Updating the 2016 FAA *Human Factors Design Standard* (HF-STD-001B): Automation, Workstation Design, and Information Management

July 29, 2021

DOT-VNTSC-FAA-22-02

Prepared for:
US Department of Transportation
Federal Aviation Administration
800 Independence Avenue, SW
Washington, D.C. 20591

U.S. Department of Transportation
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Notice

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE July 2021	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE Updating the 2016 FAA *Human Factors Design Standard* (HF-STD-001B): Automation, Workstation Design, and Information Management	5a. FUNDING NUMBERS FN03C120
6. AUTHOR(S) Kim Cardosi, Michael Zuschlag, Tracy Lennertz	5b. CONTRACT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Department of Transportation John A Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142-1093	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FAA-22-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Department of Transportation Federal Aviation Administration 800 Independence Avenue, SW Washington, D.C. 20591	10. SPONSORING/MONITORING AGENCY REPORT

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report reviews literature in the areas of automation, workstation design, and information management to identify topics to be added or updated in the Federal Aviation Administration's *Human Factors Design Standard* (HFDS; HF-STD-001B). The review for workstation design focused on large and curved displays and sit-stand workstations. For each topic area, the report includes 1) annotated bibliographies of each topic as they relate to air traffic control or airways facilities, and 2) research needs to progress guidance in these topic areas. The topic of automation was regarded as the most significant and time sensitive compared to the other topics, so a full draft of a revised chapter is provided. Some information in the automation chapter was removed for inclusion in other relevant documents, including material on alerts and alarms, training, maintenance, human-automation teaming, operational testing and evaluation, and process information.

14. SUBJECT TERMS Human Factors Design Standard, Air Traffic Control, automation, workstation design, information management	15. NUMBER OF PAGES 95
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Contents

Acronyms and Abbreviations

ACHI	Aviation human computer interface style guide
ADS-B	Automatic Dependent Surveillance – Broadcast
ANG-C1	FAA NextGen Human Factors Division
ANSI	American National Standards Institute
ATC	Air Traffic Control
ATOP	Advanced Technologies and Oceanic Procedures
ATWIT	Air Traffic Workload Input Technique
CPU	Central Processing Unit
DISA	Department of defense human computer interface style guide
DOA	Degree of Automation
DOT	US Department of Transportation
EEG	Electroencephalography
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
F(MRI)	Functional Magnetic Resonance Imaging
GUI	Graphic User Interface
HDR	High Dynamic Range
HFDS	*Human Factors Design Standard*
HFES	Human Factors and Ergonomics Society
HIDH	Human Integration Design Handbook
HMI	Human Machine Interface
Hz	Hertz
ISO	International Organization for Standardization
LED	Light-emitting diodes
mm	millimeter
ms	milliseconds
NASA	National Aeronautics and Space Administration
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NRC	National Research Council
NUREG	US Nuclear Regulatory Commission Regulation
OLEDs	Organic light-emitting diodes
OOTL	Out of the Loop
SA	Situation Awareness
SAVANT	Situation Awareness Verification and Analysis Tool
STARS	Standard Terminal Automation Replacement System
TBO	Trajectory Based Operations
TE	Task Environment
TLX	Task Load Index

TMA	Terminal Maneuvering Area (TMA)
URET	User Request Evaluation Tool
VAC	Vigilance and Attention Controller
VDT	Video Display Terminal

Preface

This report was prepared by the Transportation Human Factors Division of the Safety Management and Human Factors Technical Center at the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center. This work was sponsored by the Federal Aviation Administration's NextGen Human Factors Division, ANG-C1. Thank you to Vicki Ahlstrom, Dan Herschler, and Ben Willems for comments on an earlier draft.

For questions or comments, please contact Kim Cardosi, kim.cardosi@dot.gov.

Executive Summary

This work reviewed literature in the areas of automation, workstation design, and information management to identify topics that need to be added or updated in the relevant chapters of the Federal Aviation Administration *Human Factors Design Standard* (HFDS; HF-STD-001B). In the update of workstation design, focus was placed on 1) large and curved displays, and 2) sit-stand workstations.

The product of this work includes annotated bibliographies on each topic as they could be applied to air traffic control or airways facilities. Research that is needed to progress guidance in these areas relevant to air traffic control or airways facilities was also described. Since the topic of automation was deemed most important and time-critical, a draft of a revised chapter on automation was included.

Some material that was removed from the chapter on automation in the HFDS was set aside for inclusion in more relevant documents. This material fell into one of the following categories:

- Process information suitable for FAA HF-STD-004a – *Standard Practice Human Factors Engineering Requirements*,
- Operational Testing and Evaluation,
- Alerts and Alarms,
- Training,
- Maintenance, and
- Human-Automation Teaming.

1. Introduction

The purpose of this work was to conduct a review of the literature in the areas of automation, workstation design, and information management to identify topics that need to be added or updated in the relevant chapters of the FAA *Human Factors Design Standard* (HF-STD-001B). Early discussions with FAA indicated that the two areas that would be most useful to include in the update of the chapter on workstation design were 1) large and curved displays, and 2) sit-stand workstations.

The product of this work includes annotated bibliographies on each topic as they could be applied to air traffic control (ATC) or airways facilities. Since the topic of automation was deemed the most important and time-critical, this work includes a major revision of the chapter on automation, rather than the annotated bibliography of references.

In consultation with FAA, some material was removed from the chapter on automation in the HFDS in favor of inclusion in more relevant documents. This material fell into one of the following categories:

- Process information suitable for FAA HF-STD-004a – *Standard Practice Human Factors Engineering Requirements*,
- Operational Testing and Evaluation,
- Alerts and Alarms,
- Training,
- Maintenance, and
- Human-Automation Teaming.

For document traceability, each of the specific items in these categories, as well as the items that were deleted from the previous version of the automation chapter, are identified as such in a checklist.

This document consists of:

- A draft revised chapter on Automation in the format of the *Human Factors Design Standard* (HFDS),
- A checklist mapping items in HF-STD-001B that were deleted or reserved for other guidance material,
- Annotated bibliographies on automation, sit-stand workstations, large and curved displays, and information processing,
- Identification of guidance that would be useful to add to the HFDS in the areas of: automation, sit-stand workstations, large and curved displays, and information processing, and
- Description of further research that is needed to progress guidance in these areas relevant to air traffic control or airways facilities. The research recommendations for the topics of automation and information management were combined because of the significant overlap in content of research needs. These two complex areas are linked by the fact that many of the methods identified to assist a user in management of an abundance of information are, or can be, automated.

2. Draft Revised Automation Chapter 5

This section is proposed to replace the current Chapter 5 in the *Human Factors Design Standard* HF-STD-001B. It is formatted to conform with the current chapter and the rest of the document.

5. SPECIFIC DESIGN REQUIREMENTS

This section includes specific human factors requirements for designing or selecting systems and equipment.

5.1 Automation

The term "automation" covers a wide range of capabilities and functions. Examples include auto-correction of text, automated bank teller machines, automatic parking and automatic braking systems in cars. Within automated functions there is often a range of capabilities. For example, automated control of braking in cars ranges from anti-lock braking (which automatically pulsates the brakes to provide enhanced steering control) to collision-avoidance braking (which activates the brakes based on information from sensors and without driver input). These examples demonstrate the range of levels of autonomy collectively referred to as "automation," only some of which will be safety-critical.

The introduction of automation changes the user's role and method of operation. The expectation is that increased use of automation will reduce workload and increase efficiency. However, as was first pointed out by Bainbridge (1982), one of the 'ironies of automation' is that automation may actually increase workload. The requirements and guidance offered in this chapter will help to ensure that whatever the level of automation employed, the system is designed to support the user and is appropriate to the task, or range of tasks, in the environment in which it will be used. This will help to minimize the probability of human error and avoid unintended consequences of automation.

5.1.1 Function Allocation/Levels of Automation

Exhibit 5.1.1 shows the many possible levels of automation. At the highest level of automation, the system executes tasks. An example of a lower level of automation is a system that performs tasks when pre-specified conditions are met. An example of a still lower level of automation is a system that suggests a course of action to the user or otherwise facilitates a decision.

Exhibit 5.1.1 Levels of automation, from high to low. [Source: Sheridan & Verplank, 1978]

The system acts autonomously without human intervention.
The system informs the user after executing the action only if the system decides it is necessary.
The system informs the user after executing the action only upon user request.

The system executes an action and then informs the user.
The system allows the user a limited time to veto before executing an action.
The system executes an action upon user approval.
The system suggests one alternative.
The system narrows the selection down to a few.
The system offers a complete set of action alternatives.
The system offers no assistance.

5.1.2 General Design Guidelines

The guidance in this section applies to automated systems, automated functions, and decision support tools, regardless of the term used.

☐ **5.1.2.1 Automate with good reason.** Automated functions should be designed to support the user. [Source: Billings, 1997]

Discussion. With human-centered automation, the operator's role is based on the operator's responsibilities and capabilities, rather than as a by-product of how the automation is implemented. [Source: Parasuraman & Riley, 1997] Automation should never be added simply because the technology is available, but rather because it has a specific role in supporting the users and their tasks.

☐ **5.1.2.2 Automate to improve system performance**. Functions should be automated only if they improve system performance by supporting users' tasks. [Source: Billings, 1991]

☐ **5.1.2.3 Automate to make tasks easier to perform.** An automated task should be less difficult to perform than the manual task it replaces. [Source: AHCI, 1998]

☐ **5.1.2.4 Only automate functions performed well by machines.** Only functions that are performed well by machines should be automated, not functions that are performed better by humans. [Source: Drury, 1998]

☐ **5.1.2.5 Give tasks requiring flexibility to user.** Tasks that are performed in an unpredictable environment requiring flexibility and adaptability should be allocated to the user. [Source: AHCI, 1998]

☐ **5.1.2.6 Make roles and responsibilities clear.** The automated system should make it clear whether the user or computer is supposed to perform a particular task at a specific time. [Source: Parasuraman & Riley, 1997]

☐ **5.1.2.7 Ensure active user involvement in operation**. Users should be given an active role through relevant and meaningful tasks in the operation of a system. [Source: AHCI, 1998; Billings, 1991]

Discussion. Studies have shown that air traffic controllers who are put in a monitor role (as opposed to an active control role) have lower situation awareness – even though they might judge their own situation awareness to be the same in both conditions [Source: Willems & Truitt, 1999; see also Willems & Heiney, 2002]. Active involvement is essential for operators to exercise their responsibilities and be able to respond to emergencies. Reducing active involvement can be detrimental to the user's understanding of important information, and can lead to loss of situation awareness and longer response times in case of emergencies. In the long term, overreliance on automation can result in complacency as well as loss of relevant knowledge, and skill degradation.

□ **5.1.2.8 Ensure predictability.** Automated functions should be predictable. [Source: NUREG 0700, 2020]

Discussion. Predictability allows the user to know what to expect when the automation is functioning correctly and how it will affect the operation. This makes it easier for the user to recognize when the system is not functioning. [Source: Billings, 1996] Predictable automation is consistent with user cognitive strategies and expectations (mental model) as developed through training, use of procedures, and experience. [Source: NUREG 0700, 2020]

■ **5.1.2.9 Provide accurate and reliable information**. Automation shall provide accurate and reliable information. [Source: Andes, 1987]

□ **5.1.2.10 Avoid increasing demands for cognitive resources**. Automation should not increase the demands for cognitive resources (thinking or conscious mental processes) without a proportionate gain. [Source: Parasuraman & Riley, 1997; Wiener & Curry, 1980; Woods, 1996]

Discussion. Automation that is not user-centered can increase the demand for cognitive resources unnecessarily.

■ **5.1.2.11 Prevent interference with user tasks.** Automation shall assist the operator without interfering in those tasks that the operator is executing. [Source: Andes, 1985, as in Anoskey & Andes, 1992]

□ **5.1.2.12 Keep users aware of function.** Automated systems should keep the user aware on a continuing basis of the function (or malfunction) of each automated system and the results of that function (or malfunction). [Source: Billings, 1996]

□ **5.1.2.13 Provide brief and unambiguous command response.** Automated system responses to user commands should be brief and unambiguous. [Source: Billings, 1997]

■ **5.1.2.14 Provide immediate feedback.** To promote successful situation awareness of the automated system, the user shall be given immediate feedback to command and control orders. [Source: Morris & Zee, 1988]

Discussion. Studies using functional magnetic resonance imaging (fMRI) have shown that delays of 200 ms are perceived as 'immediate'. [Source: Kohrs, Angenstein, & Brechmann, 2016]. When a delay is expected between a command input and a response, an indication of the delay, or that the action is in progress, can serve as immediate feedback.

□ **5.1.2.15 Provide effective feedback.** Automation should provide the user with effective feedback on its actions and the purpose of these actions. [Source: Woods, 1996]

Discussion. Systems that provide poor feedback about their activities and intentions make interaction more difficult and error prone. [Source: Woods, 1996]

☐ **5.1.2.16 Provide clear explanations to user**. When the system provides explanations to the user, the explanation should use terms familiar to the user and maintain consistency with the immediate task. [Source: DISA, 1996]

☐ **5.1.2.17 Make automated tasks easily understood.** When uncommanded actions are performed by automation, the automated tasks should be easily understood by users. [Source: Billings, 1991]

Discussion. One way to make actions easily understood is to ensure that they are similar to user control actions.

☐ **5.1.2.18 Provide appropriate range of control options.** Automated systems should provide the user with an appropriate range of control options that are flexible enough to accommodate the full range of operating conditions for which it was certified. [Source: AHCI, 1998; Parasuraman & Riley, 1997; Sarter & Woods, 1995]

Discussion. Highly flexible automated systems can be useful when the user knows how to implement the various options across a wide spectrum of operational situations. However, the multiple options that are associated with highly flexible systems also require additional cognitive resources in order for the user to remember which mode is active. [Source: Woods, 1996]

☐ **5.1.2.19 Allow for different user styles.** Automated systems should be flexible enough to allow for different user styles and responses without imposing new tasks on users or affecting automation performance. [Source: Wiener & Curry, 1980; Woods, 1996]

☐ **5.1.2.20 Operator control of automated functions.** The automation should provide means for the operator to delegate, and to rescind prior delegation of, automated functions. [Source: Parasuraman & Riley, 1997]

☐ **5.1.2.21 Provide easy data access**. Automated systems should assist the user in finding necessary information quickly so that the user is not delayed by the automated function. [Source: Cardosi & Murphy, 1995]

☐ **5.1.2.22 Make automated functions observable.** Automated functions should be observability, so that the user can observe what the system is currently doing. [Source: Endsley, 2017]

Discussion. Observability is the degree to which the user can see what functions are being performed and the status of those functions. This will help to provide a basis for developing confidence in the new tools and for intervening competently when necessary. [Source: Murphy & Cardosi, 1995]

☐ **5.1.2.23 Provide automation transparency.** Automated systems should provide transparency, so that the user can understand what the system is doing, why it is doing it, and what it will do next. [Source: Endsley, 2017]

Discussion. Transparency is the degree to which the design makes it clear to the user what the automation is doing and why.

■ **5.1.2.24 Incorporate automatic self-checking components**. All essential electronic computer and peripheral components that are part of a system shall incorporate an automatic self-check diagnostic test of software and hardware, both at power up and at the request of the operator, to ensure they are functioning properly. [Source: Department of Defense [MIL-STD-1472G], 2012]

■ **5.1.2.25 Make available override and backup alternatives for critical functions**. Override and backup control alternatives shall be available for automation controls that are critical to the integrity of the system. [Source: Billings, 1996]

■ **5.1.2.26 Allow for override when operationally required**. Override and backup control alternatives shall be available for automation when the user needs to operate in out-of-tolerance conditions. [Source: Billings, 1996]

■ **5.1.2.27 Make backup information easy to get.** Information for backup or override capability shall be readily accessible. [Source: Billings, 1991]

Discussion. Information that is readily accessible can be located by the user without delay or difficulty.

5.1.3 Design for Effective Decision Aids

□ **5.1.3.1 Decision aids.** Decision aids should be used:

a. for managing system complexity;

b. for assisting users in coping with information overload;

c. for focusing the user's attention;

d. for assisting the user in accomplishing time-consuming activities more quickly;

e. when limited data results in uncertainty;

f. for overcoming human limitations that are associated with uncertainty, the emotional components of decision-making, finite-memory capacity, and systematic and cognitive biases; and

g. for assisting the user in retrieving, retaining, representing or manipulating large amounts of information, combining multiple cues or criteria, allocating resources, managing detailed information, performing computations, and selecting and deciding among alternatives. [Source: AHCI, 1998; DISA, 1996]

□ **5.1.3.2 When to avoid.** Decision aids should not be used:

a. when solutions are obvious;

b. when one alternative clearly dominates all other options;

c. when there is insufficient time to act upon a decision;

d. when the user is not authorized to make decisions; or

e. for cognitive tasks in which humans excel, including generalization and adapting to novel situations. [Source: AHCI, 1998]

☐ **5.1.3.3 Assist user decisions.** Decision aids should assist, rather than replace, human decision makers by providing data for making judgments rather than commands that the user must execute. [Source: AHCI, 1998; DISA, 1996; Parasuraman & Riley, 1997]

☐ **5.1.3.4 Let users determine decision aid use.** Users should be able to determine when and how the decision aid should be used. [Source: Parasuraman & Riley, 1997]

☐ **5.1.3.5 Use terms and criteria appropriate to users.** Decision aids should use terminology and criteria appropriate to the target user group. [Source: DISA, 1996]

☐ **5.1.3.6 Do not cancel ongoing user tasks.** Use of decision aids should not require ongoing user tasks to be cancelled. [Source: NUREG 0700, 2020]

☐ **5.1.3.7 Minimize query of user.** Decision aids should minimize query of the users for information. [Source: NUREG 0700, 2020]

☐ **5.1.3.8 Minimize data entry.** Decision aids should minimize user data entry requirements. [Source: DISA, 1996]

☐ **5.1.3.9 Be flexible in type and sequence of input accepted.** Decision aids should be flexible in the types and sequencing of user inputs accepted. [Source: NUREG 0700, 2020]

☐ **5.1.3.10 Accept user direction.** When alternative strategies are available, decision aids should accept direction from the users on which problem solving strategy to employ. [Source: NUREG 0700, 2020]

☐ **5.1.3.11 Reduce number of response options.** Decision aids should reduce the number of response options. [Source: Barnes, 1985]

Discussion. The number of options that the user must consider is expected to decrease when a decision aid is used. Reducing the response options focuses the user's attention onto the most viable options.

☐ **5.1.3.12 Alert user when unable to process.** Decision aids should alert the user when a problem or situation is beyond its capability. [Source: NUREG 0700, 2020]

☐ **5.1.3.13 Provide a recommendation if it is at least 70% reliable.** Decision aids should offer a recommendation as long as it is considered to be at least 70% reliable. [Source: Zingale & Woroch, 2019]

Discussion. Research indicates that alerts that report the likelihood of an event with at least 70-75% accuracy are more useful than no alerts at all and provide benefit, particularly when workload levels and task demands are high. [Source: Dixon & Wickens, 2006 as in Zingale & Woroch, 2019]

☐ **5.1.3.14 Estimate uncertainty**. Decision aids should estimate and indicate the certainty of analysis. [Source: NUREG 0700, 2020]

Discussion. To use the tool effectively and develop appropriate levels of trust in the system, users need information on when the tool is more and less reliable. [Source: Zingale & Woroch, 2019]

☐ **5.1.3.15 Provide a rationale**. Decision aids should provide a rationale for the recommendation (such as what information was used as the basis for the recommendation or if required information was not available). [Source: NUREG 0700, 2020]

Discussion. Without information on the rationale, users are likely to distrust the tool if/when they encounter situations in which the recommendations do not appear useful. [Source: Zingale & Woroch, 2019]. Users may prefer to have the rationale presented only upon request, as needed.

☐ **5.1.3.16 Prioritize alternatives.** When more than one alternative is available, the decision aid should provide the alternatives in a recommended prioritization scheme based on mission and task analysis. [Source: AHCI, 1998]

Discussion. Higher workload can decrease performance and increase reliance on the recommendations provided by decision support tools. For this reason, the recommendations provided under conditions of high workload need to be few and highly reliable. [Source: Woroch, Zingale, & Masalonis, 2017]

☐ **5.1.3.17 Make limitations of resolutions known**. Decision aids should make users aware of the information that the system uses and by what rules resolutions are selected and prioritized. [Source: Cardosi & Murphy, 1995]

Discussion. In many cases, the decision aid will not have access to all of the information (e.g., weather) that a user would consider in making a decision. If the user does not have a clear understanding of the information used by the system, the user may think the system is more competent than it is and mistakenly place too much trust in the system, or they may think the system is malfunctioning when it is not. If this information is not provided, then it is important to train the user on the limitations. [Source: Cardosi & Murphy, 1995] Knowledge of procedural information fosters user acceptance of the aid because the user is able to understand how the aid functions. [Source: Morris, Rouse & Ward, 1985]

☐ **5.1.3.18 Make derived or processed data accessible**. When information used by a decision aid is derived or processed, the data from which it is derived should be either visible or accessible for verification. [Source: Billings, 1996]

Discussion. Data that are not critical for operation can be made available only upon request.

☐ **5.1.3.19 Provide user controlled level of explanation detail.** When the system provides explanations to the user, it should supply a short explanation initially, with the ability to make available more detail at the user's request. [Source: DISA, 1996; NUREG 0700, 2020]

☐ **5.1.3.20 Present information with appropriate detail**. Decision aids should present information at the level of detail that is appropriate to the immediate task, with no more information than is essential. [Source: AHCI, 1998]

- ☐ **5.1.3.21 Avoid repeated information.** Decision aids should avoid repeating information that is already available. [Source: AHCI, 1998]

- ☐ **5.1.3.22 Integrate decision aids.** Decision aids should be fully integrated and consistent with the rest of the computer-human interface. [Source: NUREG 0700, 2020]

- ☐ **5.1.3.23 Alert to newly available information.** Decision aids should alert the user to changes in the status of important system information such as when critical information becomes available during decision aid utilization. [Source: NUREG 0700, 2020]

  Discussion. Critical information, in this context, refers to information that may have a significant impact on task completion.

- ☐ **5.1.3.24 Alert to meaningful events or patterns.** Decision aids should automatically notify the user of meaningful patterns or events such as when it predicts a future problem. [Source: AHCI, 1998]

- ☐ **5.1.3.25 Predict based on historical data.** Decision aids should be able to predict future data based on historical data and current conditions. [Source: AHCI, 1998]

- ☐ **5.1.3.26 Indicate level of confidence.** Decision aids that predict future data should provide an indication of statistical confidence. [Source: Sheridan, 2002]

- ☐ **5.1.3.27 Allow user to initiate automated functions.** The user should be able to invoke automated aids even if system-initiated automation is the norm. [Source: Billings, 1997]

5.1.4 Design to Minimize Human Error

- ☐ **5.1.4.1 Prompt for data entry format.** The automated system should prompt users as to the correct data entry format. [Source: Billings, 1996]

- ☐ **5.1.4.2 Design for error-resistance**. Automated functions should be designed to be error-resistant to help prevent data entry errors. [Source: Murphy & Cardosi, 1995]

- ☐ **5.1.4.3 Design for error-tolerance**. Automated functions should be designed to be error-tolerant so that data entry errors are easy to detect and correct. [Source: Murphy & Cardosi, 1995]

  Discussion. To make a system **error resistant** is to make it difficult for a user to make an error. Simplicity in design and the provision of clear information are tools to improve error resistance. **Error tolerance** is the ability to mitigate the effects of human errors that are committed. Error tolerance can be improved by adding monitoring capabilities to the automation. [Source: Billings, 1991]

- ■ **5.1.4.4 Provide interaction consistency**. The way that automation systems interact with their users shall be consistent within and between systems. [Source: NUREG 0700, 2020]

- ■ **5.1.4.5 Provide interface consistency.** Human interfaces in automation programs and systems shall be consistent within and between systems. [Source: NUREG 0700, 2020]

- ☐ **5.1.4.6 Make systems easy to understand and use.** Automated systems and associated integrated information displays should be intuitive, easy to understand, and easy to use. [Source: Billings, 1991; Sarter & Woods, 1994; Woods, 1996]

- ☐ **5.1.4.7 Make systems simple to learn.** Automation should be simple for the user to learn. [Source: Billings, 1991; Wiener & Curry, 1980]

- ☐ **5.1.4.8 Provide means to check input and setup data.** Automated systems should provide a way to check automation setup information. [Source: Wiener & Curry, 1980; Wickens, 2000]

  Discussion. Automation failures are often due to setup error. Although the automated system itself could check some of the setup, independent error-checking equipment or procedures may be needed. The user needs to be able to distinguish whether a failure occurred due to the automation setup or due to an inaccuracy in the input information. An automation failure could have been caused by a malfunction of an algorithm or by the input of inaccurate data. [Source: Wiener & Curry, 1980; Wickens, 2000]

- ☐ **5.1.4.9 Keep it simple.** Automation interfaces should represent the simplest design possible, while being consistent with the functions and tasks of the user. [Source: NUREG 0700, 2020]

  Discussion. Simplicity for the user is achieved by attaining compatibility between the design and human perceptual, physical, cognitive, and dynamic motor responsiveness capabilities. [Source: NUREG 0700, 2020]

- ☐ **5.1.4.10 Be consistent with user expectations.** Automated systems and interfaces should be consistent with the expectations and understandings of users. [Source: Billings, 1991, 1996]

- ☐ **5.1.4.11 Indicate if data are incomplete, missing, uncertain, or invalid.** The automated system should provide a means to indicate to the user that data are incomplete, missing, unreliable, or invalid, or that the system is relying on backup data. [Source: AHCI, 1998]

- ☐ **5.1.4.12 Provide usable output format.** Systems should provide information in the most usable format, eliminating the need for the user to translate information. [Sources: Cardosi & Murphy, 1995; Scerbo, 1996]

- ☐ **5.1.4.13 Show accurate status.** Information presented to the user should accurately reflect system and environment status in a manner so that the user can rapidly and easily recognize, understand, and project system outcomes in relation to system and user goals. [Source: Endsley & Kiris, 1995; NUREG 0700, 2020]

- ☐ **5.1.4.14 Situation displays.** Event data should be combined with a map background when the geographic location of changing events needs to be shown. [Source: ESD-TR-86-278, 1986]

- ■ **5.1.4.15 Present information consistent with task priorities.** Both the content of the information made available through automation and the ways in which it is presented shall be consistent with the task priorities. [Source: Billings, 1996]

  Discussion. Task priorities need to be identified in requirements documents.

- ☐ **5.1.4.16 Cueing important information.** When information must be updated quickly, the most important information should be cued to ensure it will be the first to be processed by the user. [Source: Wickens, 2000]

☐ **5.1.4.17 Queue messages automatically.** Incoming messages should be queued automatically by the system so they do not disrupt current information handling tasks. [Source: ESD-TR-86-278, 1986]

☐ **5.1.4.18 Store and prioritize lists of information.** Long lists of information and tasks should be stored and prioritized by the automated aid to minimize the number of decision alternatives, and to reduce the visual processing load of human operators. [Source: Barnes, 1981]

☐ **5.1.4.19 Integrate display elements only if performance is enhanced.** Display elements should only be automatically integrated if it will enhance status interpretation, decision-making, situation awareness, or other aspects of task performance. [Source: Billings, 1991]

☐ **5.1.4.20 Integrated displays.** Integrated displays should combine various information automated system elements into a single representation. [Source: Billings, 1996; Parasuraman et al., 2000]

☐ **5.1.4.21 Automatically arrange information depending on status.** System information should be automatically reorganized into integrated or non-integrated arrangements depending on the current system status. [Source: Forester, 1987; Parasuraman & Mouloua, 1996]

Discussion. Integrated information arrangement allows the user to assess the overall status of the system. Integrating display components into aggregated arrangements may reduce the attention demands of fault detection. Non-integrated arrangement of components draws user attention to system errors or other relevant information. Presenting the information in a format relevant to the state of the system can facilitate the ability of the user to quickly and easily assess the system status. [Source: Forester, 1987; Parasuraman & Mouloua, 1996]

■ **5.1.4.22 Make location obvious.** Aids for menu and display navigation shall inform the user of their location in the system. [Source: NUREG 0700, 2020]

5.1.5 Design to Prevent Mode Confusion

☐ **5.1.5.1 Clearly identify current modes and functions.** When multiple modes of operation exist, the automation should indicate the current mode using highly salient design features. [Source: NUREG 0700, 2020]

Discussion. Conspicuous indication of the current mode will help prevent operators from making mode errors. Mode errors are inappropriate action or failure to take appropriate action caused by thinking the system is in one mode when it is in another mode. The term “mode awareness” is used to indicate that the user is informed of the system’s operating mode, intent, function, and output.

■ **5.1.5.2 Changes in mode should be clearly indicated.** When control, display, or automation functions change in different modes of operation, the system shall provide the user a clear indication of the change and current mode, function identification, and status. [Source: MIL-STD 1472G]

Discussion. Lack of effective feedback on the state of automation (including which mode is active) can lead to mode errors. [Source: Sarter & Woods, 1995]

☐ **5.1.5.3 Make frequently used modes easy to access**. Frequently used modes should be more accessible than infrequently used modes. [Source: AHCI, 1998]

Discussion. Multiple modes can provide a means of flexibility but can also introduce more opportunities for error. Furthermore, automation that has multiple modes of operation can be difficult to learn and can produce increases in workload. Users must understand and remember how and when to use each mode, and they must remember which mode is currently active. [Source: Scerbo, 1996; Woods, 1996]

☐ **5.1.5.4 Allow switching between modes.** The user should be able to easily switch between modes. [Source: AHCI, 1998]

☐ **5.1.5.5 Provide consistent features and functions.** Features and functions that are common between display modes should be consistent. [Source: AHCI, 1998]

☐ **5.1.5.6 Alert user to potentially hazardous interactions.** The automated system should alert the user to the implications of interactions between modes, especially when they are potentially hazardous. [Source: Billings, 1996]

☐ **5.1.5.7 Prevent the selection of unsafe modes.** The automated system should prevent the use of potentially unsafe modes. [Source: Billings, 1996]

☐ **5.1.5.8 Alert user of unsafe modes.** An automated system should inform the user if potentially unsafe modes are manually selected. [Source: Sheridan, 2002]

■ **5.1.5.9 Notify user of selection override.** If an unsafe mode is selected by the user and the system overrides the selection, the system shall inform the user that the command has been rejected. [Source: Sheridan, 2002]

☐ **5.1.5.10 Notify user of mode changes.** When a mode is changed, the system should provide information about how a new mode changes the automation's functioning, the impact on operations, and the user's responsibilities. [Source: NUREG 0700, 2020]

Discussion. Providing information on the implications of mode changes will help prevent operators from making mode-related errors.

☐ **5.1.5.11 Require operator verification for significant mode changes**. When the mode change has potentially significant operational consequences, the system should require operator verification. [Source: NUREG 0700, 2020]

5.1.6 Design to Support Monitoring Functions

■ **5.1.6.1 Allow users to monitor automated systems.** The system shall be designed so that users are able to monitor the automated systems and the functionality of its hardware and software, including the display of status and trend information, as needed. [Source: Billings, 1991]

Discussion. When appropriate, allow the user to monitor the system as required by the task. [Source: Sheridan, 1992]

☐ **5.1.6.2 Integrate displays.** When users must monitor multiple displays, important events should occur in the same display in order to promote effective monitoring performance. [Source: Warm et al., 1996]

◻ **5.1.6.3 Minimize spatial uncertainty.** Important events should occur in the same location on a display in order to promote effective monitoring performance. [Source: Warm et al., 1996]

Discussion. Users will be able to detect a particular event more easily if they know where that event will occur (i.e., spatial certainty). Spatial uncertainty has been shown to increase perceived workload and decrease performance efficiency. If users do not know where on a display an event will occur, then they must engage in visual scanning to look for the event. [Source: Warm et al., 1996]

◻ **5.1.6.4 Provide indication of monitoring.** Automated systems that are without incident for long periods of time should provide some type of indication that the automation is still monitoring the system. [Source: AHCI, 1998]

◻ **5.1.6.5 Warn of user errors.** Automated systems should be able to monitor user interactions and to warn of user errors. [Source: Billings, 1991]

◻ **5.1.6.6 Monitor critical functions.** Automation should allow the user to monitor critical functions independently. [Source: Billings, 1996]

Definition. A **critical function** is a function that can cause system failure when a malfunction is not attended to immediately.

Discussion. When a function is critical, combining the monitoring of that critical function with other, possibly less critical functions may lead to delays in response. When a critical function is independently monitored, a user can respond to a malfunction very quickly (within one second). If a user is attending to another task when there is a malfunction, there will be a delay in the user’s response (several seconds). In this period of delayed response, the malfunction can cause the system to fail. For this reason, critical functions require constant attention. Critical automation functions do assist in the completion of critical tasks; however, they do not assist in freeing the user to attend to other tasks. [Source: Parasuraman & Mouloua, 1996]

5.1.7 Design for Graceful Degradation and Failure

■ **5.1.7.1 Inform the user of degradation or failure of the automated system.** An automated system shall inform the user of automation failure or degradation. [Source: Edwards & Lee, 2017]

Discussion. Early warning notification of pending automation failure or performance decrements gives the user time to adjust. [Source: Morrison, Gluckman, & Deaton, 1990]

◻ **5.1.7.2 Graceful Degradation.** Automated systems should degrade gracefully. [Source: Edwards & Lee, 2017]

Discussion. Graceful degradation requires not only that the user is informed of the degradation or failure of the automated system, but also that: the cause of the degradation is identified to the user, the impacts on the system are prevented, and the nominal operations are recovered. [Source: Edwards & Lee, 2017]

The following are techniques utilized to prevent degradation and ensure graceful degradation:

a. Use of Backup Systems: Additional components or systems that provide replacement at potentially lower levels of performance after failure of the primary system(s) that provide the function; e.g., radar as a backup to Automatic Dependent Surveillance - Broadcast (ADS-B).

b. Isolation: Physical, electrical, data/informational, and/or segregation of systems, components, and elements so the failure of one does not cause the failure of another.

c. Proven Reliability Levels: Specification of performance levels for systems, components, and elements so that coincidentally occurring, independent failures is unforeseeable. This is to ensure continued functionality of dependent components and continuous availability of the system to respond to failures.

d. Verification & Validation: Independent procedures used together for checking that a product, service, or system meets requirements and specifications, and that it safely fulfills its intended purpose.

e. Failure Warning or Indication: Features that provide detection and enunciation of system abnormalities. This includes internal monitoring: the functions added to a system or component for error checking, status and performance monitoring, and other means for self-checking its condition and outputs.

f. Procedures: Requirements for automation and human intervention specifying corrective action for use after failure (including exceedance of limits).

g. Training: The acquisition of knowledge, skills, and competencies in order to improve an individual's or a team's capability, capacity, and performance to a minimum standard.

h. External Monitor: An independent system or component (but not a human procedure) that provides error checking, status and performance monitoring, and other means for monitoring a system or component's condition and outputs; e.g. health monitoring or fast-time predictive analysis.

i. Design features and characteristics that limit the safety impact or effects of a failure, including the capability to sustain damage,

j. Design attributes that control and direct the effects of a failure in a prescribed way that limit its safety impact.

k. Design features to be error tolerant and mitigate the adverse effects of errors foreseen during the system's design, test, manufacture, operation, and maintenance.

[Source: Adapted from Bertish, Darr, Hemm, Swenor, Dickerson, Tejeda, & Gawdiak, 2013]

- **5.1.7.3 Make sensor status verifiable.** The status of sensors shall be verifiable with respect to accuracy and proper operation. [Source: NASA-STD-3000A, 1989]

- **5.1.7.4 Permit status verification without disassembly.** Equipment shall permit verification of operational status prior to installation without the need for disassembly. [Source: NASA-STD-

3000A, 1989]

- **5.1.7.5 Permit fault detection without disassembly.** Equipment shall permit fault detection and isolation without removing components, through the use of built-in tests, integrated diagnostics, or standard test equipment. [Source: Department of Defense [MIL-STD-1800A], 1990; NASA-STD-3000A, 1989]

- **5.1.7.6 Facilitate rapid fault detection.** Equipment design shall facilitate fault detection and isolation of defective items to permit their prompt removal and replacement. [Source: MIL-STD-1472G, 2012; NASA-STD-3000A, 1989]

  Discussion: The FAA Target NAS Requirements Document (2018) specifies the Reliability, Maintainability, and Availability requirements to maintain consistency of NAS services. This includes time limits for restoration of services that depend on the service availability criticality. Equipment designed to promote rapid fault detection will contribute to a reduction in the time needed to restore services.

- **5.1.7.7 Identify failures without ambiguity.** Fault detection and isolation shall identify which component has failed. [Source: MIL-STD- 1800A, 1990; NASA-STD-3000A, 1989]

2.1 Material removed from the Automation Section (5.1)

In consultation with FAA, much of the material was removed from the previous version of the chapter on automation in the HFDS (Section 5.1) in favor of putting it in a more relevant document (such as FAA HF-STD-004a) or into material that may be developed in the future, such as guidance on Human-Automation Teaming.

2.1.1 Future revision of FAA HF-STD-004a

The following material was removed from the Automation Chapter and should be considered in a future revision of FAA HF-STD-004a:

- **5.1.1.6 Provide a clear relationship with user tasks**. The relationships between display, control, decision aid, and information structure and user tasks and functions should be clear to the user. [Source: NUREG 0700, 2002; NUREG/CR-6105, 1994]

- **5.1.1.9 Implement based on goals for system.** How automation is implemented should be determined by the explicit goals of the system, not by comparison between automated and manual systems. [Source: Wiener & Curry, 1980]

  Discussion. Function allocation and automation decisions that are inherent to a previously deployed system, subsystem, or equipment selected for the system being acquired shall be analyzed to ensure that they are consistent with function allocation decisions for the rest of the system. Allocation of functions shall consider the risks of incorrectly allocating a function to software and associated user interfaces, hardware, or human operator. Designs shall provide adequate decision support to minimize situations where human decisions are made under conditions of uncertainty, time stress, or workload stress. [Source: MIL-STD-46855A 10]

- **5.1.7.5 Limit monitoring time**. Designs should not assume that users will be required to perform purely monitoring tasks for longer than 20 minutes at a time. [Source: Parasuraman & Mouloua, 1996; Warm et al., 1996]

  Discussion. Controller situation awareness (e.g. for traffic situations) is lower under monitoring conditions than under conditions of active control, even when their perception is that there is no difference between active control and passive monitoring. [Source: Willems and Truit, 1999]. Users may become complacent in monitoring automated systems if they have other tasks to complete simultaneously. Such decrements in user monitoring of automated systems have been observed to occur in the laboratory in as little as 20 minutes. [Source: Parasuraman & Mouloua, 1996; Warm et al., 1996]

- **5.1.7.12 Provide intermittent manual control.** Intermittent periods of manual control should be used during extended periods of task automation to improve monitoring of the automation. [Source: Morrison, Cohen, & Gluckman, 1993; Parasuraman & Mouloua, 1996]

  Discussion. Complacency is a major concern with automation. Intermittent periods of manual control have been advocated as a means of minimizing complacency. Automation may also result in the decrement of cognitive abilities such as instrument scan and navigation/positional [situation] awareness and the loss of manual skills, making transitions from automated to conventional systems difficult. Because automation can decrease basic manual skills, these skills should be used and maintained. Intermittent periods of manual control during which automation is suspended periodically can promote optimal user performance, and allow better recovery from failure, regardless of the type of task that is automated. [Source: Endsley & Kiris, 1995; Morrison et al., 1993; Rudisill, 1994; Scerbo, 1996]

- ☐ **5.1.7.15 Consider potential vigilance decrements.** The effects on vigilance due to the use of automation should be considered before introducing new automation. [Source: Warm et al., 1996]

  Discussion. A **vigilance decrement**, that is, a continuously decreasing ability to maintain attention over time while monitoring, may occur with the use of automation.

- ☐ **5.1.11.1 Evaluate function allocation alternatives.** Alternative function allocations including fully manual, partially automated, fully automated, and adaptive allocation should be evaluated for feasibility and effectiveness. [Source: Wiener & Curry, 1980]

- ☐ **5.1.11.2 Evaluate through simulation.** Alternative schemes for the allocation of functions should be examined in the context of the whole system through the use of high fidelity simulations. [Source: Wiener & Curry, 1980]

- ☐ **5.1.2.1 Involve users in design.** Users should be involved in the design of an automated tool. [Source: Billings, 1997; Parasuraman, Sheridan, & Wickens, 2000]

- ☐ **5.1.2.2 Design based on human-centered goals and functions.** Design of automation should begin by choosing the human-centered criteria (goals) of the system and then defining the functions that the system will perform. [Source: Wiener & Curry, 1980]

2.1.2 Operational Testing and Evaluation

The following material was removed from the Automation Chapter and should be considered in future guidance on Operational Testing and Evaluation:

- ■ **5.1.2.4 Assess overall impact.** The overall impact of automation shall be thoroughly examined before implementation to ensure that changes do not result in additional complexities, loss of situational awareness, or possibilities for error. [Source: Woods, 1996]

- ☐ **5.1.2.5 Validate system design.** Contextually valid human-in-the-loop experiments and simulations should be conducted to validate and refine automated system design. [Source: NRC, 1998]

  Discussion. Use of fast-time simulation is often helpful in identifying unexpected effects of alternative operator actions [Source: Sheridan, 1992].

- ■ **5.1.2.6 Evaluate interactions with other functions.** Possible interactions with other tools, system functions, and user tasks shall be evaluated when new automation is designed and tested. [Source: NRC, 1998]

- ■ **5.1.2.7 Test as a whole.** New automation components shall be tested with the complete system, including other automated components of the system, to ensure they function together as an effective whole. [Source: NRC, 1998]

- **5.1.2.8 Test normal and failure modes.** Automated systems shall be tested under normal modes of operation and under failure modes of the automation. [Source: NRC, 1998; Wickens, 2000]
- **5.1.2.9. Test before implementation**. Automated systems shall be tested in a realistic operational environment with representative users before implementation to ensure that operator performance is not compromised and workload is not increased. [Source: Cardosi & Murphy, 1995]" Decision support tools shall be tested according to the testing protocols described in Section 5.1.2.5 B before implementation. This assessment should examine the users response to the system with the expected reliability (accuracy and false alarm rate).

2.1.3 Alerts and Alarms

The following material was chosen to be moved from the Automation Chapter and considered for future guidance on Alerts and Alarms:

- **5.1.9.1 False alarm rates**. False alarm rates should not be so frequent as to cause the user to mistrust the automated system. [Source: NUREG/CR-6105, 1994; Wiener & Curry, 1980]

  Discussion. While a low false alarm rate is necessary for acceptance of warning systems by human operators, a very stringent criterion may not provide sufficient advance warning. The decision threshold of an automated warning system should be based on the cost of a missed signal versus that of a false alarm. [Source: Parasuraman & Riley, 1997]

- **5.1.9.2 Inform users of the probability of a true alarm**. Users should be informed of the inevitable occurrence of automation false alarms, particularly when base rates are low. [Source: NRC, 1998]
- **5.1.10.12 Train to identify normal output**. Users should be trained on what constitutes the normal automation output so that the user can easily determine whether the system is functioning properly. [Source: Morris et al., 1985]

2.1.4 Training

The following material was chosen to be moved from the Automation Chapter and considered for future guidance on Training:

- **5.1.10.1 Introducing new automation.** New automation should be introduced with advanced briefing and subsequent training procedures. [Source: Billings, 1997; NRC, 1998; Parasuraman & Riley, 1997]
- **5.1.10.2 Prepare users for changes.** Before automation is introduced, users should be informed of associated changes and increases in the work effort, as well as the benefits associated with the automation. [Source: DISA, 1996; Scerbo, 1996]

  Discussion. The roles and responsibilities of the users, cognitive demands, and operational procedures may change as a result of introducing automation.

- ☐ **5.1.10.3 Train users to understand automated functions**. Initial training in the use of automation should be sufficient for the users to fully understand how the automation functions within the particular system, as well as how to use the automation. [Source: Billings, 1997]

- ☐ **5.1.10.4 Train users to backup automation**. Users should be provided with backup training in performing any tasks replaced by automation or in operating any backup systems replaced by automation. [Source: DISA, 1996]

- ☐ **5.1.10.5 Train to recognize inappropriate use of automation**. Users should be trained to recognize inappropriate uses of an automated tool including automation bias (the use of automation in a heuristic manner as opposed to actively seeking and processing information). [Source: DISA, 1996; Dzindolet, Pierce, Beck, & Dawe, 1999; Mosier & Skitka, 1999]

- ☐ **5.1.10.6 Train users when to question automation**. Users should be trained to recognize and understand the conditions under which automation may be unreliable, and to learn the conditions where it performs well (when or when not to question the automation). [Source: Cohen et al., 1998; Dzindolet et al., 1999]

- ☐ **5.1.10.7 Avoid over-reliance on automation.** Users should be trained not to become overly reliant on automation. [Source: Mosier, Skitka, Heers, & Burdick, 1997; Parasuraman & Riley, 1997]

- ☐ **5.1.10.8 Train for risk assessment and reduction.** Users should be trained on risk assessment and actions needed for risk reduction. [Source: Mosier & Skitka, 1999]

- ■ **5.1.10.9 Train for failure recovery transitions.** Users shall be trained on transitioning from automated to conventional systems. [Source: Rudisill, 1994]

  Discussion. If automation were to fail, users need to be skilled at both recognizing the failure and taking manual control.

- ☐ **5.1.5.2 Provide training for users to develop trust in automation reliability**. Training should be provided to enable the user to calibrate their trust in the automated system. [Source: Cohen, Parasuraman, & Freeman, 1998]

  Discussion. Training can allow the user to develop an adequate model of how reliable or unreliable the automation is under specific conditions.

- ☐ **5.1.10.12 Train to identify normal output.** Users should be trained on what constitutes the normal automation output so that the user can easily determine whether the system is functioning properly. [Source: Morris et al., 1985]

- ☐ **5.1.13.4 Adapt to skill of the user.** Adaptive automation should be used to increase the performance of users with different skill levels. [Source: Norico & Stanley, 1989]

  Discussion. By adapting to the skill of the user, adaptive automation can increase the proficiency of the novice user and prevent frustration that might otherwise occur with complex systems.

- ☐ **5.1.13.5 Make adaptive automation at least as skilled as user**. Adaptive automation should be at least as skilled as the user, if not greater, to promote optimal user performance. [Source: Woods, 1996]

- **5.1.13.6 Modeling of human behavior**. Modeling of human behavior for aid- initiated intervention should at least include: task execution goal states, environment representation (graphical), situation assessment information and planning, and commitment logic. [Source: Andes & Hunt, 1989]

- **5.1.13.7 Interface adaptation.** When dynamic adaptation of the interface is used, it should be attained by utilizing information provided to the system through user interactions within a specific context. If an interface is designed to be adaptive, it must satisfy the needs of the user and the system in performing the specific task. [Source: Norcioico & Stanley, 1989]

- **5.1.13.8 Menu adaptation.** When dynamic adaptation of menus is used, the resultant menus should offer only the options that are relevant to the current environment. [Source: Barnes, 1985]

  Discussion. Dynamic adaptation of the menus occurs when menus are altered to reflect the needs of the current environment. This approach may reduce user workload. [Source: Barnes, 1985]

- **5.1.13.9 Use direct manipulation interfaces.** Direct manipulation interfaces should be used to minimize the impact of a transition to manual control. [Source: Morrison et al., 1993]

  Discussion. An example of direct manipulation is a graphical user interface (GUI). In direct manipulation, the user controls the interaction with the computer by acting directly on objects on the display screen. An object may be an icon, menu option, symbol, button, or dialog box. [Source: Shneiderman, 1998]

2.1.5 Maintenance

The following material was removed from the Automation Chapter and should be considered in a future guidance on Maintenance:

- **5.1.8.13 Provide portable diagnostic tools.** When built-in test equipment is not available, diagnostic tools or portable equipment shall be provided to aid in fault isolation. [Source: NASA-STD-3000A, 1989]

- **5.1.8.14 Identify first alarm event.** Automated warning systems should provide a means for identifying the first event in a series of alarm events. [Source: NUREG 0700, 2002]

  Discussion. When a series of interrelated alarms occur, information identifying which component first exceeded the set threshold can be valuable in determining the initiating cause of a problem. [Source: NUREG 0700, 2002]

- **5.1.8.15 Provide sufficient diagnostic information.** The user should be provided with sufficient information and controls to diagnose automated warning system operation. [Source: Wiener & Curry, 1980]

Discussion. In order for the user to diagnose the automated system, diagnostics information needs to be self-explanatory and in plain English. The diagnostic information must provide the user with the information they need without requiring the user to seek additional references, or a help function, to understand the problem and the recommended solution.

2.1.6 Human-Automation Teaming

The following material was removed from consideration in the Automation Chapter in favor of guidance being developed on Human-Automation Teaming:

- **5.1.14.30 Provide knowledge of intent**. Each element in a human- machine system shall have knowledge of the intent of the other elements. [Source: Billings, 1996; NRC, 1998; Parasuraman et al., 2000]

  Discussion. Monitoring of the system by the user and the user by the system can only be effective if each knows what the other one is trying to accomplish. [Source: Billings, 1996]

- **5.1.12.2 Provide automatic update**. When the displayed data are changed as a result of external events, the user should be provided with the option of having an automatic update of changed information. [Source: AHCI, 1998]

- **5.1.2.3 Consider effect on coordination.** When new automation is introduced, the designers shall consider the possibility of negative effects on team coordination. [Source: Wiener, 1989]

  Discussion. Automation may reduce team interaction and cooperation unless all parties are provided with information that allows them to be actively involved in the task. Automation can cause physical difficulty in seeing what the other team member is doing, reduce the ability to cross monitor, change traditional roles and responsibilities, and change the manner in which team members attempt to help one another. [Source: Danaher, 1980; Rudisill, 1994]

User needs to be aware of any changes that the automation has made.

2.1.6.1 Adaptive Automation

Definition. Adaptive automation is the real time allocation of tasks to the user or automated system in a flexible manner, changing the automation to meet current situational demands. Adaptive automation may benefit user performance by allowing the user to remain in active control of the system instead of becoming a passive observer. Successful adaptive automation will require the proper amount of automation at the proper times [Source: Scerbo, 1996]. Active control may prevent performance decrements associated with long-term monitoring, loss of situation awareness and manual skill degradation. [Source: Morrison et al., 1990; NRC, 1998; Scerbo, 1996; Scerbo & Mouloua, 1999]

Discussion. Laboratory experiments have shown that short periods of automation use (for example, 10-minute cycles of manual and automated control) do not result in performance decrements. This suggests that intermittent periods of manual control may help to maintain performance in the presence of automation. [Source: Parasuraman & Mouloua, 1996]

- **5.1.13.1 Help during high workload.** Automation should be designed to adapt by providing the most help during times of highest user workload, and somewhat less help during times of lowest workload. [Source: Billings, 1996]

- **5.1.13.2 When not to implement adaptive automation.** Adaptive automation should not be implemented unexpectedly or at a time when the user may not desire the aiding. [Source: Scerbo, 1996]

  Discussion. The timing of adaptation may have critical impact on user acceptance of automation. Studies show that users prefer to be in control of the system. However, there are times that automation may need to be initiated by the system, particularly when changes in workload occur rapidly or are unexpected by the user. [Source: Parasuraman & Mouloua, 1996]

- **5.1.13.3 When to implement adaptive automation.** Adaptive automation should be implemented at the point at which the user ignores a critical amount of information. [Source: Sen, 1984]

  Discussion. Fatigue (or other factors) may prevent users from recognizing the best time to utilize automation and performance decrements may consequently occur. One indication that the user is being overloaded is an increase in the amount of information he must ignore in order to make a timely decision. Thus, the designer can use a threshold critical amount of ignored information as an indicator that the user is overloaded and implement adaptive automation at that point (to help reduce workload). What constitutes a critical amount of information can vary depending on the particular task and may best be determined on a system-by- system basis. [Source: Parasuraman & Mouloua, 1996]

- **5.1.14.31 Adapt with situational demands.** When adaptive decision aiding is used, the level of decision aiding should change with the situational demands in order to optimize performance. [Source: Rouse, 1988]

  Discussion. The criticality of a given task can change dramatically depending on the current situation.

- **5.1.14.32 Adaptive decision aiding implementation**. Adaptive decision aiding should be applied when resource loading, performance, error frequency, and deviations from intent exceed threshold levels. [Source: Andes, 1987]

  Discussion. Resource loading, performance, errors, and deviations from intent can be used as indicators to determine when the user might need the help of the automated decision aid. The threshold levels of these indicators, specifying the optimal time to implement decision aiding may need to be determined on a system-by-system basis, possibly through simulation.

- **5.1.14.33 Provide planning assistance.** Adaptive decision aiding interfaces should allow the user to receive direct assistance in planning how to carry out the intended task. [Source: Tyler & Treu, 1989]

2.1.6.2 New material proposed for addition to future guidance on automation teaming

- **Tests of system design shall be operationally valid.** Testing needs to be carefully designed to ensure that you are testing what you intend to test (i.e., that the test is valid). Human-in-the-loop simulations shall include representative users and representative tasks. [Source: Cardosi and Murphy, 1995]. This includes controllers working in their usual team configurations. [Source: Cardosi & Murphy, 1995; Willems & Heiney, 2002]

- **The human response times assumed in the design of time-critical functions should be greater than those observed.** Response times obtained in human-in-the loop simulations should be considered ‘best case’, particularly if it is a part-task (and not full-mission) simulation. [Source: Cardosi & Murphy, 1995]

- **Consider tool accuracy**. Research indicates that decision support tools should be correct 75% of the time to be able to expect performance gains. [Source: Rein, Masalonis, Messina, & Willems, 2013]

- **Include other relevant systems.** New automation components for ATC should be tested with relevant flight deck systems. For example, decision support tools intended for use in Trajectory-Based Operations by ATC and the flight deck need to be tested in tandem in light of a concept of operations that defines how they will interact. [Source: Cardosi & Lennertz, 2020]

2.2 Annotated Bibliography: Automation

2.2.1 Annotated Bibliography of References Added to Draft Revision of *Human Factors Design Standard*

Anoskey, A. M., & Andes, Jr., R. C. (1992). *Guidelines for Adaptive Aid Design: A Review of the Literature* (Interim Report No. NAWCADWAR-92085-60). Prepared for Air Vehicle and Crew Systems Technology Department (Code 6021) Naval Air Warfare Center-Aircraft Division.

This is a very useful review of the literature that examined over 50 articles and 140 design guidelines. It details the design process and guidelines for ‘adaptive aiding,’ which the authors define as “a systems automation philosophy that proposes the use of automation to assist the operator when system performance is likely to degrade past the point of acceptability at some point in the near future” (Rouse & Rouse, 1983). Despite the focus on adaptive aids, the article applies to all automated decision aids and human-automation teaming.

Bertish, S. D., Darr, S., Hemm, R. V., Swenor, P., Dickerson, N., Tejeda, J., & Gawdiak, Y. (2013, August 12-14). Initial system integrity assessment for safety: Methods and NGOps-4 results. *Aviation Technology, Integration, and Operations Conference,* Los Angeles, CA. https://doi.org/10.2514/6.2013-4365

This extensive article starts with a description of the enterprise architecture levels of NextGen, as it was defined by the FAA Joint Planning and Development Office. It includes a discussion of vulnerabilities of complex systems (including the lack of graceful degradation). It describes several strategies for mitigating risks in complex systems that are applicable to the concept of mitigating risk with highly automated systems and graceful degradation.

Degani, A. (2001). *Taming Hal: Designing Interfaces Beyond 2001*. NY: Palgrave Macmillan.

This book focuses specifically on computer interfaces in aviation, how they go wrong, and how through improved design failures can be prevented.

Dekker, S., & Hollnagel, E. (1999). *Coping with Computers in the Cockpit*. Brookfield, VT: Ashgate. https://doi.org/10.4324/9780429460609

Sidney Dekker is a commercial pilot. Erik Hollnagel pioneered the concept of resilience in automation. This book brings together a variety of authors and perspectives about how automation should be implemented in modern aviation systems, particularly with regard to safety.

Edwards, T. E., & Lee, P. U. (2017, June 5-9). Towards designing graceful degradation into Trajectory Based Operations: A human-machine system integration approach. *17th AIAA Aviation Technology, Integration, and Operations Conference*, Denver, CO. https://doi.org/10.2514/6.2017-4487

This paper discusses the need for an increased use of automation in air traffic management systems to achieve the benefits and services identified in the NextGen Concept of Operations. Specifically, it discusses the concept of trajectory based operations (TBO). It notes that the introduction of fundamental changes to the level of automation to be used makes system safety and resilience a critical concern. In particular, there is a need for systems to ‘degrade gracefully.’ It notes that, “In order to design graceful degradation into a TBO environment, knowledge of the potential causes of degradation and appropriate solutions is required.” The paper discusses previous research on the technological causes of failure of automation in air traffic control and notes that the role of the human operator is often neglected in discussions of graceful degradation. An integrated approach to human-machine automation and its graceful degradation is discussed. The application to TBO makes the information specifically useful for ATC.

Endsley, M. R. (2017). From here to autonomy: Lessons learned from human-automation research. *Human Factors*, *59*(1), 5-27. https://doi.org/10.1177/0018720816681350

This is a good summary article of the benefits and drawbacks of automated tools. It includes the following set of 20 general guidelines:

Table 2: Guidelines for the Design of Human–Autonomy Systems (pp. 18-20)

Support human understanding of autonomous systems

1. **Automate only if necessary— avoid out-of-the-loop problems if possible**. As autonomy can lead to such significant difficulties in lack of understanding, system complexity, decision biasing, and out-of-the-loop performance problems, it should be avoided except in those situations where its assistance is really needed.
2. **Use automated assistance for carrying out routine tasks rather than higher-level cognitive functions.** Reliable autonomy that carries out the action portion of routine tasks is highly beneficial for reducing manual workload and error. Autonomy that carries

out the decision portion of tasks should be avoided, unless highly reliable due to decision biasing problems and OOTL [out of the loop].

3. **Provide SA [situation awareness] support rather than decisions**. Significant performance improvements and more robust decision making can be found with systems that enhance SA through improved information presentation to operators, integration, and projections.
4. **Keep the operator in control and in the loop**. To minimize the out-of-the-loop effect, increase operator involvement and control, improving engagement in task performance. Ensure that the operator maintains control over the automation and devise strategies that incorporate the human decision maker as an active ongoing participant, such as lower levels of automation and periods of manual control via adaptive automation.
5. **Avoid the proliferation of automated modes.** Autonomy modes increase system complexity and the ability of operators to develop a good mental model of how the system works. They also make it harder to keep up with which mode the automation is in at the present time, increasing SA errors and increasing training requirements.
6. **Make modes and system states salient.** When modes are present, the current mode should be made highly salient to the operator (including mode transitions back to manual operations). The current state of the system autonomy should be salient so that any violations of operator expectations will be readily apparent.
7. **Enforce automation consistency**. Consistency in the terminology, information placement, and functionality of the system between modes should be enforced to minimize errors in working with system autonomy.
8. **Avoid advanced queuing of tasks**. Systems that allow the operator to set up in advance a number of different tasks for the autonomy to perform are most likely to leave that operator slow to realize there is a problem that needs intervention. Approaches that maintain operator involvement in the decisions associated with execution of tasks should be considered.
9. **Avoid the use of information cuing**. Unless there is very high reliability, information cuing (automatic highlighting of information) should be avoided in favor of approaches that allow people to use their own senses more effectively. For example, systems for systematically decluttering unwanted information or improving picture clarity are preferable.
10. **Use methods of decision support that create human/system symbiosis, such as contingency planning and critiquing systems**. Decision support systems that avoid decision biasing include "what-if" analysis, encouraging people to consider multiple possibilities and perform contingency planning that can help people formulate Level 3 SA, as well as systems that help people consider alternate interpretations of data, helping to avoid representational errors in their SA.
11. **Provide automation transparency**. A high degree of transparency and observability of system behavior and functioning is needed, making it clearly apparent not only what the system is currently doing but also why it is doing it and what it will do next.

Minimize complexity of autonomous systems

12. **Ensure logical consistency across features and modes**. Inconsistencies in the logical functioning of the system dramatically increase complexity. Differences in operational logic, display of information, and different sequences of inputs that are not directly necessary for the operation of that mode or feature should be reduced or eliminated.
13. **Minimize logic branches**. Minimize complexity by reducing the linkages and conditional operations contained in the autonomy, avoiding modes with their multiple-branch logic as much as possible.
14. **Map system functions to the goals and mental models of users**. A clear mapping between user goals and system functions should be present, minimizing the degree to which operators need to understand the underlying software or hardware linkages in order to operate or oversee the autonomy. *(put into the HFDS)*
15. **Minimize task complexity**. Task complexity (the number of actions needed to perform desired tasks and the complexity of those actions) should be minimized, reducing sequence errors and cognitive load in interacting with the autonomy.

Support situation awareness

16. **Integrate information to support comprehension of information (Level 2 SA**). As attention and working memory are limited, autonomy that displays information that is processed and integrated to support operator understanding of data in relation to key goals will be beneficial.
17. **Provide assistance for SA projections (Level 3 SA**).Autonomy support for projecting possible and likely future events and states of the system should directly benefit SA, particularly for less experienced operators.
18. **Use information filtering carefully**. While extraneous information should not be shown to operators, autonomy should refrain from filtering information needed for prioritizing across operator goals or for forming projections of possible upcoming events or problems.
19. **Support assessments of confidence in composite data.** Autonomy should explicitly represent its confidence level when data are fused to form higher levels of SA or decisions to include the effects of underlying data and fusion algorithms.
20. **Support system reliability assessments.** In that trust and effective judgments on when to intervene in the performance of system autonomy depend on an accurate assessment of its reliability for performing the task at hand, interfaces should make explicit how well the autonomy is currently performing and its ability to handle upcoming or contemplated tasks.

Kohrs, C., Angenstein, N., & Brechmann, A. (2016). Delays in human-computer interaction and their effects on brain activity. *PLoS One, 11*(1), Article e0146250. https://doi.org/10.1371/journal.pone.0146250

This study used functional magnetic resonance imaging (fMRI) to examine the effect of expected and unexpected delays in feedback presentation on a computer task. In the context of this study, the experimenters first found each participant's threshold for the delay that they considered 'immediate.' The mean just noticeable delay of the participants was 327.2 ms ± 89.7 (p. 6). This result supported the conclusion that delays of 200 ms are well below the threshold of perceiving a delay. Delays of 400 ms lie in the range of a just noticeable delay, and delays of 600 ms lie above this threshold (p. 6).

Compared to immediate feedback, delays triggered an orienting response that in turn activated brain regions of action control. The strength of this activation increased with the duration of the delay. When the delays occurred frequently and became predictable, users adapted and the brain activity in the observed network diminished.

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors, 46*(1), 50-80. https://doi.org/10.1518/hfes.46.1.50_30392

The paper starts with the premise that automation is often problematic because people fail to rely upon it appropriately. It discusses the factors that affect reliance on automation, such as trust and overall comfort with advanced technology. It is particularly appropriate for ATC, since it includes situations where the complexity of the automated functions and situations "make a complete understanding of the automation impractical." The paper examines trust from the organizational, sociological, interpersonal, psychological, and neurological perspectives. It discusses how the context in which the automated function is used and the characteristics of the automated function affect the appropriateness of trust, and it explores the influence of display characteristics.

Manzey, D., Reichenbach, J., & Onnasch, L. (2012). Human performance consequences of automated decision aids: The impact of degree of automation and system experience. *Journal of Cognitive Engineering and Decision Making*, *6*(1), 57-87. https://doi.org/10.1177/1555343411433844

This interesting research paper examined the types of human errors as a function of the degree of automation and level of experience with the automation.

> "ABSTRACT: Two experiments are reported that investigate to what extent performance consequences of automated aids are dependent on the distribution of functions between human and automation and on the experience an operator has with an aid. In the first experiment, performance consequences of three automated aids for the support of a supervisory control task were compared. Aids differed in degree of automation (DOA). Compared with a manual control condition, primary and secondary task performance improved and subjective workload decreased with automation support, with effects dependent on DOA. Performance costs include return-to-manual performance issues that emerged for the most highly automated aid and effects of complacency and automation bias, respectively, which emerged independent of DOA. The second experiment specifically addresses how automation bias develops over time and how this development is affected by prior experience with the system. Results show that automation failures entail stronger effects than positive experience (reliably working aid). Furthermore, results suggest that commission errors in interaction with

> automated aids can depend on three sorts of automation bias effects: (a) withdrawal of attention in terms of incomplete cross-checking of information, (b) active discounting of contradictory system information, and (c) inattentive processing of contradictory information analog to a "looking-but-not-seeing" effect."

Of particular interest: "As was revealed by the situation awareness questionnaire, only 1 of these latter participants could correctly report what the system parameters indicated. The others had indeed looked at all the parameters but obviously had not processed the information attentively. This finding supports the looking-but-not seeing hypothesis derived from the results of the first experiment and suggests that automation bias can be associated with three different effects: (a) a withdrawal of attention in terms of incomplete cross-checks of information, (b) an active discounting of contradictory information, and (c) an inattentive processing of the contradictory information analogue to a looking-but-not-seeing effect." (p. 83)

Metzger, U., & Parasuraman, R. (2005). Automation in future air traffic management: Effects of reliable and imperfect detection aids on controller performance and workload. *Human Factors*, *47*(1), 35-49. https://doi.org/10.1518/0018720053653802

This simulation study using air traffic controllers examined the effects of an automated conflict detection tool on controller performance. The tool improved controller performance and reduced mental workload when it functioned reliably. When the automation was imperfect, however, detection of a particular conflict was better under manual conditions than under automated conditions.

Department of Defense. (2011). *Human Engineering Requirements for Military Systems, Equipment, and Facilities* (Department of Defense Standard Practice MIL-STD-46855A).

MIL-STD-46855 is identified as the "primary tasking document used by the services to specify human engineering efforts during system acquisition." It supports the human factors engineering discipline independently or as a part of Human System Integration initiatives. MIL-STD-46855 was designed to accommodate a wide range of products, including small equipment items as well as major systems. It contains useful information on task analysis and system testing and evaluation. MIL-STD-46855A NOTICE 1 (dated 24-Feb-2016) states that "MIL-STD-46855A, dated 24-May-2011, has been reviewed and determined to be valid for use in acquisition."

Murphy, E., & Cardosi, K. (1995). Issues in ATC automation. In K. Cardosi & E. Murphy (Eds.), *Human Factors in the Design and Evaluation of Air Traffic Control Systems* (pp. 219-264). DOT/FAA/RD-95/3. https://rosap.ntl.bts.gov/view/dot/8708

This chapter on automation follows chapters on perception and information processing and it precedes chapters on Computer-Human Interface considerations, workstation design, and testing and evaluation. The chapter on automation includes discussion on the following:

- General automation issues,
- Potential benefits and drawbacks of automation and their effect on controller workload,

- User-centered automation, and
- Evaluation issues.

United States Nuclear Regulatory Commission. (2020). *Human-system interface design review guidelines* (NUREG-0700). Washington, DC.

This is an updated version of "NUREG-0700 (2002). Human-system interface design review guidelines. Washington, DC: United States Nuclear Regulatory Commission."

Payton, G., McGarry, K., & Kamienski, K. (2013). *Human Factors Analysis for Automation in Human System Integration*. MITRE Product MP130323.

This is an excellent paper that begins with an overview of automation issues in air traffic control. The authors define automation as the "tools and capabilities that are directly related to controller task performance and either augment, replace of enhance the task." The paper reviews current human factors guidelines and best practices for the design and development of automated ATC systems. It describes the operational experiences with several automated ATC functions including: User Request Evaluation Tool (URET), Departure Spacing Program, Standard Terminal Automation Replacement System (STARS), Traffic Management Advisor, Advanced Technologies and Oceanic Procedures (ATOP).

Rein, J. R., Masalonis, A. J., Messina, J., & Willems, B. (2013). Meta-analysis of the effect of imperfect alert automation on system performance. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *57*(1), 280-284. https://doi.org/10.1177/1541931213571062

This study investigated how good (reliable) an automated decision support tool would need to be to see performance gains. Wickens and Dickson (2007) had found that automation reliability that was less than 70% is more likely to decrease human performance, in comparison to no-automation. This meta-analysis of 34 data points was taken from 12 studies, each representing the effect of an imperfect automation aid on system performance of various tasks. In each of these studies, the automation and the user had access to the same information (that is, the automation did not access information not available to the user). Bayesian regression analysis confirmed a consistent relationship between automation reliability (i.e., overall percent correct) and performance, with values greater than 67% associated with performance gains. The credible interval for this crossover point ranged from 55 to 75%. The authors note that, "The question 'How good is good enough?' likely does not have a single domain-general answer, with the automation performance threshold varying across task domains and other variables."

Sheridan, T. B. (1992). *Telerobotics, Automation and Human Supervisory Control*. MIT Press.

This is a review of automation and telerobotic developments from the viewpoint of human supervisory control, where the human operator supervises the computer that controls the operating system.

Sheridan, T. B. (2002). *Humans and Automation*. Wiley.

A comprehensive look at automation is offered in this article from the viewpoint of human interaction. It contains a historical perspective and discussions of how automation is used in a

wide range of industries.

Sheridan, T. B., & Parasuraman, R. (2000). Human versus automation in responding to failures: An expected-value analysis. *Human Factors*, *43*(2), 403-407. https://doi.org/10.1518/001872000779698123

This article provides an analytical approach to determine whether humans or automation would perform better on a failure detection task; it relies on knowing the probability of misses and false alarms of both the humans and the automation under consideration. It is cited as the reference for the importance of achieving stability in the system before diagnosing the failure.

Sheridan, T. B., & Verplank, W. L. (1978). *Human and Computer Control of Undersea Teleoperators*. MIT Man-Machine System Lab Rep, N00014-77-C-0256.

This article is of great historical interest as it shows how little our thinking has changed with automation and what users need. It is included because it is the original reference for the table of levels of automation.

Walker, M. (2004). *Analysis for Enabling Benefits at User Request Evaluation Tool (URET) Field Sites* (MITRE Technical Report MTR 04W0000082). MITRE Corp.

This paper is a post-implementation review of how controllers were using URET. In 2004, MITRE CAASDE personnel visited several sites where URET was implemented and identified how controllers and traffic managers were using URET. The paper is used as an exemplar of controllers finding uses for automated tools – some of which were not in the original concept of operations.

Wickens, C. D., & Dixon, S. R. (2007). The benefits of imperfect diagnostic automation: A synthesis of the literature. *Theoretical Issues in Ergonomics Science*, *8*(3), 201–212. https://doi.org/10.1080/14639220500370105

This study was the first to perform a meta-analysis to assess the effect of automation reliability on performance. Data from 20 different studies were used to compare performance on a task when there were varying levels of reliability and performance on a task when there was no automation. There was a strong linear function of benefits with reliability. The analysis revealed that a reliability of 0.70 (bounded by a 95% confidence interval of 0.14), was the ‘crossover point’ below which unreliable automation was worse than no automation at all (See also Rein et al., 2013).

Willems, B., & Heiney, M. (2002). *Decision Support Automation Research in the En Route Air Traffic Control Environment* (Report No. DOT/FAA/CT-TN02/10). Federal Aviation Administration. https://rosap.ntl.bts.gov/view/dot/16689

This study explored the effects of ATC automation on controller situation awareness, workload, and trust. Sixteen controllers from U.S. Air Route Traffic Control Centers worked simulated generic airspace under the following conditions: low and high task load, R- and D-side positions, with either no automation, limited automation or full automation. Several measures were used – among them were situation awareness (SA), workload, and trust in the Decision Support Tool

they were using. Situation awareness was assessed using the Situation Awareness Verification and Analysis Tool (SAVANT), SA Global Assessment Technique, self-report measures, and over-the-shoulder ratings by an ATC Subject Matter Expert. Workload ratings were obtained using the Air Traffic Workload Input Technique (ATWIT), National Aeronautics and Space Administration's (NASA) Task Load Index (TLX), and self-report measures. An eye tracking system collected visual scanning data. As expected, workload ratings, as measured by the ATWIT, NASA TLX, and self-report ratings, indicated that as task load increased, workload increased. Situation awareness was lower with limited automation than without or with full automation. The subjective ratings on SA for potential violations and the objective SA measures showed that controllers displayed lower SA with full automation and under high traffic task load conditions.

Willems, B., & Truit, T. R. (1999). *Implications of Reduced Involvement in En Route Air Traffic Control* (Report No. DOT/FAA/CT-TN99/22). Federal Aviation Administration. https://rosap.ntl.bts.gov/view/dot/16758

This well-designed, well-controlled experiment placed 16 air traffic controllers from various facilities at two levels of involvement of air traffic control in generic airspace – either controlling traffic as they normally would in the field or monitoring (i.e. not actively controlling or communicating with) the aircraft. Both levels of involvement were conducted with moderate and high traffic loads. The study examined: eye movements, workload, situation awareness, system performance, controller performance ratings, organization of information in memory, and responses to questionnaires. Workload correlated well with traffic volume. Under monitoring conditions, controllers perceived lower workload. However, controller situation awareness was measured as lower under monitoring conditions, while controllers perceived that their situation awareness did not change between active control and passive monitoring.

Yeh, M., Swider, C., Jo, Y., & Donovan, C. (2016). *Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls – Version 2* (Report No. DOT/FAA/TC-16/56). Federal Aviation Administration. https://rosap.ntl.bts.gov/view/dot/12411

This FAA document is identified as:

> "A single source reference document for human factors regulatory and guidance material for flight deck displays and controls, in the interest of improving aviation safety. This document identifies guidance on human factors issues to consider in the design and evaluation of avionics displays and controls for all types of aircraft (14 CFR parts 23, 25, 27, and 29). It is intended to facilitate the identification and resolution of typical human factors issues that are frequently reported by FAA Aircraft Certification Specialists. This document supersedes the Version 1 report (DOT/FAA/TC-13/44; DOT-VNTSC-FAA-13-09). Topics address the human factors/pilot interface aspects of the display hardware, software, alerts/annunciations, and controls as well as considerations for flight deck design philosophy, intended function, error management, workload, and automation." (abstract)

Zingale, C., & Woroch, B. (2019). *Air Traffic Control Decision Support Tool Design and Implementation*

***Handbook* (Report No. DOT/FAA/TC-19/37). Federal Aviation Administration. https://rosap.ntl.bts.gov/view/dot/57803**

This document reviews literature relevant to the design and use of decision support tools and offers guidelines for user interface design and training. Also included is a good general discussion of human-automation teamwork. For design guidelines, it reprints the section on Decision Aids from the 2016 version of the FAA *Human Factors Design Standard* (as Appendix A) and supplements it with nine additional guidelines with 'Design Guidelines for Decision Support Tool User Interface/Human-Computer Interaction' (as Appendix B).

2.2.2 Annotated Bibliography of Additional Useful Documents - Automation

DOT IG (2018). *FAA Has Taken Steps to Address ERAM Outages But Vulnerabilities Remain* (Report No. AV2019004).

Makes the case for sound human factors testing before implementation and contains some potentially useful quotes:

- "A new controller software application tool for controller workstations resulted in the failure of both ERAM [En Route Automation Modernization] channels and led the Center's management to declare ATC Zero. The new software caused ERAM's memory to accumulate excess data over a period of several weeks which ultimately overloaded the system's memory and caused ERAM's primary and secondary channels to fail. The resulting outage lasted for over 5 hours: almost 4 hours were spent at ATC Zero which resulted in the clearing of all aircraft from the Center's airspace. The outage resulted in 492 flight delays reported in Washington Center airspace and contributed to more than 3400 flight delays and 640 cancellations nationwide, along with impacting international air traffic entering the NAS. While the event was eventually downgraded to an ATC Alert, the ripple effects adversely impacted air traffic and travelers across the country for several days….FAA directed all Centers to stop using the new controller application." (pp. 6-7)
- "Human Error and Testing Limitations Contributed to ERAM's Outages… Both FAA's post-incident analysis and our work found that FAA does not adequately test ERAM's contingency plan." (p. 9)

Nielsen, J. (1993). Usability Heuristics. In J. Nielsen, *Usability Engineering* (pp.115-164). *Academic Press*.

This text identifies 0.1 second as the limit for the delay in feedback while having the user feel that the system is reacting instantaneously and 1.0 second as the limit for the user's flow of thought to stay uninterrupted (even though the delay will be noticed). Nielsen notes that while no special feedback is necessary during delays between 0.1 and 1.0 second, the user loses the feeling of operating directly on the data. The limit for keeping the user's attention focused on the dialogue was considered to be 10 seconds. For delays longer than 10 seconds, Neilsen recommends a percent-done indicator and an option to interrupt the operation.

Ohneiser, O., De Crescenzio, F., Di Flumeri, G., Kraemer, J., Berberian, B., Bagassi, S., Sciaraffa, N., Aricò, P., Borghini, G., & Babiloni, F. (2018). Experimental simulation set-up for validating out-of-the-loop mitigation when monitoring high levels of automation in Air Traffic Control. *International Journal of Aerospace and Mechanical Engineering, 12*, 307-318. https://doi.org/10.5281/zenodo.1316361

This experimental study used eye movement monitoring and electroencephalography (EEGs) to study the lack of attention when monitoring automated functions in air traffic control tasks.

ABSTRACT:

> "An increasing degree of automation in air traffic will also change the role of the air traffic controller (ATCO). ATCOs will fulfill significantly more monitoring tasks compared to today. However, this rather passive role may lead to Out-Of-The-Loop (OOTL) effects comprising vigilance decrement and less situation awareness. The project MINIMA (Mitigating Negative Impacts of Monitoring high levels of Automation) has conceived a system to control and mitigate such OOTL phenomena. In order to demonstrate the MINIMA concept, an experimental simulation set-up has been designed. This set-up consists of two parts: 1) a Task Environment (TE) comprising a Terminal Maneuvering Area (TMA) simulator as well as 2) a Vigilance and Attention Controller (VAC) based on neurophysiological data recording such as electroencephalography (EEG) and eye-tracking devices. The current vigilance level and the attention focus of the controller are measured during the ATCO's active work in front of the human machine interface (HMI). The derived vigilance level and attention trigger adaptive automation functionalities in the TE to avoid OOTL effects. This paper describes the full-scale experimental set-up and the component development work towards it. Hence, it encompasses a pre-test whose results influenced the development of the VAC as well as the functionalities of the final TE and the two VAC's sub-components."

Payton, G., McGarry, K., & Kamienski, K. (2013). *Human Factors Analysis for Automation in Human System Integration*. MITRE Product MP130323.

This is an excellent paper that begins with an overview of automation issues in air traffic control. It defines automation as "tools and capabilities that are directly related to controller task performance and either augment, replace or enhance the task." The paper reviews current human factors guidelines and best practices for the design and development of automated ATC systems. It describes the operational experiences with several automated ATC functions including: URET, Departure Spacing Program, STARS, Traffic Management Advisor, Advanced Technologies and Oceanic Procedures (ATOP).

Sheridan, T. B., & Nadler, E. D. (2006). *A Review of Human-Automation Failures and Lessons Learned*. (Report No. VNTSC-DOT-NASA-06-01). US Department of Transportation Volpe National Transportation Systems Center. https://rosap.ntl.bts.gov/view/dot/8879

This report provides a good summary of all of the science with many 'real world' examples of automation missteps.

Zemrowski, K. M. (2008). Impacts of increasing reliance on automation in Air Traffic Control Systems. *2nd Annual IEEE Systems Conference*, 1-6. doi.org/10.1109/SYSTEMS.2008.4518987

This paper offers a 2008 forecast – from an engineering perspective – of how the needs of pilots and controllers would change with automated functions implemented with NextGen (e.g., TBO). Over 10 years after publication, it is remarkably relevant. The article talks about changes that will need to be made to our communications system and controller displays, and it even considers holographic techniques for dynamic displays. It makes a good argument for human factors research, increased testing and strong safety management.

3. Workstation Design

3.1 Introduction

Discussions with the FAA sponsor of this work indicated that there were two areas that would be most useful to include in the update of the 2016 HFDS in the area of workstation design: 1) large and curved displays, and 2) sit-stand workstations.

3.2 Workstation Design: General Notes on References in Section 5.8.2 (Workstations and Consoles) of the HFDS:

- NASA-STD-3000A (1989) has not been updated and is no longer being maintained. The information as written in the HFDS is useful, but the reference to NASA-STD-3000A (1989) is problematic.
- NASA-STD-3000, the *Man-System Integration Standard*s, has been superseded by documents specific to space flight: NASA-STD-3001 Space Flight Human-System Standard Volumes 1 (Crew Health), NASA-STD-3001 Space Flight Human-System Standard Volumes 2 (Human Factors, Habitability and Environmental Health) and NASA/SP-2010-3407 the Human Integration Design Handbook (HIDH). While this document has a lot of the same information, the space-centric focus makes it a less valuable reference for this purpose.
- MIL-HDBK-759C, dated 31 July 1995, was cancelled without replacement. (See MIL-HDBK-759C NOTICE 3 13 March 2012). Exhibit 5.8.2.1.1 (a) depicting standard console dimensions was unclear and the source was not cited. A more detailed table is presented in TABLE XLVI in MIL-STD 1472 H (but this is a draft and not yet published).
- NOTICE 1 dated 24-Feb-2016 stated that “Human Engineering Requirements for Military Systems, Equipment, and Facilities MIL-STD-46855A, dated 24-May-2011, has been reviewed and determined to be valid for use in acquisition.”
- ANSI-HFES 100 – 2007 is the most current reference for ergonomics of ‘sit only,’ ‘stand only’ and ‘sit-stand’ workstations.
- MIL-STD-46855, Department of Defense Standard Practice Human Engineering Requirements for Military Systems, Equipment, and Facilities, is described in the document’s foreword as, “the primary tasking document used by the services to specify human engineering efforts during system acquisition. It supports the human factors engineering discipline independently or as a part of Human System Integration initiatives. MIL-STD-46855 is also written to accommodate a wide range of products, including small equipment items as well as major systems.” The document focuses on the role of human factors in: task analysis, the development of system

specifications, testing and evaluation, and fault analysis. It could be used as a citation for such details. While it does not have specific recommendations for displays or workstation design, it does refer to HUMAN FACTORS AND ERGONOMICS SOCIETY (HFES) ANSI/HFES 100 - Human Factors Engineering of Computer Workstations as a part of this military standard.

3.3 Workstation Design: Large and Curved Displays - Annotated Bibliography

Bartha, M. C., Allie, P., & Kokot, D. (2020). Field observations of placement for large-panel flat and curved displays for presbyopic and prepresbyopic computer users*. Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *64*(1), 526-530. https://doi.org/10.1177/1071181320641119

This study shows that users' perceived discomfort in the neck and shoulders was less with a curved display than with a large, flat panel display. The research examined display placement and subjective effects of large, flat, and curved computer displays on users with and without visual correction for presbyopia. All participants utilized a notebook computer in their own workstations that comprised the central processing unit (CPU) and display driver that were attached to a docking station with attachments to either a 30-inch diagonal display, a 34-inch flat screen display, and a 34-inch 3000R curved screen display. Reported discomfort in the neck and shoulders was significantly lower in the 34-inch flat and curved conditions than for a 30-inch diagonal display. (However, it should be noted that mean ratings for all perceived body discomfort were less than 0.7 on a 0 to 10 scale.) Differences in reported eye discomfort were not significant. Several participants commented that text on the curved display appeared clearer near the left and right edges of the screen, compared to the 34-inch, flat display.

Boher, P., Leroux, T., Collomb-Patton, V., & Bignon, T. (2015). Optical characterization of OLED displays. *Journal of the Society for Information Display*, *23*(9), 429-437. https://doi.org/10.1002/jsid.369

Organic light-emitting diodes (OLEDs) are a recent display technology. OLEDs are advertised as providing a number of technological enhancements over traditional LEDs such as higher-contrast ratio, wider viewing angle, and faster response time. OLEDs could be used to make paper-thin, transparent, or flexible displays. "OLEDs require very good manufacturing control to achieve optimized and homogeneous emissive properties. The emissive properties are driven not only by the properties of the emitted layers but also by the multilayer structure that can produce complex interference patterns. We have shown that angular emission of OLEDs is generally relatively complex and depends on the structure of each OLED sub-pixel." Imaging measurements have shown wavelength variations across the display that the authors note are probably due to "structural non-uniformities" – particularly in the display of long and short-wavelengths.

Boher, P., Leroux, T., Bignon, T., & Collomb-Patton, V. (2015). How to perform viewing angle

measurements on curved displays. ***Society for Information Display (SID) Symposium Digest of Technical Papers*****,** ***46*****(1). https://www.researchgate.net/publication/276700349**

> **See also: Boher, P., Leroux, T., Collomb Patton, V., Bignona, T., & Blanc, P. (2015). Viewing angle measurements on curved displays.** ***Journal of Information Display*****,** ***16*****(4), 207–216, http://dx.doi.org/10.1080/15980316.2015.1094428**
>
> Measurement of visual angle of a target on a curved display may need to take the curvature of the display into account, depending on the size of the target and the curvature of the display (Boher, Leroux, Collomb Patton, Bignon, & Blanc, 2015). Assuming that the target on the monitor is in the focused plane, the error in the measurement of the visual angle will not exceed 1° if the ratio of the size of the target over the radius of the curvature of the display is below 0.5%.

Choi, B., Lee, S., Lee, J. E., Hong, S., Lee, J., & Kim, S. (2015). A Study on the optimum curvature for the curved monitor. ***Journal of Information Display*****,** ***16*****(4), 217-223. http://dx.doi.org/10.1080/15980316.2015.1111847**

> This study points to the need to assess the benefits of a curved display in the context of the tasks for which they will be used. In this study, participants adjusted the curvature of the display to their subjective optimal curvature for various static images (text, a newspaper, a map, a picture of scenery, games). The results showed that the optimal curvature was 560.9 mm at the standard viewing distance of 600 mm (24 inches). Interestingly, the subjective optimal curvature for viewing varied with the displayed content and was significantly different for games than for the text or map. The authors concluded that further studies should be conducted on the preferred curvature for different monitor sizes, viewing distances, and patterns (including those that move).

Gyouhyung K., & Park, S. (2020). Curved versus flat monitors: Interactive effects of display curvature radius and display size on visual search performance and visual fatigue. ***Human Factors, 63*****(7), 1182-1195. https://doi.org/10.1177/0018720820922717**

> This study had participants looking for an "A" amidst alphanumerics and symbols, using the same visual search task (and maybe even the same data) as Study 1 in the Park dissertation. At viewing distance of 33-inch, 33-inch 600R and 50-inch 600R displays outperformed 33-inch and 50-inch flat displays. For accuracy, speed, and perceived visual fatigue, 33-inch 600R and 50-inch 600R provided the best or comparable results, whereas the 50-inch flat display provided the worst results. For accuracy and fatigue, 33-inch flat display was the second worst.

Imbert, J-P., Hodgetts, H. M., Parise, R., Vachon, F., Dehais, F., & Tremblay, S. (2014). Attentional costs and failures in air traffic control notifications. ***Ergonomics*****,** ***57*****(12), 1817-1832. https://doi.org/10.1080/00140139.2014.952680**

> This is an interesting study using a large (30-inch) display with a resolution of 2560 x 1600, located 70 cm in front of the participant displaying an "ATC-like synthetic environment." The participants were "Thirty ATC specialists working for the French civil aviation research centre

(mainly engineers and five controllers) who volunteered to take part in the experiment. They were all knowledgeable about operational interfaces and about air-traffic controller activity." The purpose of the study was to examine the effectiveness of various methods of displaying notifications. The types of notifications used were:

1. **Color** - a static notification that displayed the word 'FNIV' in an orange–red color. It corresponds to the design currently used operationally to signify a lower-level warning, and is associated in the experiment with the aircraft's altitude.
2. **Color-Blink** is colored text with the word 'ALRT' which blinks at a rate of 800 ms on/200ms off - this is currently used in ATC for high-priority short-term conflict alerts.
3. **Box-Animation** involves the same colored text 'ALRT' but also four yellow chevrons placed around the label of the notified plane. These chevrons move outwards from the label by 60 pixels following a slow in/slow out animation cycle of 1 Hertz (Hz). It corresponds to a radar display prototype being used in the framework of the European innovative research program (SESAR WP 4.7.2).
4. **Shadow-Mask** is an animated design that uses the opacity of the background of the radar display to differentiate the notified aircraft (other planes fade out for 300 ms). At the end of the fade-out animation, the notified object vibrates for 160 milliseconds to attract attention. The total duration of the animation is 2.56 seconds, but the radar display remains darker for 20 seconds, or until the participant validates the notification. Such a design is similar to designs inspired by the concept of cognitive countermeasures, whereby other on-screen information is temporarily removed in order to focus attention on the critical aspect and prevent perseveration on less important elements of the task. In this design, the visualization of the non-relevant information was degraded (instead of being removed) and vibration was added to ensure that the participants' attention was captured.
5. **Halo** - a prototype alert that provided both distance and direction information at a glance. In the opposite way to circles radiating out from a stone dropped in water, the circles start on the edge of the guided plane (current object in focus) and converge inwards onto the notified plane. In this way, the dynamic animation flows directly from the guided plane and towards the alert.

A range of performance measures were used, including eye-tracking and subjective reports. Results showed that use of color, even blinking color, was less effective than movement for detecting the presence of a notification. Designs that drew attention to the notified aircraft by a pulsating box, concentric circles or the opacity of the background resulted in faster perception and no missed notifications; however, these designs were intrusive and impaired primary task performance. The simpler animated box captured attention without an overhead cognitive cost.

The three animated design conditions (i.e., those that involved movement) were perceived 'quickly and without error.' Use of color and the combination of color and blinking resulted in slower validation times and some notifications went unnoticed when presented in the periphery. However, the attentional power of the animated alerts hindered performance on the primary air traffic control task. All alerts were perceived in the three animated design conditions, but operators were on average 3 seconds (100%) slower to respond to the notifications presented with Color and Color-Blink.

This study also reinforces important aspects of what is already known:

- When deeply engaged in a demanding task, the operator's functional field of view tends to narrow, making it difficult to extract peripheral information.
- Color perception is degraded as cones become more sparsely distributed with greater eccentricity. As such, alerts that are distinguished in terms of color are likely to be less effective than animation (movement).
- Alerts were responded to more quickly if they were animated (dynamic salience) and if they made use of foveal rather than peripheral vision (eccentricity from gaze). Importantly, the effects of retinal eccentricity and salience on RT were additive.
- The initiated warning will continue in the background and may become a source of visual distraction that compromises a task of potentially greater importance.
- For Shadow-Mask, attention is automatically directed to the visual warning (because all other information on the screen is darkened). It therefore demands immediate attention, which can impair situation awareness and be disruptive to more important tasks.

Kortschot, S. W., Jamieson, G. A., & Wheeler, C. (2018). Efficacy of group-view displays in nuclear control rooms. *IEEE Transactions on Human-Machine Systems*, *48*(4), 408-414. doi.org/10.1109/THMS.2018.2836798

This experimental study compared two-person team performance on a pseudo nuclear control task using either two large screen (100'') displays or redundant smaller displays for each team member. The results showed no benefit associated with the common large screen display over redundant smaller displays in the central control room. The study showed that the configuration of the shared information had minimal effect on situation awareness, team communication, or diagnostic performance. Display design, however, had a greater impact on operator behavior than the use of common large or redundant smaller displays.

Li, X., Huang, Y., Chen, C., & Lv, J. (2018). The key optical properties and measurement analysis for curved displays. *Society for Information Display (SID) Symposium Digest of Technical Papers*, *49*(S1), 235-241. https://doi.org/10.1002/sdtp.12691

This study notes that the improvement in the contrast ratio of display screens with technologies such as OLEDs, "High Dynamic Range (HDR)" technology, and the OLED flexible (curved) displays requires a higher range and sensitivity of the measurement device. To obtain accurate measurements, the range of the measurement device needs to be at least one order of magnitude higher than that of the measured object. While most devices have no problem at the high luminance levels, the lower luminance levels can be challenging. "At present, the lowest luminance of HDR display can reach 10-3cd/m2 or lower, which means that the response sensitivity of the measurement instrument should be at least 10-4cd/m2when measuring the low luminance of the black field, but the sensitivity of the ordinary luminance meter is generally 0.01cd/m2, and a few can reach 10-3cd/m2, which still cannot meet the measurement requirements of high quality curved displays." The authors note that it is necessary to use a luminance meter equipped with a high accuracy and high quality photodetector with preamplifier and advanced cooling technology.

Marsal, A., Sycev, A., Kloth, T., Lehnert, C., & Blankenbach, K. (2015). Paper No S13.4: Image quality simulations of curved displays. *Society for Information Display (SID) Symposium Digest of Technical Papers*, *46*(S1), 60. https://doi.org/10.1002/sdtp.10536

Marsal et al. developed a simulation toolkit for characterizing color shifts as a function of viewing angle effects on curved and flat displays (using viewing angle measurements). The output is either the maximum color difference or a simulated image color shifts for colors with different Red, Green, Blue (RGB) grey levels.

United States Nuclear Regulatory Commission. (2020). *Human-system interface design review guidelines* (NUREG-0700). Washington, DC.

This document contains guidance on the use of large screen displays, defined as those that "can be viewed from multiple workstations and locations in a control room" and "typically contain important information that should be commonly available to control room crewmembers." The guidance offered is for display pages that are too large to be viewed all at once from a single display screen with a level of resolution adequate for users' tasks (i.e., if the display page was reduced to fit the available space, the text and other visual details would be too small to read. This points to the fact that design guidance must be appropriate to the tasks.

Most of the recommendations regarding large displays discuss ways in which windows may be manipulated to adjust the presentation of information in a display screen. The workstation-related guidance that could be included in the HFDS is:

- Consider off-center viewing. When multiple, large display devices are used, the normal work areas of each user should be within the acceptable off-centerline viewing area of each large display that each user must view. [Source: NUREG-0700, 2020]
- Overlap off-centerline views. If the \\large display devices are adjacent to each other, they should be angled toward each other so the acceptable off-centerline viewing areas of the displays overlap. [Source: NUREG-0700, 2020]

Park, S. (2017). *Curved Displays, Empirical Horopters, and Ergonomic Design Guidelines*. Unpublished doctoral dissertation.

Study 1 examined the effects of the display curvature (400 R, 600 R, 1200 R, and flat) on brief (15 and 30 minute) visual search tasks. Twenty-seven participants completed two sets of 15-minute visual tasks with each curvature setting. In the first study, subjects looked for a capital "A" among alphanumberics and pseudotext. Results showed that the 600 R and 1200 R settings yielded better results compared to the flat setup regarding legibility and perceived visual fatigue. Compared to the center of the display, the outermost zones of both the 1200 R and flat display showed a decrease of 8%–37% in legibility, compared to the center of the flat display. However, the flat display also showed an increase of 26%–45% in perceived visual fatigue over the curved display. In Study 2, participants performed a proofreading task by comparing two sets of text. Legibility decreased by 2%–8%, and perceived visual fatigue increased by 22% compared to the curved displays. The two studies showed an increase of 102% in the eye complaint score and a decrease of 0.3 Hz in the critical fusion frequency, both of which indicated a rise in visual fatigue. A curvature of around 600 R, central display zones, and frequent breaks were recommended to improve legibility and reduce visual fatigue.

This (well-done) doctoral dissertation was the first to publish recommended guidelines for curved displays. (No other published guidelines could be found). The relevant guidelines offered are:

- “The radius of the curvature of the display should be similar to the viewing distance.”
- “A display curvature of 600 R is recommended for office VDT [video display terminal] tasks on 50” (48 inches by 15 inches) monitors at the viewing distance of 20 inches.”
- “A display curvature of 600 R is also recommended for office VDT tasks at a viewing distance of 24 inches on 27” (24 by14 inches) monitors.”

Park, S., Kyunga, G., Choi, D., Yi, J., Lee S., Choi, B., & Lee, S. (2019). Effects of display curvature and task duration on proofreading performance, visual discomfort, visual fatigue, mental workload, and user satisfaction. *Applied Ergonomics*, *78*, 26-36. https://doi.org/10.1016/j.apergo.2019.01.014

Similar to Park (2017), this study used a one-hour proofreading task with different display curvatures and a flat display. A decrease in critical fusion frequency was the measure interpreted as an increase in visual fatigue and mental workload. The curvature of 600R improved proofreading speed without deteriorating accuracy. The study had only 10 subjects per condition and has nothing notable to contribute to the HFDS, but it is one of the most recent published reports in the scientific literature.

Ramanauskaitaz, S., Čenys, A., Radvilaz, E., & Ramanauskas, N. (2018). Gaze point estimation on curved display by using session level calibration for flat screen displays. *Multimedia Tools and Application, 77*(6), 6969-6985. https://doi.org/10.1007/s11042-017-4616-y

Measurement of eye tracking may need to be adjusted when curved displays are used. The changes between the gaze point position on flat and curved screen depend upon the distance of the observer to the screen and the angle of viewing. The average difference between gaze point position on flat and curved screen modes in this study was 1.10%. At the screen’s center, the difference was almost zero. However, while looking to the left or right side of the screen, the difference between gaze point position in flat and curved screen modes increased, reaching up to 3.99%.

Society for Information Display (2012). *Information Display Measurements Standard*. IDMS Version 1.03.

This 563-page document describes measurement procedures to quantify electronic display characteristics and qualities. Measures that are applicable to several different technologies (including 3-D, but not curved displays) are discussed. The document discusses problems encountered with making display measurements, diagnostics to reveal those problems, and offers solutions to these measurement difficulties. Despite the title of the document, it does not propose performance standards or criteria. Nonetheless, it is a useful reference document as it describes display technologies and measurement procedures in detail.

ViewSonic (2019). ***Curved vs. flat monitors: What are the benefits of curved monitors?*** **https://www.viewsonic.com/library/entertainment/curved-vs-flat-monitors**

This is from a vendor's website, but has useful information. This advertisement noted that curved displays are more sensitive to glare than flat screens, because they can be affected by multiple light sources.

3.3.1 Suggested Additions to the *Human Factors Design Standard* on Large Screen Displays

Add section on curved displays:

- **Match radius of curved display to viewing distance.** The radius of the curvature of the display should be similar to the viewing distance. [Source: Park, 2017]

  Discussion. A display curvature of 600 R is recommended for office VDT tasks on 50-inch (48" by 15") monitors at the viewing distance of 20 inches and for tasks at a viewing distance of 24 inches on 27-inch (24" by 14") monitors (Park, 2017).

- **Protect displays from glare.** Since curved displays are more sensitive to glare than flat screens, workstation design should ensure that the display is protected from glare under all anticipated ambient lighting conditions. [Source: ViewSonic, 2019]
- **Ensure consistent color presentation across the display**. The presentation of all colors used on the display should be consistently presented across the display.

  Discussion. While Organic light-emitting diodes (OLEDs) provide a number of technology enhancements over traditional LEDs (such as higher-contrast ratio, wider viewing angle, and faster response time), the display of long- and short- wavelength (roughly reds and blues) will vary across the display due to 'structural non-uniformities.' [Source: Boher, Leroux, Collomb-Patton, & Bignon, 2015]

- **Consider off-center viewing.** When multiple, large display devices are used, the normal work areas of each user should be within the acceptable off-centerline viewing area of each large display that each user must view. [Source: NUREG-0700, 2020]
- **Overlap off-centerline views.** If the large display devices are adjacent to each other, they should be angled toward each other so the acceptable off-centerline viewing areas of the displays overlap. [Source: NUREG-0700, 2020]
- **Consider effect of viewing angle.** The determination of the acceptability of off-centerline

viewing for large group-view devices should consider the effect of the viewing angle upon screen characteristics, such as brightness and color rendition. [Source: NUREG-0700, 2020]

- **Determine operational effect of display size on spatial distortion.** The determination of the acceptability for large group-view devices should consider spatial distortion of the image. [Source: NUREG-0700, 2020]

  > **Discussion:** Individual viewers in a fixed location should be no more than 10 degrees off the centerline. For multiple viewers, the preferred limit should be 20 degrees and an acceptable limit should be 30 degrees off the centerline. These angle limits address spatial distortion of the displayed image caused by the viewing angle. However, off-centerline viewing of large-screen display devices may also result in (1) loss of general brightness for high-gain screens, and (2) loss of color rendition in projection-type devices caused by the angles of reflection of the separate projection elements. [Source: NUREG-0700, 2020]

3.3.2 Additional Information

The following information is outside the scope of human factors design guidelines, but is useful from a programmatic perspective:

- Color shifts as a function of off-angle viewing can be predicted for both curved and flat displays (Marsal, Sycev, Kloth, Lehnert, & Blankenbach, 2015).
- Depending on the size and position of the target relative to the curvature of the screen, eye-tracking measurements may need to be adjusted for curved displays (Ramanauskaitė, Čenys, Radvilė, & Ramanauskas, 2018). Assuming that the target on the monitor is in the focused plane, the error in the measurement of the visual angle will not exceed 1° if the ratio of the size of the target over the radius of the curvature of the display is below 0.5% (Boher, Leroux, Bignon, & Collomb-Patton, 2015; Boher, Leroux, Collomb Patton, Bignona, & Blanc, 2015).
- Technologies such as OLEDs (including flexible or curved displays) and High Dynamic Range (HDR) require the luminance measurement device used to have a greater range and sensitivity than those that are sufficient for other displays. For accurate measurements, the magnitude of the measurement instrument needs to be at least one order of magnitude higher than that of the measured object. While most instruments have no problem at the high luminance levels, the lower luminance levels can be challenging. For such measurements, a luminance meter equipped with a high accuracy and high quality photodetector with preamplifier and advanced cooling technology is recommended. (Li, Huang, Chen, & Lv, 2018).

3.4 Workstation Design: Sit-Stand Workstations - Annotated Bibliography

Agarwal, S., Steinmaus, C., & Harris-Adamson, C. (2018). Sit-stand workstations and impact on low back discomfort: A systematic review and meta-analysis. *Ergonomics*, *61*(4), 538-552. http://dx.doi.org/10.1080/00140139.2017.1402960

> The authors conducted a meta-analysis on literature published before November 2016 that addressed the relationship between sit-stand workstations and musculoskeletal discomfort, focusing on the lower back. They concluded that, in a sedentary population, changing posture may reduce low back pain among workers and reduce the chance of developing low back pain among a pain-free population.

American Optometric Association (n. d.). *Computer Vision Syndrome.* https://www.aoa.org/healthy-eyes/eye-and-vision-conditions/computer-vision-syndrome

> This article discusses the causes and remedies for 'computer vision syndrome' – the eye discomfort, blurred vision, headaches and other symptoms associated with extended use of computers and digital displays. The article has several recommendations to prevent this syndrome, including using the proper viewing distance. It specifies that, whether the user is seated or standing, the computer screen should be 20 to 28 inches from the eyes and 15 to 20 degrees (4 or 5 inches) below eye level as measured from the center of the screen (American Optometric Association, 2021).

Blatter, B. M., & Bongers, P. M. (2002). Duration of computer use and mouse use in relation to musculoskeletal disorders of neck or upper limb. *International Journal of Industrial Ergonomics*, *30*(4-5), 295-306. https://doi.org/10.1016/S0169-8141(02)00132-4

> Work-related disorders (of the neck, arms, shoulders, elbows, wrists and hands), defined as regularly occurring or long-lasting pain or discomfort during the past 12 months that were not due to a sport injury or accident were associated with working with a computer more than six hours per day particularly in women. In men, moderate associations were seen for computer use more than six hours per day. In women, such disorders were moderately increased with a duration of computer use of more than four hours per day and strongly increased with a duration of six hours or more per day (Blatter & Bongers, 2002).

Husemann, B., Von Mach, C. Y., Borsotto, D., Zepf, K. I., & Scharnbacher, J. (2009). Comparisons of musculoskeletal complaints and data entry between a sitting and a sit-stand workstation paradigm. *Human Factors*, *51*(3), 310-320. http://dx.doi.org/10.1177/0018720809338173

> This study had males aged 19-35 perform data entry tasks either sitting or using a sit-stand workstation. Musculoskeletal complaints were reduced by a sit-stand workstation with a small, but non-significant, loss of efficiency in data entry while standing.

International Organization for Standardization. (2013). *Ergonomic design of control centres — Part 4: Layout and dimensions of workstations* (ISO Standard No. 11064-400:2013). https://www.iso.org/standard/54419.html

> This is the most current ISO standard on workstation design. It does not appear to have been incorporated into the 2016 HFDS. The main difference between the material in this standard

and the material in the HFDS is that the ISO standard considers a "seated posture" to include "bent forward (monitoring at a high level of attention), erect (typing, operating controls), reclined (monitoring) and relaxed (monitoring) postures" (p.11). Table 2 shows the effect of these seated postures on the operator's eye position; the actual dimensions to be used shall be derived from the anthropometric data of the intended user population. There are corresponding effects regarding reach envelopes, body clearances, etc. While this table might be useful to include, it would not be able to be reproduced without permission.

Karakolis, T., Barrett, J., & Callaghan, J. P. (2016). A comparison of trunk biomechanics, musculoskeletal discomfort and productivity during simulated sit-stand office work. *Ergonomics*, *59*(10), 1275-1287. https://doi.org/10.1080/00140139.2016.1146343

This study defines a sit-stand workstation in the same way that it is used commonly today – that is, as one that allows a user to perform the same tasks from either a seated or standing position with a work surface height that can be adjusted quickly with minimal disruption in task performance. It starts with the well-established premise that both prolonged sitting and prolonged standing can lead to back discomfort and adds that "Increasing lumbar flexion during prolonged sitting is a known injury mechanism." The study found that the use of the adjustable workstation was associated with reduced lumbar flexion during sitting, compared to sitting only. It concluded that the use of a sit-stand workstation exhibited a potentially beneficial response of reduced lumbar flexion that could have the potential to prevent injury. Additionally, working in a sit-stand paradigm was found to have the potential to reduce discomfort, when compared to working in a sitting or standing-only configuration. The study also found that the use of the sit-stand workstation had no significant effect on productivity.

Karakolis, T., & Callaghan, J. P. (2014). The impact of sit-stand office workstations on worker discomfort and productivity: A review. *Applied Ergonomics*, *45*(3), 799-806. https://doi.org/10.1016/j.apergo.2013.10.001

This review examined the effect of sit-stand workstations on self-reported worker discomfort and on worker productivity. Fourteen articles were included in the review. Six of these studies found that implementing sit-stand workstations in an office environment led to lower levels of reported subjective discomfort (three of which were statistically significant). As a result, this review concluded that sit-stand workstations are likely effective in reducing perceived discomfort. Eight of the identified studies also reported a productivity outcome. Three of these studies reported an increase in productivity during sit-stand work, four reported no effect on productivity, and one reported mixed productivity results. From this, the review concluded that sit-stand workstations do not cause a decrease in productivity. Eight of the studies included a measure of productivity, but the operational definition of productivity used in these studies were only described as exemplars (keystrokes per minute, errors per keystroke, sick days, break time, etc.). Results from three of the eight included studies showed an increase in productivity for sit-stand work when compared to sit only (Dainoff, 2002; Hedge & Ray, 2004; Ebara et al., 2008). Four studies showed no effect on productivity (Nerhood & Thompson, 1994; Hedge et al., 2005; Davis et al., 2009; Husemann et al., 2009), while the remaining study by Hasegawa et al.

(2001) found a mixed result of a higher volume of work performed for sit-stand workers but lower quality of work. The study also noted that none of the studies establish an optimal ratio between time sitting and time standing being established.

United States Nuclear Regulatory Commission (2020). ***Human-system interface design review guidelines*** **(NUREG-0700 Revision 3). https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0700/r3/index.html**

This document contains a few design standards for sit-stand workstations that are included in the following material. However, the American National Standards Institute (ANSI) material is more detailed and comprehensive.

3.4.1 Recommended additions to HFDS: 5.8.2.1. SIT, SIT-STAND, AND STAND CONSOLES

Human Factors and Ergonomics Society. (2007). ***Human factors engineering of computer workstations*** **(ANSI/HFES 100-2007). Santa Monica, CA.**

ANSI/HFES 100-2007 is the current reference for ergonomics of ‘sit only’ and ‘stand only’ workstations. In addition, the following text is recommended for addition:

> **Discussion.** Viewing computer screens for extended periods can result in eye discomfort, and could lead to vision problems. To help minimize this ‘computer vision syndrome’, the computer screen should be 20 to 28 inches from the eyes and 15 to 20 degrees (4 or 5 inches) below eye level as measured from the center of the screen, whether seated or standing [Source: American Optometric Association, 2021].

Department of Defense (2020). ***Department of Defense design criteria standard: Human engineering*** **(MIL-STD-1472H). http://Everyspec.Com/Mil-Std/Mil-Std-1400-1499/Mil-Std-1472h_57041/**

Figure 64 from MIL-STD 1472 H (DRAFT) – *would be useful to add when the document is published*

Type of console	**Maximum total console height from standing surface**		**Suggested vertical dimension of panel (including sills)**		**Writing surface: shelf height from standing surface**		**Seat height from standing surface at midpoint of G**		**Maximum console width (not shown)**	
	A		**B**		**C**		**D**			
	cm	**in**	**cm**	**in**	**cm**	**in**	**cm**	**in**	**cm**	**in**
1. Sit (with vision over top) 1/	117	46	52	20.5	65	25.5	43	17	112	44
	134	52.5	52	20.5	81	32	59	23.5	112	44
	144	56.5	52	20.5	91	36	69	27.5	112	44
2. Sit (without vision over top)	131	51.5	66	26	65	25.5	43	17	112	44
	147	58	66	26	81	32	59	23.5	112	44
	157	62	66	26	91	36	69	27.5	112	44

Type of console	**Maximum total console height from standing surface**		**Suggested vertical dimension of panel (including sills)**		**Writing surface: shelf height from standing surface**		**Seat height from standing surface at midpoint of G**		**Maximum console width (not shown)**	
	A		**B**		**C**		**D**			
	cm	**in**	**cm**	**in**	**cm**	**in**	**cm**	**in**	**cm**	**in**
3. Sit-stand (with standing vision over top)	154	60.5	62	24.5	91	36	69	27.5	112	44
4. Stand (with vision over top)	154	60.5	62	24.5	91	36	NA	NA	152	60
5. Stand (without vision over top)	183	72	91	36	91	36	NA	NA	152	60

NOTE:

1/ The range in "A" is provided to allow latitude in the volume of the lower part of the console; note relationship to "C" and "D".

TABLE XXXIII. Advantages of workstation configurations by type. - from MIL-STD 1472 H (DRAFT) – *would be useful to add when the document is published*

Sitting Workstations	**Standing Workstations**	**Sit-Stand Workstations**
Sitting relieves the stress to the back muscles when standing for a long period of time.	Standing relieves disc pressure and stress caused by the greater curvature of the back that happens when sitting.	Users can sit when the stress to the back legs, hips, back, and neck muscle groups become painful when standing for a long period of time, or stand when the stress caused by the greater curvature of the back that sitting creates becomes painful from sitting.
Sitting relieves the constant state of contraction muscles are in when standing for long periods of time, especially to the legs, hips, and neck muscles.	Users can change postures, to reduce fatigue and boredom; many standing tasks can be done in either a sitting or a standing posture.	Users can change postures, to reduce fatigue and boredom
Sitting uses less energy than standing.	Users can move to see and use components in spaces that would be inaccessible to seated users.	Users can move to see and use components in spaces that would be inaccessible to seated users.
The performance of fine motor skills is not as good when people stand rather than sit.	User's arms can apply more muscular force and make larger movements when at a standing workstation (see 5.10.3.8.2.5.2.c).	N/A

Sitting Workstations	Standing Workstations	Sit-Stand Workstations
N/A	Standing saves space; the users can use flat working surfaces, without requiring additional knee room.	N/A

Discussion. A review of the literature [Source: Karakolis & Callaghan, 2014] and a meta-analysis of 12 studies on the use of sit-stand workstations and lower back musculoskeletal discomfort [Source: Agarwal, Steinmaus, & Harris-Adamson, 2018] showed that people with sedentary jobs can reduce low back discomfort caused by extended periods of sitting with the use of sit-stand desks. Specifically, work-related disorders of the neck, arms, shoulders, elbows, wrists and hands are associated with working with a computer more than six hours per day, particularly in women. In men, moderate associations were seen for computer use more than six hours per day. In women, such disorders were moderately increased with a duration of computer use of more than four hours per day and strongly increased with a duration of six hours or more per day [Source: Blatter & Bongers, 2002].

4. Information Management

4.1 Introduction

Note: There is currently no section in the Human Factors Design Standard (HFDS) on information management.

For the purposes of this annotated bibliography, information management refers to the arrangement, representation, and control of information to optimize operator reception *in the context of other information*. It therefore includes human factors standards and guidelines concerning:

- Timing and location of the display of information for the purpose of getting attention.
- How relatively prominent certain information should be.
- What display attributes should be used for important information.
- How easily an operator should be able to access (physically and virtually) the information.
- How a display should avoid interference or distraction among different information representations (e.g., clutter or occlusion effects).
- How to graphically distinguish information elements (especially when sharing the same place) to allow visual separation for task or semantics.
- Automatic organization of information.

4.1.1 Alarms and Alerts

The display of information for the purpose of getting the user's immediate attention falls into the domain of alerts and alarms. Notably, none of the information from the FAA literature review on visual and auditory symbols (Duncanson, 1994) was included in the HFDS. Duncanson includes Haas and Casali (1993) who studied the perceived urgency of auditory signals in a variety of parameters. Their findings included:

- The higher the pulse level, the greater was the perceived urgency and the shorter the detection time.
- Sequential signals were perceived as less urgent and took longer to detect.
- Time between pulses affected perceived urgency but not detection time.

Also of interest (in Duncanson, 1994) is Blackwell & Cuomo (1991). This study examined the discriminability of symbols and coding techniques of a set of symbols proposed as standards for space and missile warning systems. They found that:

- Participants found larger symbols faster and with fewer errors than smaller symbols.

- Participants found filled shapes fastest, hollow shapes slower and half-filled shapes the slowest.
- Participants preferred simplified, less complex shapes and found them faster.
- Participants found red and green symbols equally fast.
- If markers were added to symbols (in this case, alphabetic letters adjacent to the symbol), participants took longer to locate symbols and made more errors.

The overlap of coding of alerts and alarms and information management needs careful consideration. For example, there are conditions when information, even redundant information, transmitted by both audio and visual channels may mutually interfere, increasing cognitive workload for information-intensive tasks (Kalyuga, Chandler, & Sweller, 2004; Seagull, Wickens, & Loeb, 2001). Regardless of channel, the operator should be provided with sufficient information about the alert condition to assess its true urgency (Wipfli, Ehrler, Bediang, Bétrancourt, & Lovis, 2016). This is especially important where false alarm rates are considerable. The above articles are included in the annotated bibliography. The FAA Symbol Development Guidelines for Airway Facilities (DOT/FAA/CT-TN96/3) also has useful information that could be added to the HFDS. However, the subject of alerts and alarms was out of scope for this task as the material is being revised in a separate task.

4.1.2 Number of Windows

The FAA was particularly interested in research on the effects of the number of open windows on task performance and whether there was an operationally defined recommended limit. However, *no research could be found that addressed the recommended maximum number of open windows* associated with a workstation, application, or task. The only published guidance on the number of windows allowed to be open at one time was based on the display response time, not based on human information processing. “To ensure system response time is not compromised, design into the command and control system a defined upper limit on the number of windows allowed to be open at one time” (DOD-HFDG-ATCCS (1992). Human Factors Design Guidelines for the Army Tactical Command and Control System Soldier-Machine Interface Version 2.0, p. 7-7).

Instead, researchers have accepted that it can be necessary to keep many windows open simultaneously, and so have focused on techniques to more easily manage large numbers of windows. A multi-window user interface allows a user to monitor information from multiple sources at once, giving the user the flexibility to select and arrange windows to maximize situational awareness. However, because windows can overlap, users must carefully position and size windows so that all needed information remains visible, and this managing of windows adds to workload. It is possible for the effort of such window management to cancel the speed advantages of showing more information simultaneously in multiple windows (Plumlee & Ware, 2002). There may be situations when the system should prohibit or discourage overlapping windows (Greenberg, Peterson, & Witten, 1986), and such systems have been proposed (Kandogan & Shneiderman, 1995, 1997; Hutchings & Stasko, 2002; Bradley, 2018). However, none of this research involved air traffic control tasks, nor was any research found to contain guidance on windows management.

Multiple windows also support users' engaging in sequential multi-tasking. Because opening a file or program is time consuming, users are motivated to leave many windows open at once, even those not actively monitored, in order to allow a quick switch of tasks. However, the result is that switching tasks is typically time intensive due to the effort needed to re-arrange multiple the windows for each task (Jeuris, Tell, Houben, & Bardram, 2018).

Any cost-benefit relation between the cost of managing windows and the cost or benefit of open and closed windows will depend on the specific tasks to be performed simultaneously and the operational environment.

The two most common techniques of windows management are:

- Grouping windows
- Miniaturizing windows.

Grouping windows is a feature that supports relating multiple windows to a common abstract task. The group can then be manipulated as a unit (e.g., all related windows brought forward at once for work) to reduce the window management effort associated with task switching.

A group may be created:

- *Automatically* based on window content and/or user behavior, or
- Explicitly and manually by the user.

Automatic grouping saves the user from the effort of creating groups, which, further minimizes window management. However, its effectiveness depends on how well the groups correspond to the users' mental models of the task.

Groups may appear as:

- Clusters of window on a physical or virtual *screen*, or
- Clusters of icons on a relatively small *taskbar*-like region on the screen.

Presenting groups as clusters of windows on the screen provides a single direct concrete representation of the group, but requires either a large physical screen, a large virtual workspace, multiple smaller workspaces (which requires users to track the location of groups when they not in view), or miniaturization of the windows (see below).

No research was found that compared group appearance or automation alternatives in order to derive guidelines on which alternatives are best.

Alternatives to conventional overlapping windows for complex user interfaces avoid the inherent occlusion of content and may provide a superior solution to optimizing the information to show to the user at one time. Kandogan & Shneiderman, 1995, 1997 explored strategies using elastic windows. Matthews, Czerwinski, Robertson, & Tan (2006) explored techniques such as shrinking a window as it is moved to the periphery. Miniaturizing windows are techniques to reduce the amount of screen space used by windows that are not of primary interest. This allows more windows to be present and monitored without overlap, simplifying window management.

The exact appearance of the miniature window may be determined:

- Automatically, or
- By the user manually selecting the content of the miniature.

As with automatic grouping, automatic miniaturization can save the user work, but requires that the resulting miniature still be suitable to the task and not obscure critical information. At a minimum, the information in the miniaturized window needs to be recognizable.

No research was found that compared automatic to manual miniaturizing in order to derive guidelines on which alternative is best.

There are two methods for miniaturizing in the literature:

- Shrinking the window to a thumbnail or other distorted version of itself, or
- Cropping the window to show certain content (at full size).

Studies that have compared the two techniques report that cropping is generally more effective than shrinking (Matthews, Czerwinski, Robertson, & Tan, 2006; Miah & Alty, 2000). However, shrinking is easier to effect automatically, and it is possible that automatic shrinking may be superior to manual cropping for some situations or implementations.

To summarize, the literature does not provide guidance on the maximum number of windows that should be opened, but, instead, provides various versions of design techniques intended to mitigate the negative effects of a large number of open windows. Best practices for windows management that are appropriate for specific tasks need to be developed.

4.2 Information Management - Annotated Bibliography

Baker, J. R. (2003). The impact of paging vs. scrolling on reading online text passages. *Usability News*, *5*(1), 323-327.

> This experiment compared reading prose divided into pages (with forward and back buttons) versus a single scrolling page. Pages loaded instantly and scrolling occurred without perceptible delay. In the page conditions, the prose was split into 2 and 4 pages. In the scrolling condition, half the prose was visible at a time. Scrolling prose was read faster than the 4-page display with no significant difference in comprehension. This implies that arbitrarily splitting prose of modest length into pages imposes an unnecessary burden, assuming the users are very familiar with scrolling.

Bernard, M. L., Hamblin, C. J., & Chaparro, B. S. (2003). Comparing cascading and indexed menu designs for differences in performance and preference. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting*, 1370-1374. https://doi.org/10.1177/154193120304701111

> This experiment compared cascading hierarchical menus at the top or side, with a full-page hierarchical menu, with all menu items continuously visible and grouped in labeled categories.

All menus had two levels. Users found target menu items about 7.5 seconds faster with the full-page menu than the cascade menus. Users reported more disorientation with the cascade menus than the full-page. There was no difference between side versus top cascade menus. Rather than representing information overload, perhaps presenting all menu items at once helps users understand the categorization system used. It also allows the user to select a menu item with a single mouse slew rather than two slews. Finally, many web-based cascade menus are poorly designed (e.g., typically opening on mouse-over), making them more awkward to use than is necessary. Nonetheless, a single-page neatly organized menu should be preferred over a cascade menu when real estate allows.

Bevan, N. (2001). International standards for HCI and usability. *International Journal of Human-Computer Studies, 55*(4), 533-552. https://doi.org/10.1006/ijhc.2001.0483

This document describes the process of the development of international standards and gives an overview of 17 standards documents, mostly from ISO. It is not a compilation of usability guidelines. Interestingly, the author notes that, “The standards provide an authoritative source of reference, but designers without usability experience have great difficulty applying these types of guidelines (de Souza & Bevan, 1990). To apply guidelines successfully, designers need to understand the design goals and benefits of each guideline, the conditions under which the guideline should be applied, the precise nature of the proposed solution, and any procedure that must be followed to apply the guideline” (p. 542).

Brewster, S. A. (1997). Using non-speech sound to overcome information overload. *Displays*, *17*(3), 179-189. https://doi.org/10.1016/S0141-9382(96)01034-7

A pair of experiments tested the use of non-speech sound effect “earcons” to provide user feedback on use of scrollbars and buttons in a graphical user interface. For example, the user interface provided distinct sounds when a button is successfully selected versus when the mouse pointer slips off the button, which visually appear nearly identical. The sound effects resulted in higher user performance, faster error recovery, and lower subjective workload (NASA-TLX) when users experience information saturation. Given controllers often work with headsets, such use of sound could be employed without disturbing colleagues.

Brewster, S. A., Wright, P. C., & Edwards, A. D. (1994, April). The design and evaluation of an auditory-enhanced scrollbar. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 173-179. http://dx.doi.org/10.1145/191666.191733

This experiment tests use of auditory feedback for scrollbar interactions. An organ-sound pitch decreased when scrolling down and increased for scrolling up; scrolling though page breaks boosted volume briefly. Users scrolled to a specified page or searched for specified text. Auditory feedback yielded less subjective workload and greater subject ease-of-use. Users scrolled to a specified page faster with auditory, but the t-test of the difference in the search task was not significant (however, 9/12 users did better with auditory feedback, for a sign test p = 0.073). Auditory feedback reduced the variance of task times in both tasks, perhaps suggesting auditory feedback allowed more consistent control of the scrollbar. There were no differences in error rates.

Chung, P. H. (2006). Changing the interface with minimal disruption: The roles of layout and labels (Doctoral dissertation). Rice University, Houston, TX. https://scholarship.rice.edu/handle/1911/18882

Two experiments and a field study demonstrate that it is more important to have consistent positions for data fields for acquiring information in repeated tasks than to have color-coding or even labeling of data fields. This conflicts with "responsive design" techniques that many current web applications use where field position varies with changes in window or screen size. Given that controllers use a given window repeatedly, but may size the same window differently in order to manage information on different sessions, the need for consistent field position could be emphasized in the FAA HF guidelines.

Avery, L. W. & Bowser, S. E. (1992). *Human factors design guidelines for the Army tactical command and control system soldier-machine interface, Version 2.0* (DTIC AD-A252 410). https://apps.dtic.mil/sti/citations/ADA252410

This reference is included here because it was the only reference that discussed a critical question asked by FAA regarding the recommended number of windows allowed to be open at one time. However, as noted in the HFDS, the purpose of the limit to the number of open windows stated in this document was to ensure that system response time was not compromised. "To ensure system response time is not compromised, design into the command and control system a defined upper limit on the number of windows allowed to be open at one time" (p. 7-7). The effect of the number of open windows on human information processing was not addressed in this document.

Duncanson, J.P. (1994). *Visual and Auditory Symbols: A Literature Review*. (DOT/FAA/CT-TN94/37), Federal Aviation Administration. https://apps.dtic.mil/sti/pdfs/ADA290222.pdf

This review provides guidelines on when to use auditory icons and alarms, and recommended attributes of visual and auditory icons and alarms. Of note are:

Haas, E. C., & Casali, J. G. (1993). The perceived urgency and detection time of multi-tone and frequency-modulated warning signals. Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting. 544-548. This research examined the perceived urgency of auditory signals as a function of various parameters. Their findings included:

- The higher the pulse level, the greater was the perceived urgency and the shorter the detection time.
- Sequential signals were perceived as less urgent and took longer to detect.
- Time between pulses affected perceived urgency but not detection time.

Blackwell, J. S., & Cuomo, D. L. (1991). Evaluation of a proposed space and missile warning symbology standard for graphical displays. Proceedings of the Human Factors Society 35th Annual Meeting, 102-106. This study examined the discriminability of symbols and coding techniques of a set of symbols proposed as standards for space and missile warning systems.

They found that:

- Participants found larger symbols faster and with fewer errors than smaller symbols.
- Participants found filled shapes fastest, hollow shapes slower and half-filled shapes the slowest.
- Participants preferred simplified, less complex shapes and found them faster.
- Participants found red and green symbols equally fast.
- If markers were added to symbols (in this case, alphabetic letters adjacent to the symbol), participants took longer to locate symbols and made more errors.

Edworthy, J., Reid, S., McDogall, S., Edworthy, J., Hall, S., Bennett, D., ... Pye, E. (2017). The recognizability and localizability of auditory alarms: Setting global medical device standards. *Human Factors*, *59*(7), 1108-1127. http://dx.doi.org/10.1177/0018720817712004

In this experiment, the revised standard medical alarms demonstrated superior recognizability and localizability. The revised alarms included greater harmonic density for better localization and less acoustic masking. To improve recognizability, the revised alarms were "auditory icons" based on everyday sounds that were intended to be metaphorically related to their respective meanings. Current FAA HF guidelines provide little detail on the acoustic characteristics recommended for auditory alarms.

Edworthy, J., Reid, S., Peel, K., Lock, S., Williams, J., Newbury, C., … Farrington, M. (2018). The impact of workload on the ability to localize audible alarms. *Applied Ergonomics*, *72*, 88-93. https://doi.org/10.1016/j.apergo.2018.05.006

This experiment showed that high mental workload increases errors in localizing an alarm sound source in a room. Background noise of an operations center also increases errors. When combined with high workload, error rates were 150% more frequent than in the control condition. In work contexts where the physical location of an alarm (e.g., of which device or position) is relevant to the form or urgency of the users' responses, it may be advisable to encode the location in the alarm itself.

Greenberg, S., Peterson, M., & Witten, I. (1986). Issues and experiences in the design of a window management system. *Proceedings of the Canadian Information Processing Society*, 33-44. http://dx.doi.org/10.11575/PRISM/30714

This paper reviews the design issues in management of windows based on experiences developing the Jade system and getting user feedback: (1) Overlapping windows allow more user control (overlapped windows can be manually tiled), but complicate management. Tiling may be preferred for larger screens. (2) A compromise is often necessary between user control and program control of the place and size of windows. (3) Depending on the specifics, it may or may not be a good idea to reformat the data (e.g., zoom out) to fit the window size changes and avoid scrolling. (4) Pop-up hierarchical menus (context menus) should be backed up with keyboard accelerators, toolbars, and direct manipulation for some commands.

Hutchings, D. R., & Stasko, J. (2002). *New operations for display space management and window*

management **(Technical Report GIT-GVU-02-18). Atlanta, GA: GVU Center, Georgia Institute of Technology. https://facstaff.elon.edu/dhutchings/research.shtml**

> This paper proposes that resizing and moving windows should, as space permits, push other windows out of the way, rather than overlapping them, maintaining their relative positions in a natural way. Windows enlarge only in the direction of empty space before interacting with (moving) a window in the other direction. Movements can be successively undone.

Hutchings, D. R., & Stasko, J. (2004). Shrinking window operations for expanding display space. *AVI '04: Proceedings of the Working Conference on Advanced Visual Interfaces*, 350–353. https://doi.org/10.1145/989863.989922

> This paper proposes controls to allow users to crop windows to display only key information needed for monitoring tasks (e.g., portion of an email client that indicates arrival of new mail), thus allowing less clutter from multiple windows. The user manually defines the key region as any arbitrary rectangle, presumably by dragging, and can toggle between cropped and full display.

Jeuris, S., Tell, P., Houben, S., & Bardram, J. E. (2018). The hidden cost of window management. *ArXiv*, abs/1810.04673. https://doi.org/10.48550/arXiv.1810.04673

> This study of the use of Microsoft Windows 7 on a laptop reveals that switching tasks is typically time intensive when each task involves multiple independent windows (multiple applications), consuming an estimated 10 to 20 minutes per working day. Task switching includes configuring the old windows to mark one's place in the task and finding already-opened windows for the new task. Windows 7 Alt-Tab feature (which shows many windows irrelevant to either an old or new task) and the task bar (which groups windows by application, not task) make the latter inefficient. Because opening a file/program is so time consuming, users are motivated to leave many things open at once, even if they may not be used much anymore. Efforts to mitigate include features for users to group windows or files in specific window configurations into tasks that each can be brought up as a unit.

Kalyuga, S., Chandler, P., & Sweller, J. (2004). When redundant on-screen text in multimedia technical instruction can interfere with learning. *Human Factors*, *46*(3), 567–581. https://doi.org/10.1518/hfes.46.3.567.1640

> This series of experiments on training for a multi-step procedure compared simultaneous audio and text presentation of the identical instructions to audio alone and audio and text presented sequentially. In all experiments, simultaneous audio and text resulted in less comprehension and more subjective workload. The lower performance of redundant communication was attributed to the cognitive effort to coordinate simultaneously presented information. The results imply that complex information should be presented in a single channel at a time.

Lischke, L., Mayer, S., Hoffmann, J., Kratzer, P., Roth, S., Wolf, K., & Woniak, P. (2017). Interaction techniques for window management on large high-resolution displays. *MUM '17: Proceedings of the 16th International Conference on Mobile and Ubiquitous Multimedia*, 241–247.

https://doi.org/10.1145/3152832.3152852

This study tested four techniques for managing windows in a large display (three 50” monitors at 80+ pixels per inch). (1) Curved Zooming: ordinary windows in center, compressed windows on “side walls.” This provided a good overview of peripheral tasks, but made the windows hard to read. (2) Grouping: user can group windows and move them as a unit. This was useful for grouping windows into tasks. (3) Spinning: user can pan the desktop to center on a different portion. This was most useful for switching tasks, but it would be useful to be able to pin one primary work area or window group while others can be panned by. (4) Side Pane Navigation: user can jump to a list of all open windows, shown as thumbnails, for selection. This was useful when one does not remember the position of the window on the screen, but it consumed much space and the jumping could be confusing. All techniques were rated as useful.

United States Nuclear Regulatory Commission (2020). *Human-system interface design review guidelines* (NUREG-0700 Revision 3). https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0700/r3/index.html.

This document contains guidance on the use of large screen displays as defined as those that “can be viewed from multiple workstations and locations in a control room” and “typically contain important information that should be commonly available to control room crewmembers.” The guidance offered is for display pages that are too large to be viewed all at once from a single display screen with a level of resolution adequate for users’ tasks (i.e., if the display page was reduced to fit the available space, the text and other visual details would be too small to read. This points to the fact that design guidance must be appropriate to the tasks.

The document includes a discussion of the ways in which windows may be manipulated to adjust the presentation of information in a display screen: closing/opening, resizing, repositioning, layering (overlapping), and tiling (positioning adjacent to another window). The document notes that “The degree of automation of window management tasks may vary. For some systems, all window management tasks are performed manually; in others, they are performed automatically by the information system. Still other window management systems present windows automatically but allow the operator to make manual adjustments” (p. 2-9). It does not, however, offer recommendations as to the conditions under which any given strategy should, or should not, be used. The following may be useful to include in the HFDS:

Integrating Information within Large Display Pages. When users are required to integrate information across a large display, the design should minimize navigation burdens for paging, scrolling, and zooming. [Source: NUREG-0700, 2020]

Robertson, G., Czerwinski, M., Baudisch, P., Meyers, B., Robbins, D., C., Smith, G., & Desney, T. (2005). Large Display User Experience. *IEEE Computer Graphics and Applications*, *25*(4), 44-51. http://dx.doi.org/10.1109/MCG.2005.88

This is a Microsoft advertisement describing (then) prototype tools with some useful information. This article discusses methods for information management on displays from large desktop to wall-sized displays (but does not discriminate between the two). The researchers identified six broad categories of large-display usability issues that they encountered in their previous work:

- "Losing the cursor. As screen size increases, users accelerate mouse movement to compensate and it becomes harder to keep track of the cursor. The faster the mouse cursor moves, however, the more likely users are to lose track of it. In addition, as screen size increases, it becomes increasingly difficult to locate a stationary cursor. In addition to an 'auto locator' to the cursor, The recommended technique is to fill the space between the cursor's current and previous position with additional fill-in cursor images to create a high-density cursor to bridge gaps between cursor positions.
- Bezel problems. Bezels introduce visual distortion when windows cross them and interaction distortion when the cursor crosses them. The ability to move windows is recommended to get around this issue.
- Distance between related information. As screen size increases, accessing icons, windows, and the start menu across large distances is increasingly difficult and time consuming. The article describes techniques that were under development at the time of the article designed to help resolve such issues.
- Window management problems. Large displays lead to notification and window-creation problems because windows and dialog boxes pop up in unexpected places. Window management is made more complex on displays that use multiple monitors. An effective task management system should therefore provide convenient mechanisms that allow users to:
  - group relevant sets of windows,
  - organize the groups and windows within the groups,
  - switch between groups, and
  - lay out the groups and windows on the screen.
- Number of open windows (referred to as 'Task management problems'). The authors note that as screen size increases, so too does the number of open windows. "As a result, users engage in more complex multitasking behaviors and require better task management mechanisms." Several prototype tools were suggested that all involved the movement and/or resizing of windows.
- Configuration of multiple monitors. When users remove a monitor from the display configuration, they can lose windows as well. Also, different monitors might have different pixel densities. The authors note that "currently support is poor for dealing with such heterogeneity."

Smith, G., Baudisch, P., Robertson, G., Czerwinski, M., Meyers, B., Robbins, D. C., & Andrews, D. (2003). GroupBar: The taskbar evolved. *Proceedings of OZCHI'03: Annual Conference of the Australian Computer-Human Interaction Special Interest Group,* 41-50. https://www.microsoft.com/en-us/research/publication/groupbar-the-taskbar-evolved/

"As displays become larger, users leave more windows open for easy multitasking." This study tested a feature to allow users to group windows which can then be accessed as a unit with a single click. The challenge is minimizing the user effort for creating a group. Groups are icons on a popup, where selecting a group lists for selection the windows (as icons) that belong to it. Each group includes a tab to bring all windows to foreground at once. Context menu items also allow minimize, ungroup, arrange (in several basic patterns), and close all windows. Users can drag and drop window icons within and between groups, and to other windows to create a new group. Windows of a group are not necessary proximal on the screen, but persist as arranged by the user. Users were found to be satisfied with GroupBar. With tasks switching experimentally induced, users were faster in completing tasks with GroupBar.

Stevens, C., Perry, N., Wiggins, M., & Howell, C. (2006). *Design and Evaluation of Auditory Icons as Informative Warning Signals* (Technical Report). Canberra, AU: Australian Transport Safety Bureau. https://www.atsb.gov.au/publications/2006/grant_b20050120_001/

These two experiments tested the use of caricatures of everyday sounds for warnings on the flight deck, where the sounds bore a semantic relation to the hazard being indicated. Compared to arbitrary sounds (e.g., beeps), these “auditory icons” were learned faster, reacted to faster, and identified more accurately. Warnings also tended to be learned faster and were more accurately identified when auditory and visual indicators (whether iconic or arbitrary) were combined.

Stopper, R., Sieber, R., Wiesmann, S., & Schnabel, O. (2012). *Graphical User Interface – Layout and Design* (Technical Report). Zurich, Switzerland: Institute of Cartography and Geoinformation, ETH Zurich. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.527.6895&rep=rep1&type=pdf

This brief textbook provides guidance on design and layout of graphical user interfaces, with specific content regarding interactive maps. It includes specific examples of do’s and don’ts and examples from production applications.

Tan, D. S., Meyers, B., & Czerwinski, M. (2004). WinCuts: Manipulating arbitrary window regions for more effective use of screen space. *Proceedings of ACM Human Factors in Computing Systems CHI 2004,* 1525–1528. http://dx.doi.org/10.1145/985921.986106

This paper proposes a feature to allow users to show an arbitrary rectangular “cut” of window contents in small windows to support monitoring. Users select a cut by drag-and-drop while holding down Ctrl-`. Any updates to the parent window also appear in the cut and the user can interact with any controls in a cut. Users can share cuts across devices. Each cut is a window on the taskbar that is managed like any window.

Tashman, C., & Edwards, W. K. (2012). WindowScape: Lessons learned from a task-centric window manager. *ACM Transactions on Computer-Human Interaction*, *19*(1) 8-1-8-23. https://doi.org/10.1145/2147783.2147791

This paper proposes a window manager where inactive windows are thumbnails that expand to the position they were last in. Users position a thumbnail separately from positioning the corresponding expanded window. Users can pop all thumbnails to the front to find a window that may be occluded by the active window. A bar across the top shows a thumbnail history of windows' configurations for selection. Users can save and retrieve configurations. Users generally reported that window thumbnails and history bar were useful, as was the ability to pop up occluded thumbnails. They generally felt that the system made it easier to return to a task and find a window.

Turetken, O., & Sharda, R. (2004). Development of a fisheye-based information search processing aid (FISPA) for managing information overload in the web environment. ***Decision Support Systems*****,** ***37*****(3), 415-434. https://doi.org/10.1016/S0167-9236(03)00047-2**

This paper proposes clustering search results into a hierarchy represented visually with nested boxes that the user can selectively open. As another instance of the "fish-eye" visualization of data, the wider context (higher levels of the hierarchy) remains visible as relatively smaller boxes as the user drills down into lower levels of the hierarchy.

Van Laar, D., & Deshe, O. (2007). color coding of control room displays: The psychocartography of visual layering effects. ***Human Factors*****,** ***49*****(3), 477-490. https://doi.org/10.1518/001872007X200111**

This experiment tested the use of color to indicate importance of objects represented in graphic displays (bar graph, line graph, schematic) and tabular displays. Muted pastel low-contrast graphics and labels were compared to a black-and-white rendering (no gray scale) and high-saturation colors. In all conditions, users searched or compared data rendered in black text within the graphics, not the information the graphics themselves represented. Muted graphic coloring had faster response times, lower subjective workload, and higher subjective ratings than either high-saturation or black and white in all displays except the bar graph. The poor performance of muted colors for bar graphs was attributed to the static labels having poor contrast with the background. The study purports to test use of monocular cues to distinguish the importance of the information. However, it is plausible that all results may be attributed to the relative luminance contrast of target information versus a background of "distractor" information. The results suggest that performance for selected information in a display may be improved by enhancing the information's visual contrast, although there may be a performance decrement for the remaining information.

van Nimwegen, C. C., Burgos, D., van Oostendorp, H., & Schijf, H. H. J. M. (2006). The paradox of the assisted user: Guidance can be counterproductive. ***CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*****, Montreal, Quebec, Canada, 917-926. https://doi.org/10.1145/1124772.1124908**

In this experiment, users used graphic software to assign conference speakers to time slots of conference rooms to satisfy a list of constraints. In a "guided" condition, when the user selected a speaker, the system highlighted all slots that satisfied the constraints of that speaker, although some highlighted slots could be unsuitable because they set up a conflict with another speaker's constraints. In the non-guided condition, the system gave no such information. Total time to complete the task was the same across conditions, but the guided users were more likely to experiment with slot assignments, while non-guided users made fewer superfluous moves and thought more before starting any assignments. There are some indications that non-guided users remembered the constraints more and proceeded with a more deliberate and conscious strategy. The experiment implies providing assistance may lead to a less deep understanding of the situation, which may be undesirable in some tasks. However, given there is guidance, perhaps such understanding is less necessary in most tasks. Overall advantages of guidance or non-guidance are ambiguous as workload was not measured.

Wagner, D., Snyder, M., Dutra, L., & Dolan, N. (1997). *Symbol Development Guidelines for Airway Facilities* (DOT/FAA/CT-TN96/3). Federal Aviation Administration. https://apps.dtic.mil/sti/citations/ADA326779

This article contains guidelines on the type of data and conditions for using visual and auditory coding, including specific kinds of each (e.g., alphanumeric, shape, line, icon, color; frequency, pulse shape, and artificial speech). It was not cited in HF-STD-001B.

Waldner, M., Steinberger, M., Grasset, R., & Schmalstieg, D. (2011). Importance-driven compositing window management. ***Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 959–968. https://doi.org/10.1145/1978942.1979085.**

This study evaluates a feature to display portions of all opened and overlapping windows in see-through layers, where the portion displayed is that with greatest salience as indicated by computer vision processing (i.e., regions that visually contrast with their surroundings. The greater the salience, the less transparent the portion. A keyboard shortcut displays the window portions. Users can select and interact the portions, where the layer with the greatest salience gets focus, something which testing found to be necessary for superior user performance. In two out of three tasks tested, users were able to more quickly find information in occluded windows with this feature than with Alt-tab. As another feature, when a user drags a window, windows underneath also move to minimize overlap of salience regions, but this was not tested.

Wolfe, J. M. (2005. How might the rules that govern visual search constrain the design of visual displays? (Invited paper). *2005 Society for Information Display, International Symposium Digest of Technical Papers*, *36*(1), 1395-1397. DOI:10.1889/1.2036267

This summary of research provides basic rules for guiding visual displays for findability or detectability of graphically represented objects. Visual search can be accelerated if the target differs from the distractors on a basic visual feature (e.g., color, edge orientation), especially if it is a clear categorical difference. Objects with distinct visual features (relative to the background) also tend to attract attention. Any individual target will be less salient the greater the variation in the features of the distractors. Targets are relatively findable if they are defined by distinct features from two different dimensions (color and orientation), but less so if they are from the same dimension (e.g., an object with a distinct combination of colors). Imagery tends to be parsed into contiguous objects, so distinct objects are relatively findable, but objects distinct on a single component-feature combination are not.

Wipfli, R., Ehrler, F., Bediang, G., Bétrancourt, M., & Lovis, C. (2016). How regrouping alerts in computerized physician order entry layout influences physicians' prescription behavior: Results of a crossover randomized trial. *Journal of Medical Internet Research*, *3*(1), 1-10. https://doi.org/10.2196/humanfactors.5320

> This study compares displaying alerts near the triggering information in a complex physician order entry form versus a grouping all alerts in a centralized location on the form. Interviews with physicians suggested that the centralized location, where all alerts are managed as a separate task from initial ordering, can reduce the nuisance interruptions (many alerts provide information the physician already knows) resulting in better performance. The centralized location reduced workload and distraction as indicated by eye-tracking. There did not appear to be any change in order errors (i.e., later corrections). The results showed that how the alerts are organized affects performance and user satisfaction and implies alerts should not require user interaction to be identified when users can predict the alert, even if this means removing the alert from its immediate context.

Woodruff, A., Landay, J., & Stonebraker, M. (1998). Constant information density in zoomable interfaces. *AVI '98: Proceedings of the Working Conference on Advanced Visual Interfaces*, 57-65 https://doi.org/10.1145/948496.948505

> This informal study proposes automatically hiding map details when zooming to smaller scales (larger areas), consistent with cartographic conventions. This includes hiding less significant objects, aggregating objects, decreasing attributes to code, decreasing number of value categories to code, and using smaller symbols. Users can select with sliders the range of scales that each category of detail appears; this also shows the current scale. Such automatic control of density may be preferred for tasks that include many changes in zoom, as long as users are aware of what is hidden.

4.3 Other articles of interest

Baharuddin, R., Singh, D., & Razali, R. (2013). Usability dimensions for mobile applications - A review. *Research Journal of Applied Sciences, Engineering and Technology, 5*(6), 2225-2231. https://doi.org/10.19026/RJASET.5.4776

> While drawing from the literature on the usability of mobile applications, this review lists characteristics of usability that may be applicable to the development of human factors guidelines for any software device. The following usability characteristics were found in at least three of the nine empirical studies in the review: effectiveness, efficiency, satisfaction, usefulness, aesthetics, learnability, simplicity, and intuitiveness. The review does not formally define these characteristics; rather, the definitions and distinctions would need to be extracted from the source studies.

Badros, G. J., Nichols, J., & Borning, A. (2000). SCWM: An intelligent constraint-enabled window manager (American Association for Artificial Intelligence, AAAI Technical report SS-00-04).

***Proceedings of the AAAI Spring Symposium on Smart Graphics,* Palo Alto, CA. https://www.aaai.org/Papers/Symposia/Spring/2000/SS-00-04/SS00-04-013.pdf**

> This paper introduces the Scheme Constraints Window Manager (SCWM), which is a toolbar for users to constrain size and position windows (e.g., keep height/width below limit, keep window to left/right of another). The constraints limit window changes from other events (e.g., moving or resizing one window, moves/resizes its neighbor to maintain a relation). Constraint combinations can be visually edited, saved, and applied to arbitrary sets of windows.

Bardram, J. E., Bund-Pedersen, J., & Soegaard, M. (2006). Support for activity-based-computing in a personal computing operating system. *CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* Montréal. https://doi.org/10.1145/1124772.1124805

> This study asserts that the user interface (UI) be based, not around documents or applications, but activities, where each spans multiple documents, applications, users, and devices. A user can suspend and resume a given activity as a unit. The UI replaces Windows' (misnamed) taskbar with an activity bar where each icon is a frequent activity, and all activities are listed under a dropdown with thumbnails. A toolbar has buttons to create a new activity, suspend an activity, and invite participants to an activity. A title bar toggle button lets the user pin or unpin a window to the current activity. User can "zoom out" of an activity (preserving relative position and size of windows) to better view and select its windows, and slide the viewport around the arrangement of windows to change what's visible when zoomed in. User performance was "trivially" faster than ordinary Windows and was preferred. The study indicates that each window needs to be able to belong to more than one activity. More work is needed on handling the lifecycle of activity (build up, maintenance, merging and splitting, retirement). A window opened during an activity may need to be part of the activity, or may simply be an interruption, a fact that thwarts automatically building activities.

Bradley, E. (2018). An infinite-pane, zooming user interface window manager and survey of x window managers [Master's thesis, Oakland University, Rochester, MI]. https://our.oakland.edu/handle/10323/4785

> This thesis reviews and categorizes window managers, identifying their features and trends, focusing mostly on window managers for UNIX-based XWindows systems. The thesis then describes a new window manager with an infinite virtual desktop that extends beyond the boundaries of the screen. The user can pan and zoom around the desktop to find and use windows. New windows, by default, appear in empty space to minimize occasions of overlap. The thesis includes no user testing.

Bederson, B. B. (2000). Fisheye menus. *UIST '00: Proceedings of the 13th Annual ACM Symposium on User Interface Software and Technology*, 217-225. https://doi.org/10.1145/354401.354782

> This pilot study introduces "fisheye menus" where items around the users' current position are fully detailed, and more distant items appear as thumbnails or labeled groups, thus allowing a very long list of items to appear on the screen without scrolling or subdividing. In use of an alphabetically sorted menu of 100 websites, users preferred the fisheye menu over scrolling

arrows, scrollbars, and hierarchical (cascade) menu when browsing for something of interest to the user. Users preferred the hierarchical when directed to find specific web sites. Quantitative results are descriptive only and lack inferential statistics. Qualitative results suggest users may like the fisheye menu more, compared to the other menu options, once they are familiar with it.

Bernstein, M. S., Shrager, J., & Winograd, T. (2008). Taskposé: Exploring fluid boundaries in an associative window visualization. UIST'08 - *Proceedings of the 21th Annual ACM Symposium on User Interface Software and Technology*, 231-234. https://doi.org/10.1145/1449715.1449753

This paper suggests that each window may be associated with another to varying degrees as the tasks evolve. The Taskposé window manager shows thumbnails of windows sized by importance and positioned by association, which the user has to zoom in on. Importance is equal to how often the window gets focus. Association is how often the user switches between two windows. Ten users generally found Taskposé useful, especially when the number of open windows exceeded space on the taskbar. However, users felt a need to be able to override the size and positions. Multi-tasking tended to make windows from separate tasks become close to each other.

Furnas, G. W. (2006). A fisheye follow-up: Further reflections on focus + context. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Montreal, Quebec, Canada. https://doi.org/10.1145/1124772.1124921

This conceptual paper analyzes representation of focal information in context. It proposes that the interest in an object depends positively on its importance and negatively on its distance from the user's current focus. Techniques of combining focus and context includes "distortion" visualizations, differential magnification (e.g., overview inserts, zooming where context and focus are temporally separated), and differential resolution (without size or shape changes). These techniques control both what is shown in the context and how it is shown. Information selected from the context should be what's important to the user (e.g., headings from other sections of the document, not thumbnails of pages; zooming assumes larger things are more important, but this isn't always the case). Various theories help identify what information from the context needs to be included.

Ham, D. H., & Yoon, W. C. (2001). Design of information content and layout for process control based on goal–means domain analysis. *Cognition, Technology & Work*, *3*, 205–223. https://doi.org/10.1007/s10111-001-8003-z

This experiment demonstrates that displaying information at multiple levels of abstraction in an integrated layout facilitates operations and fault diagnosis. In the most effective layout, displays of abstract attribute values (which is algorithmically derived from system-measure physical attributes) were placed between displays of the physical attribute values. This is consistent with the means-goals (cause-effect) relations among the physical attributes. This implies that system user interfaces for tasks involving multiple interdependent entities would benefit from layouts spatially organized by the interdependencies that include derived attributes to highlight and summarize the interdependencies.

Kandogan, E., & Shneiderman, B. (1995). ***Elastic windows: Improved spatial layout and rapid multiple window operations*** **(Technical research report TR 95-89). College Park, MD: Institute for Systems Research, University of Maryland. http://hdl.handle.net/1903/5671**

> This paper proposes tiling related windows (or panes) in a nested hierarchy, where input to one pane propagates to subordinate panes. Pane stretch or shrink as other panes are added or removed during the task. Commands allow operations on multiple windows at once. Hierarchy level was indicated by border color. Compared to conventional overlapping windows, these features simplify window management and use space more efficiently.

Kandogan, E., & Shneiderman, B. (1997). Elastic windows: evaluation of multi-window operations. CHI '97: ***Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems,*** **Atlanta, GA, 250–257. https://doi.org/10.1145/258549.258720.**

> This experiment compares elastic windows, described in Kandogan and Shneiderman (1995), with conventional overlapping windows. It finds that elastic windows are quicker for setting up and switching between task environments, and for executing the tasks involving (1) sequentially scanning each window, (2) comparing contents of windows, (3) attending to a subset of all open windows, or (4) revisiting a subset of all open windows.

Lindberg, T. (2003). Effects of information density and size on the perception of graphics in user interfaces [Master's thesis, Helsinki University of Technology, Helsinki, Finland]. http://www.soberit.hut.fi/T-121/shared/thesis/Lindberg-MThesis.pdf

> In this experiment with squares (2x2 to 10x10) of unframed colored icons, space between icons (varying from 0% of icon width to 200%) had no effect on search time. Search time was roughly linearly related to the number of icons, with minimal numbers at the limits of human reaction time. Users most preferred spacing of 100% of icon and least preferred 0%. Search times elevate when icons were smaller than 0.7 degrees (equivalent to about 32 pixels on a 100 px/in screen viewed at 25 inches). This implies that icons can be placed as close as possible to each other (without overlapping) as real estate limits dictate without impacting human performance. It is possible that users may find such closely spaced icons subjectively acceptable if they are framed or separated by rules. For purposes of search, there is no reason to space icons more than 100% apart. Icons need to be relatively large for optimal performance calling into question the wisdom of recommending icons when space is limited.

Matthews, T., Czerwinski, M., Robertson, G., & Tan, D. (2006). Clipping lists and change borders: improving multitasking efficiency with peripheral information design. ***CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,*** **989-998. https://doi.org/10.1145/1124772.1124920**

> In this experiment, when users moved a window to the periphery, the window shrunk to allow more space for the central window. In one condition, the shrunk window presented a thumbnail of the content, while in the other it presented a user-adjustable fragment of the window content. The experiment also tested changing the border color to indicate content changes in shrunk windows. Users performed tasks that included events that could prompt action (e.g.,

mail arriving, upload completed). Content fragment led to faster tasks times and fewer switching among tasks, implying better workflow control (less checking to see if one needs to return to another task). Changing borders increase task switching, perhaps because they didn't indicate what had changed, so the user couldn't accurately judge if it was important to resume the task. The results imply that presenting discrete relevant semantic summary of non-current tasks aids task management of multitask environments.

Miah, T. & Alty, J. L. (2000). Vanishing Windows—a technique for adaptive window management. *Interacting with Computers*, *12*(4), 337–355. https://doi.org/10.1016/S0953-5438(99)00003-X.

Given users tend not to close windows, they can be overwhelmed by the number of opened windows as tasks evolve. This paper proposes to automatically reduce the size of a window over periods of disuse until it closes. Windows shrink in from overlapped areas first, becoming tiled. Experiment finds it is better to crop the window content than shrink it; documents are easier to identify by content than format. Cropping around illustrations in a document makes the window easier to identify than cropping around text. The system could also label a document by keywords – words that are unique to a document but relatively frequent within it. It's best if controls like menus and toolbars get cropped out.

Oliver, N., Smith, G., Thakkar, C., & Surendran, A. C. (2006). SWISH: Semantic analysis of window titles and switching history. *IUI '06: Proceedings of the 11th International Conference on Intelligent User interfaces*, 194–201. https://doi.org/10.1145/1111449.1111492

This paper proposes automatically relating windows into tasks based on their sequential activation and semantic similarity of window titles. Key words to label groups can be pulled from titles. The algorithms were tested on four hours of one user performing five different tasks, plus spurious use of other windows that didn't belong to any task (~25% of the windows). Measures of association could be used in Groupbar to suggest group membership and names.

Plumlee, M. & Ware, C. (2002). Zooming, multiple windows, and visual working memory. *AVI '02: Proceedings of the Working Conference on Advanced Visual Interfaces*, 59–68. https://doi.org/10.1145/1556262.1556270

In this experiment, users were tasked to find a pattern in one part of a screen that matches another probe part of the screen. The independent variable was either using a zoom function to see each part of the screen in detail, or a feature to make a window of fixed magnification for two parts of the screen at once (probe part and a candidate part). Users could identify reasonably likely candidates at minimal magnification. When the pattern was complex (more components), performance was faster with window function, apparently because the users could not remember the probe pattern and would have to zoom out of candidate and back in on probe to make the comparison. Overhead for the window function was rather artificially increased by initially opening the windows at an unusable size, forcing manual adjustment. Thus, performance was faster for zoom than windows with simple probe patterns users could memorize. The windows function consistently had fewer errors. The experiment illustrates the possibility of window management canceling out the speed advantages of showing more information simultaneously in a search task rather than spreading it temporally.

Robertson, G., van Dantzich, M., Robbins, D., Czerwinski, M., Hinckley, K., Risden, K., … Gorokhovsky, V. (2000). The task gallery: A 3D window manager. *CHI '00: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 494-501. https://doi.org/10.1145/332040.332482

This review introduces a window manager where windows may be grouped on walls of a 3-D hallway. Users can multi-select windows, and the system moves them together side-by-side, zooming out as necessary. Users were found to generally be able to remember what tasks they made and where they put them.

Robinson, A. C. (2013). Highlighting in geovisualization. *Cartography and Geographic Information Science*, *38*(4), 373-383. https://doi.org/10.1559/15230406384373

This paper catalogs different means of highlighting that is applicable to irregular graphic object images. These include color outlining, possibly with halo effects or contour lines; leader lines, possibly connecting the same objects in different perspectives; sharpness, to induce a depth of field effect; transparency, specifically for non-selected objects; and data tag presentation (or removal for non-selected). These provide alternatives to area shading (including reverse polarity), which may not be acceptable due to area color encoding data for the object.

Rosenholtz, R., Li, Y., Mansfield, J., & Jin, Z. (2005). Feature congestion: A measure of display clutter. *CHI '05: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 761–770. https://doi.org/10.1145/1054972.1055078

This experiment proposed objectively measuring clutter as the variability of visual features over an image (color, spatial frequency of edges, and their orientation). Subjective ratings of clutter were correlated with this measure. The modeling implies that target findability varies positively with the difference of its visual features with the local background and negatively with the variability of the features in the local background. This suggests that making each object visually distinct on a feature does not necessarily result in all objects having high findability because this raises the local variability counteracting the effect of the difference. Rather, only designer- or system-selected, high-priority objects can have high findability.

Seagull, F. J., Wickens, C. D., & Loeb, R. G. (2001). When is less more? Attention and workload in auditory, visual, and redundant patient-monitoring conditions. *Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society*, *45*(18), 1395-1399. https://doi.org/10.1177/154193120104501817

This experiment compared operator ability to detect out-of-bounds values with visual, auditory, and combined visual-auditory continuous displays while the operators performed a visual tracking task. Auditory had slower response times than visual, with or without the tracking task. Combined auditory and visual was not significantly different from visual alone. However, tracking task performance was worst with combined visual and auditory display, followed by visual alone, with auditory having the best performance. This does not appear to be due to the combined condition prompting more checks away from the tracking display towards the visual displays relative to the visual display alone. Rather, it appears to be due to the cognitive load of coordinating the visual and cognitive information flow. This implies that combined use of auditory and visual display has the potential to seriously distract the operator from a simultaneous visual task, rather than providing "the best of both worlds."

Shneiderman, B. (2003). The eyes have it: A task by data type taxonomy for information visualizations. In B. Bederson & B. Shneiderman (Eds.), *The craft of information visualization: Readings and reflections* (pp. 364-372). Burlington, MA: Morgan Kaufmann. https://doi.org/10.1016/B978-155860915-0/50044-5

This conceptual paper divides data types or structures by number of dimensions (one to three, plus multi-dimensional, as attributes of an object), plus temporal, tree, and network. Basic operations include (a) view overview, (b) zoom, (c) filter, (d) view details, (e) view relations, (f) manipulate history (undo, redo, refine-and-replay), and (g) extract data or parameters to another format or space (e.g., export to file). It is implied that a database application should by conventions support all these operations, unless any are known to be irrelevant for the tasks. Dynamic (instant apply) filtering is generally helpful. Often simple Boolean query expressions is sufficient (OR only within an attribute, AND only between attributes). When more complex expression is needed, a more sophisticated interface is called for, such as those graphically employing a plumbing metaphor.

Skupin, A. (2000). From Metaphor to Method: Cartographic Perspectives on Information Visualization. Proceedings of the *IEEE Symposium on Information Visualization (INFOVIS)*, Salt Lake City, UT. https://dl.acm.org/doi/10.5555/857190.857692

This paper proposes importing proven conventions from cartography to abstract information visualizations represented in two dimensions. This includes cartographic topics such as generalization, feature labeling heuristics, visual hierarchy, data encoding via semiotic principles, and color usage.

4.4 Annotated Bibliography of Other Human-Computer Interaction Topics of Interest

The following is a list of additional topics for consideration in inclusion in a future revision of the HFDS section on Human-Computer Interface:

- **Considerations related to web sites, web applications, and mobile applications**. These new platforms have conditions and limitations regarding user interfaces that should be addressed wherever web or mobile applications are used (Baharuddin, Singh, & Razali, 2013). These platforms have also evolved some design conventions that do not necessarily have sound human factors support, e.g., paging, certain responsive design, default table behavior (Baker, 2003; Bernard, Hamblin, & Chaparro, 2003; Chung, 2006). US GSA and Department of Health and Human Services' Usability.gov also has evidence-based guidelines for web sites.
- **Automatic control of information presentation**. While the HFDS provides wide coverage of the manual control of information presentation, information-intensive tasks may benefit from effective use of automatic control of information presentation. In addition to the automatic control of multiple windows as described above, there is automated control of information presentation *within* a window to improve information management. Research has provided various forms for accomplishing this through such features as fisheye views (Bederson, 2000; Furnas, 2006; Turetken & Sharda, 2004), intelligent agents (Edmunds & Morris, 2000), and constant density zooming (Woodruff, Landay, & Stonebraker, 1998). These techniques have the potential of freeing the user from the task of configuring information for use, allowing more time for actually using the information. Research is needed to explore automatic control of information presentation that is domain and task-specific.
- **Support of complex tasking**. Most complex systems will need to provide features to support user multi-tasking. This includes addressing other issues beyond those concerning multiple windows. The guidelines, for example, could support indicating one's place in one task so it may be restarted at the right point after attending to another task (Halverson, 1994; Jeuris, Tell, Houben, & Bardram, 2018).
- **Support for system analysis and troubleshooting**. The HFDS would benefit from more expansive coverage of the characteristics of a user interface intended for analysis and troubleshooting (e.g., for airways facilities tasks), rather than real-time normal tactical intervention. This includes representing multiple levels of abstraction of the situation and the relations among system components (Ham & Yoon, 2001).
- **Cartographic considerations**. While the FAA *Human Factors Design Standard* includes a section on maps, the section may benefit from recent research on cartography (Robinson, 2013; Stopper, Sieber, Wiesmann, Schnabel, 2012; Woodruff, Landay, & Stonebraker, 1998), including principles of semiotics (Skupin, 2000). Many of these guidelines on map displays can also be applied to any graphic visualization of information (Skupin, 2000; Van Laar & Deshe, 2007).

5. Research Recommendations

5.1 Sit/Stand Workstation

When sit/stand workstations are considered for use in an operational context, the following should be examined to determine operational suitability:

- **The effect on operationally required teamwork**. An operational assessment would need to determine whether the display is suitable in the range of heights for viewing needed information by all team members in all operational postures, or if constraints on its use are recommended.

5.2 Large and Curved Displays

When large and/or curved displays are considered for use in an operational context, the following should be researched to determine operational suitability:

- **The interaction of color shifts on large displays (as a function of viewing angle) and the colors on the FAA color palate (viewed as acceptable to be used by those with color deficiencies).** The effects of these shifts need to be considered within the range of settings available to the user by the range of color deficiencies in potential users. While color shifts can be predicted with modeling, they should be measured with the proper equipment under all anticipated operating conditions (such as the full range of settings available in the preference sets). Once these measurements are obtained, the color contrast of all targets on all backgrounds can be computed at different locations on the display to determine whether the colors are likely to be identifiable. This modeling would be followed by testing with users with the full range of color deficiencies that could be found in the user population, with the task of identifying the colors while presented on all anticipated background colors. Note that it is not sufficient for users to be able to determine that the two colors appear different (i.e., discriminate the colors), it is necessary that users are able to identify the colors for color coding to be useful. Any operational color palette proposed should be evaluated in a simulated operational environment with users performing operational tasks that involve recognizing the colors presented.
- **The preferred curvature for a given monitor size, the number of simultaneous users, the tasks, and the environment in which the monitor will be used**. When participants were asked to adjust the curvature of the display for various static images, the subjective optimal curvature varied with the displayed content and was significantly different for games than for the text or map (Choi, et al., 2015). The authors concluded that further studies should be conducted on the preferred curvature for different monitor sizes, viewing distances, and moving patterns. For an ATC application, it would be necessary to determine whether curvature effects the perceived distances between targets. The usability of a large or curved display must be assessed under all the operating conditions under

which it is expected to be used. This means that if more than one observer will be using the display simultaneously, the assessment of the color contrast (as described above) needs to be assessed from all anticipated different viewing positions.

- **Effect of screen size and curvature on reaction time to alerts**. With a larger screen (especially one intended for viewing by multiple users) the reaction time to alerts is likely to increase with the distance from a user's central field of view. For a range of screen sizes and curvature (or a proposed screen size and curvature), eye movements should be monitored while completing a typical task. Response times and accuracies to identification of alerts should be measured and associated with the distance from foveal attention when the alert is first presented, as well as response time and accuracy of alert identification. The results of such research would determine whether a proposed alerting scheme is operationally suitable for a given display size and curvature, or if adjustments need to be made.

5.3 Automation and Information Management

The research recommendations for the topics of automation and information management have been combined because of the significant overlap in content of research needs. These two complex areas are linked by the fact that many of the methods to assist a user in management of an abundance of information are, or can be, automated. Whether or not they *should* be automated depends on the tasks and environment and require operational assessment. For example, automatic grouping of windows saves the user from the effort of creating groups for information management. The presentation of information *within* a window can also be automatically controlled. However, the effectiveness of such automation depends on how well the groups of windows or automatic presentation of information within a window correspond to the users' mental models of the task and the information needs of the user as they change over time.

- **Research is needed to develop strategies for windows management that are appropriate for specific tasks in specific environments**. No research could be found that addressed strategies such as the recommended maximum number of open windows associated with a workstation, application, or task, or the best use of various window management strategies in air traffic or airways facilities tasks. This would be the first step in determining whether automated tools need to be developed to assist the user in windows/information management, or if training on best practices is sufficient.
- **Strategies for individual users (e.g., controllers, airways facilities specialists) for windows/information management should be researched based on sets of tasks that are expected to be performed simultaneously.** Such research needs take the operational environment into account and focus on the performance of operational teams, where appropriate (not just an individual performer). It should also consider the effect of interruptions on tasks and ways to assist users in dealing with interruptions while minimizing human error. Proposed strategies or automated tools could be developed using part-task simulations, but any determination as to whether the strategies are operationally suitable would require a full-mission simulation using representative

users and representative tasks. The workload level should be varied, since the usefulness of automated tools varies with workload. Objective measures (such as eye tracking, error rates, and reaction times to time-sensitive tasks) should be combined with subjective measures (such as personal assessments of the usefulness of the strategies or tools). The results of such testing and evaluation would determine whether the proposed strategies or tools for information/windows management are operationally useful and effective.

- **Taxonomy of information requirements for current and future tasks**. An operational assessment of current and future tasks and their information requirements should be conducted to identify needs for future tools for information management. This would require developing a taxonomy of information required by task (and the various presentations of the same information, if appropriate). The importance of each type of information would be rated by subject matter experts by task. This information taxonomy would be used to ensure that critical information is always present, important information is readily available, and information that is not needed is not distracting nor contributing to display clutter. When applied to future tasks (such as those required for Trajectory-Based Operations), such an analysis of information by importance would support identification of what would be useful in the area of automated decision support tools for specific applications.
- **Operational assessment of tools.** Once tools are developed, operational assessments are needed to ensure that the tools are suitable and properly integrated into the workstation, and to identify any necessary adjustments. Procedures for operational testing and evaluation are well known and include representative users performing representative tasks and in a full-mission simulation with objective and subjective measures of performance.
- **Continued performance monitoring**. Once new tools or procedures are implemented, ongoing performance monitoring is recommended to refine procedures and recommend 'best practices' for operations. Such performance monitoring should include objective measures of performance of the procedure or tool, anonymous reports of user errors or other problems, and assessment of operational benefits associated with the procedure or tool.

Appendix - Checklist of items removed or revised from the Automation Chapter

KEY

REMOVED
REVISED (Note that if the should/shall column is highlighted, the text was changed from a 'shall' to a 'should' or vice versa.)
IDENTIFIED AS MATERIAL TO BE MOVED INTO OTHER DOCUMENTS

Should/ Shall	Guideline Number		Guideline title	Guideline
	NEW	**OLD**		
Should		5.1.1.1	Minimum automation human factors requirements.	An automated system should
				a. provide sufficient information to keep the user informed of its operating mode, intent, function, and output;
				b. inform the user of automation failure or degradation;
				c. inform the user if potentially unsafe modes are manually selected;
				d. not interfere with manual task performance; and
				e. allow for manual override.
Shall		5.1.1.2	Place user in command.	Automated systems shall prevent the removal of the user from the command role.
Shall	5.1.2.2	5.1.1.3	Automate only to improve performance.	Functions shall be automated only if they improve system performance without reducing human involvement, situation awareness, or human performance in carrying out the intended task.
Should	5.1.2.1	5.1.1.4	Automate with good reason.	Automation should be used to support the user(s) where appropriate (human-centered automation), not implemented simply because the technology is available (technology-centered automation).
Shall		5.1.1.5	Enable users to carry out tasks.	Automation shall help or enable the users to carry out their responsibilities and tasks safely, efficiently, and effectively.
Shall		5.1.1.6	Provide a clear relationship with user tasks.	The relationships between display, control, decision aid, and information structure and user tasks and functions shall be clear to the user.
Shall	5.1.2.7	5.1.1.7	Ensure active user involvement in operation.	Users shall be given an active role through relevant and meaningful tasks in the operation of a system.
Should		5.1.1.8	Make procedures suitable to user expertise.	Procedures employed in automation should be appropriate to the user's level of expertise with the system.
Should		5.1.1.9	Implement based on goals for system.	How automation is implemented should be determined by the explicit goals of the system, not by comparison between automated and manual systems.
Should	5.1.2.10	5.1.1.10	Avoid increasing demands for cognitive resources.	Automation should not increase the demands for cognitive resources (thinking or conscious mental processes).

Should/ Shall		Guideline Number	Guideline title	Guideline
Should		5.1.1.11	Avoid extreme workload levels.	Extreme levels of workload (low or high) due to automation use should be avoided.
Shall		5.1.1.12	Prevent distraction from operations.	User interaction with automation shall not require the user to take significant amounts of attention away from the primary task.
Should		5.1.1.13	Avoid interruption at inappropriate times.	Automation should not interrupt at inappropriate times such as during periods of high workload or during critical moments in a process.
Should	5.1.2.3	5.1.1.14	Make tasks easier to perform.	An automated task should be less difficult to perform than the manual task it replaces.
Should		5.1.1.15	Guide the use of automation.	Standard operating procedures and company policies should guide users in the appropriate use of automation, but give the user ultimate responsibility over the decision to use or not use the automation.
Shall	5.1.2.21	5.1.1.16	Provide easy data access.	Data that are needed by the user shall be easily accessible.
Should	5.1.4.1	5.1.1.17	Prompt for data entry format.	The automated system should prompt users as to the correct data entry format.
Should	5.1.4.2	5.1.1.18	Make it error resistant and error tolerant.	Automation should be error resistant and error tolerant.
Shall	5.1.2.8	5.1.1.19	Make system behavior predictable.	Automated systems shall behave predictably so that the user knows the purpose of the automation and how the operation will be affected by that automation.
Shall		5.1.1.20	Ensure safe operations are within human capacity.	Systems shall not be so reliant on automation that human users can no longer safely recover from emergencies or operate the system manually if the automation fails.
Should		5.1.1.21	Provide means of user override.	The automation should not be able to veto user actions leaving the user without means to override or violate the rules that govern the automation unless there is not enough time for the user to make a decision.
Shall	5.1.4.4	5.1.1.22	Provide interaction consistency.	The way that automation systems interact with their users shall reflect a high degree of consistency within and between systems.
Should	5.1.4.6	5.1.1.23	Make systems easy to understand and use.	Automated systems and associated integrated information displays should be intuitive, easy to understand, and easy to use.
Should	5.1.4.7	5.1.1.24	Make systems simple to learn.	Automation should be simple for the users to learn.
Should	5.1.4.8	5.1.1.25	Provide means to check input and setup data.	Automated systems should provide a way to check automation setup and to check information used as input for the automated system.
		5.1.2	**Design and evaluation**	
Should		5.1.2.1	Involve users in design.	Users should be involved in the design of an automated tool.
Should		5.1.2.2	Design based on human-centered goals and functions.	Design of automation should begin by choosing the human-centered criteria (goals) of the system and then defining the functions that the system will perform.
Shall		5.1.2.3	Consider effect on coordination.	When new automation is introduced, the designers shall consider the possibility of negative effects on team coordination.
Shall		5.1.2.4	Assess overall impact.	The overall impact of automation shall be thoroughly examined before implementation to

Should/ Shall		Guideline Number	Guideline title	Guideline
				ensure that changes do not result in additional complexities, loss of situational awareness, or possibilities for error.
Should		5.1.2.5	Validate system design.	Contextually valid human-in-the-loop experiments and simulations should be conducted to validate and refine automated system design.
Shall		5.1.2.6	Evaluate interactions with other functions.	Possible interactions with other tools, system functions, and user tasks shall be evaluated when new automation is designed.
Shall		5.1.2.7	Test as a whole.	New automation components shall be tested with the complete system, including other automated components of the system, to ensure they function together as an effective whole.
Shall		5.1.2.8	Test normal and failure modes.	Automated systems shall be tested under normal modes of operation and under failure modes of the automation.
Shall		5.1.2.9	Test before implementation.	Automated systems shall be tested in a realistic operational environment with representative users before implementation to ensure that operator performance is not compromised and workload is not increased.
		5.1.3	**System response and feedback**	
Should		5.1.3.1	Visualize consequences of decisions.	The user should be able to visualize the consequences of a decision, whether made by the user or the automated system.
Should	5.1.2.13	5.1.3.2	Provide brief and unambiguous command response.	Automated system responses to user commands should be brief and unambiguous.
Should	5.1.2.12	5.1.3.3	Keep users aware of function.	The automated system should keep the user aware on a continuing basis of the function (or malfunction) of each automated system and the results of that function (or malfunction).
Should	5.1.2.15	5.1.3.4	Provide effective feedback.	Automation should provide the user with effective feedback on its actions and the purpose of these actions.
		5.1.4	**Interface**	
Should	5.1.4.9	5.1.4.1	Keep it simple.	The automation interfaces should represent the simplest design consistent with functions and tasks of the users.
Shall	5.1.4.5	5.1.4.2	Provide interface consistency.	Human interfaces in automation programs and systems shall have a high degree of consistency.
Should	5.1.4.10	5.1.4.3	Be consistent with user expectations.	Automated systems and interfaces should be consistent with the expectations and understandings of users.
Shall		5.1.4.4	Make interface structure logical.	Automation interfaces shall reflect an obvious logic based on user task needs and capabilities.
Shall	5.1.4.22	5.1.4.5	Make location status obvious.	Interfaces and navigation aids shall make it easy for users to know where they are in the data space.
Should		5.1.4.6	Use spatial representations where possible.	Where possible, spatial representations of information should be used instead of verbal or textual displays in high workload situations.
Should		5.1.4.7	Present dynamic information in real	Dynamic information (information that changes over time) should be presented in real time and

Should/ Shall		Guideline Number	Guideline title	Guideline
		🟥	time.	on demand to ensure accurate and timely decision-making.
		5.1.5	**User acceptance and trust**	
Should		🟥 5.1.5.1	Increasing user trust in automation.	To increase user trust in automation, automation performance should be
				a. reliable and predictable with minimal errors,
				b. robust (able to perform under a variety of circumstances),
				c. familiar (use terms and procedures familiar to the user), and
				d. useful.
Should		🟨 5.1.5.2	Provide training for users to develop trust in automation reliability.	Training should be provided to enable the user to calibrate their trust in the automated system. [Source: Cohen, Parasuraman, & Freeman, 1998]
Should		🟥 5.1.5.3	Ensure automation availability.	The automated system should be available to the user as needed.
Shall	5.1.2.11	🟩 5.1.5.4	Prevent interference with user tasks.	The automated system shall not interfere with task performance.
Shall	5.1.2.9	5.1.5.5	Provide accurate and reliable information.	Automation shall provide accurate and reliable information.
Should		🟥 5.1.5.6	Minimize changes due to automation.	Changes in cognitive processing, ways of thinking, and methods and skills used for new automation should be minimized.
		5.1.6	**Modes**	
Should	5.1.5.1	🟩 5.1.6.1	Clearly identify modes and functions.	When control, display, or automation functions change in different modes of operation, mode and function identification and status should be clear.
Should		🟥 5.1.6.2	Identify alternatives in rarely used modes.	Seldom-used modes and functions should be clearly identified.
Should	5.1.5.3	5.1.6.3	Make frequently used modes easy to get to.	Frequently used modes should be more accessible than infrequently used modes.
Should		🟥 5.1.6.4	Number of modes.	The number of different modes for a given system should be minimized.
Should	5.1.5.4	5.1.6.5	Allow switching between modes.	The user should be able to easily switch between modes.
Should	5.5.5.5	5.1.6.6	Provide consistent features and functions.	Features and functions that are common between display modes should be consistent.
Should	5.1.5.6	5.1.6.7	Alert user to potentially hazardous interactions.	The automated system should alert the user to the implications of interactions between modes, especially when they are potentially hazardous.
Should	5.1.5.7 and .8	🟩 5.1.6.8	Alert users of unsafe modes.	The automated system should either prevent the use of potentially unsafe modes or alert the user that a particular mode may be hazardous.
		5.1.7	**Monitoring**	
Shall	5.1.6.1	5.1.7.1	Allow users to monitor automated systems.	The system shall be designed so that users are able to monitor the automated systems and the functionality of its hardware and software, including the display of status and trend information, as needed.
Should		🟥 5.1.7.2	Display changing data as graphic.	Changing data that must be monitored by the users should be displayed in a graphic format.
Should	5.1.2.7	🟩 5.1.7.3	Make users active in control and	Automation should be designed so that users are involved in active control and monitoring

Should/ Shall		Guideline Number	Guideline title	Guideline
			monitoring.	rather than just passive monitors.
Should		5.1.7.4	Allocate cognitive resources for monitoring.	System designers should allow adequate cognitive resources for monitoring by ensuring that task load does not become excessive.
Should		5.1.7.5	Limit monitoring time.	Users should not be required to perform purely monitoring tasks for longer than 20 minutes at a time.
Should	5.1.6.2	5.1.7.6	Integrate displays.	When users must monitor multiple displays, important events should occur in the same display in order to promote effective monitoring performance.
Should	5.1.6.3	5.1.7.7	Minimize spatial uncertainty.	Important events should occur in the same location on a display in order to promote effective monitoring performance.
Should	5.1.6.4	5.1.7.8	Provide indication of monitoring.	Automated systems that are without incident for long periods of time should provide some type of indication that the automation is still monitoring the system.
Should	5.1.6.5	5.1.7.9	Warn of potential user errors.	Automated systems should be able to monitor user interactions and to warn of user errors.
Should	5.1.6.6	5.1.7.10	Monitor critical functions.	Critical automation functions should be independently monitored by the user.
Should		5.1.7.11	Ensure adequate understanding.	Users should be given an adequate understanding (mental model) of how the automated system works in order to monitor effectively.
Should		5.1.7.12	Provide intermittent manual control.	Intermittent periods of manual control should be used during extended periods of task automation to improve monitoring of the automation. (See adaptive automation-Section 5.1.15.1.)
Should		5.1.7.13	Minimize noise.	Environmental noise should be minimized to ensure optimal vigilance.
Should		5.1.7.14	Consider circadian rhythm effects on performance.	System designers should consider the effects of circadian rhythms on user vigilance and monitoring performance.
Should		5.1.7.15	Consider potential vigilance decrements.	The effects on vigilance due to the use of automation should be considered before introducing new automation.
		5.1.8	**Fault management**	Fault management relates to how the user notices and recovers from system failures. Such failures may or may not be detected by automation. Fault management has been defined to include the four distinct tasks of detection, diagnosis, prognosis, and compensation.
Shall		5.1.8.1	Ensure safety should automation fail.	Automated systems shall allow for manual control and preservation of safe operations should the automation of one or more components of the system, on which the automation depends, fail.
Shall	5.1.7.1	5.1.8.2	Make failures apparent.	Automation failures shall be made unambiguously obvious to the user.
Should	5.1.7.1	5.1.8.3	Provide adequate early warning notification.	Early warning notification of pending automation failure or performance decrements should use estimates of the time needed for the user to adjust to task load changes due to automation failure.
Shall	5.1.7.1	5.1.8.4	Inform user of	The user shall be informed of automation

Should/ Shall		Guideline Number	Guideline title	Guideline
			potential failure.	performance decrements, potential failures, and malfunctions.
Shall		5.1.8.5	Automate diagnostic aids.	Fault isolation, inspection, and checkout tasks shall be automated to the extent practical.
Shall	5.1.2.24	5.1.8.6	Incorporate automatic self-checking components.	All essential electronic computer and peripheral components that are part of a system shall incorporate an automatic self-check diagnostic test of software and hardware, both at power up and at the request of the operator, to ensure they are functioning p
Shall		5.1.8.7	Provide capability for on-demand system check.	On-demand system checkout shall be available.
Shall	5.1.7.3	5.1.8.8	Make sensor status verifiable.	The status of sensors on replacement units shall be verifiable with respect to accuracy and proper operation.
Shall	5.1.7.4	5.1.8.9	Permit status verification without disassembly.	When feasible, equipment shall permit verification of operational status prior to installation without the need for disassembly.
Shall	5.1.7.5	5.1.8.10	Permit fault detection without disassembly.	Equipment shall permit fault detection and isolation without removing components, through the use of built-in test, integrated diagnostics, or standard test equipment.
Shall	5.1.7.6	5.1.8.11	Facilitate rapid fault detection.	Equipment design shall facilitate rapid fault detection and isolation of defective items to permit their prompt removal and replacement.
Shall	5.1.7.7	5.1.8.12	Identify failures without ambiguity.	Fault detection and isolation shall identify without ambiguity which component has failed.
Shall		5.1.8.13	Provide portable diagnostic tools.	When built-in test equipment is not available, diagnostic tools or portable equipment shall be provided to aid in fault isolation.
Should		5.1.8.14	Identify first alarm event.	Automated warning systems should provide a means for identifying the first event in a series of alarm events.
Should		5.1.8.15	Provide sufficient diagnostic information.	The user should be provided with sufficient information and controls to diagnose automated warning system operation.
		5.1.9	**False alarms**	
Should		5.1.9.1	False alarm rates.	False alarm rates should not be so frequent as to cause the user to mistrust the automated system.
Should		5.1.9.2	Inform users of the probability of a true alarm.	Users should be informed of the inevitable occurrence of automation false alarms particularly when base rates are low.
		5.1.10	**Training**	
Should		5.1.10.1	Introducing new automation.	New automation should be introduced with advanced briefing and subsequent training procedures.
Should		5.1.10.2	Prepare users for changes.	Before automation is introduced, users should be informed of associated changes and increases in the work effort, as well as the benefits associated with the automation.
Should		5.1.10.3	Train users to understand automated functions.	Initial training in the use of automation should be sufficient for the users to fully understand how the automation functions within the particular system, as well as how to use the automation.
Should		5.1.10.4	Train users to backup automation.	Users should be provided with backup training in performing any tasks replaced by automation

Should/ Shall		Guideline Number	Guideline title	Guideline
				or in operating any backup systems replaced by automation.
Should		5.1.10.5	Train to recognize inappropriate use of automation.	Users should be trained to recognize inappropriate uses of an automated tool including automation bias (the use of automation in a heuristic manner as opposed to actively seeking and processing information).
Should		5.1.10.6	Train users when to question automation.	Users should be trained to recognize and understand the conditions under which automation may be unreliable, and to learn the conditions where it performs well (when or when not to question the automation).
Should		5.1.10.7	Avoid over-reliance on automation.	Users should be trained not to become overly reliant on automation.
Should		5.1.10.8	Train for risk assessment and reduction.	Users should be trained on risk assessment and actions needed for risk reduction.
Shall		5.1.10.9	Train for failure recovery transitions.	Users shall be trained on transitioning from automated to conventional systems.
Should		5.1.10.10	Stress interaction skills.	Training programs should stress user-automation interaction skills and cognitive/problem solving skills rather than psychomotor skills.
Should		5.1.10.11	Train for changes due to automation.	When automation requires different kinds of cognitive processing, ways of thinking, and discarding of traditional methods and skills, then training should be designed to address problems related to these changes.
Should		5.1.10.12	Train to identify normal output.	Users should be trained on what constitutes the normal automation output so that the user can easily determine whether the system is functioning properly.
		5.1.11	**Function allocation/levels of automation**	??
Should		5.1.11.1	Evaluate function allocation alternatives.	Alternative function allocations including fully manual, partially automated, fully automated, and adaptive allocation should be evaluated for feasibility and effectiveness.
Should		5.1.11.2	Evaluate through simulation.	Alternative schemes for the allocation of functions should be examined in the context of the whole system through the use of high fidelity simulations.
Should	5.1.2.4	5.1.11.3	Only automate functions performed well by machines.	Only functions that are performed well by machines should be automated, not functions that are performed better by humans.
Should		5.1.11.4	Automate full behavioral modules.	Behavioral modules in their entirety should either be automated or preserved as manual subtasks, not fractionally (partially) automated.
Should	5.1.2.5	5.1.11.5	Give tasks requiring flexibility to user.	Tasks that are performed in an unpredictable environment requiring flexibility and adaptability should be allocated to the user.
Should	5.1.2.6	5.1.11.6	Make roles and responsibilities clear.	The automated system should make it clear whether the user or computer is supposed to perform a particular task at a specific time.
Should		5.1.11.7	Provide means for changing roles and responsibilities.	The automated system should provide a means for changing the allocation of roles and responsibilities.
Should		5.1.11.8	Automation of high-	For system tasks associated with greater

Should/ Shall		Guideline Number	Guideline title	Guideline
		🟥	risk actions or decisions.	uncertainty and risk, automation should not proceed beyond the level of suggesting a preferred decision/action alternative.
		5.1.12	**Information automation**	
Should	5.1.4.11	5.1.12.1	Indicate if data are incomplete, missing, uncertain, or invalid.	The automated system should provide a means to indicate to the user that data are incomplete, missing, unreliable, or invalid or that the system is relying on backup data.
Should		5.1.12.2	Provide automatic update.	When the displayed data are changed as a result of external events, the user should be provided with the option of having an automatic update of changed information.
Should		5.1.12.3	Provide multiple output formats.	System designers should provide information in multiple formats (for example, text, graphics, voice, and video) to allow better communication and reduction of workload.
Should	5.1.4.13	5.1.12.4	Show accurate status.	Information presented to the user should accurately reflect system and environment status in a manner so that the user rapidly recognizes, easily understands, and easily projects system outcomes in relation to system and user goals.
Should		5.1.12.5	Minimize errors.	Error-prone conditions should be minimized by maintaining user awareness, providing adequate training, developing standard operating procedures, and fostering crew coordination.
Shall		5.1.12.6	Information displays.	Information displays shall support and reinforce status and situation awareness at all times.
Should	5.1.4.14	5.1.12.7	Situation displays.	Event data should be combined with a map background when the geographic location of changing events needs to be shown.
Shall	5.1.4.15	5.1.12.8	Present information consistent with task priorities.	Both the content of the information made available through automation and the ways in which it is presented shall be consistent with the task priorities.
Should	5.1.4.16	5.1.12.9	Cueing important information.	When information must be updated quickly, the most important information should be cued to ensure it will be the first to be processed by the user.
Should	5.1.4.17	5.1.12.10	Queue messages automatically.	Incoming messages should be queued automatically by the system so they do not disrupt current information handling tasks.
Should		5.1.12.11	Highlight changed data.	Data changes that occur following automatic display update should be temporarily highlighted.
Should	5.1.4.18	5.1.12.12	Store and prioritize lists of information.	Long lists of information, tasks, and so on, should be stored and prioritized by the automated aid to minimize the number of decision alternatives and reduce the visual processing load of human operators.
Should	5.1.4.19	5.1.12.13	Integrate display elements only if performance is enhanced.	Display elements should only be integrated if it will enhance status interpretation, decision-making, situation awareness, or other aspects of task performance.
Should	5.1.4.20	5.1.12.14	Integrated displays.	Integrated displays should combine various information automated system elements into a single representation.

Should/ Shall		Guideline Number	Guideline title	Guideline
Should	5.1.4.21	5.1.12.15	Automatically arrange information depending on status.	System information should be automatically reorganized into integrated or non-integrated arrangements depending on the current system status.
Should		5.1.12.16	Make cues equally prominent.	Automated and non-automated cues should be made equally prominent to enable users to collect confirming/disconfirming evidence before deciding on appropriate action.
		5.1.13	**Adaptive automation**	Definition. Adaptive automation is the real time allocation of tasks to the user or automated system in a flexible manner, changing the automation to meet current situational demands.
Should		5.1.13.1	Help during high workload.	Automation should be designed to adapt by providing the most help during times of highest user workload, and somewhat less help during times of lowest workload.
Should		5.1.13.2	When not to implement adaptive automation.	Adaptive automation should not be implemented unexpectedly or at a time when the user may not desire the aiding.
Should		5.1.13.3	When to implement adaptive automation.	Adaptive automation should be implemented at the point at which the user ignores a critical amount of information.
Should		5.1.13.4	Adapt to skill of the user.	Adaptive automation should be used to increase the performance of users with different skill levels.
Should		5.1.13.5	Make adaptive automation at least as skilled as user.	Adaptive automation should be at least as skilled as the user, if not greater, to promote optimal user performance.
Should		5.1.13.6	Modeling of human behavior.	Modeling of human behavior for aid-initiated intervention should at least include: task execution goal states, environment representation (graphical), situation assessment information and planning, and commitment logic.
Should		5.1.13.7	Interface adaptation.	When dynamic adaptation of the interface is used, it should be attained by utilizing information provided to the system through user interactions within a specific context.
Should		5.1.13.8	Menu adaptation.	When dynamic adaptation of menus is used, the resultant menus should offer only the options that are relevant to the current environment.
Should		5.1.13.9	Use direct manipulation interfaces.	Direct manipulation interfaces should be used to minimize the impact of a transition to manual control.
		5.1.14	**Decision aids**	Definition.
Should	5.1.3.1	5.1.14.1	When to use.	Decision aids should be used
				a. for managing system complexity;
				b. for assisting users in coping with information overload;
				c. for focusing the user's attention;
				d. for assisting the user in accomplishing time-consuming activities more quickly;
				e. when limited data results in uncertainty;
				f. for overcoming human limitations that are associated with uncertainty, the emotional components of decision-making, finite-memory

Should/ Shall		Guideline Number	Guideline title	Guideline
				capacity, and systematic and cognitive biases; and
				g. for assisting the user in retrieving, retaining, representing or manipulating large amounts of information, combining multiple cues or criteria, allocating resources, managing detailed information, performing computations, and selecting and deciding among alternatives.
Should	5.1.3.2	5.1.14.2	When to avoid.	Decision aids should not be used
				a. when solutions are obvious;
				b. when one alternative clearly dominates all other options;
				c. when there is insufficient time to act upon a decision;
				d. when the user is not authorized to make decisions; or
				e. for cognitive tasks in which humans excel, including generalization and adapting to novel situations.
Should	5.1.3.4	5.1.14.3	Let users determine decision aid use.	Users should be able to determine when and how the decision aid should be used.
Should	5.1.3.5	5.1.14.4	Use terms and criteria appropriate to users.	Decision aids should use terminology and criteria appropriate to the target user group.
Should	5.1.3.11	5.1.14.5	Reduce number of response options.	Decision aids should reduce the number of response options.
Should	5.1.3.3	5.1.14.6	Assist user decisions.	Decision aids should assist, rather than replace, human decision makers by providing data for making judgments rather than commands that the user must execute.
Should		5.1.14.7	Make support consistent with mental models.	The support provided by decision aids should be consistent with user cognitive strategies and expectations (mental models).
Should	5.1.3.6	5.1.14.8	Do not cancel ongoing user tasks.	Use of decision aids should not require ongoing user tasks to be cancelled.
Should	5.1.3.7	5.1.14.9	Minimize query of user.	Decision aids should minimize query of the users for information.
Should	5.1.3.8	5.1.14.10	Minimize data entry.	Decision aids should minimize user data entry requirements.
Should		5.1.14.11	Provide ability for planning strategy or guiding process.	Decision aids should be capable of planning a strategy to address a problem or guide a complex process.
Should	5.1.3.10	5.1.14.12	Accept user direction.	Decision aids should accept direction from the users on which problem solving strategy to employ when alternative strategies are available.
Should	5.1.3.16	5.1.14.13	Prioritize alternatives.	When more than one alternative is available, the decision aid should provide the alternatives in a recommended prioritization scheme based on mission and task analysis.
Should	5.1.3.12	5.1.14.14	Alert user when unable to process.	Decision aids should alert the user when a problem or situation is beyond its capability.
Should	5.1.3.9	5.1.14.15	Be flexible in type and sequence of input accepted.	Decision aids should be flexible in the types and sequencing of user inputs accepted.
Should	5.1.3.14	5.1.14.16	Estimate uncertainty and rationale.	Decision aids should estimate and indicate the certainty of analysis and provide the rationale for the estimate.
Should	5.1.3.18	5.1.14.17	Make derived or processed data	When information used by a decision aid is derived or processed, the data from which it is

Should/ Shall		Guideline Number	Guideline title	Guideline
			accessible.	derived should be either visible or accessible for verification.
Should		5.1.14.18	Provide hard copy of decision aid use.	The user should be able to obtain hard copy print outs of data including screen displays, rules and facts, data employed, hypotheses tested, and summary information.
Should		5.1.14.19	Allow access to procedural information.	Decision aids should give the user access to procedural information used by the aid.
Should	5.1.3.19	5.1.14.20	Provide user controlled level of explanation detail.	When the system provides explanations to the user, it should supply a short explanation initially, with the ability to make available more detail at the user's request, including access to process information or an explanation for the rules, knowledge-basis and solutions used by the decision aid.
Should	5.1.2.16	5.1.14.21	Provide clear explanations to user.	When the system provides explanations to the user, the explanation should use terms familiar to the user and maintain consistency with the immediate task.
Should	5.1.3.20	5.1.14.22	Present information with appropriate detail.	Decision aids should present information at the level of detail that is appropriate to the immediate task, with no more information than is essential.
Should	5.1.3.21	5.1.14.23	Avoid repeated information.	Decision aids should avoid repeating information that is already available.
Should	5.1.3.22	5.1.14.24	Integrate decision aids.	Decision aids should be fully integrated and consistent with the rest of the computer-human interface.
Should	5.1.3.23	5.1.14.25	Alert to newly available information.	Decision aids should alert the user to changes in the status of important system information such as when critical information becomes available during decision aid utilization.
Should	5.1.3.24	5.1.14.26	Alert to meaningful events or patterns.	Decision aids should automatically notify the user of meaningful patterns or events such as when it predicts a future problem.
Should	5.1.3.25	5.1.15.1.27	Predict based on historical data.	Decision aids should be able to predict future data based on historical data and current conditions.
Should		5.1.14.28	Provide ability to represent relationships graphically.	Decision aids should be able to graphically represent system relationships, its rules network, and reasoning process.
Should		5.1.14.29	Identify simulation mode.	When decision aids have a simulation mode, entering the simulation mode should require an explicit command and result in a distinguishable change in output.
Shall		5.1.14.30	Provide knowledge of intent.	Each element in an intelligent human-machine system shall have knowledge of the intent of the other elements.
Should		5.1.14.31	Adapt with situational demands.	When adaptive decision aiding is used, the level of decision aiding should change with the situational demands in order to optimize performance (See Section 5.1.13 on adaptive automation).
Should		5.1.14.32	Adaptive decision aiding implementation.	Adaptive decision aiding should be applied when resource loading, performance, error frequency, and deviations from intent exceed threshold levels (See Section 5.1.13 on

Should/ Shall		Guideline Number	Guideline title	Guideline
				adaptive automation).
Should		5.1.14.33	Provide planning assistance.	Adaptive decision aiding interfaces should allow the user to receive direct assistance in planning how to carry out the intended task.
Should	5.1.3.27	5.1.14.34	Allow user to initiate automation implementation.	The user should be able to initiate automated aids even if system-initiated automation is the norm.
		5.1.15	**Control automation**	Definition.
Should	5.1.2.17	5.1.15.1	Make automated tasks easily understood.	When automated control actions are performed, the automated tasks should be easily understood by users and similar to user control actions.
Should		5.1.15.2	Limit control automation authority.	Control automation should not be able to jeopardize safety or make a difficult situation worse.
Should	5.1.2.18	5.1.15.3	Provide appropriate range of control options.	Automated systems should provide the user with an appropriate range of control options that are flexible enough to accommodate the full range of operating conditions for which it was certified.
Shall	5.1.2.14	5.1.15.4	Provide immediate feedback.	To promote successful situation awareness of the automated system, the user shall be given immediate feedback to command and control orders.
Should	5.1.2.19	5.1.15.5	Allow for different user styles.	Control automation should be flexible enough to allow for different user styles and responses without imposing new tasks on users or affecting automation performance.
Shall	5.1.2.25	5.1.15.6	Make available override and backup alternatives.	Override and backup control alternatives shall be available for automation controls that are critical to the integrity of the system or when lives depend on the system.
Shall	5.1.2.27	5.1.15.7	Make backup information easy to get.	Information for backup or override capability shall be readily accessible.
Should	5.1.2.26	5.1.15.8	Allow overriding out-of-tolerance conditions.	When a user might need to operate in out-of-tolerance conditions, then a deliberate overriding action should be possible.

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