on the Data Display Simulator, others are based on findings in scientific and technical literature. Topics include: display conventions, alphanumeric displays, graphics displays, display organization, commands, command entry, command feedback, and tutorials.

ORIGINAL PAGE IS
OF POOR QUALITY

NASA/GSFC, Human Factors in Control Room Design, RECON Search, NASA/GSFC, Greenbelt, MD, Mar 1982, pp. 1-27.

A NASA RECON Search was run on the topic of human factors in control room design, resulting in this 115 item annotated bibliography. It is a very good source document providing listings of many hard to obtain technical reports.

NASA/GSFC, Payload Operations Control Centers User's Services Guide,MCD,MDOD, NASA/GSFC, Greenbelt, MD, MOD-1PUG/0180, Apr 1981.

This is a user's manual for NASA/GSFC personnel within the Payload Operations Control Centers(POCCs), and related support facilities. The document is intended to be an avaliable resource for both potential and current users. It covers the following: POCC description, support philosophy, related support elements, POCC support personnel, typical spacecraft support operations, test and data flow support, documentation, and future plans.

NASA/GSFC, Control Center System Manual-MSOCC - 1, NASA/GSFC, Greenbelt MD, CCS-4CSM/0277, Aug 1981.

This is a work manual for NASA/GSFC personnel involved in the Multi-Satellite Operations Control Center 1(MSOCC 1). It covers the MSOCC 1 facilities, data distribution subsystems, application processing subsytems, data handling subsystems, displays and interactive keyboards,and MSOCC 1 software.

NASA/GSFC, Integrated Command, Control, Communications and Computation System Functional, Computer Technology Associates, Greenbelt,MD, NAS5-26369, Mar 1981.

This document attempts a unified picture of the requirements which define those functions necessary to control spacecraft likely to fly in the 1980's and 1990's. It also provides the basis for the development of a functional architecture for a generic Integrated Command, Control, Communications and Computation system which can be applied to many spacecraft being developed in the 1980's.

NASA/GSFC, AIAA/NASA Symposium on Space Tracking and Data Systems, NASA/GSFC, Pentagon City, VA, Jun 1981.

This document contains only those papers which were prepared by the authors in time to be preprinted for the Symposium. Ten articles are included. Some titles are: Mission Control, Ground-to-Ground Communications for Mission Support, NASA Activities and Plans, NASA Tracking and Data Acquisition in the 1990's, Deep Space Projects in Japan, and Consolidation of NASA Tracking Stations into a Single Ground Network in the TDRSS Era.

NASA/GSFC, Systems Engineering Task Study Summary Report, Computer Science Corp., Greenbelt, MD, A83-D-17301-05, Jun 1981.

This document summarizes three system engineering studies performed at GSFC Code 511. Included are the LAN Requirements Study, the KCRT Replacement Study, and the MSOCC-1 5-Year Transition Study.

ORIGINAL PAGE IS
OF POOR QUALITY

NASA/GSFC, Systems Test and Operations Language(STOL) User's Guide, Computer Sciences Corporation, Greenbelt,MD, SCPB I-82-008, Aug 1982.

This document describes the usage and functional capabilities of the Systems Test and Operations Language(STOL). It is designed to assist STOL users in the fundamentals of STOL operations and to provide the information necessary to perform STOL functions in an online environment with multibackground tasks.

NASA/GSFC, Keyboard/Cathode Ray Tube (KCRT) Replacement Study, Computer Sciences Corp., Greenbelt, MD, NAS5-24300, Jun 1981.

This working paper contains the following: a examination of the current and future requirements to be satisfied by the KCRT units in the MORs, a sample survey of the current KCRT market, an examination of the various options for the implementation of new KCRTs in MSOCC environments, and an assessment of the impacts of KCRT replacement on the existing MSOCC-1 hardware/software.

NASA/GSFC, Operational Requirements Study for the Automated MSOCC-1 DOCS, Computer Sciences Corp., Greenbelt, MD, NAS5-24300,17400, Jun 1981.

This document presents the operational requirements compiled by Computer Sciences Corporation for the proposed automated DOCS. This system will be incorporated in the MSOCC-1 at NASA/GSFC.

NASA/GSFC, Preliminary ERBS Command Panel Functional Specification, Ball Aerospace Systems Division, Boulder, CO, NAS5-26458, Feb 1982.

The preliminary document for ERBS command panel specification containing functional requirements and sample layouts. It is currently being reviewed by the Human Factors Group and future research on the specifications is pending. The document is of particular interest to NASA/GSFC personnel, especially ERBS Project staff. However, those interested in command panel technology and layout in general may also want to review this.

NASA/GSFC, Mission Operations Plan, ERBS, Ball Aerospace, Greenbelt, MD, ERBS-011,A, Jan 1982.

This document provides the NASA/GSFC ERBS Flight Operations Team with an overview of operations plans and requirements for all phases of the ERBS mission. It provides an overall management level plan that describes the ERBS spacecraft, instruments, subsystems and interfaces with required GSFC support facilities to meet mission objectives.

NASA/GSFC, Integrated Command,Control Communications,and Computation System Design Study, Computer Associates Technology, Greenbelt, MD, NAS5-26689, Jan 1981.

This is a progress report for the C4 System Design Study that covers the following tasks: a review of Data System Modernization documentation, an analysis of SMM operations, and a description of the User Computer Interactive Demonstration System.

ORIGINAL PAGE IS
OF POOR QUALITY

NASA/GSFC, MSOCC-1, 5-Year Transition Plan, Computer Sciences Corp., Greenbelt, MD, NAS5-24300,TA17301, Mar 1981.

This document describes the activities currently scheduled for the MSOCC-1 environment during the next five years as determined by a study performed by Computer Sciences Corporation. It is a transition plan that was generated to act as a planning tool, t o aid in the assessment of requirements impact, to provide a basis for the monitoring of implementation activities, and to assist in the refinement of implementation schedules and budget estimates.

NASA/GSFC, Advanced Space Systems Automation Workshop, Computer Technology Associates, Greenbelt MD, S-04278-8C, Mar 1981.

This is a summary and evaluation of a workshop on automation which was conducted at NASA-Goddard in 1981. Participants represented operations personnel and leading technologists. The intent was to promote meaningful discussion on the issues of operational automation in Goddard's command and control environments.

NASA/GSFC, ERBS Mission Operation Procedures, Ball Aerospace Systems Division, Boulder CO, NAS5-26458, DR#405, Jun 1982.

This document provides the instructions and detailed procedures for the operation of the Earth Radiation Budget Satellite at NASA/GSFC, in all phases of the mission. The ERBS/Orbiter operating instructions and procedures, observatory operating procedures, and control center operations procedures are covered. It is a highly specific document, however, those interested in satellite systems may find it useful. The command and control aspects of ERBS are being investigated by the NASA/GSFC HFG.

NBS,DOC, "Proceedings of Human Factors in Computer Systems Conference", Gaithersburg, MD, Mar 1982.

All of the Proceedings (with the exception of the opening and closing sessions) of the landmark conference on Human Factors In Computer Systems are included. The Conference was held over three days and covered such topics as:naming commands,displaying information,cognitive aspects of software,social factors, research methodology, managing dialogues, perceptual issues, evaluating text editors, user cognition teaching human factors, and design guidelines among others. A valuable and timely document.

NIOSH, Potential Health Hazards of Video Display Terminals, U.S. Dept. of Health & Human Service, Cincinnati, OH, DHHS 81-129, Jun 1981.

This report describes the findings of a field investigation carried out by the National Institute for Occupational Safety and Health(NIOSH). The investigation was conducted at three companies in the San Francisco-Oakland Bay area at the request of three l abor unions to determine the potential health hazards associated with the use of video display terminals.

ORIGINAL PAGE IS
OF POOR QUALITY

NRC, Guidelines for Control Room Design Reviews, U.S. Nuclear Regulatory Commission, Washington, D.C., NUREG-0700, Sep 1981.

This extensive guideline document resulted from the documentation following the Three Mile Island-2 accident. Its purpose is to ensure implementation of human factors considerations in control room design. It devotes great attention to the planning, review, assessment and implemention, and report phases of a detailed control room review. Thorough control room human engineering guidelines are included, with checklists after each page for ease of use. It is a current and valuable source document.

NRC, Human Factors Acceptance Criteria for the Safety Parameter Display System, U.S. Nuclear Regulatory Commission, Washington, D.C., NUREG-0835, Oct 1981.

Draft report for comment. Contains human factors engineering design review acceptance criteria developed by the Human Factors Engineering Branch of the NRC to use in evaluation designs of the SPDS. These criteria were developed in response to the functional design criteria for the SPDS defined in NUREG-0696, Functional Criteria for Emergency Response Facilities. The purpose is to identify criteria for the SPDS installed in the control room of a nuclear power plant. Use of CRT displays is anticipated.

NRC, Functional Criteria for Emergency Response Facilities, Nuclear Regulatory Commission, Washington DC, NUREG-0696, Feb 1981.

Describes the facilities and systems to be used by nuclear power plant licensees to improve responses to emergency situations. Facilities include the technical report center, onsite operational support center, and nearsite emergency operations facility, as well as a brief discussion of the emergency response function of the control room itself. Data systems include the safety parameter display system and the nuclear data link. Together, these make up the total emergency response facilities.

NRC, Evaluation Criteria for Detailed Control Room Design Review, U.S. Nuclear Regulatory Commission, Washington, D.C., NUREG-0801, Oct 1981.

This document is a draft report for comment consisting of evaluation criteria for assessing human engineering discrepancies in nuclear power plant control room reviews. It is the companion document for NUREG-0700, and it details the acceptance guidelines for the licensing of facilities by the NRC. Four phases of evaluation are necessary: an evaluation of the program plan, on-site visits by NRC personnel, evaluation of the design review results, and final verification.

Nat.Res.Coun, Data Management and Computation. Vol. 1:Issues and Recommendations, National Academy Press, Washington, D.C., 1982.

The Committee on Data Management and Computation examines the management of existing and future data acquisitions from spacecraft and associated computations in the areas of the space and earth sciences in this book. It makes recommendations for improvements from the point of view of the scientific user.

ORIGINAL PAGE IS
OF POOR QUALITY

Navon, D. & D. Gopher, On the Economy of the Human-Processing System, Psychological Review, Vol. 86, No. 3, 1979, pp. 214-255.

A review of the human processing system using a utilities approach for allocation of resources. Channel capacity models of information processing are supported.

Neisser, U., Cognitive Psychology, Prentice-Hall, Inc., Englewood Cliffs NJ, 1967.

This is a classic text, outlining the processes of and experimental work on the field of cognitive psychology. It provides excellent coverage of the material and is a valuable source document.

Newman, W. M. & R. F. Sproull, Principles of Interactive Graphics (2nd Edition), McGraw-Hill Book Co., New York, NY, 1979.

A classic text for interactive graphics. The book is organized around the basic topics of: basic concepts of computer-based graphics; graphics software packages; interactive graphics; raster graphics; 3-dimensional graphics; and graphics systems combining hardware and software into a practical tool for computer-naive users.

O'Neil, H. F., Ed., Computer-Based Instruction, A State-of-the-Art Assessment, Academic Press, Inc., New York, NY, 1981.

This book attempts to provide an intellectual framework for computer assisted instruction (CAI) research. It includes an introduction to CAI, an idealized computer-managed instructional system as a conceptual framework for the field, assessments of hardware and software and of courseware, and management of CAI projects.

Palmer, E. A., S. J. [illegible] & S. L. O'Conner, Perception of Horizontal Aircraft Seperation on a Cockpit Display of Traffic, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 605-20.

Describes an experiment in which subjects were required to judge whether an intruder craft would pass before or after their own craft. Displayed history did not improve performance, although it was desired by pilots. Pilots made fewer errors when they had predictive data, especially with the predicter curved proportionally to turn rate. Neither varying the rate of updating information on the display from 0.1 to 4 seconds nor varying viewing time from 1 to 16 seconds effected performance.

Parsons, H. M. & W. E. Perry, Concepts for Command and Control Systems, Office of Naval Research, System Development Corp., Falls Church, VA, NTIS #AD479368, Dec 1965.

Defines "command & control system" by outlining a model of the embedding military process consisting of 5 functions: sense, analyze, decide, act, & communicate. Suggests that methodology for improving command & control systems can be improved by considering 5 "trouble-points": function & system boundary interfaces, front end data input, noise-data conversions, consideration of the "ant-system", and system exercising. Urges an empirical approach to the study of such trouble points.

ORIGINAL PAGE IS
OF POOR QUALITY

Parsons, H. M., Man-Machine System Experiments, The John Hopkins Press, Baltimore,MD, 1972.

This book is the outcome of a study done to assess two decades of man-machine system experimental research. It describes previous work in the field, the methods used, and the problems encountered. It is a valuable reference document containing numerous experiments, but is somewhat dated as it only covers work completed through the late sixties.

Pew, R. W. & S. Baron, Perspectives on Human Performance Modelling, Proceedings of the Conference on Analysis, Design and Evaluati, Baden-Baden,German, Sep 1982.

This paper suggests four activities for considering the contribution of human performance to the overall success of complex man-machine systems during the design stage: task analysis, modelling, simulation and functional specification. The focus of the document is on human performance modelling.

Pew, R. W. & A. M. Rollins, Dialog Specification Procedures (revised edition), Bolt Beranek and Newman, Inc., Cambridge, MA, BBN No. 3129, 1975.

This dialogue specification manual is intended to promote the development of easily interpreted, friendly dialogues by encouraging uniformity of dialogue from one application to another, by exploiting the full capabilities of programmable terminals for creating interactive dialogues, and providing programmers aids for dialogue creation and documentation.

Pew, R. W., Human Information Processing and Reaction Time, Bolt Beranek and Newman,Inc., Cambridge,MA, BBN No.2111, Mar 1971.

An excellent report summarizing principles of reaction time from a human factors system design viewpoint. Several examples are given to illustrate each principle.

Pew, R. W., S. Baron & C. E. Feehar, Critical Review and Analysis of Performance Models Applicable to Man-Machine, Air Force OSR, Bolt Beranek and Newman, Inc., Cambridge, MA, BBN No. 3446, Mar 1977.

Reviews potentially relevant models and identifies issues in model development and application that may have an important impact on models for large-scale man-machine systems. The review is both historical and cross-sectional; abstracts of 40 models are included. Presents a detailed and critical evaluation of human performance models. Examines interrelationships among existing models. Identifies needs and gaps in available knowledge and technology. Gives recommendations for further research.

Poock, G. K., Color Coding Effects in Compatible and Noncompatible Display-Control Arrangem, Journal of Applied Psychology, Vol. 53, No. 4, 1969, pp. 301-303.

Reports an experiment designed to assess the effect of color coding in compatible and noncompatible display-control arrangements. Color coding was found to be effective when displays and controls were noncompatibly arranged. Color coding had no effect when displays and controls were compatibly arranged. The results support the importance of compatibility in display-control arrangement.

ORIGINAL PAGE IS
OF POOR QUALITY

Prince, M. D., Integrated Displays and Controls Design Factors for the 1990's Transport Aire, Lockheed-Georgia Co.,Electronics Div, Marietta, GA, TIS A81-30338, 1980, pp. 1082-89.

Advanced flight station concepts utilizing integrated displays and controls will be necessary in the future and this paper suggests four factors which influence the design of integrated displays and controls: the mission and its environment, the systems environment, the availability of technology and human characteristics.

Prine, G. E., F. M. Brod & P. Burch, Payload Operations Control Center Networks Mission Operations Room Study Repo, Computer Sciences Corporation, Greenbelt MD, NAS5-24300, Dec 1978.

The report is a requirements study for a NASA-Goddard mission operations room (MOR) in a POCCNET environment.

Raloff, J., VDT's The European Experience, Science News, Vol. 120, No. 9, Aug 1981, pp. 137-43.

Report on symposium on VDTs and the vision of workers at the National Academy of Sciences. European researchers lead in this area of investigation and heir research suggests that VDTs are not as benign as their promoters claim. Grandjean showed a statistical correlation between VDT quality and fatigue. Ostberg reported on temporary loss of visual acuity. Haider found such temporary myopia to be influenced also by the color of the display.

Ramsey, H. R., M. E. Atwood & P. J. Kirshbaum, A Critically Annotated Bibliography of the Literature of Human Factors in Com, Science Applications, Inc., Englewood, CO, NTIS# ADA058081, May 1978.

This annotated bibliography is a companion document to Human Factors in Computer Systems: A Review of the Literature, by the same authors. It contains 564 entries ranging from hardware and software considerations to analysis procedures. It is a very valuable source document from the human factors field.

Ramsey, H. R., M. E. Atwood & J. K. Willoughby, Man-Machine Interface Analysis of the Flight Design System, Science Applications, Inc., Englewood, CO, SAI-78-089-DEN, Jun 1978.

A brief, broad human factors analysis of the Flight Design System, a computer software system for use in Shuttle-era flight design by the Mission Planning and Analysis Division at NASA Johnson Space Center. Special attention is paid to support of a mixed staff of engineers and technicians on the system. Specific recommendations are made for development of clear and reliable conversations with the computing system by diffferent classes of users.

ORIGINAL PAGE IS
OF POOR QUALITY

Ramsey, H. R., M. E. Atwood & G. D. Campbell, An Analysis of Software Design Methodologies, ARI, Science Applications, Inc., TR 401, Aug 1979.

Describes and analyzes at a high level several software development techniques and 4 formal methodologies: Structured Design, Jackson's, Integrated Software Development System (Higher Order Software), and Warnier's Logical Construction of Programs. A good assessment of their relative strengths, weaknesses, commonalities, and application domains is made. Identifies several major human factors deficiencies and problems with these methodologies.

Ramsey, H. R., M. E. Atwood & G. D. Campbell, Human Factors in Computer Systems: A Review of the Literature, Science Applications, Inc., Englewood, CO, NTIS# ADA075679, Sep 1979.

This technical report presents a critical outline and summary of a thorough review of the literature in the area. The purpose was to assess the current state of the knowledge and to determine whether that knowledge is sufficient to support the development of human factors guidelines for the design of interactive computer systems. Topics include user and task properties, requirements analysis methods and problems solving aids, interactive dialogues, input and output devices and techniques.

Rasmussen, J., Human Factors in High Risk Technology, High Risk Safety Technology, E.A.Green (Ed), John Wiley & Sons, Ltd., London, 19fc.

This is a draft of a report to be published in "High Risk Safety Technology" addressing some critical issues in reliability vs. risk analysis in automated command and control environments. A number of the concepts are quite generalizable for designing systems for reliability and risk management.

Rasmussen, J. & W. B. Rouse, Ed., Human Detection and Diagnosis of System Failures, Plenum Press, New York, NY, 1981.

This book includes all of the papers presented at the NATO Symposium on Human Detection and Diagnosis of System Failures. A group of 85 psychologists and engineers coming from industry, government, and academia convened to discuss and to generate a "state of the art" consensus of the problems and solutions associated with the human's ability to cope with the increasing scale of consequences of failures within complex technical systems. Many of the articles are very pertinent.

Rieger, C. J., R. Wood & E. Allen, Large Human-Machine Information Spaces, U. of Maryland, Maryland Artifical Intelligence Grp., College Park, MD, 1024 (NAS5-25764), Mar 1981.

Describes an I-SPACE, a large man-machine information 'space' for environments where large amounts of distributed information and tools for using that information must be made available to a wide variety of users in real time. The I-SPACE presents a powerful, uniform, and easy-to-use face to all users. It permits users to synthesize information from diverse parts of the I-SPACE for simultaneous use on a 'cluttered desktop' where jobs can be temporarily set aside and yet remain active.

ORIGINAL PAGE IS
OF POOR QUALITY

Rieger, C. J. & M. D. Weiser, Development & Application of Natural Human-to-Machine Interfaces for NASA MIS, U. of Maryland, Computer Science Dept., College Park, MD, technical proposal.

A renewal proposal for continued research and development of the I-SPACE, a human-machine interface system for large-scale, real-time information spaces, sponsored by NASA GSFC. The project is aimed at the real-time acquisition and synthesis of information from diverse, often geographically distributed sources. The user is given the illusion of cluttered desktop of powerful windows through which he can look at data that may be changing in real time. Quite thought provoking.

Rogers, J. G. & C. D. Pegden, Formatting & Organization of a Human Engineering Standard, Human Factors, Vol. 19, No. 1, 1977, pp. 55-61.

The article describes a detailed analytical review of two existing government human engineering standards and the results of a user survey on human engineering standards. The review revealed formatting and organizational problems in current human engineering standards which detract from their utility to the designer. Problems identified and recommended solutions are presented.

Rogers, J. G. & R. Armstrong, User of Human Engineering Standards in Design, Human Factors, Vol. 19, No. 1, 1977, pp. 15-23.

This study evaluated the impact of human engineering standards on product designs by: a comparison of two displays designed to the same standard, an analytical evaluation of two existing standards, and a survey of standard users. The study concludes that existing standards appear to have little effect on product design. Likely reasons include: deficiencies in the standards, education and interdisciplinary communication, as well as designer preference.

Rouse, W. B., Problem Solving Performance of First Semester Maintenance Trainees in Two Fau, Human Factors, Vol. 21, No. 5, Feb 1979, pp. 611-618.

The article describes an experiment in which 48 first semester trainees in an FAA certificate program participated in an experimental study of trouble-shooting of two different types of graphically displayed networks. Effects were: network size, redundancy, feedback, computer-aiding and training. It was found that performance degraded as network size increased, degraded as the level of feedback was reduced, improved with computer-aiding, and that skills developed with aiding transferred to other tasks.

Rouse, W. B., Design of Man-Computer Interfaces for On-Line Interactive Systems, Proceedings of the IEEE, Vol. 63, No. 6, Jun 1975, pp. 847-857.

The paper integrates a wide range of material into a conceptual structure for the design of human-computer interfaces for on-line interactive systems. Typical roles for the human in human-computer systems are considered. Suggestions for the design of systems are developed in discussions of displays and input devices, visual information processing, and mathematical models of human behavior.

ORIGINAL PAGE IS
OF POOR QUALITY

Rouse, W. B., Human-Computer Interaction in the Control of Dynamic Systems, Computing Surveys, Vol. 13, No. 1, Mar 1981, pp. 71-99.

This article is a review of pertinent literature and current research on modes of human-computer interaction in the control of dynamic systems and the problems of task allocation. This is a comprehensive treatment of the subject and makes a good tutorial on man-machine issues in automated command and control situations.

Rouse, W. B., Human-Computer Interaction in Multitask Situations, IEEE Trans on Systems, Man & Cybernetics, Vol. SMC-7, No. 5, May 1977, pp. 384-392.

Human-computer interaction in multitask decisionmaking situations is considered, and it is proposed that human and computers have overlapping responsibility. Queueing theory is employed to model this dynamic approach to the allocation of responsibility between human and computer. Results of simulation experiments are used to illustrate the effects of several variables including: number of tasks, mean time between arrivals of action-evoking events, human-computer speed, probability of error.

Rouse, W. B., Adaptive Allocation of Decision Making Responsibility Between Supervisor & Co, Monitoring Behavior & Supervisory Control, Plenum Press, New York, NY, 1976.

This articles suggest dynamic allocation of tasks betwen human and computer in control systems with multitask environments. A simulation using queueing theory is described, prerequisites to the real-world realization are considered, and two laboratory experiments are discussed.

Rouse, W. B., Systems Engineering Models of Human-Machine Interaction, North Holland, New York, NY, 1980.

This text is an excellent reference text and introductory tutorial offering a wide variety of mathematical tools which are useful in analyzing human-machine interaction. Topic include: estimation theory, control theory, queueing theory, fuzzy set theory production systems, pattern recognition, and Markov Chains.

Rouse, W. B., Problem Solving Performance of Maintenance Trainees in a Fault Diagnosis Task, Human Factors, Vol. 21, No. 2, 1979, pp. 195-203.

The article describes an experiment in which 40 FAA certificate program trainees participated in a study to evaluate trouble-shooting of graphically displayed networks. Effects were network size, computer aiding, and training. Performance degraded as network size increased, improved with the use of computer aiding, and skills developed with computer aiding that were transferred to the unaided situation.

ORIGINAL PAGE IS
OF POOR QUALITY

Ruffner, M. A., Human Factors in Systems Analysis, IEEE Trans. of Systems, Man, & Cybernetics, Vol. SMC11, No. 7, Jul 1981, pp. 509-514.

Critical to an understanding of contemporary systems design and analysis is appreciation of the epistemological and cultural constructs that condition and constitute the assumptive background of our knowledge and orientation. In such a context this correspondence focuses on how the tacit dimension and the very primacy of perception transect and impact upon systems analysis—how in an integral view of living systems and dynamic systems, "soft" human factors interconnect with "hard" science & technique.

Rutenfranz, J., W. P. Colquhoun & P. Knauth, "Hours of Work and Shiftwork", Proceedings - 6th Congress Intern. Ergonomics Assoc., Jul 1976, pp. XLV-LII.

First the time elements of a working day, the duration of working time and the time positioning of working time are considered ergonomically. Second, the reasons for shiftwork, different types of shift work as well as effect on health and family and social life are discussed. Finally, psychological criteria for optimal shift schedules are presented.

Sage, A. P., Behavioral & Organizational Considerations in the Design of Information Syste, IEEE Trans. on Systems, Man, & Cybernetics, Vol. SC11, No. 9, Sep 1981, pp. 640-678.

Reviews and attempts to integrate the literature from many areas having import for the design of decision support systems. There are 415 references cited and most of the important ones are discussed in the text. Sage reviews cognitive style and human information processing in decision making, decision rules, contingency models of task structure, and decision frameworks & organizational settings.

Samet, M. G. & R. E. Geiselman, Developing Guidelines for Summarizing Information, Human Factors, Vol. 23, No. 6, 1981, pp. 727-736.

Reports a study conducted to test the validity and generalizability of previously developed guidelines for summarizing military message content. The task required staff officers to summarize tactical messages; these summaries were then evaluated by raters . The summaries prepared with the guidelines were judged to be better summaries. The highest rated summaries were used to derive a general schema for describing message contents.

Samet, M. G. & K. B. Davis, Computer-based Supervisory System for Managing Information Flow in C3 Systems, DARPA, Perceptronics, Inc., Woodland Hills CA, NTIS# ADA040359, Mar 1977.

Progress on work concerning on the demonstration of a system of integrated on-line adaptive user models designed to automatically select and pace information in a simulated command, control, and communication system. The report includes a human factors rationale for improving data flow in C3 systems; a description of mods made to the Tactical & Negotiations Game; and the conceptual specification of a real-time computer-based model for automatically adapting message pacing rate to the user.

ORIGINAL PAGE IS
OF POOR QUALITY

Seeberger, J. J. & W. W. Wierville, Estimating the Amount of Eye Movement Data Required for Panel Design & Instru, Human Factors, Vol. 18, No. 3, 1976, pp. 281-292.

> Presents a procedure for estimating the amount of eye movement data required to obtain a specified statistical accuracy with a given degree of confidence. It is applicable when eye movement statistics are to be used in panel redesign and instrument placement. The procedure should be applicable to a variety of human factors design problems.

Seminara, J. L., W. R. Gonzalez & S. O. Parsons, Human Factors Review of Nuclear Power Plant Control Room Design, Electric Power Research Institute, Palo Alto, CA, EPRI NP-309,501, Mar 1977.

> This is the summary document that preceded the EPRI NP-1118 study on human factors of nuclear power plant control rooms. It consists of a survey of five control room simulators and their corresponding operational plants. Several human factors problem areas were identified and future study needs were suggested.

Seminara, J. L., W. R. Gonzalez & S. O. Parsons, Human Factors Methods for Nuclear Control Room Design, Vol. 3:HF Methods for, Electric Power Research Institute, Palo Alto, CA, EPRI NP-1118,501-3, Feb 1977.

> The third volume of the EPRI NP-1118 series consists of human factors methods for conventional control board design. Analyses of control and display requirements (e.g. sytems analysis, function, and task analysis), human engineering of conventional control boards, warning system design approaches, and control board design evaluations are the topics discussed.

Seminara, J. L. & S. O. Parsons, Human Factors Methods for Nuclear Control Room Design, Vol. 2:HF Survey of Cont, Electric Power Research Institute, Palo Alto, CA, EPRI NP-1118,501-3, Nov 1979.

> The second volume in the EPRI NP-1118 series focuses on a human factors survey of control room design practices. The methodology used in the survey was a thirty-item structured interview form, along with biographical questions, both of which are included in the Appendix. Control room concepts and design processes are discussed and a design review and evaluation is included.

Seminara, J. L., S. O. Parsons & W. J. Schmidt, Human Factors Review of Power Plant Maintainability, Electric Power Research Institute, Palo Alto CA, EPRI NP-1567-SY, Oct 1980.

> In response to EPRI NP-309-SY and EPRI NP-1118-SY, this study was undertaken to examine plant and equipment design in terms of maintainability from a human factors perspective. Nine existing facilities were surveyed, both nuclear and fossil fuel plants. The methods used to conduct the study include structured interviews, checklist guided observations, task analyses, photodocumentation, and maintenance error analysis, among others. The results indicate a variety of human factors problems present.

ORIGINAL PAGE IS
OF POOR QUALITY

Seminara, J. L., S. R. Eckert & S. Seidenstein, Human Factors Methods for Nuclear Control Room Design, Electric Power Research Institute, Palo Alto , CA, EPRI NP-1118-SY, Jun 1979.

This is the summary report of the Electric Power Research Institute's Project 501-3, summarizing four volumes listed here individually. The study documented human factors techniques required to provide a sustained concern for the man-machine interface fr om control room concept definition to system implementation.

Seminara, J. L. & S. R. Eckert, Human Factors Methods for Nuclear Control Room Design,Vol.4:HF Considerations, Electric Power Research Institute, Palo Alto, CA, EPRI NP-1118,501-3, Mar 1980.

The last volume in the EPRI NP-1118 series deals with human factors considerations for advanced control board design. Several topics are adressed: information accessing schemes, display system parameters, information coding, display formatting, advanced warning systems, interface hardware, and hybrid systems. A summary of this and the previously listed three volumes can be found in document EPRI NP-1118-SY.

Seminara, J. L., S. R. Eckert & S. Seidenstein, Human Factors Methods for Nuclear Control Room Design,Vol. 1:HF Enhancement, Electric Power Research Institute, Palo Alto,CA, EPRI NP-1118,501-3, Nov 1979.

This is the first volume of a series of evaluative reports on human factors in nuclear power plant control rooms published in response to EPRI NP-309, a human factors review of existing power plant control rooms. This report considers human factors enhancements of existing nuclear control rooms; board enhancement possibilities, reorganizations of existing control boards, and an in-depth look at three human factors enhancement examples.

Senders, J. W. & M. J. M. Posner, A Queueing Model of Monitoring & Supervisory Behavior, Monitoring Behavior and Supervisory Control, Plenum Press, New York, NY, 1976.

The article reviews models to calculate the staffing requirements and reliability of the human-machine interaction in automated control settings. The article is part of a chapter devoted to preview models of the human/monitor/supervisor.

Shackel, B., Ed., Man-Computer Interaction: Human Factors Aspects of Computers and People, Kluwer Boston Inc., Hingham, MA, 1981.

The book is based on papers presented by invited speakers at the NATO Advanced Studies Institute on Man-Computer Interaction. Papers address topics including: conversation and communication between people and computers, aspects of hardware and software interfaces, training and education, organizational and managerial issues, modelling and problem solving, designing for specialist users, and evaluation.

ORIGINAL PAGE IS
OF POOR QUALITY

Sheridan, T. B. & W. R. Ferrell, Man-Machine Systems: Information, Control & Decision Models of Human Performa, MIT Press, Cambridge, MA, 1981.

A heavily mathematical text. The nature and conclusions of models of human performance derived from information theory, control theory, and decision theory are developed. The concern is the development of mathematical models to predict human behavior in man-in-the-loop control situations. Topics include: information measurement and channels; continuous information; quasi-linear control models in the frequency domain; nonlinear performance characteristics; signal detection; formal games.

Sheridan, T. B. & G. Johannsen, Ed., Monitoring Behavior and Supervisory Control, Plenum Press, New York, NY, 1976.

This text is the proceeding of the NATO Conference Symposium on Monitoring Behavior and Supervisory control. It contains many excellent, state of the art papers examining the implications of introducing increased automation in the command and control environment.

Sherr, S., Electronic Displays, John Wiley and Sons, New York NY, 1979.

A highly technical text focusing on the electronics and the physics of display devices. A comprehensive survey of available electronic display devices and their characteristics. The first chapter provides a technical discussion of human perceptual factors and visual parameters and their significance to display system performance. At times, recommendations and requirements suggested by Sherr are at odds with similar guidelines in the literature. A strong emphasis on the display of alphanumerics.

Shneiderman, B., Software Psychology: Human Factors in Computer & Information Systems, Winthrop Publishers Inc., Cambridge, MA, 1980.

A seminal work in the application of psychology to the study of computers. Surveys the literature and tours the computing world from the perspective of interesting psychological questions to be posed. Includes the motivation for a psychological approach and research methods, programming as human performance, programming style, software quality evaluation, team organization and group processes, database systems and data models, database query & manipulation languages, & interactive interface issues.

Shneiderman, B., Hardware Options, Evaluation Metrics, & a Design Sequence for Interactive Inf, Information & Management, Vol. 3, 1980, pp. 3-18.

This article is adapted from Shneiderman's Software Psychology.

ORIGINAL PAGE IS
OF POOR QUALITY

Shontz, W. D., G. A. Trumm & L. G. Williams, Color Coding for Information Location, Human Factors, Vol. 13, No. 3, 1971, pp. 237-46.

The findings in this study indicate color coding for information location is effective. Search time of subjects viewing achromatic versus chromatic maps were evaluated. The effectiveness of color appears dependent on the number of categories coded, discriminability in peripheral vision, and keeping the number of objects per category at or below 11. Colors should be selected on the basis of their discriminability in peripheral vision.

Shurtleff, D. A., How to Make Displays Legible, Human Interface Design, La Mirada, CA, 1980.

An interesting and recent study of hardware and software specifications required to ensure legibility of computer-generated displays. Conducted by Mitre from 1961 - 1975, the report includes a discussion of luminance, stroke width, height-to-width ratio, and symbol height.

Siegel, A. I. & J. J. Wolf, Man-Machine Simulation Models, John Wiley & Sons, Inc., New York, NY, 1969.

A dated but still valuable work. The authors abstract and present the results of 10 years of research and modelling directed to the development of quantitative techniques for alternative system evaluation when personnel performance and interpersonnel relationships are recognized to be of importance to total system effectiveness. A goal of these models is to predict system efficiency levels under various conditions that affect the performance of the man-machine system involved.

Simpson, H., A Human-Factors Style Guide for Program Design, BYTE, Apr 1982, pp. 108-31.

The important issue stressed in this human factors article is to take the user into account when designing software. Specific design principles mentioned include: provide feedback, be consistent, minimize human memory demands, keep the program simple, match the program to the operator's skill level. Further guidelines concentrate on data entry and display screen design.

Sinaiko, H. W. & E. P. Buckley, Ed., Selected Papers on Human Factors in the Design and Use of Control Systems, Dover Publications Inc., New York NY, 1961.

The first paper in this book is a valuable introduction to the human factors field even though it is over twenty years old. The other papers are also interesting, but dated. Each provides an excellent bibliography to that point in time. Topics include: methods for analyzing errors, design philosophy, sensory capabilities, effects of acceleration, and measurement of human performance.

ORIGINAL PAGE IS
OF POOR QUALITY

Sinaiko, H. & E. P. Buckley, Human Factors in the Design of Systems, In H.W.Sinaiko(Ed.), Selected Papers on Human Factors in the, Dover Publications, Inc., New York, NY, 1961.

The human component & the process of designing systems is reviewed. Ten characteristics of the human component are listed and defined (physical dimensions, capabilities for data sensing, data processing, motor activity & learning, physical & psychological needs, sensitivities to physical & social environment, coordinated action & individual differences) and appropriate systems design considerations are given for each characteristic.

Singleton, W. T., R. S. Easterby & D. C. Whitfield, Proceedings of the Conference on the Human Operator in Complex Systems, Taylor & Francis, Ltd., London, 1971.

Although the text is not recent, many of the contributed papers are classics in the areas of human factors principles and human-machine interface issues in command and control environments, particularly process control and industry control rooms. Topics include discussions of system design methods, analytical techniques, methods of function allocation, methods of task description, issues in training, job aids and maintenance, and miscellaneous applications.

Smith, S. L., Requirements Definition & Design Guidelines for Man-Machine Interface in C3 S, Mitre Corp, Bedford, MA, NTIS# ADA087258, Jun 1980.

Smith proposes a requirements matrix to help ensure effective software design for man-machine interfaces. The functional capabilities are categorized on the basis of requirements for characteristic user tasks. He suggests that design guidelines for specific systems can be tailored using this matrix. Major matrix categories include: dialogue type; data entry/input; data display/output; sequence control; user guidance; and data transmission/communication.

Smith, D. C., C. Irby & R. Kimball, Designing the Star User Interface, BYTE, Apr 1982, pp. 242-82.

The Star user interface is an example of formulating the user concepts before the software written. Also, hardware specifications come afterward. A methodology was established for the design; a task analysis defined the set of objectives and methods to be provided by the new system. The principles used in design include: universal commands, consistency, simplicity, user tailorability, and familiar user's conceptual model.

Smith, S. L., Letter Size and Legibility, Human Factors, Vol. 21, No. 6, 1979, pp. 661-70.

This study on letter size and legibility covered 2000 measures for over 300 printed displays. Results found a mean letter height of .00019 rad (7 min) at the limit of legibility. There was 90 % legibility at .003 rad. This data supports current standards used for letter size. Adjustments might be necessary in certain circumstances.

ORIGINAL PAGE IS
OF POOR QUALITY

Smith, S. L., Ed., Human Interaction With Computers, Academic Press, Inc., New York NY, Vol. 21, No. 6, 1979, pp. 661-70.

Applications of sociology to computing. The first section looks at general approaches to the study of people-oriented computer systems. The second is concerned more specifically with the techniques that have been adopted in a number of application areas. The third section turns to the nuts and bolts of computing, the programming languages, to consider how their design and use could be improved. Sample chapters: The Human as Systems Component; Information Retrieval; Programming as Cognitive Activity.

Smith, S. L., Man-Machine Interface Requirements Definition and Design Guidelines Progress, The Mitre Corp., Bedford, MA, NTIS# ADA096705, Feb 1981.

This report extends the work of a previous report addressing the need for man-machine interface requirements definition and guidelines in the design of computer-based information systems. Over 400 guidelines are presented with appropriate comments. Areas covered include: user characteristics, task analysis, functional capabilities, data entry, sequence control, and continued development and application.

Smith, M. J., B. G. Cohen & L. W. Stammerjohn, An Investigation of Health Complaints and Job Stress in Video Display Operati, Human Factors, Vol. 23, No. 4, Aug 1981, pp. 387-400.

Part of the NIOSH study, this study reports on the results of a questionnaire survey dealing with working conditions, job stress factors, health complaints and psychological mood state filled out by 250 VDT operators and 150 non-VDT operators. Clerical VDT users reported higher levels of job stress and health complaints but little difference in mood than did professional VDT operators and the control subjects. Job stressors showed greatest impact on clerical operators.

Spencer, R. A., "Man/Machine Interface Considerations for a Teleoperator Spacecraft Control St", Proceedings - 17th Annual Meeting of the Human Factors Society, Human Factors Society, Santa Monica, CA, 1973, pp. 326-333.

Reports on the design, mockup, and evaluation by simulation of a physical configuration for a Teleoperator Spacecraft Control and Display Station. A good exemplar for the conduct of human factors design evaluations using mockups and experimentation.

Stager, P. & T. G. Paine, Separation Discrimination in a Simulated Air Traffic Control Display, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 631-636.

Reports experiment in which terminal area controllers made separation judgements concerning whether displayed pairs of aircraft were more than or less than the standard separation of 3 nautical miles (nm). The pairs of aircraft varied with respect to their location, their orientation, and their separation. It was found that the mean increment in separation required for discrimination was 0.14 nm, regardless of map scale.

ORIGINAL PAGE IS
OF POOR QUALITY

Stammerjohn, L. W., M. J. Smith & B. G. Cohen, Evaluation of Work Station Design Factors in VDT Operations, Human Factors, Vol. 23, No. 4, Aug 1981, pp. 401-412.

Part of the NIOSH study, this article describes an onsite evaluation conducted at five establishments using VDTs in order to examine VDT workstation design. A number of design problems were found, including excessive keyboard heights and screen positioning. A majority of the operators found a number of factors to be bothersome, including screen readability, reflected glare, screen brightness, and flicker. A number of the dissatisfaction parameters were found to be related to health complaints.

Stammers, R. B. & J. M. Bird, Controller Evaluation of a Touch Input Traffic Data System: An "Indelicate" E, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 581-590.

Describes an evaluation of a system for data transfer and display for airport air traffic control by practicing controllers. The system displays the data on a single screen; data transfer and modification are done via a touch sensitive surface on the screen. The objective was to ascertain the opinions and attitudes of controllers. Experimental data were gathered by questionnaires and video tape.

Stevens, P. & B. Shneiderman, "Exploratory Research on Training Aids for Naive Users of Interactive Systems", Proceedings - ASIS Conference, Washington, DC, Oct 1981.

Describes two exploratory experiments in training naive users of interactive bibliographic retrieval systems. The paper emphasizes the methodology of evaluating training rather than experimental results.

Stewart, L. J., E. D. Murphy & C. M. Mitchell, Human Factors Analysis of Workstation Design:Earth Radiation Budget Satellite, NASA/GSFC, George Mason University, Greenbelt,MD, TM 84943, Dec 1982.

This report documents the human factors analysis of workstation design for the Earth Radiation Budget Satellite(ERBS) Mission Operations Room(MOR) at NASA/GSFC. Principles for workstation design are reviewed; a general method for conducting a workstation design analysis is proposed; a detailed case study is given; recommendations for enhancing the ERBS MOR are made; and a discussion of significant issues is included.

Sugarman, R., Nuclear Power & the Public Risk, IEEE Spectrum, Vol. 16, No. 11, Nov 1979, pp. 61-69.

This article relates risk, human error, and control room design. Cites studies indicating that the most prevalent cause of nuclear incidents result from human error. The TMI accident is examined in detail from the perspective of human and design errors.

ORIGINAL PAGE IS
OF POOR QUALITY

Swain, A. D., Description of Human Factors Reports by Sandia National Laboratories, Author, Albuquerque NM, Jan 1982.

This annotated bibliography contains 63 entries describing the human factors work at Sandia National Laboratory. It is an excellent source document that is up to date, and provides a listing of hard to locate technical reports. Topics covered include: human reliability analysis methodology, data collection and management, human performance data and information, changing people verses work situations, and safety.

Swain, A. D., System and Task Analysis, A Major Tool for Designing the Personnel Subsystem, Sandia Corporation, Albuquerque, NM, Jan 1962.

This document discusses the history of System and Task Analysis, and defines the basic method used by human factors specialists in conducting these analyses. It is a somewhat dated look at the topic, but is valuable because relevant literature is sparse.

Swain, A. D., Human Factors in Nuclear Power Plant Operations, Sandia National Labs, Albuquerque NM, SAND80-1837C, Aug 1980.

A highly readable paper describing some of the human factors problems in nuclear power plants and the technologies which can be used to reduce these problems. Swain argues that many of the changes to improve the human factors engineering of existing plants are expensive and that the gains to be expected in human reliability are substantial.

Swain, A. D. & H. E. Guttman, Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant A, Sandia National Labs, NUREG/CR-1278, Oct 1980.

Draft Report written to aid qualified persons in evaluating the effects of human error on the availability of engineered safety features and systems in nuclear power plants. Expands the human error analysis presented in WASH-1400. Includes principles of human behavior and ergonomics, analytical procedures, mathematical models, and human error probabilities derived from related performance measures. The derived probabilities can be used to determine the relative merits of different resource configurations.

Szoka, K., Practical Considerations on the Use of Color, Computer Sciences Corp., Silver Spring, MD, Apr 1982.

A brief (7-page) memo providing guidance in the use of color in the computer generation of graphs, pie-charts, and other data presentations. Szoka suggests that color highlights information and should be constrained to that use.

Tabor, M., Video Display Terminals: The Eyes Have Had It, Occupational Health and Safety, Sep 1981, pp. 30-38.

This document discusses some of the visual discomforts associated with the use of VDTs in the workplace. Some recommendations for improvement are made.

ORIGINAL PAGE IS
OF POOR QUALITY

Teichner, W. H. & M. J. Krebs, Laws of the Simple Visual Reaction Time, Psychological Review, Vol. 79, No. 4, 1972, pp. 344-58.

An examination of reaction time results to a flash of light in terms of luminance, duration, size of stimulus, response to onset verses termination of the signal and monocular verses binocular viewing.

Topmiller, D. A., Man-Machine Command-Control-Communication Simulation Studies in the Air Force, Air Force Systems Command, Aerospace Medical Research Lab, Wright-Pat.AFB, OH, NTIS# ADA042148, Sep 1976.

Reviews 15 years of man-machine simulation research in C3 systems conducted by AMRL. Decision aiding techniques for tactical command decision making conducted by Ohio State are summarized. Simulations include: BUIC III, AWACS, and RPVS. A comparison of results obtained with real-time man-in-the-loop simulations with computer simulations using a Systems Integrated Network of Tasks (SAINT) model predictions are illustrated to demonstrate the power and utility of iterating computer with real-time simulation.

Tullis, T., An Evaluation of Alphanumeric, Graphic, and Color Information Displays, Human Factors, Vol. 23, No. 5, Oct 1981, pp. 541-550.

Four CRT display formats were evaluated for a telephone line testing system; the formats were: narrative with complete words and phrases, structured with tabular format, black and white graphics schematic, and a color graphics schematic. The evaluation measured speed and accuracy. Accuracy did not vary with format but speed did. Response times for both graphics were considerably shorter than those for the narrative. With practice, response time for the structured format were as short.

Tuckington, C., Computers in Class: Who Gets to Learn?, APA Monitor, Vol. 13, No. 6, Jun 1982.

This article in the American Psychological Association's newspaper addresses several social issues brought out by increased use of computers, especially in the classroom. Whether or not children of all social-economic backgrounds will have access to computers, the ease with which children learn to use computers, and the educational and psychological learning implications are discussed.

Umbers, I. G., Models of the Process Operator, International J. of Man-Machine Studies, Vol. 11, 1979, pp. 263-284.

This article presents a review of the process control literature exploring various aspects of the human operator which include: characteristics of human control behavior, development of process control skills, individual differences between process operators, task factors which affect performance, and the organization of control behavior. The review concludes that an information processing approach based on protocol data seems to be the most fruitful technique for modelling the human process controller.

ORIGINAL PAGE IS
OF POOR QUALITY

Underwood, G., Ed., Strategies of Information Processing, Academic Press, New York, NY, 1978.

An excellent, broad review of the theory of strategies for information processing. Information processing of several sensory channels is addressed as are several cognitive behaviors, from a strategies approach.

Underwood, G., Concepts in Information Processing Theory, in G. Underwood(Ed.), Strategies of Information Processing, Academic Press, New York,NY, 1978, pp. 1-22.

An excellent introduction to information processing and the concept of strategies is provided by this chapter in an excellent book concerned with strategies for information processing. The logic and writing style are straightforward making this enjoyable reading for the lay person as well as the psychologist.

Uttal, W. R., A Taxonomy of Visual Processes, Lawrence Erlbaum Associates, Inc., Hillsdale NJ, 1981.

Deals with the empirical data base and the theories concerning visual perception, the set of mental responses to photic stimulation of the eyes. Presents a general taxonomy of visual processes and phenomena. The book's goal is to provide a classification system that integrates and systematizes the data base of perceptual psychology into a comprehensive intellectual scheme through metatheory. Massive work (1096 pages). Quite technical, with 63 pages of references in small type.

Van Cott, H. P. & M. J. Warrick, Man as a System Component, in VanCott & Kinkade(Eds.),Human Engineering Guide to Equipmen, McGraw-Hill, Co., New York,NY, 1972, pp. 17-39.

This is an excellent chapter in a valuable source book. The human is viewed from an information processing perspective with applications for system design.

Van Cott, H. P. & R. G. Kinkade, Ed., Human Engineering Guide to Equipment Design, McGraw-Hill Co., New York, NY, 1963.

A classic and widely used manual for system designers interested in human factors considerations. Excellent reading for on the job problems. Topics include: an introduction to engineering analyses, a discussion of the human as system component, visual presentation of information, auditory and other sensory forms of information presentation, speech communication, man-machine dynamics, data entry devices, design of controls, individual workplaces, multi-man-machine work areas, and anthropometry.

ORIGINAL PAGE IS
OF POOR QUALITY

Van Eekhout, J. M. & W. B. Rouse, Human Errors in Detection, Diagnosis, & Compensation for Failures in the Engi, IEEE Trans of Systems Man & Cybernetics, Vol. SMC11, No. 12, Dec 1981, pp. 813-816.

This study was conducted in a simulator to see how 7 crews of officers handled the task of coping with failures. Measures included verbal protocol,computer logs, and questionnaires. Results show errors involving wrong indentification of the failure were related to ignorance of functioning of the system. Errors related to procedure correlated with control panel layout inadequacies. More specific operator training is needed.

Van Nes, F. L. & H. Bouma, On the Legibility of Segmented Numerals, Human Factors, Vol. 22, No. 4, 1980, pp. 463-474.

This research concerns the discriminability of segmented numerals used in modern technology (CRTs). Seven segmented numerals can be confused. As they differed in more line segments, perception improved. A set of numerals is presented that increases discriminability and more closely resembles traditional numeral shapes. Testing on these new shapes not yet performed.

Verhagen, L. H. J., Experiments with Bar Graph Process Supervision Displays on VDUs, Applied Ergonomics, Vol. 12, No. 1, 1981, pp. 39-45.

Bar graph presentations of process variables are compared with alternatives (stroke-type and 'T'-type, combined bar and stroke) in experiments with human subjects, using either an automatic slide projector or a closed circuit TV system. The stroke-type appears to give superior results when used for detection of off-normal conditions.

Walden, R. S. & W. B. Rouse, A Queueing Model of Pilot Decision Making in a Multi-Task Flight Management T, IEEE Trans on Systems, Man & Cybernetics, Vol. SMC-8, No. 12, Dec 1978, pp. 867-875.

This article looks at the problem of allocation of decision-making responsibility between pilot and computer. An experiment was conducted using simulated flight conditions. A queueing model that describes pilot decision-making is reviewed. Also, attention is directed to predicting pilot performance in a subsystem monitoring task. The queueing model looks attractive for a control and monitoring situation.

Webb Assoc., Anthropometric Source Book, VolIII: Annotated Bibliography of Anthropometry, NASA/Johnson Space Center, Houston TX, NTIS# N79-13712, Jul 1978.

Volume III of the set is an annotated bibliography covering a broad spectrum of topics relevant to applied physical anthropology with emphasis on anthropometry and its applications in sizing and design. This series of reports is not only a comprehensive source of specific anthropometric data but also a guide to the effective application of such data.

ORIGINAL PAGE IS
OF POOR QUALITY

Webb Assoc., Anthropometric Source Book, Vol.II: A Handbook of Anthropometric Data, NASA/Johnson Space Center, Houston TX, NTIS# N79-13711, Jul 1978.

Volume II of the three volume set contains data from surveys of military and civilian populations of both sexes from the U.S., Europe, and Asia. Some 295 measured variables are defined and illustrated.

Webb Assoc., Anthropometric Source Book, Vol.I: Anthropometry for Designers, NASA/Johnson Space Center, Houston TX, NTIS# N79-11734, Jul 1978.

Volume I of a 3 volume publication which brings together a large mass of anthropometric data which define the physical size, mass distribution properties, and dynamic capabilities of U.S. and selected foreign adult populations. Aimed specifically to meet the needs of design engineers engaged in the design and execution of clothing, equipment, and workspaces for the NASA Space Shuttle Program, the series is designed to be of use to human engineers in a wide variety of fields. Includes physical data.

Weger, C., Issue Paper—High-Density Alphanumeric CRT Displays, NASA/GSFC, Greenbelt, MD, Sep 1982.

This is a draft of one paper in a series of issue papers prepared by Computer Sciences Corporation addressing the changing needs of MSOCC-1 as it moves into the TDRSS era, in particular, the changing configurations of hardware and software.

Weitzman, C., Distributed Micro/Mini Computer Systems, Structure, Implementation, & Applica, Prentice-Hall, Inc., Englewood CliffsNJ, 1980.

Clear and extensive treatment of distributed or "multi"processor systems, concentrating on the interconnect architecture of multiprocessor systems.Covers network software and hardware, analyses of existing products, and practical design and tradeoff procedures. Appendices define a number of data link control protocols. Noteworthy for Weitzman's discussion of the GSFC POCCNET system as an application example, including requirements, design approach, error-handling philosophy, and a comparative evaluation.

Welford, A. T., Perceptual Selection and Integration, Ergonomics, Vol. 13, No. 1, 1970, pp. 5-23.

A good, but somewhat dated review of the literature pertaining to the perceptual processes of selection and integration of information. Implications for display design are considered.

Wherry, R. J., The Human Operator Simulator HOS, Monitoring Behavior & Supervisory Control, Plenum Press, New York, NY, 1976.

The article describes a practical computer simulation tool to simulate human operators in a variety of tasks. Input includes hand reaches, control device manipulations, eye shifts, and internal decision. Outputs include distribution and sequences of task times, devices, and body parts used.

ORIGINAL PAGE IS
OF POOR QUALITY.

Whitfield, D., R. G. Ball & G. Ord, Some Human Factors Aspects of Computer-Aiding Concepts for Air Traffic Contro, Human Factors, Vol. 22, No. 5, Oct 1980, pp. 569-580.

Sets out the philosophy of a program of computer-aiding concepts for the ACT's decision making. Reviews early work on the computer-assisted approach sequencing concept for a major airport. The main topic is the Interactive Conflict Resolution concept for assisting the enroute controller in conflict detection and resolution. Reports a real-time simulation experiment in which each of 3 pairs of controllers acted as an executive/support team in handling traffic samples in a busy sector.

Whiting-O'Ke, P. M. & C. G. Kerno, Study of the Human-to-Machine Interface Technology in the POCCs, SRI, Greenbelt, MD, Project 6387, Oct 1977.

This is a final report from a NASA-Goddard sponsored research project conducted by SRI. A fairly shallow study, recommendations focused on hardware devices for interaction and data base technologies.

Williams, T. J., Ed., PartVI Guidelines for the Design of Man/Machine Interfaces for Process Contro, Purdue Lab. for Applied Ind. Control, West Lafayette, IN, NTIS# ADA036457, Jan 1977.

This document is Part VI of a six volume set resulting from the International Purdue Workshop on Industrial Computer Systems held over eight years (1969-1977). It addresses overall operations requirements, control center requirements, man/machine interface design factors, and implementation. The document is in guideline format and a good bibliography is included.

Williams, R. D., The Management of Software Development, TRW.

This document is a set of view graphs used in a TRW presentation to Goddard management addressing "The Management of Software Development.

Williges, B. H. & R. C. Williges, User Considerations in Computer-based Information Systems, VPI/Industrial Engineering/Operation, Blacksburg,VA, NTIS# ADA106194, Sep 1981.

This technical report is a compilation of various user considerations relating to software design of computer-based information systems. Thirteen source documents were summarized and 500 specifications/guidelines included. Major topics are: data organization, dialogue modes, user input devices, command language and command processing, feedback and error management, security and disaster prevention, and multiple user communication. This is a helpful document for system designers.

Williges, R. C., Applying the Human Information Processing Approach to Human/Computer Interact, in W.C. Howell & E.A. Fleishman(Eds.),Human Performance and Pr, Lawrence Erlbaum Associates, Hillsdale, NJ, 1982.

An interesting examination of human information processing issues regarding human/computer interfaces. User roles are classified as student, operator/analyst, and programmer, suggesting that different users require different interfaces.

ORIGINAL PAGE IS
OF POOR QUALITY

Williges, R. C. & W. W. Wierville, Behavioral Measures of Aircrew Mental Workload, Human Factors, Vol. 21, No. 5, 1979, pp. 549-574.

This article provides an integrated review of behavioral workload measures oriented to flight test and evaluation areas. Results indicate there is no single measure of mental workload. Best approaches include using multiple measures: subjective opinions spare mental capacity, and physiological correlates.

Wimmer, W., Remote Control of Satellites and Applied Automation, European Space Operations Center, Darmstadt, FDR.

This paper provides an introduction to the automatic instrument control implemented in the European Space Operaitons Center (ESOC).

Witten, I. H., Communicating with Micro-Computers, Academic Press, New York, NY, 1980.

Introduces the non-specialist with some electronics knowledge to the technology of communicating with microcomputers. Covers hardware elements of microprocessors, communication buses, and various microcomputer interfaces, including DMA, graphics devices and speech recognition devices. A slender book (158 text pages) which provides a basic overview for the newcomer and review for the experienced.

Wohl, J. G., Maintainability Prediction Revisited: Diagnostic Behavior, System Complexity, IEEE Trans on Systems, Man & Cybernetics, May 1982.

Using repair time for complex systems and equipment, it was hypothesized that repair time could be related to the way in which maintenance technicians interact with the equipment and the environment in the diagnostic process. A three parameter interactive model was developed and tested. Implications of the model for military standards, equipment design, circuit partitioning, and diagnostic testing are discussed.

Wohl, J. G., Information Automation & the Apollo Program: A retrospective, IEEE/SMC Transactions, Nov 1981.

Using the Apollo program as a case in point, the author illustrated some of the problems caused by the introduction of automation into complex human-machine systems. The examples demonstrate how the computer can be used to serve human needs for real-time information management, processing and display in ways which keep people very much "in-the-loop".

Woodson, W. E., Human Factors Design Handbook, McGraw-Hill Inc., New York NY, 1981.

An extensive and extremely thorough text providing information and guidelines for the design of systems, facilities, equipment and products for human use. Topics include: system conceptualization, subsystem design, component and product design, anthropometric data, and human engineering methods.

ORIGINAL PAGE IS
OF POOR QUALITY

Work.Wom.Ed., Warning:Health Hazards for Office Workers, Working Women Education Fund, Cleveland, OH, Apr 1981.

This report addresses health and safety issues in the office. It discusses job stress, video display terminals, air quality and ventilation, design problems, and the results of a survey on working women's office health and safety.

APPENDIX B
VITAE OF RESEARCH PERSONNEL

ORIGINAL PAGE IS
OF POOR QUALITY

CHRISTINE M. MITCHELL

Decision Sciences Faculty
George Mason University
4400 University Drive
Fairfax, Virginia 22030
(703) 323-2779

8510 Westover Court
Springfield, Virginia 22152
(703) 569-3675

EDUCATION

Ph.D., The Ohio State University, Industrial and Systems Engineering, 1980.
DISSERTATION: The Design of Computer Based Integrated Information Displays.

M.S., John Carroll University, Mathematics, 1975.
THESIS: Estimation of the Weibull Parameters by the Method of Maximum Likelihood.

B.A., University of Dayton, English and Mathematics, 1972.

RESEARCH INTERESTS

Modelling and Design of Human-Machine Interfaces
Design of Computer-Based Information Systems
Computer-Assisted Problem Solving
Discrete Event and Real Time Simulation

PUBLICATIONS

Mitchell, Christine M. and R.A. Miller, "Design Strategies for Computer-Based Information Displays in Real Time Systems," Journal of the Human Factors Society, submitted for publication.

Mitchell, Christine M. and R.A. Miller, "Formal Specification of the Relations Defining Model Validity," Proceedings of the 1982 International Conference in Cybernitics and Control, October ,1982.

Mitchell, Christine M. and Greenland, Arnold, "Simulation as a Tool to Assist in the Design and Analysis of Decentralized Control Systems," Proceedings of the 1982 International Conference on Cybernetics and Control, October ,1982.

Mitchell, Christine M., "Human Factors Dimensions in the Evolution of Increasingly Automated Control Rooms for Near-Earth Satellites," Proceedings of the 26th Annual Meeting of the Human Factors Society, October, 1982.

Greenland, Arnold and Christine M. Mitchell, "Simulation of Decentralized Control System," Proceedings of the 10th IMACS World Congress on System Simulation and Scientific Computation, August, 1982.

PRECEDING PAGE BLANK NOT FILMED

ORIGINAL PAGE IS
OF POOR QUALITY

Mitchell, Christine M., Paula M. Van Balen, and Karen L. Moe (Eds.), Proceedings of NASA-Goddard Symposium on Human Factors Considerations in System Design, NASA Conference Proceedings CP-2246, 1982.

Mitchell, Christine M., Alexander Bocast, and Lisa J. Stewart, "Guidelines on Ergonomic Aspects of Control Rooms and Highly Automated Environments," in Proceedings of NASA-Goddard Symposium on Human Factors Considerations in System Design, Mitchell, Christine M., Paula M. Van Balen, and Karen L. Moe (Eds.), NASA Conference Proceedings CP-2246, 1982.

Mitchell, Christine M., "Human as Supervisor in Automated Systems," in Proceedings of NASA-Goddard Symposium on Human Factors Considerations in System Design, Mitchell, Christine M., Paula M. Van Balen, and Karen L. Moe (Eds.), NASA Conference Proceedings CP-2246, 1982.

Mitchell, Christine M., Lisa J. Stewart, and Alexander Bocast, Human Factors Aspects of Control Room Design, NASA Technical Memorandum, 1982.

Mitchell, Christine M., "Human-Machine Interface Issues in the Design of Increasingly Automated NASA Central Rooms," Proceedings of the 1982 Annual Conference on Manual Control, 1982.

Mitchell, Christine M. and R.A. Miller, "A Conceptual Framework for Model Validity," Proceedings of the 1981 International Conference on Cybernetics and Society, October 1981.

Mitchell, Christine M., Human-Machine Interface Issues in the Multisatellite Operations Control Center (MSOCC), NASA Technical Memorandum, 1981.

Mitchell, Christine M. and R.A. Miller, "A Systems Oriented Approach to Information Display," Proceedings of the 1980 International Conference on Cybernetics and Society, October, 1980.

Miller, R.A., Christine M. Mitchell, Rajendra Nalavadi, Anant Misal and Chang Feng-Chang, Finite State Models of Manned Systems: Validation, Simplification and Extensions. U.S.A.F. Office of Scientific Research, Report No. AFOSR-79-0015), 1980.

PROFESSIONAL EXPERIENCE

DECISION SCIENCES FACULTY. September 1980 to present. George Mason University. Assistant Professor of Decision Sciences: Graduate and undergraduate teaching in the areas of information systems, operations research, and statistics.

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING. January, 1979 to August 1980. The Ohio State University.
Instructor: ISE 534, "Introduction to Operations Research and Industrial Engineering."

ORIGINAL PAGE IS
OF POOR QUALITY

NATIONAL REGULATORY RESEARCH INSTITUTE. May, 1978 to April, 1979. The Ohio State University.
Research Associate: Coordinated, modified and implemented RAm, a computerized financial analysis model used in the regulation of electric utilities; developed and offered a training program for RAm to the staff of state public utility commissions.

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING. September, 1977 to June, 1978. The Ohio State University.
Teaching Assistant: ISE 760, "Systems Theory;" ISE 435-436, "Introduction to Mathematical Statistics," ISE 750.01. "Introduction to Stochastic Processing."

INTERNAL AUDIT DEPARTMENT. July, 1975 to August, 1976. The Federal Reserve Bank of Cleveland. Auditor: Conducted on-site analyses of procedures and personnel to ensure proper control and efficiency; reviewed and critiqued all statistical proposals such as sampling procedures; technical liaison to various internal departments.

MATHEMATICS DEPARTMENT. September, 1973 to June, 1975. John Carroll University. Instructor: Taught "Introductory Calculus with Business Applications" (two course sequence); assisted in "Elementary Fortran" and "Introductory Statistics."

AWARDS AND HONORS

IEEE System, Man and Cybernetics Society Award for the Outstanding Paper Presented at the 1981 Outstanding Paper Presented at the 1981 International Conference on Cybernetics and Society, October ,1982.
NASA/ASEE Summer Faculty Fellowship, 1981.
Graduate Student Alumni Research Award, The Ohio State University, 1980.
University Fellowship, The Ohio State University, 1976.
Leonard A. Mann Award of The Outstanding Senior in the College of Arts and Sciences, University of Dayton, 1972.
B.A., Cum Laude, University of Dayton, 1972.

HONORARY AND PROFESSIONAL SOCIETIES

Alpha Pi Mu, The Industrial Engineering Honor Society
Pi Mu Epsilon, The Mathematics Honor Society
The Institute for Management Sciences (TIMS)
The Human Factors Society
American Society for Engineering Education (ASEE)
Association of Women in Science (AWIS)
Institute for Electrical and Electronic Engineers (IEEE)
Software Psychology

ORIGINAL PAGE IS
OF POOR QUALITY

LISA J. STEWART

George Mason University
Decision Sciences
4400 University Drive
Fairfax, Virginia 22030
(703) 323-3549

3327 Lauriston Place
Fairfax, Virginia 22031
(703) 698-9268

EDUCATION

M.A., George Mason University, Industrial/Organizational Psychology, 1982.
APPLIED THESIS: Human Factors Issues in the Design of Command and Control Systems.

B.A., William Smith College, Psychology, 1980.

RESEARCH INTERESTS

Human Factors in Command-and-Control Environments
Human Information Processing
Statistical Analysis
Management and Organizational Development

PUBLICATIONS

Stewart, Lisa J., Elizabeth D. Murphy, and Christine M. Mitchell, Human Factors Analysis of Workstation Design: Earth Radiation Budget Satellite Mission Operations Room, NASA Technical Memorandum, TM 84943, 1982.

Mitchell, Christine M., Lisa J. Stewart, Alexander K. Bocast, and Elizabeth D. Murphy, Human Factors Aspects of Control Room Design: Guidelines and Annotated Bibliography, NASA Technical Memorandum, TM 84942, 1982.

Stewart, Lisa J., "Conceptual Models of Information Processing," in Proceedings of NASA-Goddard Symposium on Human Factors Considerations in System Design, Mitchell, Christine M., Paula M. Van Balen, and Karen L. Moe (Eds.), NASA Conference Proceedings CP-2246, 1982.

Mitchell, Christine M., Alexander K. Bocast, and Lisa J. Stewart, "Guidelines on Ergonomic Aspects of Control Rooms and Highly Automated Environments," in Proceedings of NASA-Goddard Symposium on Human Factors Considerations in System Design, Mitchell, Christine M., Paula M. Van Balen, and Karen L. Moe (Eds.), NASA Conference Proceedings CP-2246, 1982.

PROFESSIONAL EXPERIENCE

DECISION SCIENCES. May 1982 to present. George Mason University. Research Consultant: Analysis of workstation design for the Earth Radiation Budget Satellite Mission Operations Room; researched, prepared, and presented two papers at NASA-Goddard/Symposium on Human Factors Considerations in System Design; developed and wrote research proposals; responsible for administrative co-ordination of NASA Project at George Mason University.

PRECEDING PAGE BLANK NOT FILMED

ORIGINAL PAGE IS
OF POOR QUALITY

DECISION SCIENCES. January 1982 to April 1982. George Mason University. Graduate Assistant/Research Associate: Coordinated and conducted an extensive literature review of human factors issues in the design of command and control systems and jointly authored the resultant annotated bibliography, held charter membership in NASA-Goddard Space Flight Center's Human Factors Group, coordinated design and development for a NASA-Goddard/George Mason University Symposium, "Human Factors Considerations in System Design."

FAIRFAX COUNTY PUELIC SCHOOLS: November 1980 to December 1981. Fairfax County High Schools.
Substitute teacher: Taught English and English as a Second Language. managed classroom activities and wrote reports on daily accomplishments, listed as preferred substitute by Falls Church High School.

RDA CONTAINER CORPORATION. June 1975 to August 1979.
Administrative assistant and production employee: Five summers of progressively responsible experience within an industrial setting.

AWARDS AND HONORS

Invited Membership, Outstanding Young Women of America.
Dean's List, William Smith College.
New York State Regents Scholarship, York Central School.

HONORARY AND PROFESSIONAL SOCIETIES

Psi Chi, The National Psychology Honor Society
Human Factors Society
Human Factors Society, The Potomac Chapter
Software Psychology Society, The Potomac Chapter

ORIGINAL PAGE IS
OF POOR QUALITY

Alexander K Bocast

office: (703) 323-2455
home : (703) 671-3478

Education

1979- Doctoral student: Public Administration and Public Policy, Virginia Polytechnic Institute and State University. Dissertation field: administrative policies for extraterrestrial development.

1978 M.S. Systems Management, University of Southern California. Specialization: Systems technology and federal systems acquisition management.

1974 B.S. Systems, University of California, Santa Barbara. Specialization: Simulation and modelling.

Professional Skills

policy analysis	systems analysis	human factors analysis
program & project management	modelling & simulation	writing & editing
MIS design & development	computing	forecasting

Computing Skills

scientific programming	language & translation	interactive graphics
interaction techniques	file management	development environments
documentation environments	human factors	interface design

Programming Languages

FORTRAN & RATFOR	Pascal	BASIC
IBM CMS EXEC	Z80 & Z80SCION (Assembler)	SCIGRAPH (Graphics)
DYNAMO (Simulation)	IBM TSO & JCL	

Machines

IBM 360 & 370 & 4341	SCION MicroAngelo & MightyAngelo (Graphics)	
TRS - 80 Model II	HP2000	CYBER 720 (NOS)

Professional Experience

1981- School of Business Administration, Decision Science Faculty, George Mason University, Fairfax VA. Instructor. Teach graduate and undergraduate courses in information systems and computing (BASIC, FORTRAN, Pascal). Currently working for NASA/Goddard Space Flight Center on project to prepare Human Factors Guidelines for GSFC Automated Control Rooms. Member of the GSFC Human Factors Research Group. Invented the Power Region Selection interaction technique.

1980-1981 Department of Computer Science, Graduate Program in Computer Science & Applications, Virginia Teach, Dulles VA. Instructor and Program Director. Management of the Computer Science graduate program for Virginia Tech in Northern Virginia. Taught graduate courses in data structures and programming systems., using Pascal.

1979-1980 Center for Public Administration and Policy, Virginia Tech, Dulles VA. Center Associate. Development of Center programs in research and executive development. Began continuing research in the modelling of recursive logistics systems.

1979- Design Services Group, Inc., Arlington VA. President. Information system and software consulting. Clients have included the U.S.Army, small businesses, and a graphics system manufacturer.

1976-1979 General Research Corporation, McLean VA. Senior Analyst. Project and task management. Primary support for ELIM-COMPLIP, the official Army manpower programming system. Resource allocation studies. Statistical and time-series modelling. Systems design and implementation.

Projection methodologies and systems. Cost and utility studies. Proposal and report writing. In-house instruction in programming systems.

1975-1976 Economic Policy Office, Anti-Trust Division, U.S.Department of Justice, Washington DC. Economic Research Analyst. Statistical research and development of data bases. Development of statistical evidence for anti-trust prosecutions.

1975 Delta Dental Manufacturing Co., Colorado Springs CO. Project Systems Analyst. Development of management planning tools to forecast resource requirements.

1974-1975 Goals for Global Society, Department of Philosophy, State University of New York, Geneseo NY. Faculty Research Associate. Research in world models for the Club of Rome, including Meadow's "Limits to Growth" model. Project administration.

1974 Community and Organizations Research Institute, Department of Economics, University of California, Santa Barbara CA. Research Assistant. Development of data in support of NIE study, "University Resources in the Production of Education: A Model of Individual Student Choice," Drs. McGuckin and Winkler.

1973-1974 Chancellor's Office, University of California, Santa Barbara CA. Assistant to the Executive Vice-Chancellor. Research and reviews in academic administration and in educational delivery systems.

1971-1972 Chancellor's Office, University of California, Santa Barbara CA. Student Intern. Assisted in development of specific proposal for implementation of the U.C. External University program.

1969-1970 Loyola Industries, Inc., Los Angeles CA. Design Engineer. Design and prototyping of physical packaging for power control equipment.

Memberships

Member, American Society for Public Administration
Member, Association for Computing Machinery
Member, Human Factors Society, Potomac Chapter

Civil Service Eligibility

GS-14 Program Analysis Officer

Security Clearances

Department of Defense (Secret) DISCO, 1977-1981.
Nuclear Regulatory Commission (L type) NRC 1977-1979.

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

PERSONAL BIBLIOGRAPHY

(With others) The Extended University - A Proposal for Implementation, University of California, Santa Barbara, 1972.

On the Modeling of Values and the World, invited paper, Ninth Conference on Value Inquiry, Geneseo NY, Spring 1975.

w/ Anthony J. Fedanzo, Jr., Goals for Global Society: A Third Generation Report to the Club of Rome, Technological Forecasting and Social Change, Summer 1975.

AUTO User's Manual for OLS Regressions, U.S. Department of Justice/CSC-Infonet Government Users' Library, 1976.

Development of Utility Functions for Life-Cycle-Cost Attrition Models, General Research Corporation, 1977.

w/ Jan Hillman, Expansion of the Naval Delayed Entry Program, General Research Corporation, 1977.

(With others) Development of Methods for Analysis of the Cost of Enlisted Attrition, General Research Corporation Report, 1977.

IRIS: Information Retrieval for the ELIM-COMPLIP System, General Research Corporation Report, 1977.

(With others) Analysis of Selected Military Compensation Issues, General Research Corporation Report, 1977.

(With others) Study of the Development of Qualification Requirements, Training Programs, Career Plan and Methodologies for Effective Management and Training of Inspection and Enforcement Personnel, Task V: Automated Personnel Data Base System Specifications, General Research Corporation Report, 1978.

Structured Programming Using FORTRAN Without the GOTO Statement, General Research Corporation, 1978.

(With others) Design and Development of ELIM-IV/COMPLEX-G3, General Research Corporation Report, 1978.

Projection Capabilities of the Qualitative Factor Development Module for ELIM-IV, Design Services Group, DSG-R7901, 1979.

Distributions of Accessions Among Characteristic Groups Within the ELIM-IV QFDM, Design Services Group, DSG-R7902, 1979.

Users and Operators Guide to the Qualitative Factor Development Module for ELIM-IV, Design Services Group, DSG-R7903, 1979.

Discretionary Authority: The Byck Case, United States Secret Service, Senior Agent Training Program, 1980.

Implementation of Exponential and e-fit Phasing Techniques, with Notes on Exponential Targetting of Smoothing Constants, Design Services Group, DSG-R8001, 1980.

NASA and the Elephant, Insight, National Space Institute, June/July 1980.

The MIS Bureaucracy and Decision Making in the Public Sector, paper presented, ASPA National Conference, April 1981.

Z80SCION: A Z80 Assembler for the Preparation of SCION Graphics Downloads, TM8201, Department of Computer Science, Virginia Tech, 1982.

SCIGRAPH: A High Level Implementation of SCION Graphics Primitives and Functions: User's Manual, TM8202, and Maintenance Manual, TM8203, Department of Computer Science, Virginia Tech, 1982.

AKBFORT: A Programmer's Library of FORTRAN & RATFOR Procedures, TM8204, Department of Computer Science, Virginia Tech, 1982.

Extensions to CMS for a Program Development and Documentation Environment, TM8205, Department of Computer Science, Virginia Tech, 1982.

Protocols for Interactive Dialogue under CMS FORTRAN: A Human Factors Approach, TM8206, Department of Computer Science, Virginia Tech, 1982.

w/ Christine Mitchell & Lisa Stewart, Guidelines on Ergonomic Aspects of Control Rooms and Highly Automated Environments, Proceedings: Human Factors Considerations in System Design, NASA/ GSFC Symposium, May 25-26, 1982.

Information Display and Interaction in Real-Time Environments, Proceedings: Human Factors Considerations in System Design, NASA/GSFC Symposium, May 25-26, 1982.

Information Management, in Handbook of Organization Management, William B Eddy, editor, Marcel Dekker: New York, forthcoming.

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

ELIZABETH D. MURPHY

George Mason University
Decision Sciences
4400 University Drive
Fairfax, Virginia 22030
(703) 323-2783

3267 Rose Glen Court
Falls Church, Virginia 22042
(703) 532-8580

EDUCATION

M. A., George Mason University, Industrial/Organizational Psychology, 1983.
M. A. T., Wesleyan University, English and Education, 1966.
A. B., Cornell University, English, 1964.

RESEARCH INTERESTS

Human Factors in Command-and-Control Environments
Computer-Assisted Technical Writing and Editing
Comparative Methods of Program Evaluation
Management Styles and Productivity

PUBLICATIONS

Mitchell, Christine M., Lisa J. Stewart, Alexander Bocast, and Elizabeth D. Murphy, Human Factors Aspects of Control Room Design: Guidelines and Annotated Bibliography, NASA Technical Memorandum, TM 84942, 1982.

Stewart, Lisa J., Elizabeth D. Murphy, and Christine M. Mitchell, Human Factors Analysis of Workstation Design: Earth Radiation Budget Satellite Mission Operations Room, NASA Technical Memorandum, TM 84943, 1982.

PROFESSIONAL EXPERIENCE

DECISION SCIENCES AND NASA/GODDARD HUMAN FACTORS GROUP. September 1982 to present. George Mason University. Graduate Assistant/Research Associate: Analysis of workstation design for the Earth Radiation Budget Satellite Mission Operations Room; development of a generic methodology for human factors analysis of real-time support applications; technical editing of guidelines on human factors issues in control room design.

OFFICE OF RESEARCH AND STATISTICS. June 1982 to August 1982. Fairfax County, Virginia. Research Analyst: Collection, analysis, and dissemination of demographic data; development and analysis of survey instruments; preparation of statistical tables and narrative commentary for the 1982 Standard Reports and the 1982 Fairfax County Profile; technical editing of county government productivity study.

WOODBURN CENTER FOR COMMUNITY MENTAL HEALTH. January 1979 to June 1981. Annandale, Virginia. Co-chair, Citizens Committee on Evaluation; Member, Governing Board: Planning and co-ordination of community needs assessment; development of research instruments; priority ranking of mental health services.

ORIGINAL PAGE IS
OF POOR QUALITY

FAIRFAX HIGH SCHOOL. September 1969 to June 1970. Fairfax, Virginia. Teacher of English: Freshman- and junior-level instruction in oral and written communication; training students in analysis of fiction and nonfiction; initiation of contractual writing projects.

NATIONAL CATHEDRAL SCHOOL. September 1967 to June 1969. Washington, D. C. Teacher of English: Instruction in writing and literature, ninth grade; school newspaper advisor; freshman class sponsor.

NEW CANAAN HIGH SCHOOL. September 1966 to June 1966. New Canaan, Connecticut. Teacher of English: Instruction of freshmen and sophomores in grammar, composition, and literature; development of creative writing projects.

AWARDS AND HONORS

Graduate Fellowship, Wesleyan University
Dean's List, Cornell University
New York State Regents Scholarship
National Merit Scholarship Corporation Letter of Commendation

HONORARY AND PROFESSIONAL SOCIETIES

Psi Chi, National Psychology Honor Society, George Mason University
Software Psychology

ORIGINAL PAGE IS
OF POOR QUALITY

INDEX

Page

Adjustability of the screen 74

Air quality 23

Alphanumeric keyboard 101

Ambience 28

Announcing systems 45

Anthrompometry,
  applications of 8
  capabilities and limitations 11
  definition 7
  relevance to GSFC 11
  scope 7
  tradeoffs 12

Appendices,
  annotated bibliography 259
  vitae of research personnel 319

Backspace capability 75

Chair, seating height, and back support 70

Character font 75

Character formation and display legibility attributes 74

Choosing subjects for mockup evaluations,
  basis for test subject evaluation 220
  number of evaluators 220

Chord interaction technique 105

Coding,
  Color 49
  Other coding techniques 49

Cold and performance 23

Command languages 124

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Command panel controls,
color coding 54
compatibility 51
labeling 55
location coding 55
selection and choice 51
size coding 54
shape coding 55

Command panel displays,
selection and choice 46

Command panel layout 56

Communication systems,
general requirements 44

Communications between and among team members 190

Communications between system and team,
control instruments 188
displays 188

Communications for teams separated spatially and temporally 194

Computer-generated messages 131

Conceptual issues in human engineered displays 141

Conceptual models of information processing,
definitions 142
design guidelines 154
summary 157

Console dimensions 41

Control room communications 11

Control room design 11

Control room operations 11

Cursor 75

Cursor control 76

Cursor control keys 100

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Design implications of the STM/LTM information processing model 149

Design issues for computer-based information displays 114

Design rules,
"average man" fallacy 15
fifth and ninety-fifth percentile specifications 15

Desk height 70

Display density 133

Display enhancement features 76

Display height 71

Document holders 70

Environmental design considerations for computer workstations 71

Environmental issues 21

Equipment design 41

Ergonomics of color attributes,
color perception 85
guidelines in the use of color 88
information contents 87
technical definition 79

Ergonomics of VDTs,
environmental and workstation design 67
health, safety hazards and complaints 62

Evaluation design 221

Experimenting with alternative panel layouts 219

Flicker 73

Footrests 70

Formatting alphanumeric data 136

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Formatting computer-based displays 134

Formatting graphical data 136

Formatting tabular data 135

Form-filling dialogue 122

Frequency arrangement 56

Function keyboard 105

Functional arrangement 56

Furniture and equipment,
  circulation 40
  communication access 40
  maneuvering space 40
  visual access 39

Future research 33, 58, 109, 137

Fuzzy set theory 227

Glare 26

Glare and reflection 71

Goals of environmental design 21

Graphic or pictorial arrangement 58

Graphical vs. nongraphical displays 135

Hardware 37

Heat and performance 22

Human as system supervisor,
  allocation of responsibilities 163
  interface for the human-computer dialogue 172
  summary and conclusions 177

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Human factors engineering methodologies,
Department of Defense 231
George Washington University 243
National Aeronautics and Space Administration 242
Nuclear Regulatory Commission 238

Human factors of computer systems,
hardware 61
software 113

Human vs. computer information processing 143

Human-machine system and environment 219

Humidity levels 23

Illumination,
recommended levels 24

Illuminiation or ambient light level 71

Image and screen attributes 73

Image polarity 74

Importance arrangement 58

Information processing models 223

Information properties of VDTs 132

Interaction techniques and tasks,
guidelines 92

Interactive dialogues,
design of 118
properties of 118
types of 122

Issues in multiperson control teams 180

Issues in multiperson supervisory teams 180

Joystick 99

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Key characteristics 77

Keyboard attributes,
general criteria 76

Keyboard layout 77

Management philosophy 195

Maneuvering space 28

Manual control models 224

Markov chains 227

Mathematical modelling techniques used in human factors analysis 222

Menu selection 123

Mockup techniques,
erector set mockups 218
hard mockups 216
miniature scale mockups and models 218
other mockups 217
paper mockup 215
soft 3-dimensional mockup 215

Mockup test facility 211

Mockups,
determining type and level of 217

Models of decision making 224

Mouse 99

Natural language dialogue 125

Newer modelling approaches 226

Noise,
effect on communication 26
effects on safety 26
recommended levels 26

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Normal environment 22

Onsite observation 210

Organizational support 21

Pattern recognition 227

Performance support 21

Personal space and privacy 33

Phosphor 74

Physical environment 22

Physical layout,
  accessibility 39
  coverage 39
  documents 40
  other personnel access 41
  peripheral concerns 40
  supervisor access and communications 41

Power region control keys 101

Pre-design considerations 37

Presence of others 32

Principles for effective designs 116

Production systems 227

Query languages 125

Question-and-answer dialogue 123

Queueing theory 226

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Resolution 75

Role definition 33

Screen memory and scrolling 76

Seated operations 42

Seating dimensions 43

Semantic/episodic long term memory model 148

Sensors 106

Sequential arrangement 56

Serial vs. parallel processing 154

Shiftwork,
design of 32
effects on health 31
effects on performance 31
physical effects 31
psycho-social effects 31

Short term memory/long term memory model 145

Sit-stand operations 43

Social psychological environment 30

Soft keys 105

Standardization versus efficiency 17

Standing operations 41

Strategies for information processing model 150

Symbol contrast 73

Symbol dimension 75

Tablet and stylus 99

ORIGINAL PAGE IS
OF POOR QUALITY

Page

Task analysis 203

Telephone systems 45

Temperature,
recommended levels 23

Tools for human factors design and evaluation 203

Touch panel 96

Trackball 99

User population 38

VDT software coding techniques,
alphanumeric coding 127
blink coding 130
color coding 127
highlighting 129
miscellaneous codes 130
shape coding 127

Ventilation 24

Vibration 28

Viewing distance 71

Visual properties,
miscellaneous considerations 77

Voice interaction 106

Working level 70

Workstation design 37

END

DATE

FILMED

MAY 5 1983

3 1176 00020 8620