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Symbol Development Guidelines for Airway Facilities

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16. Abstract

This document presents a general methodology for developing Airway Facilities (AF) symbols and provides guidelines for the coding of visual symbols and auditory signals. Coding refers to the characteristics of a symbol that developers can change to improve its interpretation or message content. These coding guidelines should not be considered exhaustive but rather represent a compilation of the most important items to consider when developing visual or auditory symbols. The decision to use a visual symbol, an auditory signal, or both, will depend on the nature of the displayed information, operational conditions, and users requirements. A list of questions for determining the best coding technique is provided. AF symbols represent facilities, equipment, services, and status information such as alarms and alerts. These guidelines also provide a systematic methodology for developing symbols that will help in the creation and testing of effective symbols.

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1. Introduction

This document presents a general methodology for developing symbols and provides guidelines for designing effective symbols for use in the Airway Facilities (AF) environment. These guidelines represent a compilation of the most important items to consider when developing visual or auditory symbols. In addition, they present examples of symbol-coding techniques and some of the underlying rationale.

1.1 Background

Symbol use has become highly prevalent with the arrival of computer displays. Graphical User Interfaces (GUIs) often utilize symbols to aid in the selection of files and programs. Operational environments use symbols to display system status such as alarms and alerts. Well-designed symbols aid in item recognition, are easier to recognize, and often require less space than words. Poorly designed symbols foster confusion and can cause costly identification errors.

1.2 Objective

The objective of this document is to present a general, systematic methodology for developing symbols that will result in an effective human-machine interface. Conformance to these guidelines will help make status symbols more effective in alerting the user to system degradation or failure. Symbol requirements are usually driven by

a. a need to represent new facilities, equipment, or services;

b. a need to include additional visual, auditory, or other coding techniques; and

c. a major change in the purpose, scope, or policy concerning information display.

2. The Symbol Development Process

The symbol development process begins with a requirement and continues through four phases.

a. Phase 1 - Problem Definition

b. Phase 2 - Technical Preparation

c. Phase 3 - Design of Candidate Symbols

d. Phase 4 - Test and Evaluation

Each phase will use the products of the previous phase. Figure 1 presents an overview of the symbol development process.

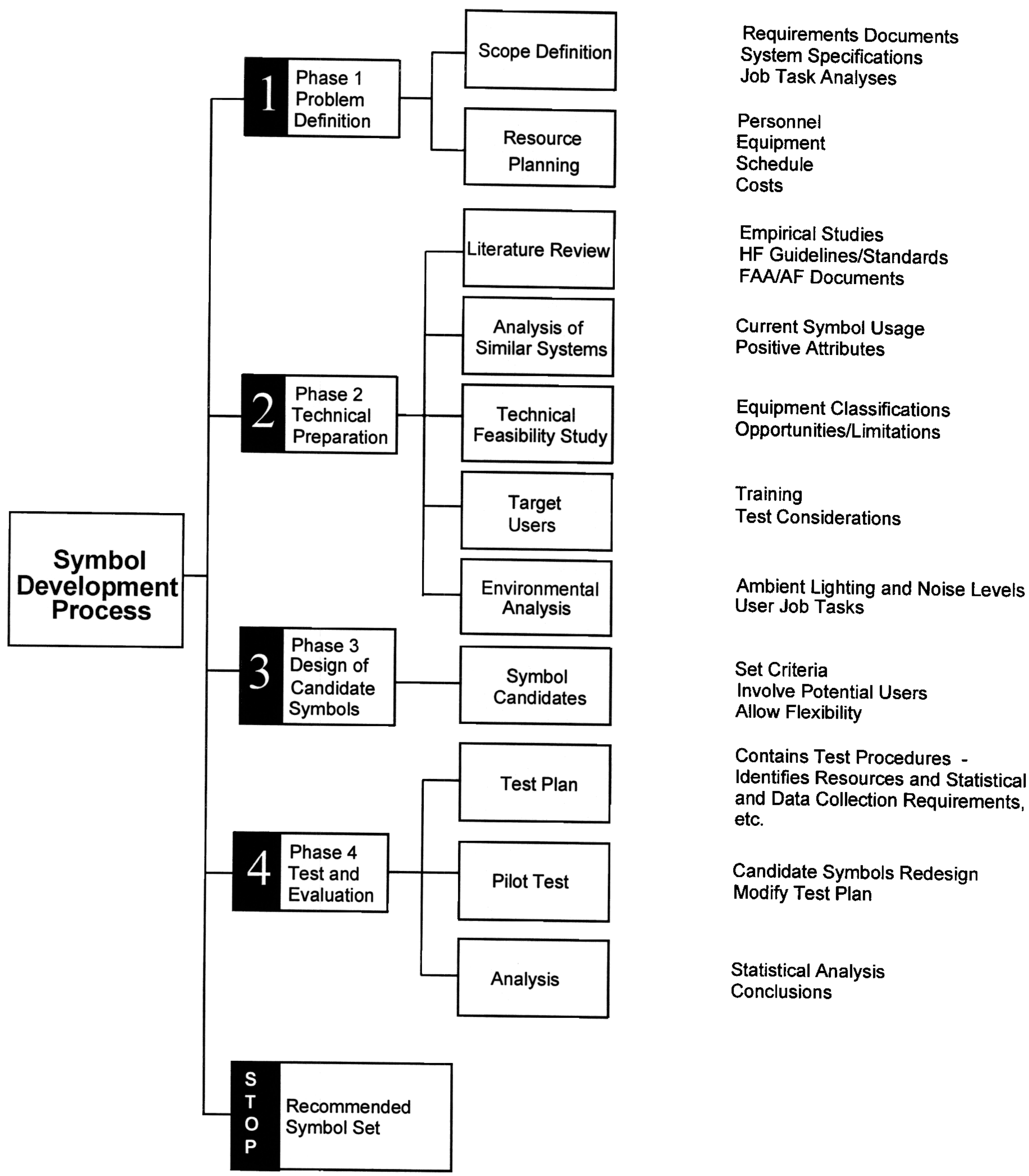

Figure 1. Symbol development phases.

2.1 Phase 1 - Problem Definition

The first phase of the symbol development process includes the following two activities.

Scope Definition identifies the systems and types of information requiring a symbol. Ideally, symbols in need of development are evident from requirements documents or system specifications. Project documentation often describes system requirements, user tasks, status requirements, job task analyses, and operational concepts. This documentation normally identifies requirements for the development of symbols.

Scope definition provides the following for resource planning:

a. information to be represented by the new symbols,

b. symbol types to be developed, and

c. number of symbols to be developed.

Resource Planning identifies the resources necessary to implement the entire symbol development process. Development planning will determine the amounts of money, time, and personnel that are needed. The availability of computers, software, and test personnel will impact the duration of the development effort. Necessary resource requirements are essential to effective symbol development.

2.2 Phase 2 - Technical Preparation

Typically, the technical preparation phase includes five activities.

Literature Review should be conducted to assess the various coding techniques that are beneficial to symbol design. This guideline document, military human factors handbooks, and system specifications contain design guidelines or requirements. A review of the appropriate FAA system specification will identify any unique symbol requirement(s).

Analysis of Similar Systems will familiarize designers with current symbol usage. This analysis will help the designer incorporate attributes that will make the symbol compliant with accepted guidelines and practices.

Technical Feasibility explores the capabilities of computer systems to support the desired level of symbol complexity.

Analysis of Target Users describes the targeted user population and their characteristics that may affect symbol design, such as hearing, vision, color perception, and familiarity with the objects or concepts being symbolized. This analysis will likely identify training and test considerations.

Environmental Analysis describes the ambient environmental characteristics. Ambient lighting and noise levels will affect the coding techniques that the developer might use.

2.3 Phase 3 - Design of Symbol Candidates

This phase results in the development of candidate symbols. The developer should use the information gained from the technical preparation phase and from Section 3 of this symbol development guideline for the basis of symbol design. Requirements and operational considerations drive symbol design. To create optimum symbols, the developer should design several candidate symbols for each facility, equipment, or service.

2.4 Phase 4 - Test and Evaluation

Test and Evaluation (T&E) is important to the implementation of symbols. Symbol candidates designed in Phase 3 will be evaluated for suitability and performance. If symbol candidates fail to provide acceptable performance, symbols and coding techniques must be reconsidered and reevaluated.

T&E begins with the development of a test plan. The test plan will identify test resources, present schedule information, identify data collection and analysis requirements, and present detailed test procedures.

A pilot test will help determine the potential acceptability and usability of the symbol candidates and the test procedures. The pilot test will determine if the candidate symbols require redesign or if the test procedures require modification.

Formal testing should involve participants from the anticipated user population. Data analysis will determine if the symbol is acceptable.

3. Design Guidelines

The decision to use visual symbols, auditory displays, or artificial speech will depend on the nature of the information, operational conditions, and user requirements. Table 1 provides a list of questions that will help determine the visual or auditory application.

3.1 Visual Coding

There are several ways of coding visual symbols. Although definitive rules have not been developed for every situation, symbol coding will often depend on the display and amount of information to be presented. The following guidelines have been formulated from studies and experience gained from developing and using symbols.

a. Alphanumerics (to code numerous categories of quantitative information)

   The amount of information conveyed through letters and numbers is unlimited. Meaningfully grouped letters and numbers result in efficient use of memory. Place letters together to form words, and group numbers to enhance reading and recall.

Table 1. Questions Related to Sensory Mode

Questions	Use Visual Symbols	Use Auditory Signals
Will the ambient noise levels be too high?	Yes	No
Will the ambient light be too bright or too dark?	No	Yes
Will the visual symbols clutter the display?	No	Yes
Will there be too many auditory signals to discriminate?	Yes	No
Will the user be away from the display yet need to respond?	Depends on information to be communicated, operational environment, and specified requirements.	Favored
Will the information presented be short or simple?	Depends on information to be communicated, operational environment, and specified requirements.	Favored
Will the information presented be needed only once?	Depends on information to be communicated, operational environment, and specified requirements.	Favored
Will the information presented require a quick response? Note: Fire alarms should be both visual and auditory. Use auditory warnings to direct attention to visual information.	Depends on information to be communicated, operational environment, and specified requirements.	Favored

b. Shapes (to code discrete categories of static, qualitative information)

Use geometric-shaped coding to represent static information. Use shape changes to represent category differences. Generally, use five shapes or less for a symbol set. Few shapes have inherent or stereotypical meanings.

c. Lines (length and direction to code magnitude, orientation, or deviations)

Use varying types of lines to best portray complex information involving magnitude, orientation, or direction.

d. Pictorials (to code complex concepts, relationships, and entities)

Pictorials are comprehensive, graphical representations that are normally used for static, dynamic, qualitative, or quantitative information. Pictorials foster fast association and enable users to quickly monitor or analyze data. Graphic presentations rely heavily on associative meaning to present large volumes of information.

e. Icons (to code a large number of static, qualitative categories of information)

Visual icons are symbols with pictographic representations of objects. Icons differ from true pictures in that they provide only skeletal representation of static and qualitative information.

f. Color (to show relationships or direct user attention to qualitative information)

Color is one of the simplest and most common methods of coding visual information. Use it to represent qualitative information. When data are dispersed on a display, color coding should show the relationship between items in the same category. Experience and tradition have provided certain color cultural stereotypes. These stereotypes aid in learning and retention of new symbols. Because of ambient light effects, individual user deficiencies, and the need to view color within 30 degrees of the line of sight, color should not be the primary coding technique. Use color coding as a secondary redundant coding technique. People see the same color wavelength but call it different things. Optimum color coding should employ less than seven colors.

g. Highlighting (to direct user attention to qualitative and quantitative information)

Highlighting is a visual coding method designed to attract user attention to a particular symbol on a display. Highlighting includes foreground/background contrasting, blocking, bolding, and using fonts. Highlighting can be used to code almost any type of information. However, use highlighting sparingly and consistently in an application for maximum effectiveness.

h. Flash coding (to direct user attention)

Use flash coding to direct user attention to a specific symbol or to a limited number of items. Individual flash rates have little or no absolute meaning but do have relative meaning associated with relative differences (i.e., faster blink rate to indicate increasing urgency). Flashing reduces legibility and can impact size and shape coding. Although users can identify four flash rates, ideally do not use more than two flash rates.

Size (to show relationships between qualitative and quantitative information)

Use size to code either qualitative or quantitative information. Size coding should be used sparingly due to space requirements necessary to support this type of coding. Users normally make poor judgments about absolute size but can readily comprehend relative relationships between data items. The number of different sizes used as codes should not exceed three.

3.1.1 Alphanumeric

3.1.1.1 Confusion

Confusion occasionally occurs between certain letters and numbers, such as O and 0 or Z and 2 in a symbol or icon. Use these characters sparingly or carefully differentiate between them. See Figure 2 for discernibility in the presentation of letters and numbers.

- Ensure discernibility of letters and numbers.

Poor	**Better**
O , 0	O , Ø
Z , 2	Ƶ , 2

Figure 2. Letter and number discernibility.

3.1.1.2 Strings and Chunking

Typically, a person will remember a string of characters equal to seven, ± two.

- Limit the number of characters when alphanumeric codes are abstract.

The three-to-four chunking method used with telephone numbers (456-3434) is the most familiar. No chunking (AGHJYTE) or poor chunking (complex 1-5-1 (A-GHJYT-E) pattern) make remembering difficult. See Figure 3 for information chunking.

- Use three-to-four character chunking for large groups of text or numbers.

555-1212 PHL ARSR

DNE 3844

Figure 3. Information chunking.

3.1.1.3 Grouping

Grouping similar items improves learning and retention. Searching or reviewing information requires less effort when grouping similar items. See Figure 4 for information grouping.

- Group letters with letters and numbers with numbers.

Poor	**Better**
A6H9VB27D	AHVBD 6927

Figure 4. Grouping information.

3.1.1.4 Specialized Fonts and Font Styles

Specialized fonts and font styles can reduce the legibility of letters and numbers. The same font, style, and case allow easier reading and understanding of single words. See Figure 5 regarding the importance of using consistent font, style, and case.

- Use block (sans serif) style letters and numbers.
- Display letters and numbers in a consistent font, style, and case.

Poor	**Better**
Lax	LAX
*ASR*9	ASR9

Figure 5. Consistent fonts, styles, and cases.

3.1.1.5 Size and Spacing

Each character should be of sufficient size and clarity to be perceived separately in the expected operational environment. Size and space characters projected on a screen for viewers to see them at the maximum expected viewing distance.

- Use large letters and numbers for visual search tasks and tasks involving projected material or large-screen displays. Minimum recommended character height is 1/200 of viewing distance.

Adequately space each character and line to enable the viewer to distinguish one from another. This will ensure clear reading from an optimum reading distance.

Use character spacing that is at least 10 percent of character height.

- Use at least one character width between words for equally spaced characters.
- Use the width of a capital N between words for proportionally spaced characters. This space is in addition to any space required for accent marks on upper case characters and descenders on lower case letters.

See Figure 6 for the importance of proper letter spacing.

Spacing between words should be

One character or more.

Figure 6. Letter spacing.

Properly spaced lines result in easier reading of text. Figure 7 presents an example of lines poorly spaced and lines properly spaced.

- Use the greater of two stroke widths or 15 percent of character for spacing between lines.

Lines that are too close together are difficult to read.	However, lines that are properly spaced will facilitate reading.

Figure 7. Line spacing.

3.1.1.6 Optimization

An alphanumeric character stroke width is expressed as the ratio of stroke thickness to the letter or numeral height. The stroke width interacts with the text color, background, and illumination. This interaction results in reduced alphanumeric legibility when presenting white characters on a black background, but not when displaying black characters on a white background.

Use a stroke width:height ratio of 1:6 to 1:8 for black characters on a white background.

- Use a stroke width:height ratio of 1:8 to 1:10 for white characters on a black background.

- Use a character width:height ratio of 0.7:1 to 0.9:1 for equally spaced characters and lines of 80 or fewer characters.

- Use a character width:height ratio of at least 0.5:1 if it is necessary to have more than 80 characters per line.

Use a character width:height ratio equal to or less than 1:1 for proportionally spaced characters such as M and W.

- Use a minimum 6:1 contrast ratio between light characters and a dark background or 1:6 contrast ratio for dark characters on a light background. The preferred values are 10:1 and 1:10, respectively.

$$C_R = \text{Contrast Ratio} = L_{max}/L_{min}$$

L_{max} is the higher luminance of the background or character

L_{min} is the lower luminance of the two (area of least intensity)

3.1.2 Shape

3.1.2.1 Discernibility

Learning time increases and recall decreases as the number of shapes increases.

- Limit the number of shapes to five to achieve optimum coding effectiveness.

Shapes should be discernible from each other, such as those depicted in Figure 8.

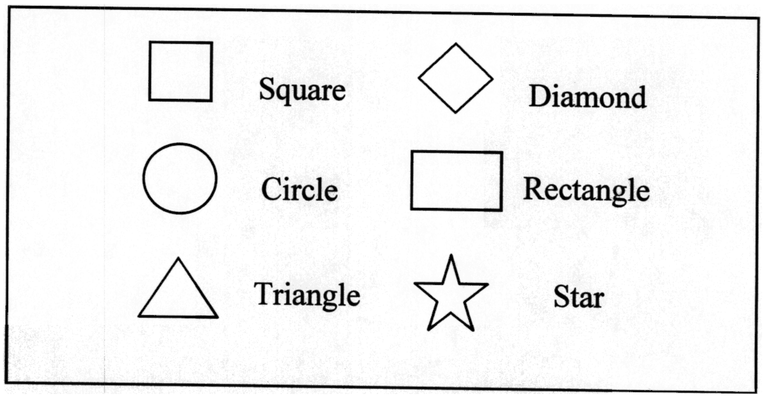

Figure 8. Differentiating shapes.

3.1.2.2 Geometric Shapes

Increase the size of the geometric-shaped symbols when viewed under poor illumination, from a distance, or when the shapes are subject to change. Common sizes range from 0.10 in. to 0.18 in. for geometric symbols. Developers should use the relative size of shapes to portray quantitative differences.

- Avoid similarly appearing geometric forms.

- Do not use shape symbols smaller than 0.10 in. in the smallest dimension.

3.1.3 Line

3.1.3.1 Velocity Representations

Shorter lines indicate less information and a slower rate of change. Lines that rise above the baseline indicate an increase, while lines that descend below the baseline indicate a decrease. Add arrowheads to lines to indicate direction. Figure 9 illustrates usage of arrowheads and line length.

- Use line length and arrowheads to represent amplitude, direction, or velocity.

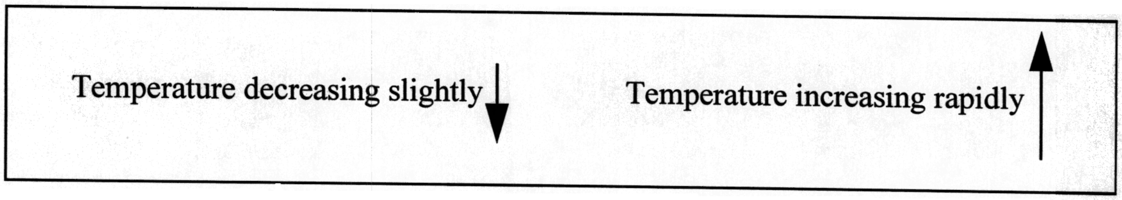

Figure 9. Line length representations.

3.1.3.2 Deviations

A change from normal alignment, as shown in Figure 10, indicates a deviant reading. A change in line length can indicate a doubling or tripling of the data.

- Use different line lengths or directions to highlight deviant readings or to show relative information.

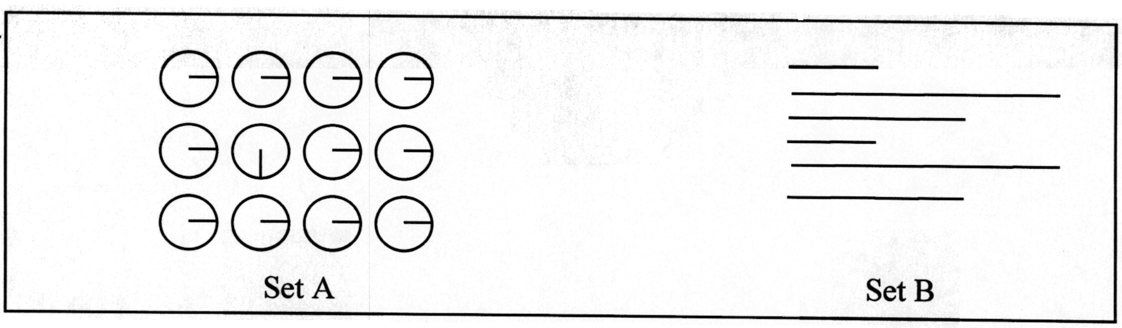

Figure 10. Deviation in alignment (Set A) and relative amounts of data (Set B).

3.1.3.3 Types

Some symbol designs require several distinguishable line types to enhance symbol clarity. Using a single line type makes the comprehension of relational differences difficult. A combination of the line types will help a symbol to effectively convey information. See Figure 11 for line type illustrations.

- Limit the number of line types to six or less.

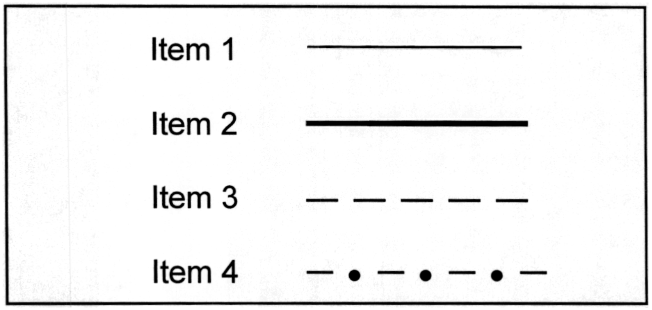

Figure 11. Line types.

3.1.3.4 Characteristics

Symbol relational differences are difficult to recognize when a single line represents more than four items. In other words, do not use more than four attributes (line type, direction, length, thickness, color, etc.) per line to code information.

- Limit the number of line characteristics to four.

A line less than 0.10 in. is extremely difficult to distinguish from background text or other symbols.

- Do not use lines shorter than 0.10 in.

3.1.4 Pictorials

Prohibitive symbols require longer processing time because they do not explicitly state the desired action. Despite the advantage of permissive symbols, it is sometimes difficult to design appropriate permissive symbols. Providing a clear understanding of the message or required action is more important than whether a symbol is permissive or prohibitive. See Figure 12 for prohibitive and permissive type symbols.

- Make pictorials permissive, when possible.

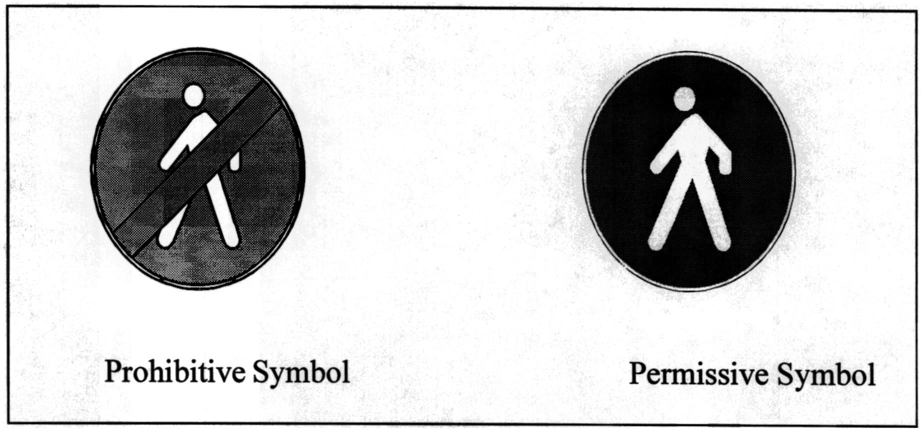

Figure 12. Prohibitive and permissive type symbols.

3.1.4.1 Effectiveness

The effectiveness of a pictorial depends on several factors. The following guidelines will maximize the effectiveness of pictorials.

- Make the edges apparent.
- Use a contrast boundary, a solid shape (see Figure 13b), instead of a line boundary.
- Use a closed figure.
- Make as simple as possible.
- Keep as unified as possible.
- Label for clarity where practical and necessary.

Figure 13 illustrates the use of these guidelines.

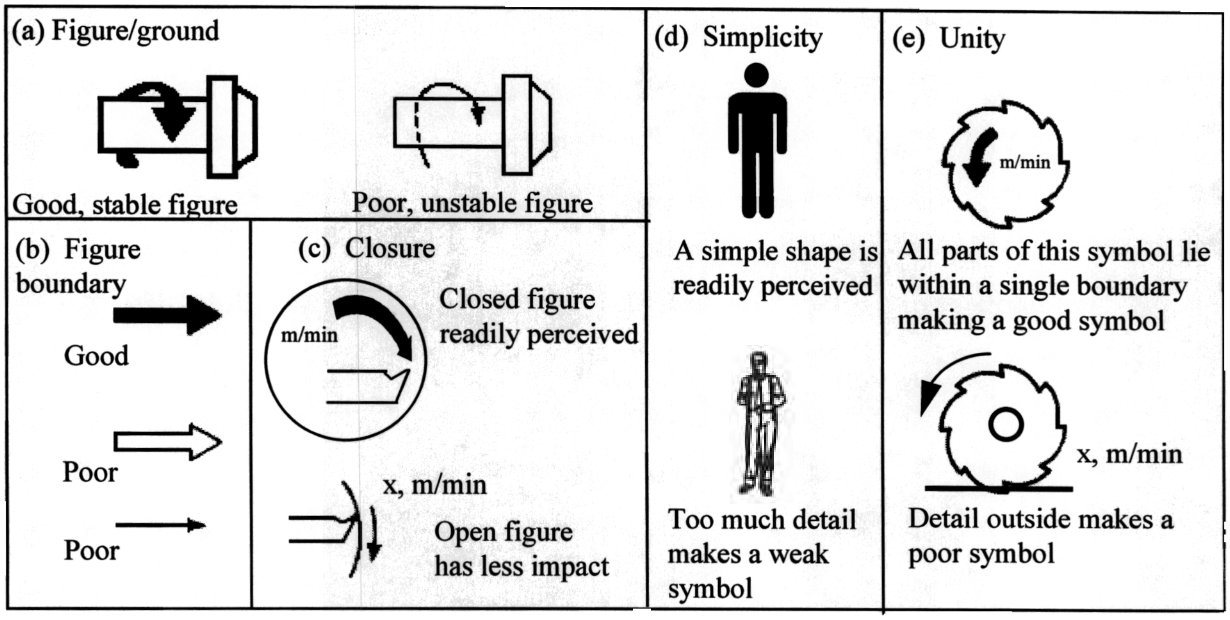

Figure 13. Pictorial effectiveness factors.

3.1.5 Icons

Icons rely on associations between characteristics and implied meanings. Therefore, they should be skeletal representations of objects and can contain more information with less space than symbols. Icons generally use unique characteristics of the object to be coded. Incorporate only the critical attributes of an object that are necessary for identification. These characteristics may be associated with the appearance of the object, the function of the object, the relationship among object components, or the relationship of the object to associated objects. Use the associations that best capture the essence of the identity of the icon.

- Use icons to represent much information in a small space.
- Icons should be simple, uncluttered, and distinctive within the user's set of icons.

Weak boundaries make icons more difficult to perceive. Open figures have less impact than closed figures.

- Make the boundary around an icon solid, closed, and contrast-bounded.

Icons previously implemented or used within a field are typically easier to learn because they are familiar. Figure 14 presents the skeletal concepts used by typical icons.

- Use established icons when possible.
- If there are many icons or infrequently used icons, consider making an identity label for the icon available (upon pointing) or making it always present.
- A large set of icons will require special user training.

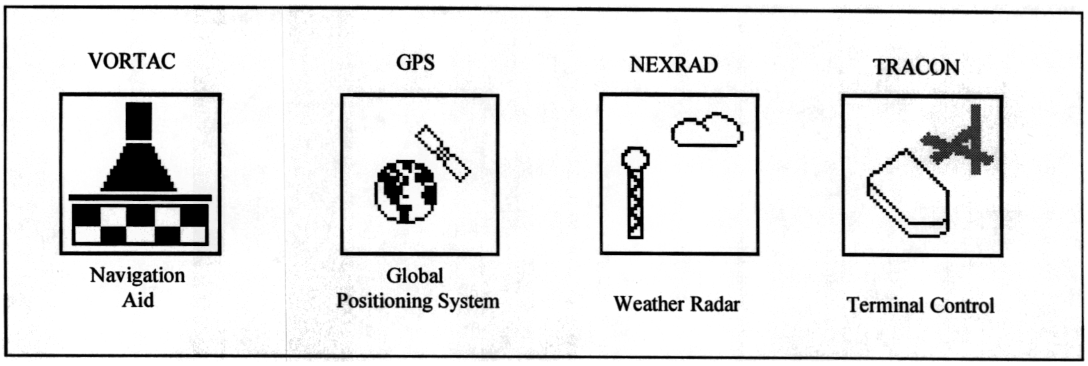

Figure 14. Typical icons.

When detailed information is not critical, use a generic icon to represent a concept. Do not use icons for each object of a class. For example, use a single radar icon rather than separate icons for each radar type (e.g., ASR-7, ASR-8, or ASR-9).

- Use a generic icon to represent a concept.
- Use a single icon to represent several objects when detailed information is not critical.
- Use a distinguishable icon for each object if the symbol requires class object distinction.
- Use labels with icons to improve identification.
- Combined icons and acronyms can enhance reaction times. Users prefer combined symbols over acronyms or icons alone.

3.1.6 Color

Developers should use color as a secondary coding feature. Stop signs and yield signs are color coded, but the color reinforces the shape and the words stop or yield. The traditional traffic light uses color to reinforce the position of the red, yellow, and green lights. Maps are an exception to this rule because they use color to depict features such as elevation.

3.1.6.1 Color and Information Differentiation

Figure 15 uses color to identify two classes of data and demonstrates the capability of color to improve information assimilation.

- Use color to attach a specific meaning to a portion of text or symbol
- Use a unique color to represent data items from the same classification.
- Use color sparingly as an information discriminator.

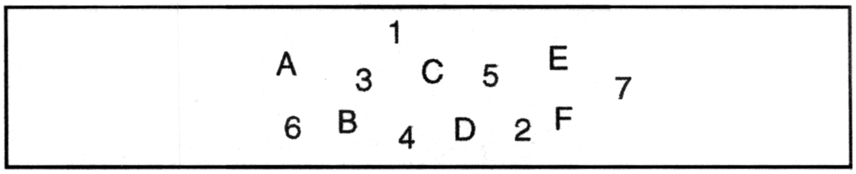

Figure 15. Color use to improve information assimilation.

3.1.6.2 Color and Ambient Lighting Conditions

Colors must be distinguishable under ambient environmental conditions. For example, colors must be distinguishable when used in a dimly illuminated control room or bright sunlight.

- Ensure colors are easy to see under conditions of high ambient illumination if using hue saturation combinations.
- Consider the color spectrum of the light source and the pigments in the reflective surface when selecting colors.
- Use highly saturated colors to maximize differences among colors.

See Figure 16 for presentation of color saturation.

SATURATED COLORS ARE
MORE DISTINGUISHABLE
THAN DESATURATED COLORS

Figure 16. Highly saturated color example.

If a developer has assigned a specific use or meaning to a color, use no other color for the same purpose and do not use that color for any other purpose.

- Use one meaning per color.
- Use color consistently in the development of icons or symbols.

Add color after maximizing the effectiveness of a display in an achromatic format. The following guidelines apply for the use of colors.

- Use foreground colors that contrast highly with background colors.
- Use standardized color coding across applications, such as using red for alarms or danger.
- Use less than seven colors to achieve optimum color effectiveness.

- Use bright colors to emphasize the most important or critical information.

- Avoid using highly saturated colors from opposite ends of the color spectrum next to each other.

3.1.6.3 Specific Colors

Even though users can perceive over 7 million colors, they can reliably discriminate some colors better than others.

- Use up to six colors to obtain maximum color discrimination. Optimum colors for discrimination include: red, orange, yellow, blue, green, and purple.

- Use neutral colors for backgrounds or highlighting.

  Use neutral colors, brown, black, white, and gray, for noncritical information.

  Use orange only when a viewer can differentiate it from red, yellow, and white. Orange is between red and yellow in the visible spectrum.

- Use magenta sparingly

- Use green, yellow, and red in combination with other coding, such as intensity and saturation, to enhance their discernibility.

- Use similar colors to represent related information or categories.

Some color combinations may cause illusions because the retina of the eye cannot readily focus on those colors.

- Avoid using blue on a dark background for text, thin lines, or high resolution information.

- Avoid using blue as a foreground color for highly detailed symbols.

- Avoid using the following color combinations: red and blue, blue and green, red and green, yellow and purple, magenta and green.

3.1.6.4 Reserved Colors

Five colors typically have reserved meanings. A developer should not use them to mean something else.

  Use red to indicate conditions such as no-go, error, failure, or malfunction.

- Use flashing red as double coding to indicate emergency conditions requiring immediate user action to avoid personnel injury or equipment damage.

  Use yellow to alert users to situations where caution or rechecking is necessary.

- Use green to indicate equipment performance is within tolerance, a condition is satisfactory, or to proceed with an operation.

- Use white to indicate alternative functions or system conditions having no operability or safety implications.

- Use blue as an advisory color.

3.1.7 Highlighting

Highlighting normally emphasizes an object or symbol. Accomplish highlighting in the following ways:

a. increase the object intensity;
b. present it in a different style or size font;
c. flash the object;
d. reverse the object image, such as light letters on a dark background or dark letters on a light background; or
e. put graphics composed of asterisks around or near the object.

Since highlighting is binary, either present or not, it is ideal for category discrimination.

- Use highlighting for discriminating between two categories.

Highlighting should have the same meaning for all applications.

- Use highlighting consistently.

Too much highlighting loses its effectiveness in attracting attention. Figure 17 presents an illustration contrasting acceptable highlighting and too much highlighting.

- Keep the amount of highlighting to a minimum.

> Highlight only **important** items.
> **Too much highlighting reduces visual impact.**

Figure 17. Highlighting example.

Symbols should be bright enough to stand out clearly against the background on which they appear under all expected lighting conditions, but they should not be so bright as to blind the operator. In work stations that are darkened at night, provision should be included for dimming the symbols when other lights are dimmed; this can be accomplished by tying in symbols with the same control used to dim the background.

- Use a contrast ratio of 2:1 between highlighted and nonhighlighted information.

- Use relative brightness for highlighted and nonhighlighted information.

3.1.8 Flash Rate

Although trained users can identify the frequency of flashing from 0.25 flashes per second to 12 flashes per second, it is recommended that the frequency remain between three and five flashes per second. In addition, the number of flashing rates should not exceed two.

- If the number of flashing rates is one, maintain a frequency of flashes between three and five flashes per second.

- If the number of flashing rates is two, maintain the slower frequency at one flash per second and the faster frequency at four flashes per second.

- Use equal on and off durations.

Unsynchronized flashing symbols are disturbing and decrease user performance.

- Synchronize the flashing of symbols when they are coded with the same frequency.

Blinking characters may also reduce legibility and can cause visual fatigue if used extensively. A technique used to avoid legibility loss is to use a marker that flashes for the symbol.

- Make the flashing symbols legible.

- Use a slower flashing frequency to show slow changes, less information, and less urgency.

3.1.9 Size

Figure 18 demonstrates size relationships to depict relative quantities of data.

- Use no more than three symbol sizes.

- Use larger symbols to mean more data and smaller symbols to signify less data.

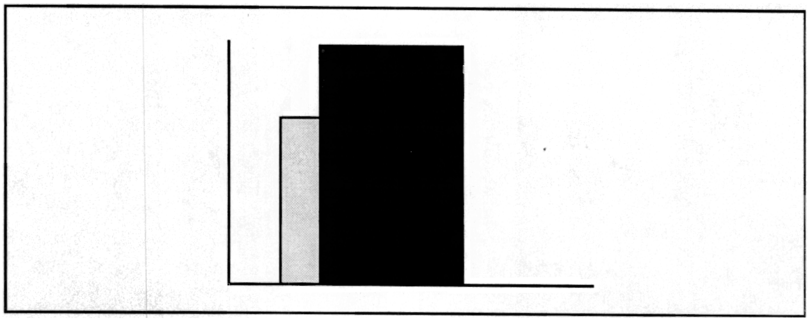

Figure 18. Size demonstration.

Use the following proportional guidelines when working with different symbol sizes.

a. The height:width ratio should remain constant between symbols.

b. Larger symbols should be at least 1.5 times the height and width of the next smaller symbol.

c. Symbol sizes should subtend a minimum visual angle of at least 20 minutes. This means that, at a viewing distance of 800 mm (31.5 in.), a symbol should be at least 5 mm (0.2 in.) high.

Figure 19 illustrates proportional relationships. Set A depicts two symbols; the larger symbol is 1.5 times the height and width of the smaller symbol. (Note: the height:width ratio remains a constant 2:1). Set B also depicts two symbols with the larger symbol 1.5 times the height to width of the smaller symbol. In this case, the height:width ratio remains a constant 1:1.

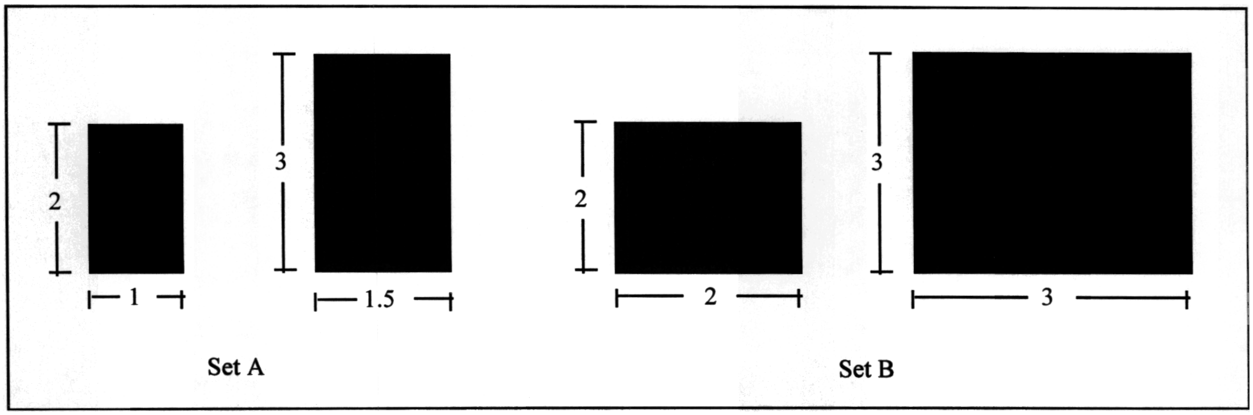

Figure 19. Proportional relationships.

3.2 Auditory Coding

Audio coding consists of varying frequency, pulse shaping, and duration. These audio characteristics are typically applied to audio displays such as buzzers, horns, and whistles. Audio coding is also applied to computer-generated voice or artificial speech. Developers should integrate auditory coding to direct attention to visual warnings. Use the following sound characteristic guidelines when developing auditory symbols.

3.2.1 Intensity

The intensity of sound measured in decibels (dB) is the mechanical pressure a sound wave exerts on the eardrum. The unit dB(A) is used to express intensity using a sound meter with an A-weighted network. The A-weighted response drops rapidly as frequency decreases below 1000 Hz, is maximum at 2500 Hz, and gradually increases above 4000 Hz, thereby approximating the frequency dependent human response to moderate sound levels.

- The intensity of a signal should exceed the ambient noise level by 10 dB(A), but the overall intensity should not exceed 90 dB(A).
- Do not code information by varying the intensity of the signal (use frequency, duration, or pulse shape instead).

3.2.2 Frequency

The human auditory system is sensitive to frequencies from about 20 to 20,000 Hz. The auditory system has the greatest sensitivity to frequencies around 200 to 5000 Hz. The ideal frequency range for a symbol is 500 to 3000 Hz. There is hearing loss with advanced age for frequencies below 500 Hz and for frequencies above 10,000 Hz. Use the following guidelines when coding audio signals.

- Use no more than five distinctive frequencies to code auditory signals.
- Use 500 and 3000 Hz as the lower and upper limits for auditory symbols.
- Use discrete frequencies when coding audible symbols with a bandwidth of at least 100 Hz.
- Space discrete center frequencies with intervals of 500 to 1000 Hz to prevent harmonic frequency overlap.

3.2.3 Pulse Shape

Pulse shape refers to the rise and decay patterns of sound for coding information.

- Use no more than three pulse shapes when coding auditory signals.

A listener perceives onset rates of less than 1 dB(A)/ms as continuously rising, which produces little or no startle response. Short onset rates produce greater startle responses.

- Use very rapid sound onset to code for fast response.
- Use very rapid sound onset rates to code critical information.

3.2.4 Duration

Base auditory signals on sound duration. Long and short signals, or combinations thereof, can be used to code different information characteristics.

Audio warning detectability increases with long durations. To demand attention, modulate the signal to give intermittent beeps, or modulate the frequency to make the pitch rise and fall. Implement a manual shutoff to ensure the warning continues until a user acknowledges it. Use the following duration guidelines when coding auditory signals.

- Discriminate between first 0.5 second of an audio signal requiring fast reaction from the first 0.5 second of any other signal.
- Transmit all essential information in the first 2 seconds.
- Limit the number of data characteristics coded by duration to three.
- Maintain audio warning signals for at least 0.5 second.

3.2.5 Auditory Display

The following list describes commonly used auditory displays.

a. Buzzers operate in the low frequency range of 150 to 400 Hz. They often have the lowest intensity auditory code. Buzzers command attention but do not cause alarm. They have a poor ability to penetrate background noise and, thus, they are not suitable for warnings.

b. Bells normally have a higher intensity level and frequency than buzzers. They are more appropriate for areas with high intensity and low frequency ambient noise. They have excellent attention-getting qualities and are suitable as warning devices.

c. Horns fall into two categories. Growlers are horns that use high intensities, 90 to 100 dB(A), and operate in the low frequencies. Screamers are horns with similar high intensity but operate in the 300 to 5000 Hz frequency range. Horns often direct sound in one direction; however, rotating the horn achieves a wide directional coverage.

d. Chimes and Gongs have low-to-medium intensities and frequencies. They are not adequate for attracting attention or penetrating ambient noise. Do not use chimes and gongs as warning or emergency signals.

e. Whistles have high intensities and a range of potential frequencies from low to high. Their attention-getting and noise-penetration capabilities are good, and they prove very reliable as warning and emergency signals.

f. Sirens have high intensities and a wide range of frequency possibilities. Sirens with wailing frequencies (i.e., frequency rises and falls) are especially useful as warning codes because they attract attention rapidly. High intensity sirens that reach the upper limit of human tolerance become annoying; use in critical situations only.

3.2.6 Artificial Speech

The use of computer-generated speech requires careful consideration.

a. Voice output should be easily discriminable from other speech.

   - Use speech output qualitatively different from other voices in the environment.

b. Using synthesized speech for information other than warnings may require some means of directing attention to the voice warnings.

   - Do not use alerting tones if using synthesized speech exclusively for warnings.

c. Overall intensity of speech varies from person to person and for different situations. Male speech intensity tends to be higher than female by 3 to 5 dB(A). Speech intensity usually varies from about 45 dB(A) for weak conversational speech; to 55 dB(A) for conversational speech; to 65 dB(A) for telephone-lecture speech; to 75 dB(A) for loud, near-shouting speech; and to 85 dB(A) for shouting.

   - Make speech output intensity adjustable within the speech communications range above.

d. Speech intelligibility is highest for sentences, less for isolated words, and lowest for nonsense syllables. Intelligibility is very dependent on context and expectations. Arranging words in sentences increases intelligibility.

   - Use complete sentences to increase the message intelligibility.

     Apply standard sentence construction with information always transmitted in the same order.

e. Effective speakers use longer syllable duration, speak with greater intensity, fill most of the total speech time with speech sounds, and vary their speech with fundamental vocal frequencies.

   - Include the characteristics of effective speech in speech output.

f. A phoneme is the shortest segment of speech that, if changed, would change the meaning of a word. A listener confuses certain speech sounds more easily than others. Letters in the following groups are frequently confused with others within their group: DVPBGCETZ, FXSH, KJA, and MN.

   - Select phonemes that are differentiable.

g. Two groups of consonants, MNDGBVZ and TKPFS, tend to be confused within sets but not between sets.

   - Avoid using single letters as codes.

h. Intelligibility is greater for familiar and longer words.

   - Select familiar words when possible.

i. Computer performance is highly dependent upon the size of the active vocabulary.

Keep active vocabulary to a minimum to maintain the fastest voice response.

j. Poorly developed synthesized speech can be very irritating.

Compare speech synthesizers in the intended operational environments.

k. The capability to replay or interrupt a message should be incorporated in a synthesized voice system. An entire message should not require replay each time the system is used.

- Provide a replay control.

Implement synthesized speech when appropriate and acceptable to the users.

Use voice output sparingly.

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